DELINEATION OF THERMAL REQUIREMENTS OF MAIZE (*Zea mays* L.) IN DIFFERENT SOWING WINDOWS

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
AGRICULTURAL METEOROLOGY
(Minor Subject: Agronomy)**

By

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(L-2019-A-31-M)**

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CERTIFICATE I

This is to certify that the thesis entitled, **"Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows"** submitted for the degree of **M.Sc.**, in the subject of **Agricultural Meteorology** (Minor subject: **Agronomy**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Manjima Bhowmik (L-2019-A-31-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, "**Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows**" submitted by **Manjima Bhowmik (L-2019-A-31-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Agricultural Meteorology** (Minor subject: **Agronomy**) has been approved by the Student's Advisory Committee along with External Examiner after an oral examination on the same.

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ABSTRACT

Climate change has a detrimental effect on maize productivity mostly temperature and precipitation have opposite impacts on maize yield. The present study entitled "Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows" was carried out during Kharif season 2020-21 at research farm PAU to assess the impact of climate change. The experiment was conducted with two maize varieties (PMH1 and PMH2) under four dates of sowing dates (25th May, 5th June, 15th June and 25th June). In field experiment, maximum calendar days (92), accumulated growing degree days (1936.2) and grain yield (50.0 q ha^{-1}) were recorded for 25th May sown crop. Results of trend analysis recorded highest rate of increase in AGDD in Patiala (14.81℃ day year^{-1} and highest rate of increase in HUE in Ludhiana (0.046 kg ha^{-1} ℃ day year^{-1}). In the whole state, to complete different phenological stages during different pentads under four sowing windows, the highest heat units were accumulated by the crop at Muktsar during period P1 (1991-1995) to P6 (2016-2020). The lowest heat units were accumulated by S.B.S. Nagar from pentad P1 (1991-1995) to P6 (2016-2020). During future time series under four sowing windows, the highest heat units will be accumulated at S.B.S. Nagar during period F1 (2021-2025) to F6 (2046-2050) and the lowest heat units will be accumulated by Hoshiarpur from pentad F1 (2021-2025) to F6 (2046-2050). Spatio-temporal interpolation of variability of thermal requirements of maize in different districts of Punjab had been demarcated using geo-spatial technology. The results showed that growing degree day accumulation had increased in all the districts of Punjab from 1991-2020. Pentad wise analysis revealed that under all sowing windows, maximum variability in HUE was observed during P5 (2011-2015) and minimum during P1 (1991-1995). The Mann-Kendall test results revealed that long term (1991-2020) decadal variability showed the highest significant increase in heat unit accumulation in Fatehgarh Sahib @ 33.05°C year^{-1} and significant decrease in heat unit accumulation in Faridkot @ -19.4°C year^{-1} during 2011-2020 under sowing window II. The study concluded that increasing pattern of thermal requirements warns about more warming scenarios in future and thus, creating a strong need to develop region specific climate smart adaptation strategies.

Keywords: Accumulated growing degree days, Climate change, Geo-spatial technology, Heat use efficiency, Mann Kendall's Test

Signature of Major Advisor **Signature of the student**

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ਸਾਰ

ਜਲਵਾਊ ਪਰਿਵਰਤਨ ਦਾ ਮੱਕੀ ਦੀ ਉਤਪਾਦਕਤਾ ਉਪਰ ਮਾੜਾ ਪ੍ਰਭਾਵ ਪੈਂਦਾ ਹੈ ਖਾਸ ਕਰਕੇ ਤਾਪਮਾਨ ਅਤੇ ਵਰਖਾ ਦਾ ਮੱਕੀ ਦੇ ਝਾੜ ਉੱਪਰ ਬਹੁਤ ਹੀ ਮਾੜਾ ਪ੍ਰਭਾਵ ਪੈਂਦਾ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ "ਵੱਖੋ-ਵੱਖਰੇ ਬੀਜਾਈ ਅੰਤਰਾਲਾਂ ਵਿੱਚ ਮੱਕੀ (*ਜ਼ੀਆ ਮੇਜ਼* ਐਲ.) ਦੀਆਂ ਉਸ਼ਮੀ ਲੋੜਾਂ ਦੀ ਮੁਲਾਂਕਣ" ਅਧੀਨ ਜਲਵਾਊ ਪਰਿਵਰਤਨ ਦੇ ਪ੍ਰਭਾਵ ਦਾ ਮੁਲਾਂਕਣ ਕਰਨ ਲਈ ਸੰਨ 2020-21 ਦੀ ਸਾਉਣੀ ਰੁੱਤੇ ਪੀ ਏ ਯੂ ਖੋਜ ਫਾਰਮ ਵਿਖੇ ਕੀਤਾ ਗਿਆ। ਤਜ਼ਰਬੇ ਲਈ ਚਾਰ ਬੀਜਾਈ ਮਿਤੀਆਂ (25 ਮਈ, 5 ਜੂਨ, 15 ਜੂਨ ਅਤੇ 25 ਜੂਨ) ਅਧੀਨ ਮੱਕੀ ਦੀਆਂ ਦੋ ਕਿਸਮਾਂ (PMH1 ਅਤੇ PMH2) ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਖੇਤ ਤਜ਼ਰਬੇ ਦੌਰਾਨ ਦੇਖਿਆ ਗਿਆ ਕਿ, 25 ਮਈ ਨੂੰ ਬੀਜੀ ਗਈ ਫ਼ਸਲ ਵਿੱਚ ਕੈਲੰਡਰ ਦਿਨ (92), ਵਧੇ ਹੋਏ ਡਿਗਰੀ ਦਿਨ (1936.2) ਅਤੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ (50.0 q ha^{-1}) ਸਭ ਤੋਂ ਵੱਧ ਸੀ। ਨਤੀਜਿਆਂ ਦੇ ਮੁਲਾਂਕਣ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ AGDD ਦੇ ਵਾਧੇ ਦੀ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਦਰ ਪਟਿਆਲਾ (14.81°C ਦਿਨ ਪ੍ਰਤੀ ਸਾਲ) ਵਿੱਚ ਅਤੇ HUE ਦੇ ਵਾਧੇ ਦੀ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਦਰ ਲੁਧਿਆਣਾ (14.81 kg ha^{-1} °C ਦਿਨ ਪ੍ਰਤੀ ਸਾਲ) ਵਿਖੇ ਸੀ। ਸਾਰੇ ਰਾਜ ਵਿੱਚ, ਚਾਰ ਬੀਜਾਈ ਅੰਤਰਾਲਾਂ ਅਧੀਨ ਵੱਖੋ-ਵੱਖਰੇ ਪੈਂਟਾਡਸ (ਪੰਜ ਸਾਲਾਂ ਦਾ ਅੰਤਰਾਲ) ਦੌਰਾਨ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਫਿਨੋਲੋਜੀਕਲ ਪੜਾਵਾਂ ਦੀ ਪੂਰਤੀ P1 (1991-1995) ਤੋਂ P6 (2016-2020) ਦੌਰਾਨ ਮੁਕਤਸਰ ਵਿਖੇ ਬੀਜੀ ਗਈ ਫ਼ਸਲ ਵਿੱਚ ਸਭ ਤੋਂ ਵਧੇਰੇ ਅਤੇ ਐਸ.ਬੀ.ਐਸ. ਨਗਰ ਵਿਖੇ ਬੀਜੀ ਗਈ ਫ਼ਸਲ ਵਿੱਚ ਸਭ ਤੋਂ ਘਟਟ ਗਰਮੀ ਯੂਨਿਟਸ ਦੀ ਜਜ਼ਬਤਾ ਹੋਈ। ਭਵਿੱਖ ਵਿੱਚ ਚਾਰ ਬੀਜਾਈ ਅੰਤਰਾਲਾਂ ਅਧੀਨ, F1 (2021-2025) ਤੋਂ F6 (2046-2050) ਦੌਰਾਨ ਐਸ.ਬੀ.ਐਸ. ਨਗਰ ਵਿਖੇ ਬੀਜੀ ਵਿੱਚ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਅਤੇ ਹੁਸ਼ਿਆਰਪੁਰ ਵਿਖੇ ਬੀਜੀ ਗਈ ਫ਼ਸਲ ਵਿੱਚ ਸਭ ਤੋਂ ਘੱਟ ਗਰਮੀ ਯੂਨਿਟਸ ਦੀ ਜਜ਼ਬਤਾ ਹੋਵੇਗੀ। ਭੂ-ਸਥਾਨਿਕ ਤਕਨੀਕ ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਪੰਜਾਬ ਦੇ ਵੱਖੋ-ਵੱਖਰੇ ਰਾਜਾਂ ਵਿੱਚ ਮੱਕੀ ਦੀਆਂ ਉਸ਼ਮੀ ਲੋੜਾਂ ਦੀ ਵਿਭਿੰਨਤਾ ਦੀ ਸਥਾਨਿਕ-ਅਸਥਾਈ ਅੰਤਰਾਲ ਦੀ ਹੱਦਬੰਦੀ ਕੀਤੀ ਗਈ। ਨਤੀਜਿਆਂ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ ਸਾਰੇ ਪੰਜਾਬ ਵਿੱਚ 1991 ਤੋਂ 2020 ਤੱਕ ਵਧੇ ਹੋਏ ਡਿਗਰੀ ਦਿਨਾਂ ਵਿੱਚ ਵਾਧਾ ਹੋਇਆ। ਪੰਜਾਂ ਸਾਲਾਂ ਦੇ ਅੰਤਰਾਲ ਦੌਰਾਨ ਕੀਤੇ ਗਏ ਮੁਲਾਂਕਣ ਤੋਂ ਇਹ ਤੱਥ ਸਾਹਮਣੇ ਆਏ ਕਿ ਸਾਰੀਆਂ ਬੀਜਾਈ ਮਿਤੀਆਂ ਅਧੀਨ, HUE ਵਿੱਚ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਵਿਭਿੰਨਤਾ P5 (2011-2015) ਵਿੱਚ ਅਤੇ ਸਭ ਤੋਂ ਘੱਟ ਵਿਭਿੰਨਤਾ P1 (1991-1995) ਵਿੱਚ ਆਈ। ਮਾਨ-ਕੇਂਡਲ ਟੈਸਟ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ ਬੀਜਾਈ ਅੰਤਰਾਲ II ਅਧੀਨ, ਲੰਮੇ ਸਮੇਂ (1991-2020) ਦੌਰਾਨ ਹੋਣ ਵਾਲੀ ਜਲਵਾਯੂ ਤਬਦੀਲੀ ਨਾਲ ਉਸ਼ਮੀ ਯੂਨਿਟ ਜਜ਼ਬਤਾ ਵਿੱਚ ਫਤਿਹਗੜ੍ਹ ਸਾਹਿਬ (@ 33.05°C ਪ੍ਰਤੀ ਸਾਲ) ਵਿੱਚ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਵਾਧਾ ਹੋਇਆ ਅਤੇ ਫਰੀਦਕੋਟ (@ 33.05°C ਪ੍ਰਤੀ ਸਾਲ) ਵਿੱਚ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਸਭ ਤੋਂ ਘੱਟ ਕਮੀ ਆਈ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਸਿੱਟਾ ਕੱਢਿਆ ਗਿਆ ਕਿ ਫ਼ਸਲ ਦੀਆਂ ਉਸ਼ਮੀ ਲੋੜਾਂ ਵਿੱਚ ਹੋਣ ਵਾਲੇ ਵਾਧੇ ਤੋਂ ਇਹ ਚਿਤਾਵਨੀ ਮਿਲਦੀ ਹੈ ਕਿ ਭਵਿੱਖ ਵਿੱਚ ਗਰਮੀ ਵਿੱਚ ਵਾਧਾ ਹੋਵੇਗਾ ਅਤੇ ਇਸ ਲਈ ਖੇਤਰ ਅਧਾਰਿਤ ਜਲਵਾਯੂ ਅਨੁਕੂਲਨ ਨੀਤੀਆਂ ਵਿਕਸਤ ਕਰਨ ਦੀ ਬਹੁਤ ਵਧੇਰੇ ਲੋੜ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਵਧੇ ਹੋਏ ਡਿਗਰੀ ਦਿਨ, ਜਲਵਾਯੂ ਤਬਦੀਲੀ, ਭੂ-ਸਥਾਨਿਕ ਤਕਨੀਕ, HUE, ਮਾਨ-ਕੇਂਡਲ ਟੈਸਟ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

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CHAPTER I

INTRODUCTION

Agriculture represents the backbone of the Indian economy sustains livelihood to 70% of population and provides 52% of total employment in India. Agriculture contributes around 17% to total GDP and plays a significant role in development of the country (Arjun 2013). The main determinant of agricultural production is climate and is regulated by prevailing climatic factors including light intensity, sunshine hours, precipitation, temperature, wind pressure and relative humidity level over the region. Agriculture is sensitive to the seasonal, annual and longterm variation in climate. Climate change and agriculture are closely related to each other on global basis. Climate change associates with changes in temperature, precipitation and other climatic parameters, that affect agriculture. The spatio-temporal variability analysis of temperature has shown a significant temperature increase across different areas in Punjab (Kingra *et al* 2017). The temperature increase will have an extreme impact on agricultural productivity by increasing respiration rate, reducing net photosynthesis, and ultimately resulting in reduced agricultural productivity (Rao *et al* 2015). Studies have reported that by the end of the 21^{st} century, temperature will increase by 1.6-5.8°C (Pachauri and Reisinger 2007). Under future climate change scenarios, the northern part of Indian sub-continent will experience high risk of heat stress (Teixeira *et al* 2013).

Climate change becomes a major environmental threat associated with global warming, increase in atmospheric CO_2 concentration and uncertainties in mean temperature and precipitation have huge impact on Indian agriculture (Ahmad *et al* 2020). Climate change will affect agriculture in complex ways, positive as well as negative. Global carbon dioxide concentrations in the atmosphere are expected to rise from 350 ppm to over 400 ppm by 2030. Average global temperatures are projected to rise by between 1.6 and 5.8˚C by 2100. By 2030 the increase will be rather lower than this, between 0.5 and 1˚C (FAO 2002). Climate change has a detrimental effect on maize productivity mostly temperature and precipitation have opposite impacts on maize yield. Studies have shown that 1°C increase in global temperature lead to 17% reduction in maize yield (Oseni *et al* 2011). From the last few decades, Punjab has experienced changing climatic conditions, so microclimatic modifications are required to manage canopy temperature, heat use efficiency, and sustain crop productivity in these regions. In Punjab, spatio-temporal analysis has reported increase in temperature in different regions. Since the past few decades, minimum temperature has increased by 1°C, relative humidity has increased by 5% and number of rainy days has decreased in Punjab (Kingra *et al* 2017).

Maize is one of the most important cereal crops after wheat and rice. It is used both as a food and feed crop as well as it is used as an industrial raw material such as alcoholic beverages, pharmaceuticals, gums, textiles, oil, proteins, food sweeteners and in paper and packaging industries etc (Kumar *et al* 2018). Maize has highest genetic potential which allows it to grow in tropical, sub-tropical and temperate climates (Rathod *et al* 2017). To feed the world's increasing population, it is important that the production of three important cereal crops (rice, wheat, and maize) be increased by 70% by 2050. But due to climate change agricultural production is likely to be adversely affected, which may hinder the capability of many areas to attain the required goals for future food security (Lobell *et al* 2008). In India during 2018-2019, the area under maize was 9.2 million hectares with a total production of 27.8 million tonnes and productivity 29.6 qha^{-1}. In Punjab, maize is grown over 114.6 thousand hectares of area with total production and productivity of 410.5 thousand tonnes and 35.82 q ha^{-1} respectively during 2019-20 (Anonymous 2021).

Variability in weather is one of the most important factors for the inter-annual variability of crop growth and productivity in different environments. Cardinal temperatures include maximum temperature (T_{max}), minimum temperature (T_{min}) and optimum temperature (T_{opt}), are considered in case of study the responses of crops to ambient air temperature (Wang *et al* 2014). The sensitivity of crop yields to increased temperature is often estimated through analysis of variability in annual yield and growing season temperature. The increasing air temperature causes damage on growth, development, and productivity of maize by affecting yield, physiology, and phenology (Butler *et al* 2013). International Food Policy Research Institute (IFPRI) report on 'Climate Change: Impact on Agriculture and Costs of Adaptation' revealed temperature increase will reduce maize yield ranging from 9 to 19% by 2050 (IFPRI 2009). Due to increase in temperature, yield and duration of the maize crop also decrease. 1˚C increase in temperature may decrease the duration of this crop by 4.3 days (Patidar *et al* 2020).

Weather and atmospheric conditions during different growing stages directly influence the development of plant and ultimately affect the average yield (Khushu *et al* 2008). Temperature and photoperiod are two of the most important environmental factors have direct impact on plant growth and development. The most commonly used temperature index to determine is heat units or thermal units or growing degree days. Growing degree days are also known as growing degree units. The idea related to growing degree days was established assuming that crop growth and temperature are directly related. The concept growing degree days was developed first by Reanumur in 1730. Growing degree days involve the relation between average day temperature and base or threshold temperature. The thermal responses of various crops act as independent variable for depicting the plant development. Plants require definite ambient temperature for attaining certain phenological stages. Photoperiod is influenced by shifting of dates of sowing. To study these effects may help in selecting the right time of sowing and match crop phenology in specific environment to achieve higher use efficiency. In this approach, temperature based agrometeorological indices such as Heliothermal units (HTU), Growing degree days (GDD) are useful in predicting growth and productivity of the crops (Sreenivas *et al* 2010). The estimation of occurrence of various phenological events during the crop growth period in relation to temperature can be done by computing accumulated growing degree days (Gouri *et al* 2005).

Growing degree days (GDD) is a basic temperature based agrometeorological index of crop growth and development. The influence of temperature on yield is parameterized using growing degree days (GDDs). GDDs are a commonly used measure for the cumulative warmth a crop has experienced over the growing season and defined as the sum of all daily average temperatures over the growing season in excess of 8 °C (Butler *et al* 2013). The growing degree days (GDD), photothermal unit (PTU) and heliothermal unit (HTU) are some simple tools to find out the relationship between plant growth, temperature, bright sunshine hours and day length. Under field conditions, the impact of temperature on the growth and productivity of crop plants is analysed using accumulated heat unit systems as plants have a definite temperature requirement prior to attainment of certain phenological stage. The knowledge of heat units depicts the various development stages and date of harvesting of the crop.

Geographic Information System (GIS) is one of the most powerful tools that can depict the various local production variables like temperature, humidity, soil type, soil drainage etc and their relative weight in terms of their importance to achieve optimum productivity through different approaches (Raza *et al* 2018). Under the changing climatic scenarios, agricultural planning and use of agricultural technologies need precise spatio-temporal meteorological and crop information for accurate data analyses, forecasts and their effective application in agricultural planning and management decisions, irrigation scheduling, crop stress management and preparedness for calamities and sustainability of natural resources and ecosystems over different regions (Kingra *et al* 2016). By the spatio-temporal interpolation, maps regarding temperature based agrometeorological indices can be generated by using data collected from the different meteorological stations (Zhang *et al* 2013). This will be further used for the calculations of spatio-temporal variations in maize yield and thermal requirements in different maize growing areas of Punjab. Due to differential behaviour of maize cultivars, this present study was conducted to analyse the phenological behaviour, heat unit requirement and heat unit efficiency of maize cultivars under different sowing dates. Under field experiment, growing degree days of maize crop is analysed under different date of sowing. Further the contributions of temperature variability to state-level maize productivity are assessed during the historical period ranging from 1991 to 2020 and ultimately to reveal the future exposure (2021-2050) to extreme temperature stress under the RCP8.5 scenario in maize growing regions in the Punjab state.

As the Punjab state is recognized with huge increment in terms of food grain production during green revolution era but sustainability of natural resources got endangered. Due to increase in temperature, there will be shortening of growing period of maize plants and ultimately resulting in decline in crop productivity. Although Punjab state is the breadbasket of India contributing 10.02% of total food grain production in the country (Directorate of Economics and Statistics, Department of Agriculture and Cooperation, 2016-17) so the fluctuation in maize production in the Punjab state can significantly affect the food grain distribution policies, national food security and price regulations. For accurate yield estimations, evaluation of different thermal requirements of maize under different sowing windows is necessary for harvesting maximum yield potential of crop including sustainability of natural resources and executing future suitable policies to control the impact of climate change. The present study entitled "Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows" was undertaken to accomplish the following objectives:

1. To study the spatio-temporal variations in maize productivity in maize growing area in Punjab.
2. To study the thermal requirements with actual experimental data under staggered planting.
3. To study the shifting of thermal requirements of maize under future climate change scenario.

CHAPTER II

REVIEW OF LITERATURE

A brief series of the studies conducted at the national and international level relevant to the present study entitled, **"Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows"** has been reviewed and presented under the following headings:

2.1. Effect of temperature on productivity of maize

2.2 Effect of date of sowing on growth, yield, and heat unit requirement of maize

2.3 Effect of climatic variability on growth, yield, and heat unit requirement of maize

2.1 Effect of temperature on maize productivity

Almaraz *et al* (2008) conducted a study in south-western Quebec to evaluate the Climate change impact on corn yield. The relationship between corn yield and climatic parameters were established using the climate data of 33 years (1973-2005) and historical corn yield and statistical models. The results showed that under the normal weather conditions corn yield increased at the rate of 118 kg ha^{-1} $year^{-1}$ from 1973 to 2005. This increase in yield was mainly due to variations in technology mainly genetic and management. Among the climatic variables, the temperature of July and precipitation of May are the key factors affecting the yield of maize crop. It was concluded that temperature of July below normal and precipitation of May above normal reduces the maize yield and the increase in September temperature had caused the warming of the growing season conditions.

Chen *et al* (2011) investigated in northeast China to show the effect of higher minimum temperatures on corn production. They showed that the rise of mean, minimum and maximum temperature every ten years on an average by 0.31°C, 0.42°C and 0.23°C respectively. Despite of the large differences in the precipitation between the years, no meaningful change in precipitation was found. The results of the regression analysis concluded that maize yield showed an increase of 303 kg ha^{-1} and 284 kg ha^{-1} in May and September respectively due to 1°C rise in minimum temperature. The study also showed of the adoption of the longer duration variety in climate change conditions.

Harrison *et al* (2011) conducted a field study in Mozambique to evaluate the impacts of temperature variations on maize production. Heat stress exposure and changes in maize phenology was examined over the 1979-2008 period. It was shown that warming temperature accelerated the plant development which leads to the shortening of the length of the growth period for the grain size and optimum plant growth. This rapid phenological development also changes the timing of high plant water demand. The higher temperature during the early season leads to the early reproductive period, thereby increasing the risk of water stress and heat. This also concluded that this less time for maturation, independent of effects of availability of water, yield potential was becoming narrowed by warming itself. Substantial losses in yield in some locations of Mozambique will be there due to the continuation of the current climatic trends. Changes to planting dates and maize varietal types could avoid some losses to the maize yield.

Tao *et al* (2015) carried out a field experimentin China to show the spatial and temporal variations of maize yield potentials and yield gaps. The study used MCWLA-Maize model to simulate the yield potentials of maize across the different regions of China. The results concluded that during the period from 1980-2008, the maize yields get stopped at 32.4% of the maize growing areas. The yield gap (%) was generally less than 40% in north-eastern and south-western China. In contrast in northern and southern China where the actual yields were higher, in that areas yield gap (%) was more than 40%. In north China plain and southern China the yield potentials decreased due to the increase in temperature and decrease in solar radiation. Due to increase of both temperature and solar radiation the yield potentials in northern, south-eastern, and north-eastern China gets increased. In north China plain and south-western China, there was the shrinkage in the yield gaps due to rise in actual yields and fall in yield potentials. The study also showed the importance for the breeding of the new cultivars to increase the yield potentials.

Hatfield (2016) conducted a study to show the increased temperature effects on growth and grain yield of three maize hybrids. To show the effect of temperature on maize development and production, comparison was made between the normal seasonal temperature for Ames, IA, during 1980-2010 and normal temperature +4°C with no change in water vapour deficit. The higher temperature caused the increase in the phenological development. Dry matter production and leaf area development showed no changes on increased temperature, but the maize grain yield was decreased from 84 to 100% due to the reduction in the pollination on exposure to the increased temperature causing the reduction in kernels per ear. Increased temperature will affect the maize yield and thereby overhang the food security.

Tesfaye *et al* (2017) conducted a study in south Asia to show the impacts of climate change and the potential advantages of heat-tolerant maize. The study showed that the annual mean maximum temperature can be increased in 2030 by 1.4-1.8°C and in 2050 by 2.1-2.6°C with spatial, monthly and seasonal variations over south Asia. The extent of the area in south Asia showing the increase in heat stress could raise up to 12% in the year 2030 and up to 21% in the year 2050 as compared to the baseline. The effect of heat stress and advantages of heat tolerant varieties changes with the level of the temperature rise and planting season. The results showed that at a regional scale if current varieties would be grown in the future period, the yield of the rainfed maize would decrease in 2030 on an average by 3.3-6.4% and in 2050 by 5.2-12.2%. The yield of the irrigated maize would decrease on an average by 3-8% in 2030 and by 5-14% in 2050. They also concluded that under projected climate change, heat tolerant varieties would benefit the crop and can reduces the yield loses up to 36% and 93% in 2030 under the rainfed and irrigated conditions and up to 33% and 86% in 2050 under the rainfed and irrigated conditions. Thus, heat tolerant varieties will benefit the farmers under the future climate change.

Ahmed *et al* (2018) assessed the impact of climate variability on maize using simulation modelling under semi-arid environment of Punjab, Pakistan. Experimental treatments included three maize hybrids (Syngenta-NK8711, Mosanto-DK6103 and Pioneer-1543) and four dates of sowing (January 27, February 16, March 8 and March 28). Model was calibrated and evaluated. Climatic variability was assessed through the model. The results of the analysis showed that temperature rise was negatively correlated with days to anthesis and maturity. The values of coefficient of regression for grain yield and biological yield reported was 0.63-0.85 while this value ranged was 0.76-0.89 kg ha^{-1} respectively. The results also concluded that sowing between January 17 and February 6 benefited the two hybrids (Mosanto-DK-6103 and Pioneer-1543) and sowing before 17 January leads to severe yield reduction of all the hybrids.

Moghaddam *et al* (2018) conducted a field experiment to show the benefits of adaptation strategies in reducing the negative impact of climate change on grain maize. The study used the APSIM crop model to show the interaction between the cultivar and sowing date when considering the climate and high temperature. The study was conducted at nine locations of the Khuzestan province of south-western Italy. Future climate of the Khuzestan province was projected under Microc5 model under the two Representative Concentration Pathway (RCPs) (RCP 4.5 and RCP 8.5) for the period 2040-2070. The number of days having the temperature more than 36°C was considered as the high-risk window period during the pre-flowering and flowering. The results showed that the yield decreased in all the study locations except the Masjed Soleyman as compared to the baseline by -13.7% and 22.8% under the RCP 4.5 and RCP 8.5 respectively for the mid-future (2050) period. This occurred due to the increase in the length of the high-risk window from 18.8 to 26.3 days for the RCP 4.5 and RCP 8.5 respectively. The farmers in the study area were unaware that they were sowing the crop under high-risk window for the extreme temperature. The probability of the economic grain yield would be reduced by 50% if the farmers will not adopt the adaptive options. The study also showed that the hot areas of the Khuzestan province would be suffer in reductions in maize agroecosystem due to the rise in the temperature by the middle of the 21st century if proper sowing date cultivar were not applied for the summer and winter sowing dates.

2. 2 Effect of date of sowing on growth, yield and heat unit requirement of maize

Kara (2011) conducted a field study with Lumina F1 hybrid sweet corn cultivar to examine optimum sowing date, yield potential and accumulated growing degree days under the region of South-western Anatolia by using different date of sowing. This study reported that sowing dates had huge impact over fresh ear production and other yield attributes. They suggested that from May 1 to May 15 could be the optimum sowing period in South-western Anatolia region.

Dahmardeh *et al* (2012) conducted a field experiment to determine the effect of different sowing dates on GDD accumulation, growth, and yield of maize. This experiment was carried out with five different maize cultivars (SC 108, SC 301, SC 604, SC 704 and PVG) by using different sowing dates (6th July, 21st July and 20th August) in a randomized complete block design with split plot arrangements with three replications. The results showed that the best hybrid SC 704 accumulated growing degree days (GDD) and was the highest for seed yield and all yield components. The plant sown on 5th August, accumulated suitable GDD and produced the highest seed yield, biological yield and harvest index.

Sharma *et al* (2014) carried out a field experiment Farm of SKUAST-J, Chatha during summer season of 2011 to study the effect of sowing schedules and varieties on growth, yield and economics of baby corn (*Zea mays*). Experiment was laid out in split plot design and replicated thrice with four dates (31st March, 15th April, 30th April and 15th May) allotted to main-plots and three varieties (VL-1, Prakash and Punjab Sathi) allotted to sub-plots. The experimental results revealed that among various sowing dates, 31st March recorded significantly higher baby corn yield (2167.70 kg ha^{-1}) than other sowing dates with a benefit cost ratio of 2.76. Among varieties, VL-1 produced significantly higher baby corn yield (2101.92 kg ha^{-1}) with benefit cost ratio of 2.69 followed by Prakash and Punjab Sathi. Growth parameters and yield attributes were also significantly affected due to sowing dates. Dry matter accumulation, number of baby corns per plant, baby corn length and baby corn weight followed the trend same as baby corn yield i.e. 31st March, sowing schedule remained superior than other three (15th April, 30th April and 15th May) schedules. Succeeding sowing dates from 31st March to 15th April showed significant reduction in baby corn yield.

Sulochana *et al* (2015) conducted an experiment to study the effect of date of sowing on growth, yield, and different agrometeorological indices for five maize varieties (HQPM-1, PEHM-2, Pratap Makka-5, Pratap QPM-1 and BIO-9637) by using Split Plot Design (SPD) with four replications. This study consisted of three different sowing dates (15 June, 30 June, and 15 July). In this study, June 30 and July 15 sown crops required less number of days and accumulated GDD for attaining different phenological stages as compared to crop sown on June 15. Crop sown on 30 June was recorded with higher heat use efficiency, yield potential, leaf area index and dry matter accumulation. BIO-9637 obtained higher grain yield among other varieties.

Bhusal *et al* (2016) carried out study at National Maize Research Program, Rampur, Chitwan, Nepal to evaluate the effect of sowing dates on growth and grain yield of maize inbred lines. Seven maize inbred lines namely NML-2, RML-17, RML-32, RML-4, RML-86, RML-95 and RML-96 were planted on three different dates i.e., September 02, September 12, and September 22, 2015 during winter using randomized complete block design with two replications. The results of this study revealed that the growth and yield traits were significantly affected by different planting dates. The inbred line RML-17 produced the highest grain yield whereas NML-2 gave the lowest yield during winter season. The highest yield was obtained when inbred lines were planted on September 12 and the lowest yield on September 2. The planting from September 2 to September 12 increased the grain yield. The delay in planting i.e., September 22 decreased grain yield. Therefore, September 12 planting was suitable for inbred lines to maximize grain yield production.

Shrestha *et al* (2016) conducted a field experiment on different maize cultivars planted at different sowing dates were accomplished at Kawasoti-5, Nawalparasi during spring season of 2013 to find suitable sowing date and maize cultivar for the location. The result showed that RML-4/RML-17 produced higher kernel rows ear^{-1} (13.77), kernel per row (30.42) and test weight (244.9 g). Significantly higher grain yield was also found for RML-4/RML-17 (6.03 t ha^{-1}) compared to Poshilo makai-1 (4.73 t ha^{-1}), Arun-2 (3.55 t ha^{-1}) and Local (2.92 t ha^{-1}). Earlier sowing date (7th April) produced higher kernel row^{-1} (27.97), kernel rows ear^{-1} (12.89) and 1000 grain weight (230 g). Significantly higher grain yield (5.13t ha^{-1}) was obtained in earlier sowing date (7th April).

Prasad *et al* (2017) carried out a field experiment consisting of four dates of sowing (15th June, 25th June, 5th July and 15th July)and five maize hybrids of different maturity group namely, HQPM-1 (long), HM-4 (medium), HM-5 (long), HM-6 (early) and HM-7 (extra early) to assess the effect of sowing dates on various growth parameters. Ten days advance, normal and 10 days delay sowing being at par recorded significantly higher plant height, dry matter, crop growth rate, as compared to delay in sowing by 20 days from normal sowing. Among hybrids, HM-5 recorded highest dry matter followed by HQPM-1, HM-4, HM-6 and lowest in case of HM-7. HM-5 recorded higher crop growth rate from 60 DAS to maturity.

Days to 50% tasseling, 50% silking and maturity were delayed in last date of sowing. HQPM-1 recorded highest plant height at harvest followed by HM-4, HM-7, HM6 and lowest in HM-5. HM-6 and HM-7 recorded lowest crop growth rate between 60 DAS to harvest. HM-7 and HM-6 took lower number of days to attain 50% tasseling, 50% silking and maturity stage. HQPM-1 and HM-5 being at par, took higher number of days to 50% tasseling, 50% silking and maturity as compared to HM-4.

Rani *et al* (2017) conducted a field experiment to evaluate the effect of different date of sowing, mulching and irrigation levels on microclimate and heat unit requirement of maize. In this study, it was examined that early sown crop was grown under mulch application having high photo-synthetically active radiation interception and atmospheric humidity. The study concluded that early sown crop irrigated at IW:CPE 0.75 having most significant microclimate. They depicted a linear relationship between accumulated growing degree days and yield potential.

Sheikh *et al* (2017) conducted a field experiment to assess the impact of sowing dates on phenology, growth, and quality of sweet corn (*Zea mays saccharata* L.) at SKUASTK, Shalimar during *kharif* season 2014. They assigned cultivar Misthi of Sweet corn for the study. The experiment comprised of two factors with four sowing dates viz. 24th May (D_1), 02nd June (D_2), 11th June (D_3) and 19th June (D_4) as main-plot treatments and three plant spacing viz. 60 cm x 20 cm(S_1), 70 cm x 20 cm (S_2) and 80 cm x 20 cm (S_3) as subplot treatments replicated thrice. The results of the experiment revealed that 24th May (D_1) sowing recorded significantly highest plant height and number of functional leaves as compared to other sowing dates. More number of days was taken by sweet corn sown on 24th May (D_1) and accumulated more heat compared to delay sowing.

Hassan (2018) conducted two field experiments to study the effect of sowing date on performance of hybrids yellow maize in two successive summer seasons 2016 and 2017 at the Toshka Experimental station of Desert Research Center, Abu Simbel City, Aswan Governorate. He assigned five sowing dates (March 1st, March 20th, April 10th, July 20th, and August 10th) to study the yield and its attributes of four yellow maize hybrids (S.C. 168, S.C. 176, T.W.C.353 and T.W.C. 360). The results showed that sowing date and hybrids significantly affected on plant height, number of grains per row, 1000 grain weight and grain yield kg/fed. The late sowing on 10th August produced the highest significant parameters of maize plants; plant height, No. of ears/plant, number of grains ear^{-1}, 1000-grain weight, and grain yields. On the reverse, the lowest values were obtained at medium sown on 10th April on sown T.W.C. 360 hybrid was significantly higher than other hybrids in all traits under study in two seasons.

Swethasree *et al* (2018) conducted a field experiment at Regional Agricultural Research Station Farm, Tirupati during *kharif* season, 2016, to assess the impact of dates of sowing on leaf Area Index (LAI), dry matter accumulation and yield of different maize hybrids. The three hybrids (D.S 900M, Pinnacle and CP818) are major treatments and sub treatments are four dates of sowing (June II FN, July I FN, July II FN, and August I FN). Among the hybrids, higher leaf (15.6 g plant^{-1}), stem (78.9 g plant^{-1}), tassel (2.6 g plant^{-1}) and cob weight (177 g plant^{-1}) was observed in D.S 900M on par with Pinnacle and CP818. Pinnacle recorded numerically higher yield (3006.58 kg ha^{-1}) than D.S 900 M (2748 kg ha^{-1}) but was significantly higher than CP818 (2678.4 kg ha^{-1}). Among the dates of sowing, D1 (June II FN) recorded significantly higher yield (3684.36 kg ha^{-1}) than D2 (3207.72 kg ha^{-1}), D3 (2628 kg ha^{-1}) and D4 (1724.26 kg ha^{-1}). Hence, the hybrid Pinnacle sown at June II FN gave the best yield compared to the other interactions of hybrids and dates of sowing.

Khanal *et al* (2019) conducted field experiment to assess the effect of sowing dates on growth and productivity of maize hybrids in spring season at Lamahi, Dang in 2019. The experiment was laid out in two factor factorial Randomized Complete Block Design with four replications. The treatment consisted of combination of three different sowing dates (February 1, February 12 and February 23) and two maize varieties (Arun-2 i.e., OPV and hybrid Bioseed-9220). The result revealed that earlier planting on February 1 produced the highest yield (8265 Kg ha^{-1}) which was significantly superior to latter planting of February 12 (6099 kg ha^{-1}) and February 23 (5934 kg ha^{-1}). The higher yield in earlier planting was due to significantly higher no of kernel per ear, non-significant but higher number of cobs per unit area, thousand grain weight. Similarly, Bioseed 9220 produced higher yield (7798 kg ha^{-1}) compared to Arun-2 (5,734 kg ha^{-1}). The higher yield of hybrid Bioseed 9220 was because of higher number of cobs per unit area harvested and more number of kernels per cob.

Bonea (2020) conducted an experiment at ARDS Simnic, Craiova to examine the effect of sowing environments on phenophases, yield, and quality parameters of maize. Delay in sowing of crop was found to affect phenophases of maize crop leading to reduced period of phenophases and growing degree days. The grain yield and HUE were significantly more as compared to the crop sown at later.

Dadapeer *et al* (2020) conducted a field experiment to know the crop weather relationships under different sowing windows and hybrids in maize at the College of Agriculture, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, during *Kharif* 2015. There were eight treatment combinations, including four-date of sowing (15th June, 30th June, 15th July and 30th July) and two hybrids (PAC740 and CP-818). The results showed that maize sown on 15th June recorded highest grain yield (7632.57 kg ha^{-1})

and among the hybrids, CP-818 (7060.72 kg ha^{-1}) was found superior to PAC-740 (6776.93 kg ha^{-1}).

Jajoria *et al* (2020) conducted an experiment during *kharif* season of two consecutive years 2013 and 2014 at the Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur to evaluate the effect of sowing dates on yield attributes and yield of maize cultivars. The experiment was conducted using two sowing dates with four cultivars (Pratap HQPM – 1, Bio – 9637, Pratap Makka – 3 and Pratap Makka – 5). The results showed that 25^{th} June sown maize recorded significantly higher yield attributing characters viz. cobs $plant^{-1}$, grains cob^{-1} and 1000 grains weight as compared to 15^{th} July sown maize. 25th June sown maize also gave significantly higher grain yield (4819 kg ha^{-1}), stover yield (8733 kg ha^{-1}), biological yield (13552 kg ha^{-1}) as compared to 15^{th} July sown maize. Amongst the cultivars of maize, Pratap HQPM–1 gave highest cob length, cob girth, grains cob^{-1}, grains row cob^{-1}, 1000 grain weight, grain yield (5098 kg ha^{-1}) and harvest index (39.86 %). Whereas Pratap Makka – 3 gave maximum stover yield (9009 kg ha^{-1}) as compared to other maize cultivars.

Kaur *et al* (2020) conducted an experiment to assess the effect of sowing dates on thermal time requirement and heat use efficiency of maize using variety PMH-1 sown on three sowing dates (D_1 -Third week of May, D_2 -Second week of June and D_3 - First week of July) under two irrigation regimes (I_1 = IW :CPE 1.0 and I_2 IW:CPE 0.75) and mulch application (M_1 : straw mulch @ 5 tha^{-1} and M_2 : without mulch) in a split plot design. The results revealed that the early sown crop (third week of May) took more number of days and heat units to attain different phenophases. Maize variety PMH-1 consumed maximum heat units of 1952˚C days for maturity under early sown condition. The heat use efficiency was highest (3.04 kg ha^{-1}°C day^{-1}) for the crop sown during June.

Sridhara *et al* (2020) conducted a field experiment at college of Agriculture, UAHS, Shivamogga during *kharif* 2015 to study the effect of date of sowing and hybrids on growth and yield of Maize (*Zea mays* L.). The experiment was laid out in randomized complete block design (RCBD) with factorial concept and replicated thrice. There were eight treatment combinations which includes four dates of sowing (15^{th} June, 30^{th} June, 15^{th} July and 30^{th} July) and two hybrids (PAC-740 and CP-818). The results showed that crop sown on 15th June recorded significantly higher plant height (201.03 cm), number of green leaves (3.03), leaf area (992.49 cm^2), LAI (0.74), total dry matter (305.65 g), cob length (22.16 cm), kernels cob^{-1} (670.93), kernel yield cob^{-1} (230.95 g), test weight (43.08 g), kernel yield (7632.57 kg ha^{-1}), stover yield (9512.56 kg ha^{-1}) and harvest index (44.52 %) as compared to other sowing dates. Among the hybrids CP -818 recorded significantly higher plant height (191.85 cm), number of green leaves (2.72), leaf area (954.32 cm^2), LAI (0.71), total dry matter (277.65 g), cob length (19.81 cm), kernels cob^{-1} (541.88), kernel yield cob^{-1} (207.71 g), test weight (39.16 g), kernel yield (7060.72 kg ha^{-1}), stover yield (8839.98 kg ha^{-1}) and harvest index (44.44%) as compared to PAC-740.

2.3 Effect of climatic variability on growth, yield, and heat unit requirement of maize

Thavaprakaash *et al* (2007) conducted a study to analyze the impact of phenology and different heat units on baby corn yield. They reported that GDD, PTU, HTU and RTD had a negative relationship whereas HUE and PTI had a positive relationship with baby corn yield.

Akpalu *et al* (2008) conducted an experiment to analyse the effect of climatic variability on maize yield by using Generalized Maximum Entropy (GME) Estimator and Maximum Entropy Leuven Estimator (MELE). They used precipitation and temperature as climatic indices and combined these indices with various input variables. They reported that change in precipitation had stronger impact on grain yield than temperature.

Meza *et al* (2008) conducted a study to assess the main impacts of climate change scenarios on maize productivity in central Chile, an irrigated Mediterranean region. The results of this study revealed that maize can be affected by climate change, with yield reductions between 10% and 30%, depending on climate change scenario and the type of hybridised. In addition, climate change will also affect other relevant variables such as the rate of development, allowing the crop to complete its growing cycle in shorter periods of time.

CropSyst model was validated for maize yield and consumptive use of water and to predict the expected yield in the year of 2038s under different scenarios. The results indicated that CropSyst predictions for yield and consumptive use were highly accurate. A_2 scenario predicted reduction in maize yield at higher rate as compared to B_2 scenario in the year of 2038. The results also demonstrated that under climate change condition, maize hybrid TWC324 was more tolerant to heat stress than TWC310 in both growing seasons. This result implied that TWC324 possess traits of yield stability under the variability of climate (Ouda *et al*, 2009).

Sowunmi (2010) conducted a study to analyse changes in various climatic and agronomic parameters for maize production in different areas of Nigeria and studied degree of variability in those parameters. The results showed that significant change in annual rainfall and temperature exhibited predominant effect on grain yield.

Oseni *et al* (2011) conducted a study to investigate the impact of climate variability on maize yield and food security. They revealed that reduction in annual and planting season precipitation had a negative impact on maize yield.

Lakshmi *et al* (2012) conducted a field study at Acharya NG Ranga Agricultural University, Andhra Pradesh to determine the effect of climatic variability over yield and stability of sweet corn hybrid (Sugar 75). This study revealed that the yield of sweet corn was mostly influenced by air temperature and temperature-based indices viz., GDD and HUE.

Kaur *et al* (2012) conducted an experiment to assess the impact of elevated CO_2 concentration and temperature on yield, evapotranspiration, and Nitrogen requirements of maize crop. They reported that elevated CO_2 level and temperature had a positive relationship with maize yield, evapotranspiration, and Nitrogen uptake.

Singh *et al* (2013) conducted a field study in Krishi Vigyan Kendra research area under Rajmata VijyarajeScindia Krishi Vigyan Kendra, Zonal Agriculture Research Station, Morena, M. P. to evaluate the impact of climatic variability on various pest infestations on maize. They reported that relative humidity and air temperature were the most responsible factors for pest infestation on maize.

Adamgbe *et al* (2013) conducted anexperiment to examine the effect of variability in rainfall features on maize yield. They involved in collection and assessment of data on rainfall and crop yield. They showed that number of rainy day and total amount of rainfall had a positive relationship with maize grain yield.

Magehema *et al* (2014) conducted a study to analyse the impact of rainfall variability on maize production. They reported that seasonal rainfall variability had a significant effect on maize yield rather than average annual rainfall. The study recommended to utilize irrigation facility inspite of depending solely on rainfed cultivation.

Deb *et al* (2015) conducted a study to evaluate the impacts of climate change on rainfed maize (*Zea mays*) yield and different agro-adaptation measures to counteract its negative impacts at Sikkim, a Himalayan state of India. Future climate scenarios for the 10 years centered on 2025, 2055 and 2085 were obtained by down scaling the outputs of the HadCM3 General Circulation Model (GCM) under for A_2 and B_2 emission scenarios. The daily maximum and minimum temperatures are projected to rise in the future and precipitation is projected to decrease (by 1.7 to 22.6% relative to the 1991–2000 baseline) depending on the time period and scenarios considered. The crop simulation model CERES-Maize was used to simulate maize yield under future climate change for the future time windows. The simulation results revealed that climate change could reduce maize productivity by 10.7–18.2%, compared to baseline yield, under A_2 and 6.4–12.4% under B_2 scenarios. However, the results indicated that the projected decline in maize yield could be offset by early planting of seeds, lowering the farmyard manure application rate, introducing supplementary irrigation, and shifting to heat tolerant varieties of maize.

Edem *et al*(2016) conducted a study to examine the effect of rainfall variability on maize production and trends in rainfall variability and maize yield. They showed that there is a low relationship between rainfall variability and maize yield.

Jabeen *et al* (2017) conducted an experiment to determine the effect of climate change on maize crop using CERES-Maize model. This study reported that grain yield had a positive and negative relation with CO_2 concentration in air and air temperature respectively.

Salvacion (2017) conducted a study to analyse spatio-temporal changes in maize climatic suitability under future climate scenario in Philippines. He reported that variations in climatic parameters had a negative effect on climatic suitability of maize.

Singh *et al* (2017) conducted the present investigation to evaluate the climatic variability patterns and its effect on maize yield. The results revealed variability in intra-seasonal rainfall, maximum temperature and annual maximum temperature effect on maize crop. The reduction in rainfall and increasing trends of seasonal maximum temperature had negative impact on maize production.

Mumo *et al* (2018) conducted a study to assess the relationship between climate variability and maize grain yield. They used Mann-Kendall test to determine trends in precipitation, maximum and minimum temperature. They reported that precipitation had a predominant impact on grain yield as compared to temperature.

Kaur (2018) conducted a field experiment at the Research Farm of the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana to analyze and manage the effect of climatic variability on evapotranspiration and water productivity of maize. The results showed that water productivity elevated with an increase in CO_2 concentration and decreased with an increase in air temperature.

Huang *et al* (2018) conducted an experiment combining model simulation of Hybrid-Maize, and a field study using meteorological data from 1954 to 2014 at one representative station in the North China Plain (NCP) to detect climate change impacts on maize yield and to assess the adaptive effects of cultivars. Three maize cultivars with contrasting lengths of growing period were grown at three specific plant densities. Cultivar with a long growing period (LG) was grown at 67500 (optimal density), 82500, and 97500 plant ha^{-1}, medium-growing (MG) cultivar at 82500 (optimal), 97500, and 112500 plant ha^{-1}, and short-growing (SG) cultivar at 97500 (optimal), 112500, and 124500 plant ha^{-1}. During the past six decades, temperature increased, and solar radiation decreased significantly in the total, vegetative, and reproductive growing periods of maize in the NCP with a slight decline in precipitation. These climate changes significantly reduced yield at a rate of 30.8, 31.3, and 25.0 kg ha^{-1} yr^{-1}, respectively, for SG, MG, and LG maize cultivars. Decline in growing degree days

(GDD) use efficiency of LG cultivar with changing climate was one-fold slower than that of SG and MG cultivars. MG maize cultivar was estimated to produce the highest grain yield in NCP owing to its relatively long growing period and high tolerance of plant density. LG maize cultivar has a larger potential to adapt changing climate but has a larger difficulty in improving yield because of lower tolerance of high plant density.

Kaur *et al* (2019) conducted an experiment to analyze the effect of changes in temperature and rainfall on grain yield utilizing crop growth simulation model. They reported that elevated temperature had a detrimental impact on maize yield. They also revealed that effect of increased temperature and rainfall on growth and phenology of maize resulted in reduced grain yield.

In a field experiment at the Water Management Research Center (WMRC), University of Agriculture Faisalabad, Pakistan, Ahmed *et al* (2018) evaluated the CERES-Maize to study climate variability. During both the years of study model underestimated days to anthesis and maturity with RMSE < 2 days. However, the model predicted with a reasonable extent (RMSE value of 963 and 451 kg ha^{-1} respectively) so far as biological yield and grain yield are concerned.

Amouzou *et al* (2019) conducted a study to assess the impact of climate change on water- and N-use efficiencies, and yields of maize in the dry savanna of northern Benin considering three soil fertility management options (return of crop residues, mineral NPK fertilizer application, and combinations of both) and three bias-corrected ensemble mean predictions (BNU-ESM, CanESM2, and MPI-ESM-MR models) of future climate (2080–2099) under Representative Concentration Pathways (RCPs) of 2.6, 4.5, and 8.5. Seasonal rainfall is projected to decrease by 2% under RCP 2.6 and by 4% under RCP 4.5, and to increase by 1% under RCP 8.5 relative to the baseline mean (1986–2005). Increasing trends in minimum temperature of +1.0 °C (RCP 2.6), +2.0 °C (RCP 4.5), +4.7 °C (RCP 8.5) and maximum temperature of +1.1 °C (RCP 2.6), +2.0 °C (RCP 4.5), +4.6 °C (RCP 8.5) are also predicted. Solar radiation was projected to decrease by about 0.4 $MJm^{-2}d^{-1}$. Under these projected climate scenarios, CERES-Maize simulated positive responses in aboveground biomass accumulation during the vegetative growth stages. The predicted increase in above ground biomass growth will be largest under RCP8.5 and smallest under RCP 2.6.

Patidar *et al* (2020) carried out simulation experiment using Agriculture Production Systems Simulator (APSIM) model to assess the impact of climate change on productivity of maize in the state Madhya Pradesh. A well-parameterized and validated APSIM model was used to simulate the effects of temperature and rainfall on maize grain and biomass yield. Increase in temperature has negative effects on both grain and biomass yield of maize. While increasing the temperature from base to 5°C, the grain and biomass yield of maize decreased by 40% and 28%, respectively. Further, increase in temperature by 1°C could reduce the grain and biomass yield by 10% and 8%, respectively. A small increase in maize yield was observed by 10% decrease of rainfall from the base. While rainfall increase by 10% or more and decrease by >20% would results in lower maize yield and biomass. The reduction in maize yield due to increase in temperature could be attributed to decrease in duration of the crop. 1 °C increase in temperature may decrease the duration of crop by 4.3 days. This study also revealed that agronomic management practices such as delaying of sowing dates could reduce the impact of climate change on crop yield to a considerable extent. By adopting the date of sowing between 7th and 14th July, it may reduce the impact of temperature on maize grain and biomass yield in central Indian condition.

Huang *et al* (2020) conducted a study by assessing future maize yield changes under 1.5°C (2018–2037) and 2°C (2044–2063) warming scenarios and investigated the adaptation potential across China's Maize Belt by optimizing the date of sowing and cultivar using the APSIM-Maize model. In comparison to the baseline scenario, under the 1.5°C and 2°C warming scenarios, the result revealed that without adaptation, maize yields would increase in the relatively cool regions with a single-cropping system but decrease in other regions. However, in comparison with the baseline scenario, under the 1.5°C and 2°C warming scenarios with adaptation, maize yields would increase by 11.1%–53.9% across the study area. Across the maize belt, compared with the baseline scenario, under warming of 1.5°C, the potential sowing window would increase by 2–17 d, and under warming of 2°C, this sowing window would increase by 4–26 d. The optimal sowing window would also be significantly extended in the regions with single-cropping systems by an average of 10 d under the 1.5°C warming scenario and 12 d under the 2°C warming scenario. Late maturing cultivar achieved higher yield than early middle maturing cultivars in all regions except the north part of Northeast China. Adjusting the sowing date by increasing growth-period precipitation contributed more (44.5%–96.7%) to yield improvements than shifting cultivars (0%–50.8%) and climate change (−53.1% to 23.0%) across all maize planting regions except in the wet southwestern parts of the maize belt.

Saddique *et al* (2020) conducted a study to assess effects of elevated air temperature and CO_2 on maize production and water use efficiency under future climate change scenarios in shaanxi province, china the crop-environment resource synthesis (CERES)-Maize 4.6.7 model was used to project the maize crop yield in the Shaanxi Province of China over future periods. In this context, the downscaled ensemble projections of 17 general circulation models (GCMs) under four representative concentration pathways (RCP 2.6, RCP 4.5, RCP

6.0, and RCP 8.5) were used as input for the calibrated CERES-Maize model. Results showed a negative correlation between temperature and maize yield in the study area. It is expected that each 1.0 ˚C rise in seasonal temperature will cause up to a 9% decrease in the yield.

Jiang *et al* (2021) conducted a study to evaluate the impacts of climate change on maize yield and partial factor productivity of nitrogen (PFPN) and explore potential adaptation strategies in Northeast China. The Decision Support System for Agrotechnology Transfer (DSSAT) model was calibrated and validated using the measurements from nine maize experiments. DSSAT performed well in simulating maize yield, biomass, and N uptake for both calibration and validation periods (normalized root mean square error (nRMSE) < normalized average relative error (nARE) < 5% and index of agreement (d)> 0.8). Compared to the baseline (1980–2010), the average maize yields and PFPN would decrease by 7.6–32.1% and 3.6–14.0 kg N kg^{-1} respectively under future climate scenarios (2041–2070 and 2071–2100) without adaptation. Optimizing N application rate and timing, establishing rotation system with legumes, adjusting planting dates and breeding longseason cultivars could be effective adaptation strategies to climate change.

CHAPTER III

MATERIAL AND METHODS

The details of methods and techniques used in the study are described in this chapter under the following heads and subheads:

3.1 Location:

Department of Climate Change, & Agricultural Meteorology, Punjab Agricultural University, Ludhiana.

3.2 Punjab and its administrative set-up

Punjab state forms a part of the northwest India extending from 29˚ 30' Northern to 32˚ 32' North latitude and 73˚ 55' East to 76˚ 50' East latitude. The state, has Himachal Pradesh to the east, Pakistan to the west, Haryana to the south and southeast, Rajasthan to the southwest and Jammu and Kashmir to the north. The state comprises of the total geographical area of 50,362 sq. km forming 1.53% of the total geographical area of India. The Punjab state consists of 5 divisions, 22 districts, 90 Tehsils, 81 Sub- Tehsils and 149 blocks (Anonymous 2018).

3.3 Climate

The large variations in temperature from month to month are due to subtropical latitudinal location and geography of Punjab. Mid-May and June usually experiences the maximum temperature, remaining above 40°C during this period in the whole region. The minimum temperature is recorded from December to February, remaining below 5°C for almost two months during the winter season. There is a balanced combination of heat during summer, rain during monsoon and cold during winter. The rainfall for the region is mostly provided by the monsoon season ranging from 250 mm to 1000 mm. The monsoon rainfall in the state is essential for growing the *Kharif* crops. The Shivalik Hills experiences the maximum falling and the desert in the west experiences the minimum falling.

Table 3.1 Weather parameters recorded in Agrometeorological observatory (*Kharif* 2020-21)

Month	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Rainy Days	Wind velocity (km/hr)
	Maximum	Minimum	Morning	Evening			
May	36.9	22.3	58	28	1.6	5	5.7
June	37.6	26.5	64.6	39.2	0.3	2	5.6
July	34.4	26.6	80.6	60.8	7.5	11	5.2
August	33.6	26.8	83.1	66.8	4.7	8	4.7
September	34.5	24.9	86.6	54.5	0.5	1	2.8
October	32.6	15.9	88	28	0.0	0	2.2

3.4 Treatment and experimental details

A) Experiment No. 1

I) Data collection

3.4.1 Weather data collection:

The data with respect to maximum and minimum temperature was collected from the

- Department of Climate Change and Agricultural Meteorology
- India Meteorological Department, Chandigarh

3.4.2 Crop data collection: District wise data on maize productivity for different regions of Punjab was collected from statistical abstracts of Punjab.

3.4.3 Computation of long-term thermal requirements, heat use efficiency of maize and its spatial interpolation:

The thermal requirements and heat use efficiency of maize were computed by using the following equations

- Growing Degree Day (GDD) = [Tmax + Tmin] / 2 – Tb

 Where,

 Tmax – Total Maximum Temperature (°C)

 Tmin – Total Minimum Temperature (°C) and

 Tb – Base Temperature (10°C) (Nielsen and Hinkle, 1996)

- HUE (kg/ha/°C days) = Yield (kg ha^{-1}) / Accumulated GDD (°C days)

3.4.4 Effect of past climatic trend on thermal requirements of Maize

The past trend for the time series as per table given below was generated and thermal requirements was computed.

Time series	Range of the data for analysis
P_1	1991-1995
P_2	1996-2000
P_3	2001-2005
P_4	2006-2010
P_5	2011-2015
P_6	2016-2020

II) Spatial Interpolation of accumulated growing degree days of maize

Spatial interpolation of accumulated growing degree days of maize was done with Arc GIS 10.4 by using Inverse Distance Weighted Method (IDW). It is a technique of spatial interpolation based on group of known scattered points from which value of unknown points are calculated.

The steps used in IDW are as following:

- Click on point layer in the table of contents of Arc map that contains the attribute table we are interested in.
- Then, click on the geostatistical wizard and then select the data field.
- Inside the data field, choose the attribute which we want to interpolate.
- After the IDW, go for the rectangular extent of shape file and export the shape file and export the data to raster form.
- After exporting, do the masking of the extracted layer.
- After masking and classification, maps are generated.

B) Experiment No. 2

(I) Assessment of thermal requirements of Maize under different sowing environments

Treatment details

Crop	:	Maize (*Zea mays* L.)
Variety	:	Two
		PMH-1
		PMH-2
Date of Sowing	:	Four
		D_1 - 25 May
		D_2 - 5 June
		D_3 -15 June
		D_4 - 25 June
Design	:	Randomized block design (RBD)
Replications	:	Three
Treatments	:	8
Total No. of Plots	:	24

3.5 Cultural practices

3.5.1 Field preparation

The field was prepared with tractor drawn disk harrow and cultivator, and made ready for sowing of the crop.

LAYOUT

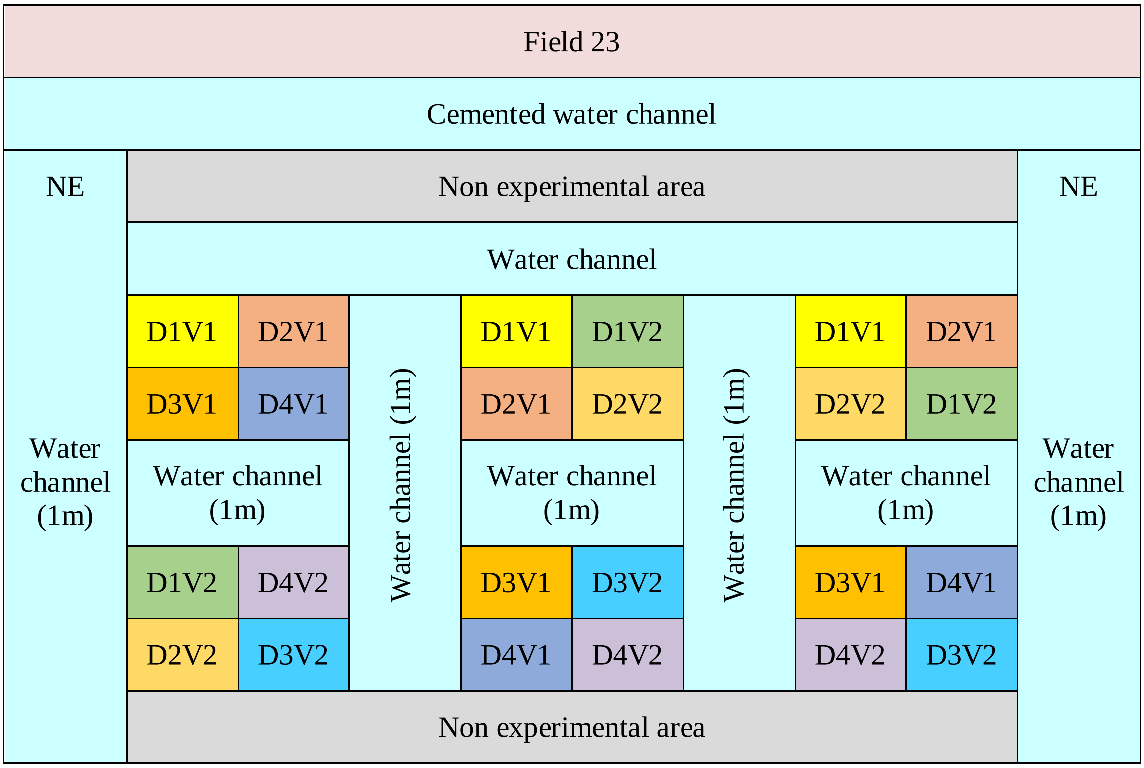

Fig. 3.1: Layout plan of experiment

3.5.2 Sowing

The seeds of PMH1 and PMH2 were sown at 3-5 cm deep in lines with a seed-cum-fertilizer drill on field. After that light and frequent irrigation was given.

3.5.3 Irrigation

The field was given 4 irrigations at 15 days interval.

3.5.4 Fertilizer Application

The fertilizers were applied as per recommendation of PAU at the rate of 110 kg N/ acre in the form of Urea, 55 kg P_2O_5/ acre in the form of DAP and 20 kg K_2O in the form of MOP.

3.5.5 Weed Management

The removal of weeds from the plot was done manually as per requirements; two hand weeding were done at 15 days interval.

3.5.6 Harvesting and Threshing

The crop was harvested manually at maturity.

3.6 Meteorological observations

3.6.1 Temperature Data

The temperature data were obtained from the agrometeorological observatory installed at the farm of Department.

3.7 Micrometeorological, observations

3.7.1 Photosynthetically active radiation

It was calculated as under:

$$\text{Intercepted PAR (\%)} = \frac{[\text{IPAR} - (\text{TPAR} + \text{RPAR})]}{\text{IPAR}} \times 100$$

Where,

IPAR, = Incoming PAR,

TPAR = Transmitted PAR,

RPAR = Reflected PAR,

3.8 Phenological Observations

Phenological data was recorded tasseling, 50% silking, dent and physiological maturity stages of maize crop.

3.9 Biometric Observations,

3.9.1 Yield data

Yield data were collected at the time of harvesting.

C) Experiment No. 3

3.10 Effect of future climate change on thermal requirements of Maize

Future climate trends were generated by using **"MarkSimGCM"** for obtaining the future temperature trends. MarkSimGCM gives the output for 17 models along with average of 17 models. The future trends for the time series as per table given below were generated and thermal requirements were computed.

Future trends of thermal requirements

Time series	Range of the data for analysis
F_1	2021-2025
F_2	2026-2030
F_3	2031-2035
F_4	2036-2040
F_5	2041-2045
F_6	2046-2050

3.11 Statistical Analysis

3.11.1 Mean – Mean was calculated as following:

$$A = \frac{A_1 + A_2 + \ldots\ldots + A_n}{n}$$

Where, A_1, A_2 are the values of a dataset, n is their number.

3.11.2 Standard error (σ_x): Standard error was calculated as following:

$$\sigma_x = \frac{\sigma}{\sqrt{n}}$$

Where σ_x is standard error, σ is standard deviation and n is sample size.

3.11.3 Mann Kendall test of trend analysis - It was developed by Mann and Kendall to identify direct or indirect trends. A normalized test statistic Z was computed as following:

$$Z = \frac{S-1}{[VAR(S)]^{1/2}} \qquad \text{if } S > 0$$

$$= \quad 0 \qquad \text{if } S = 0$$

$$Z = \frac{S-1}{[VAR(S)]^{1/2}} \qquad \text{if } S < 0$$

The probability density functions for a normal distribution of average 0 and standard deviation 1 was calculated as following:

$$f(z) = \frac{1\, e^{-(Z^\wedge 2/2)}}{2\pi}$$

3.11.4 Sen's slope estimation test

Sen's slope was estimated as following (Sen (1968); Hirsch *et al* (1982)):

$$Q_i = \frac{x_j - x_k}{j-k} \quad i = 1, 2, \ldots N,\ j > k$$

If there are n values x_j in the time series we get as many as N = (n(n-1))/2 slope estimates Q_i,

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present study entitled "**Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows**" obtained from historical, present, and future data analysis regarding the trends of thermal requirements of maize on geo-spatial domain has been presented in the graphs, tables and maps generated by Arc GIS 10.4 and are discussed under the following headings and subheadings:

4.1 Effect of dates of sowing on maize crop.

- 4.1.1 Effect of dates of sowing on the phenology of maize crop.
- 4.1.2 Effect of dates of sowing on the accumulation of growing degree days at different phenological stages of the maize crop.
- 4.1.3 Effect of dates of sowing on PAR interception at different phenological stages of the maize crop.
- 4.1.4 Effect of dates of sowing on grain yield in maize.

4.2 Spatio-temporal variability in thermal requirements of maize in Punjab under four sowing windows from 1991 to 2020.

- 4.2.1 Trend analysis of accumulated growing degree days of maize under sowing window I.
- 4.2.2 Trend analysis of accumulated growing degree days of maize under sowing window II.
- 4.2.3 Trend analysis of accumulated growing degree days of maize under sowing window III.
- 4.2.4 Trend analysis of accumulated growing degree days of maize under sowing window IV.

4.3 Decade-wise variability in Accumulated growing degree days of maize in different districts of Punjab.

4.4 Spatio-temporal variability in heat use efficiency of maize in Punjab under four sowing windows from 1991 to 2020.

4.4.1 Trend analysis of heat use efficiency of maize under sowing window I.

- 4.4.2 Trend analysis of heat use efficiency of maize under sowing window II.
- 4.4.3 Trend analysis of heat use efficiency of maize under sowing window III.
- 4.4.4 Trend analysis of heat use efficiency of maize under sowing window IV.
- 4.4.5 Variability in heat use efficiency of maize under different sowing windows

4.5 Spatio-temporal variability in thermal requirements of maize in Punjab under four sowing windows by using geospatial technology.

- 4.5.1 Spatio-temporal variability in thermal requirements of maize under sowing window I.

4.5.2 Spatio-temporal variability in thermal requirements of maize under sowing window II.

4.5.3 Spatio-temporal variability in thermal requirements of maize under sowing window III.

4.5.4 Spatio-temporal variability in thermal requirements of maize under sowing window IV.

4.6 Spatio-temporal variability in predicted thermal requirements of maize in Punjab under four sowing windows by using geospatial technology.

4.6.1 Spatio-temporal variability in predicted thermal requirements of maize under sowing window I.

4.6.2 Spatio-temporal variability in predicted thermal requirements of maize under sowing window II.

4.6.3 Spatio-temporal variability in predicted thermal requirements of maize under sowing window III.

4.6.4 Spatio-temporal variability in predicted thermal requirements of maize under sowing window IV.

4.7 Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows.

4.8 Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows.

4.1 EFFECT OF DATES OF SOWING ON MAIZE CROP

4.1.1 Effect of dates of sowing on the phenology of maize crop

Phenology is the phasic development of crop with respect to the surrounding environment. It is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant life. The expression of plant depends on many factors like heredity, temperature, photoperiod, and nutrition etc. The duration of each phenophase determines the accumulation and partitioning of dry matter in different parts (Dalton 1967).

The data regarding days taken by different maize varieties to reach different phenological stages i.e., tasseling, silking, dent and physiological maturity sown under four growing environments shown in Table 4.1. The crop shows the variation because of variation in weather conditions/factors viz. temperature and relative humidity in the atmosphere during the crop growth and phenophasic change based on change with growing environments. Thus, crop sown on 25th May (D_1) took greater number of days to reach maturity stage as compared to delayed growing environments on 25th June (D_4). The early sown crop takes more number of days to reach phenological stage. Analysis of variance shows sufficient variation among varieties in all growing environments and yield. This might be due to the early sowing of crop that was sown in optimum temperature which took more number of days for flowering and maturity as compared to late sown crop. Apart from these phenophases, other phenological events also decreased by some days under delayed sown condition. These statements are agreeing with the findings of Kaur (2019), Narwal *et al* (1986), Tsimba *et al* (2013) and Amgain (2011).

Table 4.1: Phenology of maize crop under four sowing windows

Phenology	Sowing Window I	Sowing Window II	Sowing Window III	Sowing Window IV
Sowing	25 May	5 June	15 June	25 June
Tasseling	27 June	2 July	12 July	26 July
50% Silking	4 July	15 July	24 July	31 July
Dent	17 July	31 July	9 August	14 August
Physiological maturity	23 August	27 August	2 September	9 September

4.1.2 Effect of dates of sowing on the accumulation of growing degree days at various phenological stages of the maize crop

Growing degree days is an index used in agriculture to estimate sowing time and dates of different phenological stages. It is a heat index that enables us to predict maturity dates. Accumulated growing degree days (AGDD) are a measure of warmth that plant has accumulated over the past days. Maize is a thermo-sensitive crop and temperature is the main limiting factor for the development of plant and accumulated growing degree days give the direct measure of this ‘driving factor’.

The accumulated growing degree days (GDD) of different maize varieties were described under different growing environments from sowing to maturity in Table 4.2. Highest accumulated growing degree days (GDD) were recorded under D_1 growing environment in PMH1 (1936.2) at maturity stage. In case of PMH2 the highest accumulated growing degree days (GDD) was observed under D_1 growing environments (1761.8) followed by D_2 growing environments (1713.7), D_3 growing environments (1634.3) and lowest was observed under D_4 growing environments (1514.8). Similarly, in PMH 1 the highest value of accumulated growing degree days (GDD) was observed with D_1 (1936.2) followed by D_2 (1829.9), D_3 (1731.2) and lowest was observed under D_4 (1592.7). The accumulated GDD are varying especially as per maturity period of different varieties. In general, the accumulated growing degree day values decreased with delayed sowing due to early maturity of crops under delayed sown condition because of high value of temperature at maturity. These results are in general agreement with the findings of Dahmardeh *et al* (2012), Gowda *et al* (2013) and Parashar *et al* (2014).

Table 4.2 Accumulated growing degree days (AGDD) in variety PMH 1 and PMH 2 under different dates of sowing during *Kharif* season in Ludhiana

Phenology	25 May		5 June		15 June		25 June	
	DAS	AGDD	DAS	AGDD	DAS	AGDD	DAS	AGDD
PMH 1								
Sowing	0	22.9	0	19.7	0	23.8	0	21.0
Tasseling	39	809.1	35	780.3	35	768.6	34	712.7
50 % Silking	49	1058.9	44	962.2	42	903.5	42	878.5
Dent	70	1486.1	66	1415.7	63	1345.1	59	1224.6
Physiological maturity	92	1936.2	87	1829.9	83	1731.2	78	1592.7
PMH 2								
Sowing	0	22.9	0	19.7	0	23.8	0	21.0
Tasseling	37	809.1	34	760.1	34	747.4	32	668.3
50 % Silking	41	858.1	39	820.7	38	788.7	36	734.0
Dent	57	1226.0	54	1162.7	54	1156.4	51	1068.5
Physiological maturity	83	1761.8	81	1713.7	78	1634.3	74	1514.8

DAS= Days after sowing
AGDD = Accumulated growing degree days (°C)

4.1.3 Effect of dates of sowing on PAR interception at various phenological stages of the maize crop

The microclimate of a crop stand is highly influenced by photosynthetically active radiation (PAR) interception. PAR is that part of electromagnetic spectrum which is used as source of energy for photosynthesis by green plants. Photosynthetically Active Radiation (PAR) is the amount of light available for photosynthesis, which is in the wavelength range of 400-700 nanometer.

The data of incoming, reflected, and transmitted PAR were recorded hourly for different phenological stages and PAR interception was calculated. Proper interception and transmission of PAR above and inside the crop canopy lead to increased production levels. Generally, interception and efficiency of solar radiation are low during early developmental stages of crop and attains peak at vegetative phase and then again start to decrease as the crop progresses towards maturity. Interception of PAR was less during morning hours, then reached maximum at noon hours (between 12 PM to 2 AM) and then again started to decrease afterwards. The data on photosynthetically active radiation (PAR) interception (%) were taken at tasseling, 50% silking, and dent stages as shown in Figs 4.1, 4.2 and 4.3 and 4.4. Taking into consideration different dates of sowing and phenological stages, the highest PAR interception of 85.0% was recorded in case of 25th May sown crop at tasseling stage while minimum interception of 68.2% was recorded for 25th June sown crop at dent stage. At tasseling stage, 25th May crop recorded PAR interception of 85.0% while 5th June, 15th June, and 25th June crop recorded 83.25%, 81.75 %and 79.75% PAR interception respectively. At 50% silking, all dates of sowing recorded PAR interception of <80%. PAR interception of 79.75%, 77.5%, 75.25%, and 72.0% were recorded for 25th May, 5th June, 15th June, and 25th June crop respectively. In case of dent stage, maximum PAR interception of 75.25% was recorded for 25th May crop followed by 5th June, 15th June and 25th June crop where, PAR interception was 72.0%, 70.0%, and 68.0% respectively. Ghosh *et al* (2017) reported that PAR interception was highest at tasseling stage as compared to other stages.

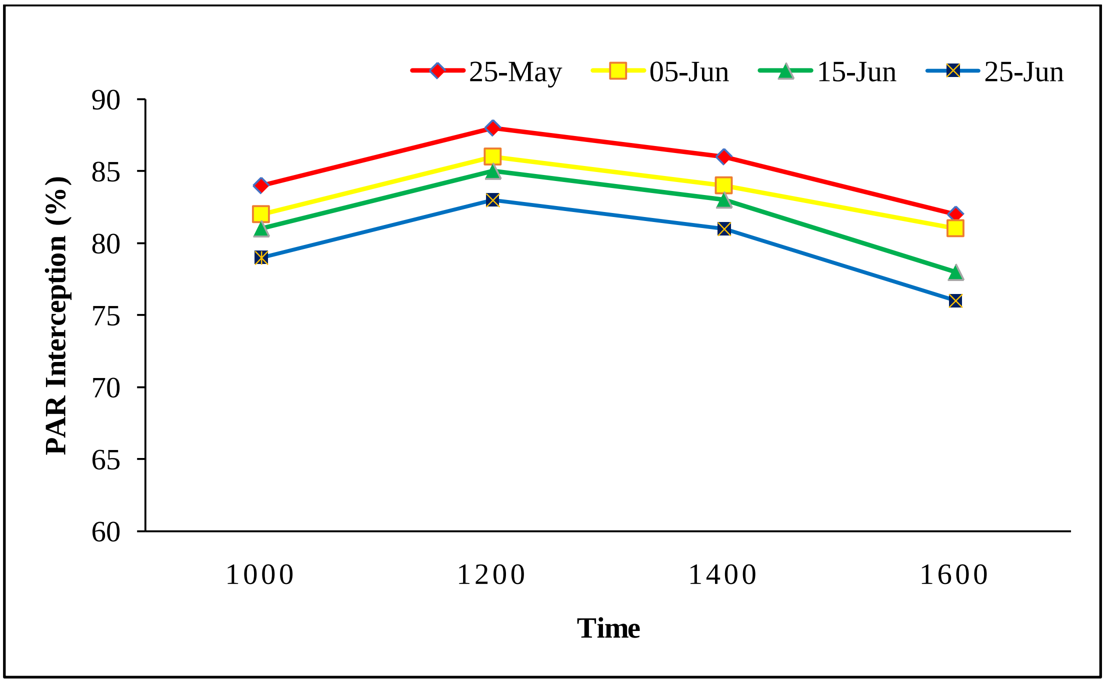

Fig. 4.1: PAR interception (%) at tasseling stage under different dates of sowing

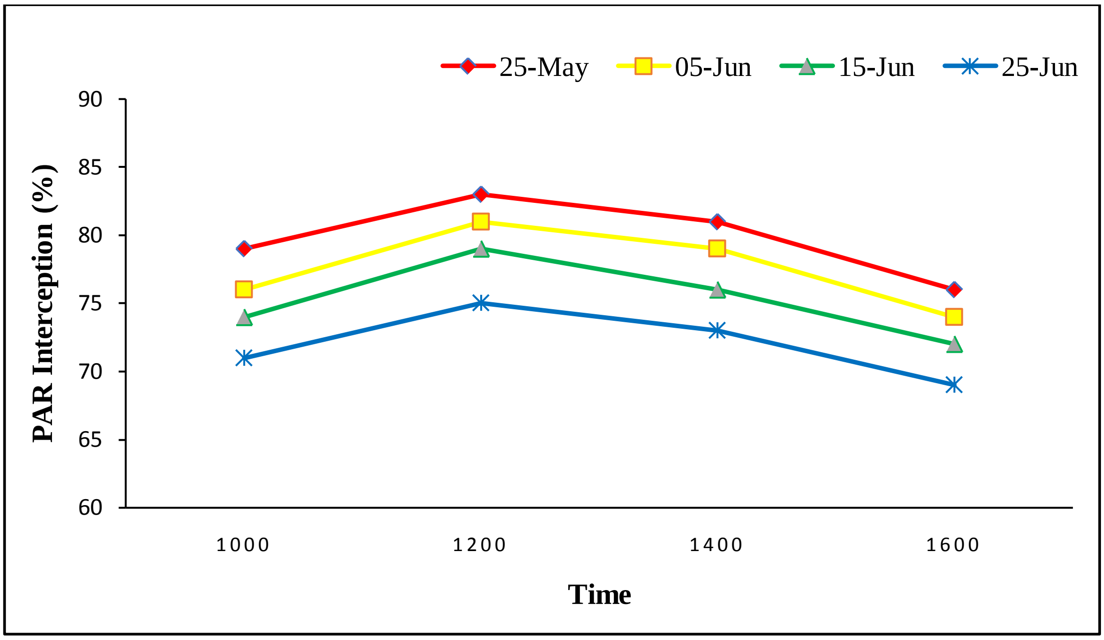

Fig. 4.2: PAR interception (%) at 50% silking stage under different dates of sowing

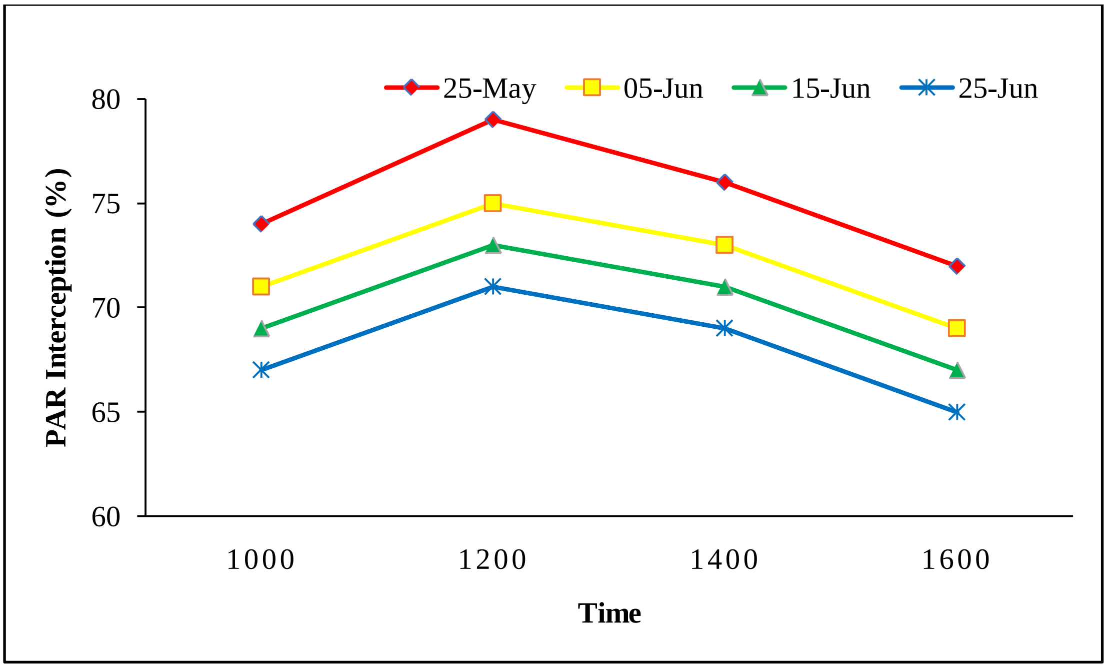

Fig. 4.3: PAR interception (%) at dent stage under different dates of sowing

4.1.4 Effect of dates of sowing and varieties on grain yield in maize crop

Sowing dates and Varieties had significant effect on grain yield. Among the dates of sowing, D_1 resulted in maximum grain yield, but it was significantly at par with the grain yield produced by D_2 which in turn significantly at par with the grain yield produced by D_3 and which in turn significantly at par with the grain yield produced by D_4. The grain yield of cultivar PMH1 was significantly higher than the cultivar PMH2. The grain yield of cultivar PMH1 was significantly high as compared to PMH2 (Kaur 2018) (Table 4.3).

Table 4.3: Grain yield (q ha^{-1}) of maize cultivars under different dates of sowing

Dates	Varieties				
	25 May (D_1)	**5 June (D_2)**	**15 June (D_3)**	**25 June (D_4)**	**Mean**
PMH1	50.0	49.2	46.6	42.1	46.9
PMH2	43.5	45.1	42.4	39.1	42.5
Mean	46.7	47.2	44.5	40.6	
CD (P=0.05%)		Varieties		2.73	
		Dates		3.86	
		Interaction		NS	

4.2 SPATIO-TEMPORAL VARIABILITY IN THERMAL REQUIREMENTS OF MAIZE UNDER DIFFERENT SOWING WINDOWS

4.2.1 Trend analysis of accumulated growing degree days from 1991-2020 under sowing window I

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under sowing window I and presented in Figures from 4.4 to 4.20. Variation in accumulated growing degree days was observed during different time periods but the trend increased in all the districts except Ludhiana and Bathinda. Among all, the highest R^2 value was found for Gurdaspur (0.74) and lowest for Bathinda (0.09). The rate of increase in AGDD was highest for Patiala (14.81 ˚C day year^{-1}**)** followed by Kapurthala (12.41 ˚C day year^{-1}) and lowest was for Bathinda (2.20 ˚C day year^{-1}**)** and Ludhiana (2.48 ˚C day year^{-1}**)**. The rate of increase was 6.50 ˚C day year^{-1} in Amritsar, 5.09 ˚C day year^{-1} in Faridkot, 11.55 ˚C day year^{-1} in Fatehgarh Sahib, 8.13 ˚C day year^{-1} in Ferozepur, 9.07 ˚C day year^{-1} in Gurdaspur, 5.53 ˚C day year^{-1} in Hoshiarpur, 9.14 ˚C day year^{-1} in Jalandhar, 4.84 ˚C day year^{-1} in Mansa, 4.43 ˚C day year^{-1} in Moga, 9.21 ˚C day year^{-1} in Muktsar, 4.09 ˚C day year^{-1} in Rupnagar and 5.23 ˚C day year^{-1} in Sangrur, and 9.91 ˚C day year^{-1} in S.B.S. Nagar. Similar work was also done by Yin *et al* (2013) in eastern Gansu of Northwest China to show spatio-temporal variation patterns of thermal requirement of spring maize from 1961 to 2010 and the result presented a fluctuated increase in thermal requirement of spring maize growth period.

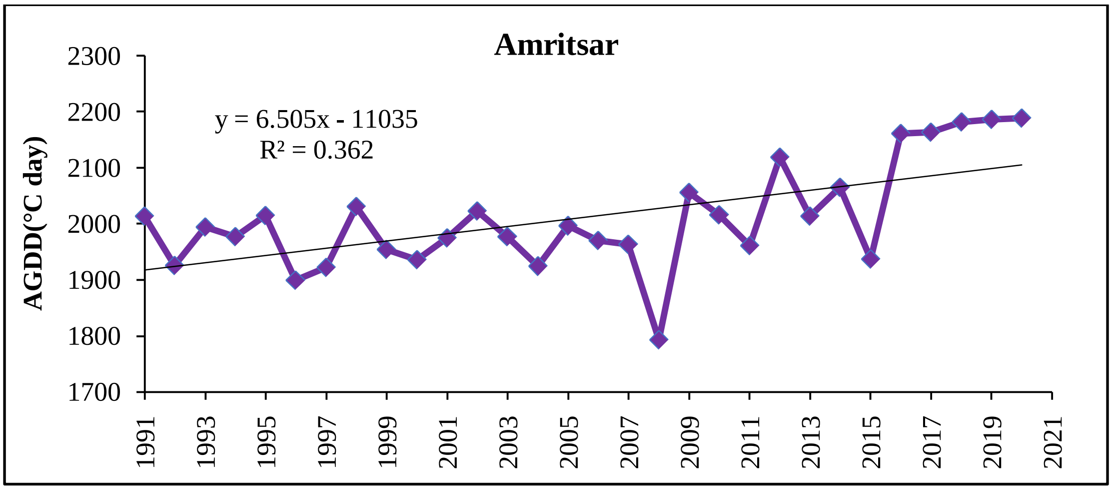

Fig. 4.4: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Amritsar under sowing window I

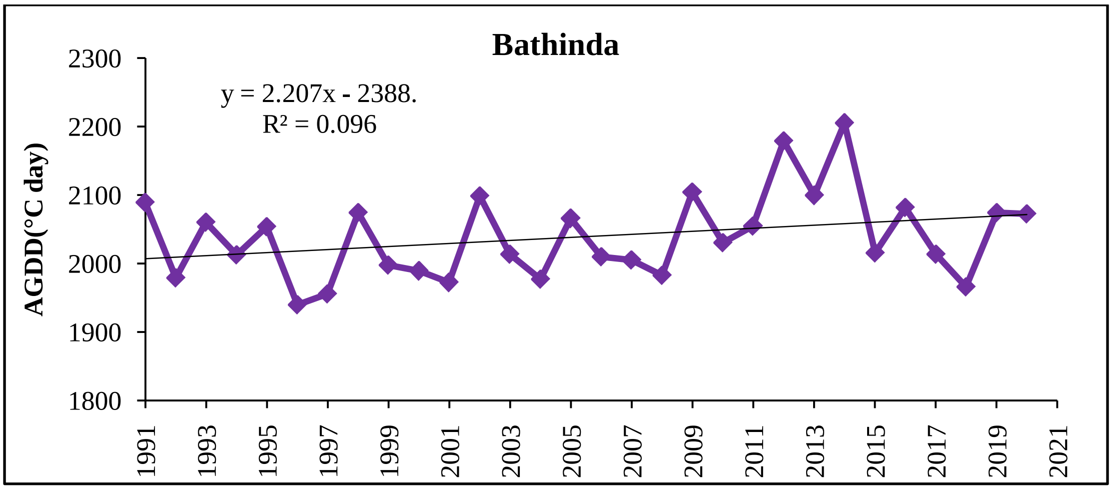

Fig. 4.5: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Bathinda under sowing window I

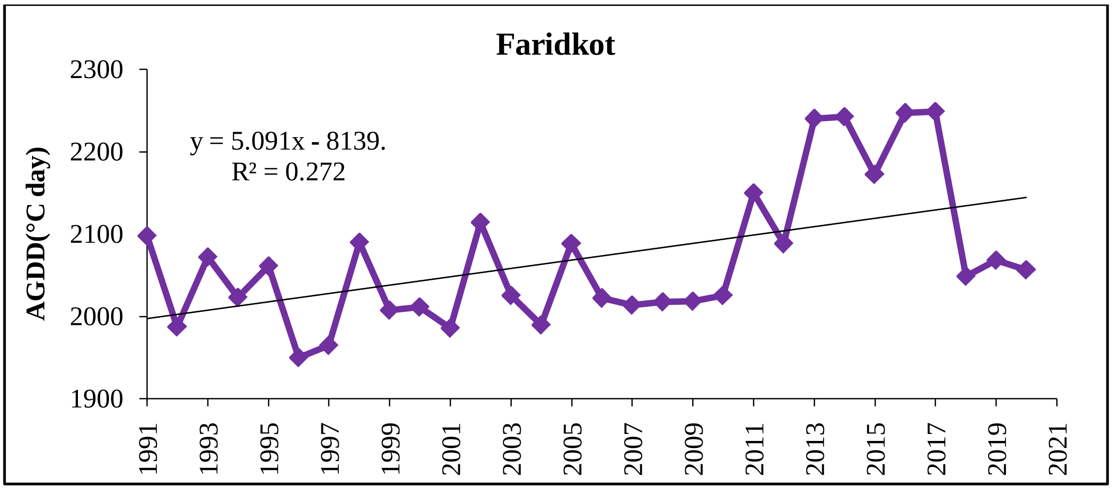

Fig. 4.6: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Faridkot under sowing window I

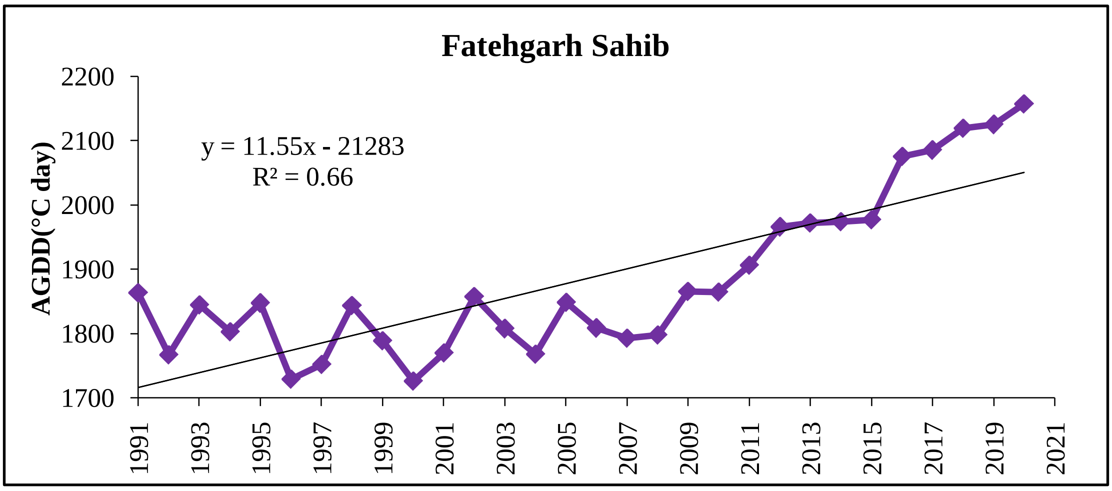

Fig. 4.7: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Fatehgarh Sahib under sowing window I

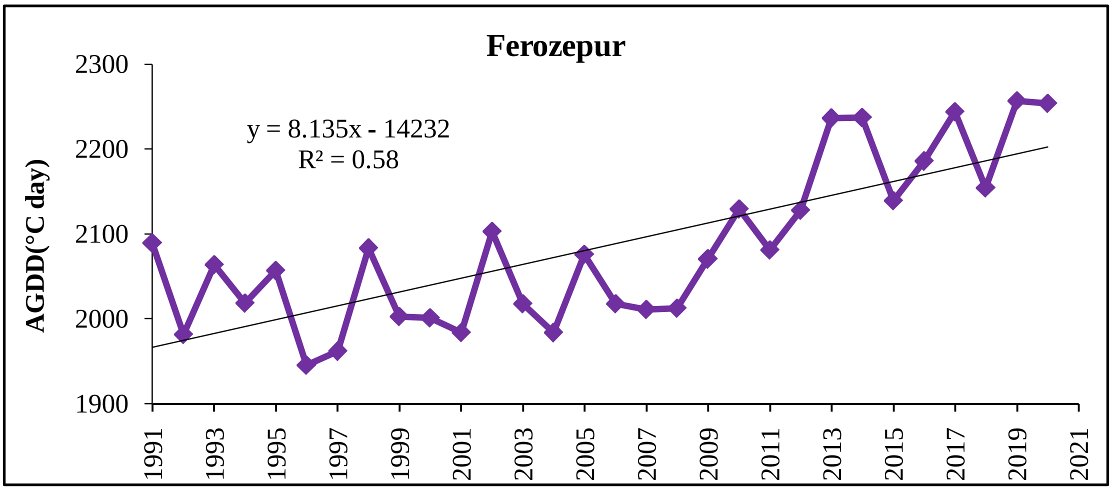

Fig. 4.8: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Ferozepur under sowing window I

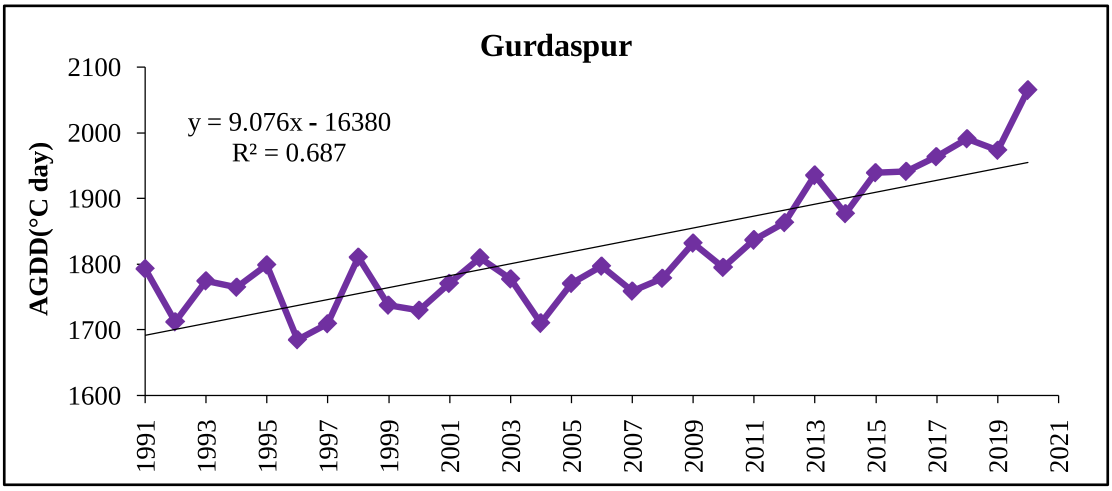

Fig. 4.9: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Gurdaspur under sowing window I

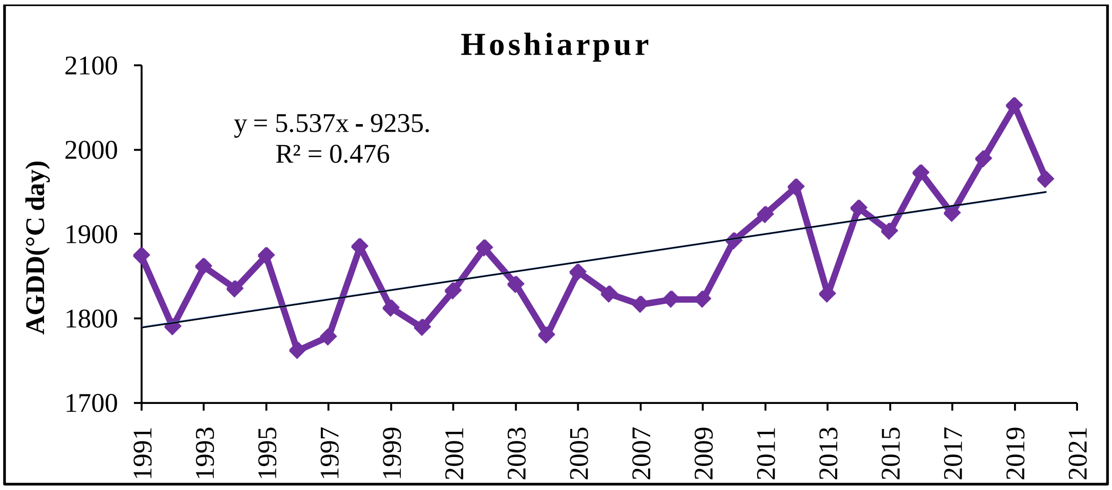

Fig. 4.10: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Hoshiarpur under sowing window I

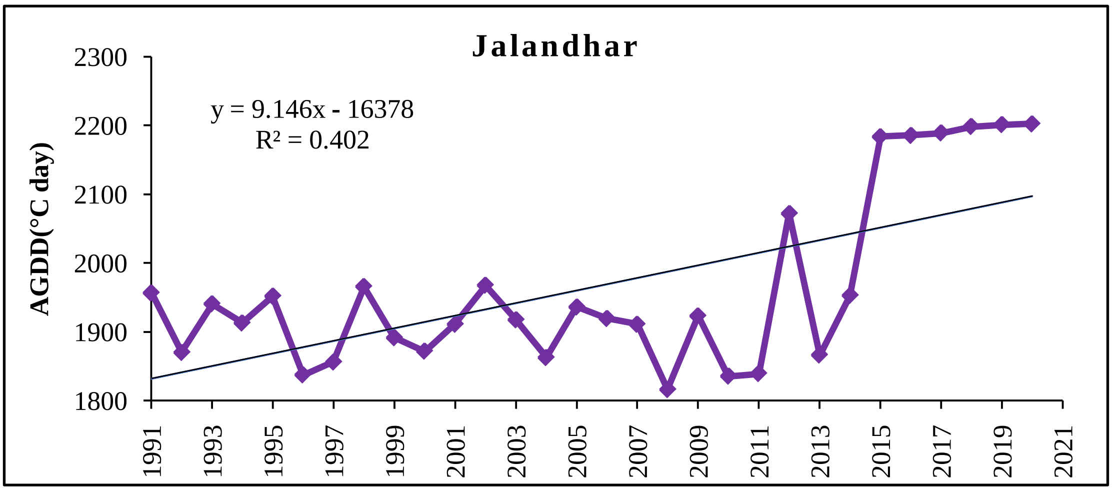

Fig. 4.11: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Jalandhar under sowing window I

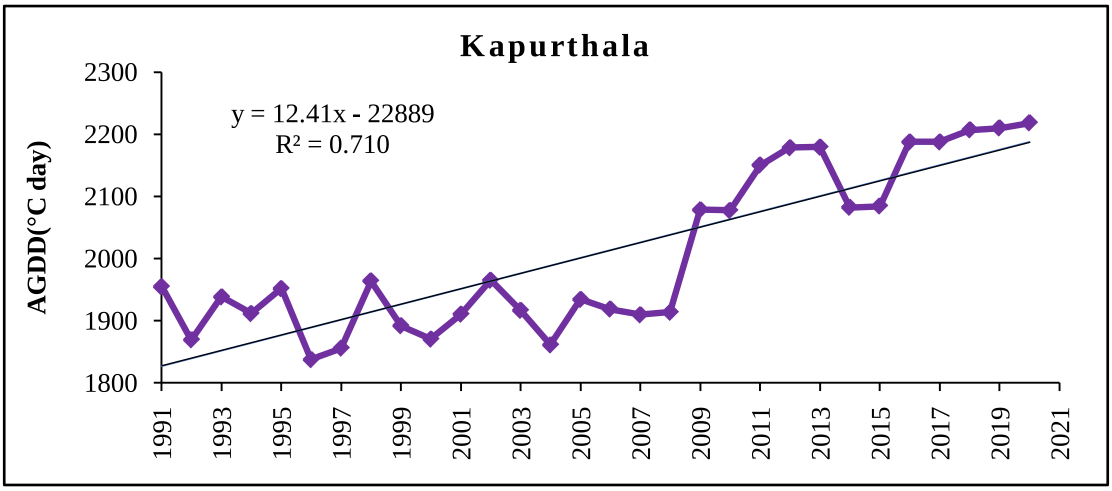

Fig. 4.12: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Kapurthala under sowing window I

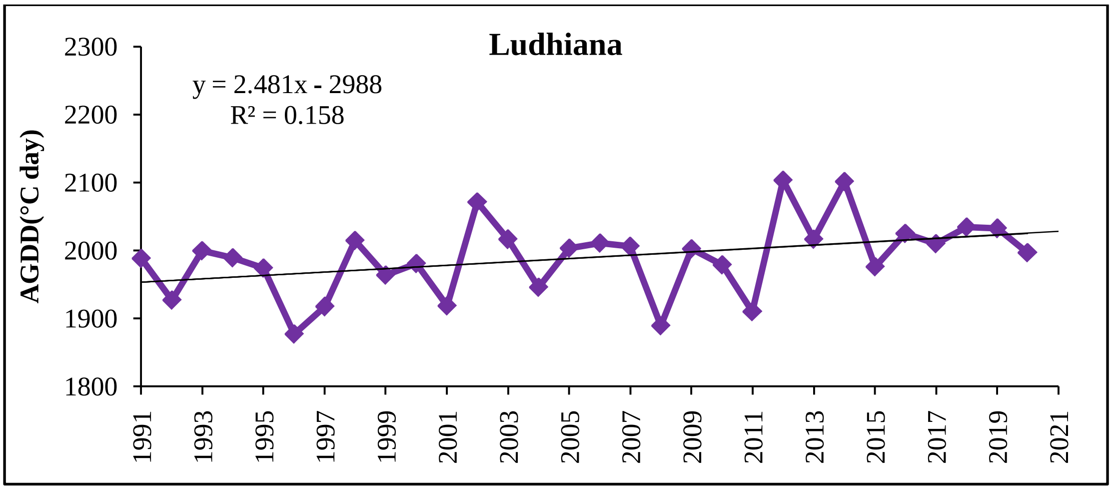

Fig. 4.13: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Ludhiana under sowing window I

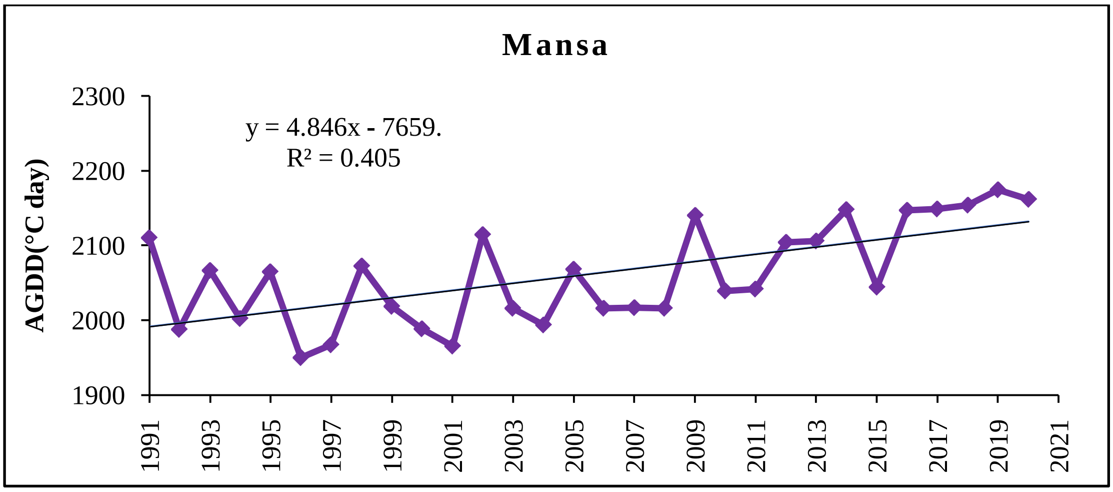

Fig. 4.14: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Mansa under sowing window I

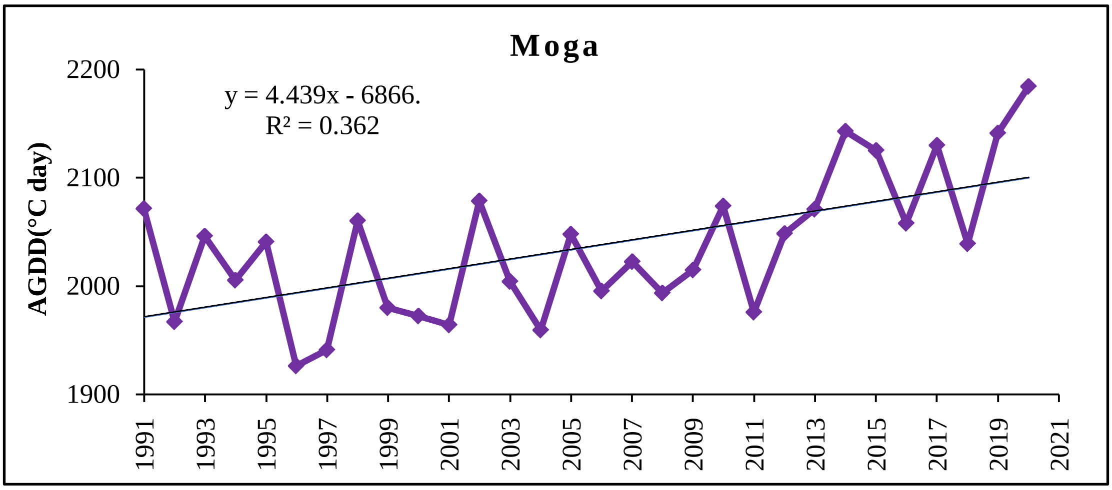

Fig. 4.15: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Moga under sowing window I

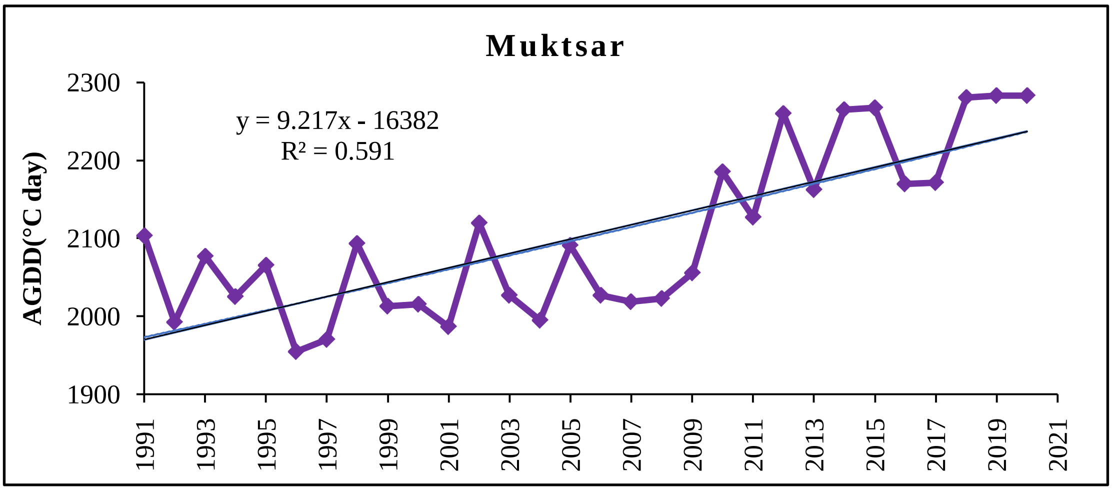

Fig. 4.16: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Muktsar under sowing window I

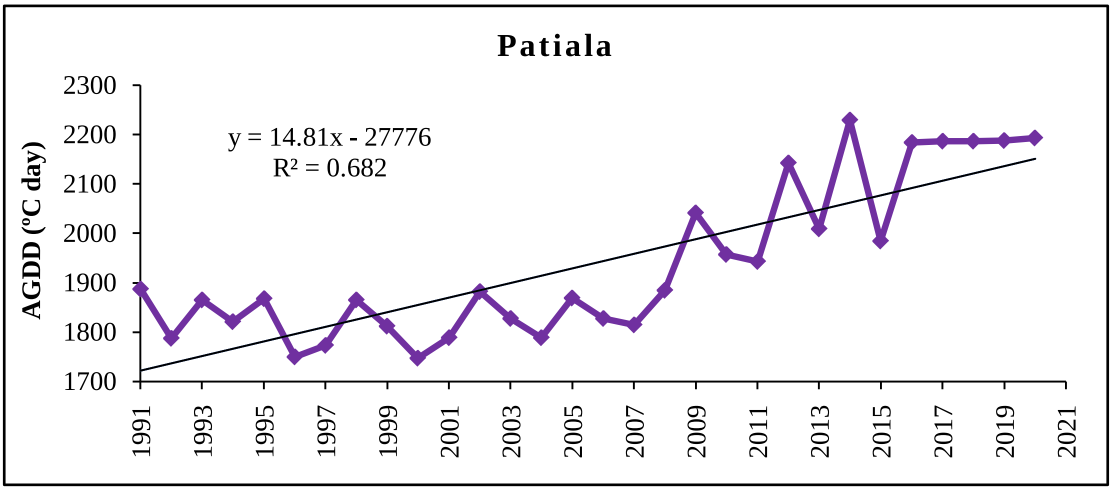

Fig. 4.17: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Patiala under sowing window I

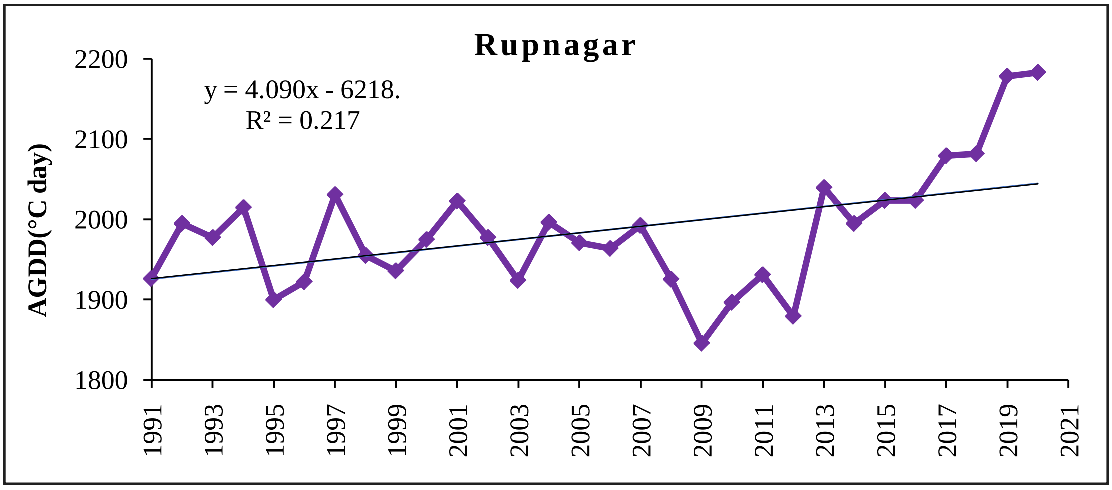

Fig. 4.18: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Rupnagar under sowing window I

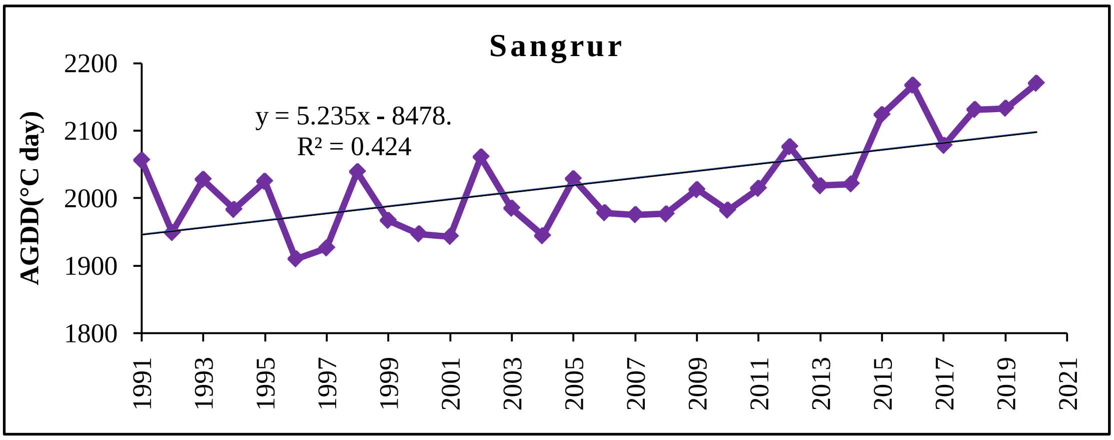

Fig. 4.19: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at Sangrur under sowing window I

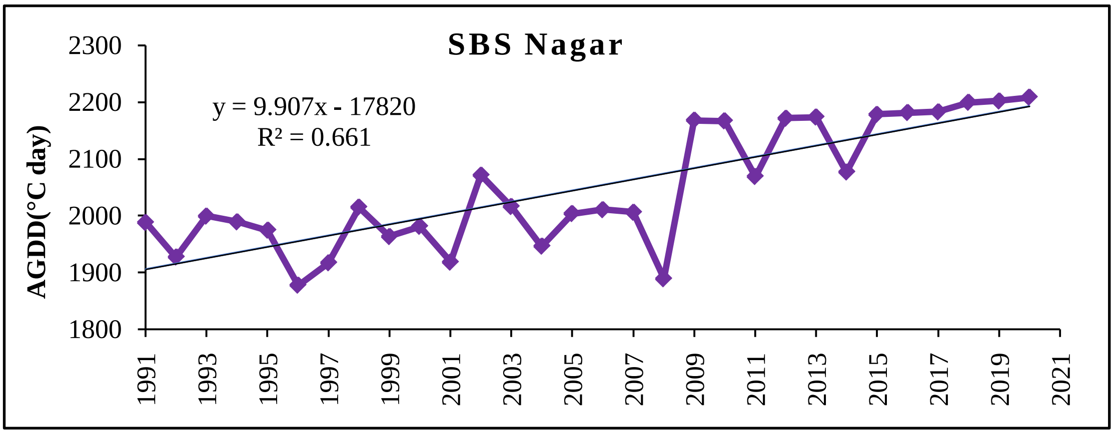

Fig. 4.20: Variability in accumulated growing degree days (AGDD) from 1991 to 2020 at SBS Nagar under sowing window I

4.2.2 Trend analysis of accumulated growing degree days from 1991-2020 under sowing window II

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under sowing window II and presented in Figures from 4.21 to 4.37. Variation in accumulated growing degree days was observed during different time periods but the trend increased in all the districts except Ludhiana and Bathinda. Among all, the highest R^2 value was found for Gurdaspur (0.74) and lowest for Bathinda (0.10). The rate of increase in AGDD was highest for Patiala (14.78 ˚C day year^{-1}) followed by Kapurthala (10.5 ˚C day year^{-1}) and lowest was for Bathinda (2.08 ˚C day year^{-1}**)** and Ludhiana (2.54 ˚C day year^{-1}**)**. The rate of increase was 6.19 ˚C day year^{-1} in Amritsar, 5.678 ˚C day year^{-1} in Faridkot, 9.90 ˚C day year^{-1} in Fatehgarh Sahib, 9.30 ˚C day year^{-1} in Ferozepur, 14.92 ˚C day year^{-1} in Gurdaspur, 8.58 ˚C day year^{-1} in Hoshiarpur, 8.88 ˚C day year^{-1} in Jalandhar, 3.95 ˚C day year^{-1} in Mansa, 6.76 ˚C day year^{-1} in Moga, 6.48 ˚C day year^{-1} in Muktsar, 7.74 ˚C day year^{-1} in Rupnagar, 8.41 ˚C day year^{-1} in Sangrur, and 9.17 ˚C day year^{-1} in S.B.S. Nagar.

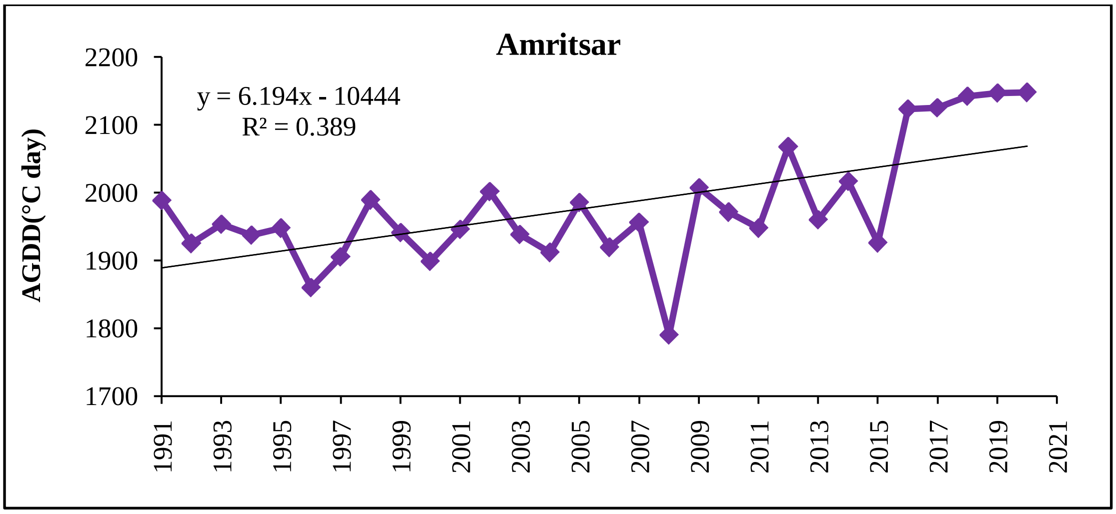

Fig. 4.21: Variability in accumulated growing degree days from 1991 to 2020 at Amritsar under sowing window II

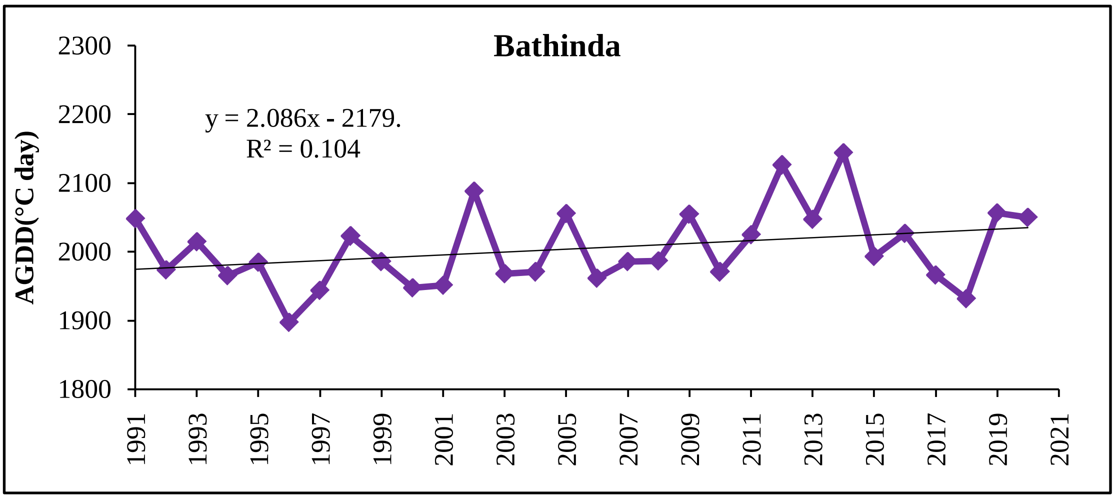

Fig. 4.22: Variability in accumulated growing degree days from 1991 to 2020 at Bathinda under sowing window II

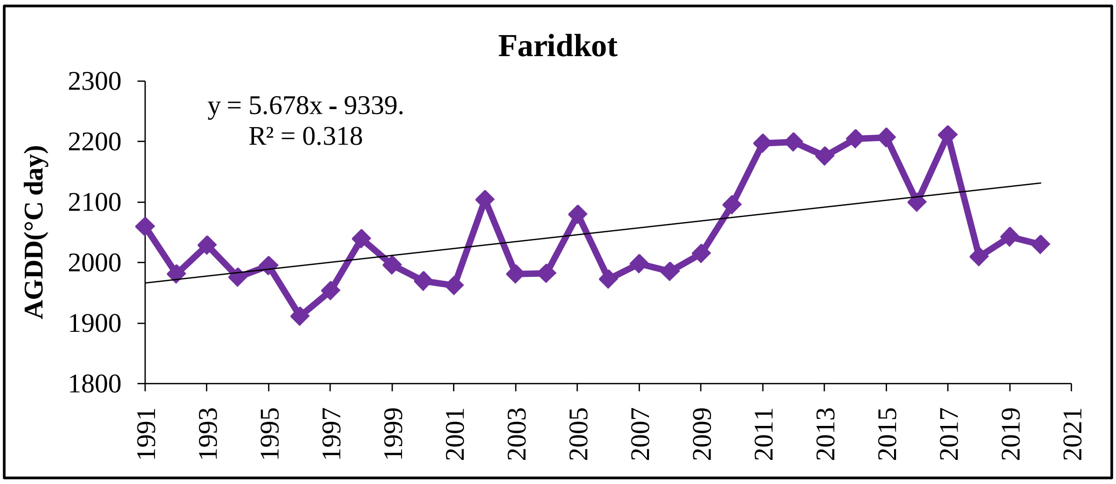

Fig. 4.23: Variability in accumulated growing degree days from 1991 to 2020 at Faridkot under sowing window II

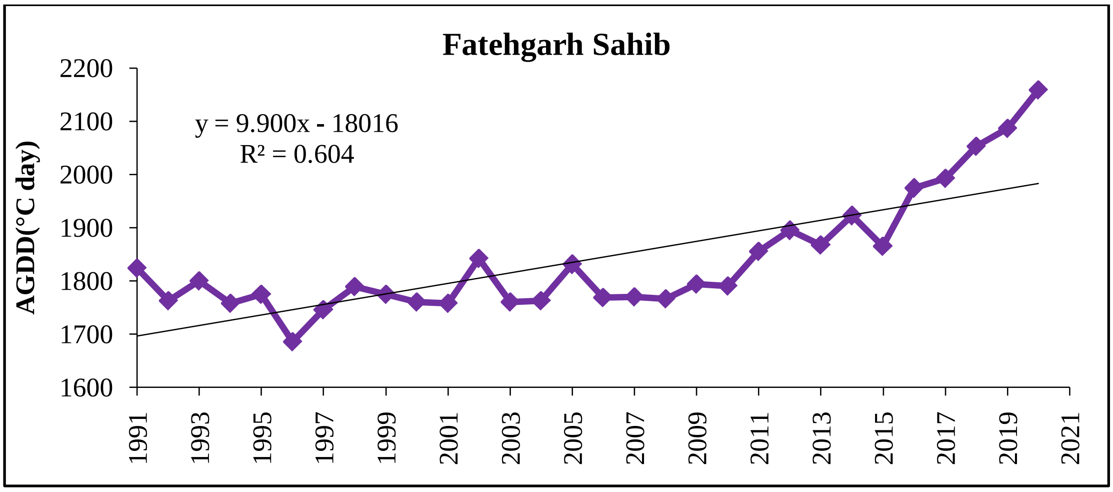

Fig. 4.24: Variability in accumulated growing degree days from 1991 to 2020 at Fatehgarh Sahib under sowing window II

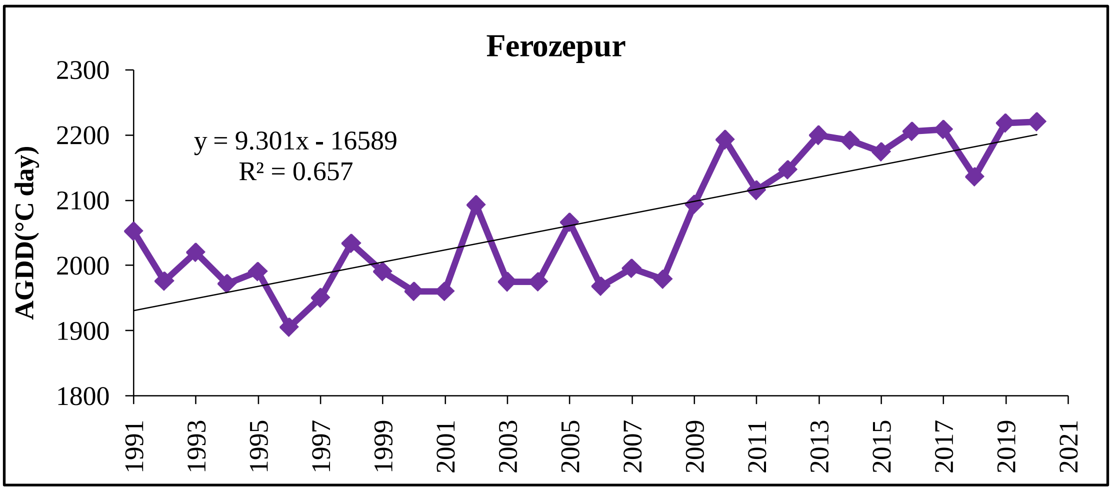

Fig. 4.25: Variability in accumulated growing degree days from 1991 to 2020 at Ferozepur under sowing window II

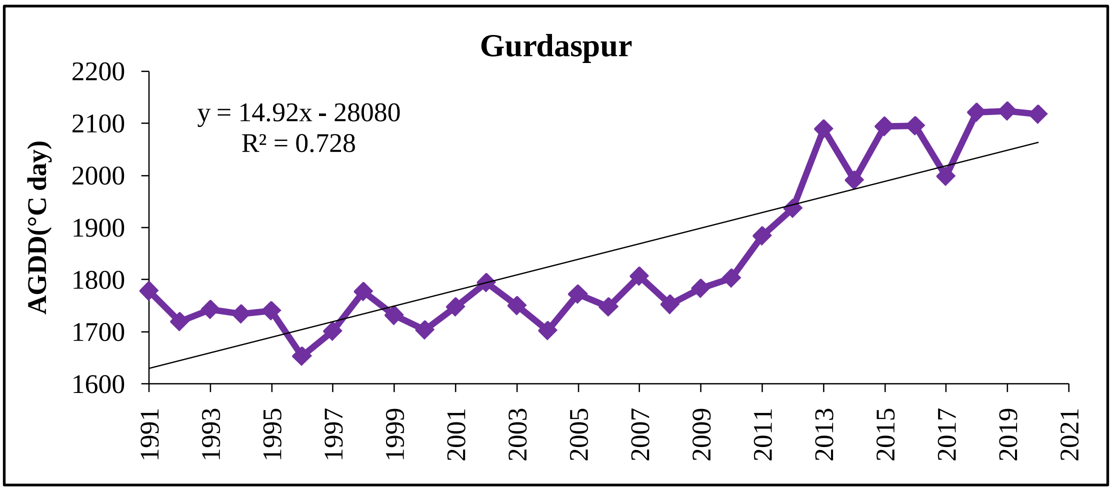

Fig. 4.26: Variability in accumulated growing degree days from 1991 to 2020 at Gurdaspur under sowing window II

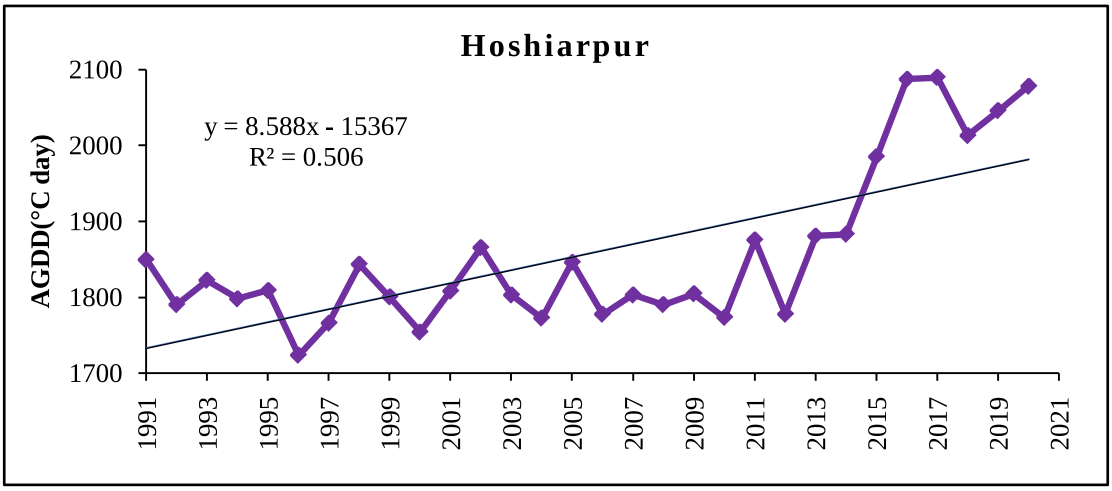

Fig. 4.27: Variability in accumulated growing degree days from 1991 to 2020 at Hoshiarpur under sowing window II

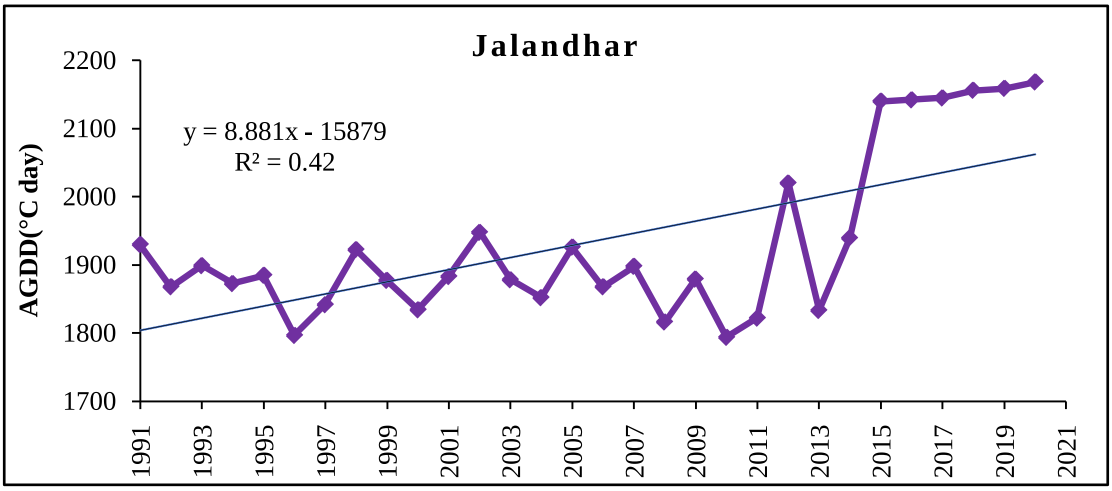

Fig. 4.28: Variability in accumulated growing degree days from 1991 to 2020 at Jalandhar under sowing window II

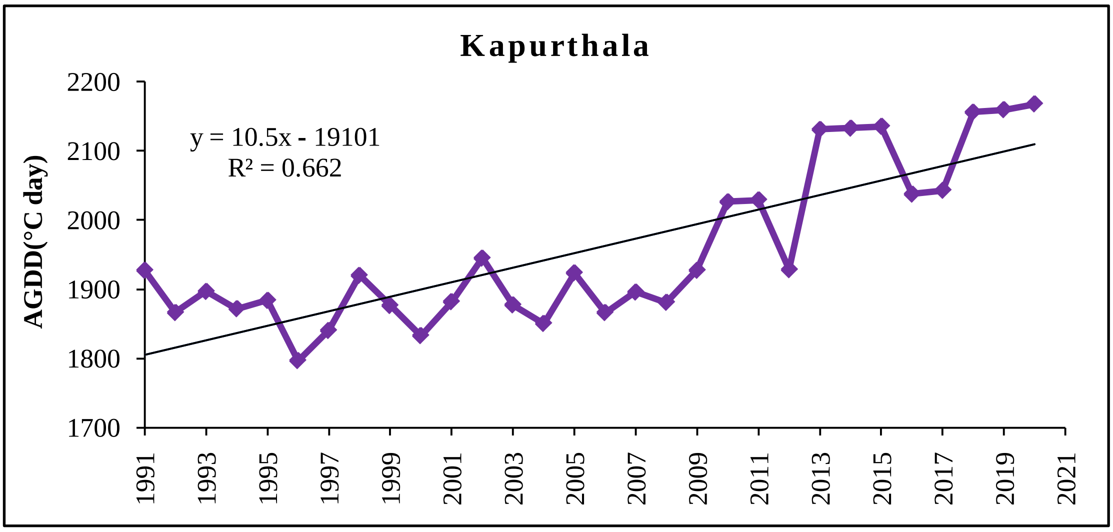

Fig. 4.29: Variability in accumulated growing degree days from 1991 to 2020 at Kapurthala under sowing window II

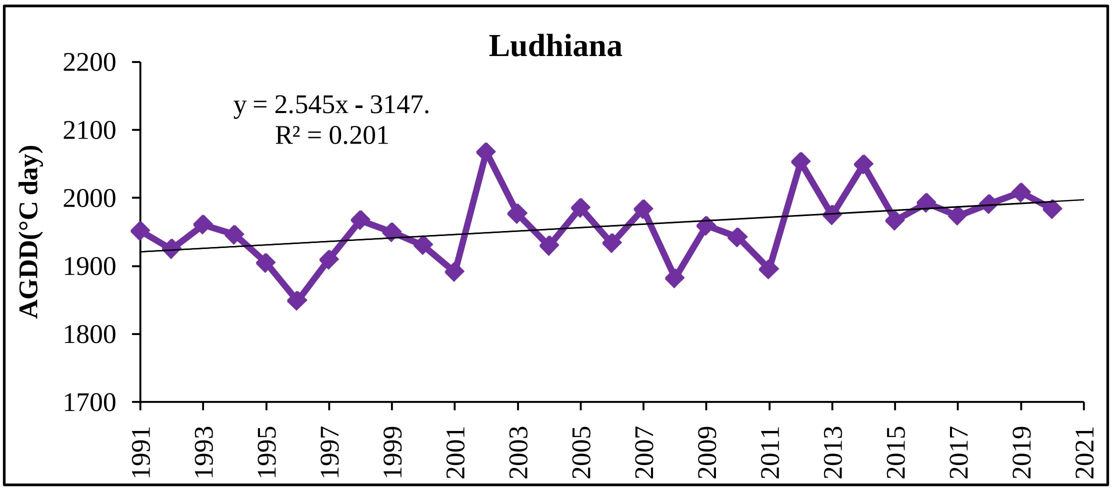

Fig. 4.30: Variability in accumulated growing degree days from 1991 to 2020 at Ludhiana under sowing window II

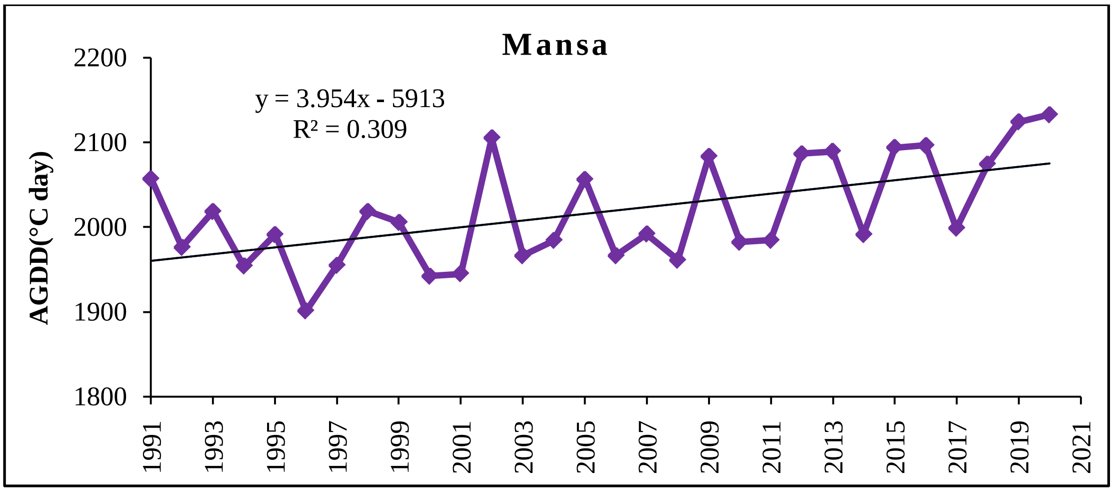

Fig. 4.31: Variability in accumulated growing degree days from 1991 to 2020 at Mansa under sowing window II

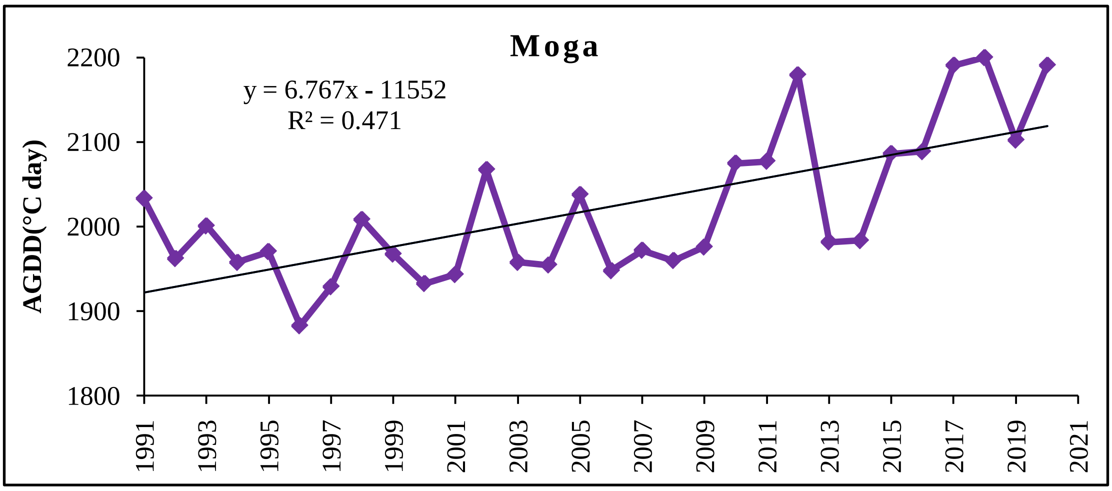

Fig. 4.32: Variability in accumulated growing degree days from 1991 to 2020 at Moga under sowing window II

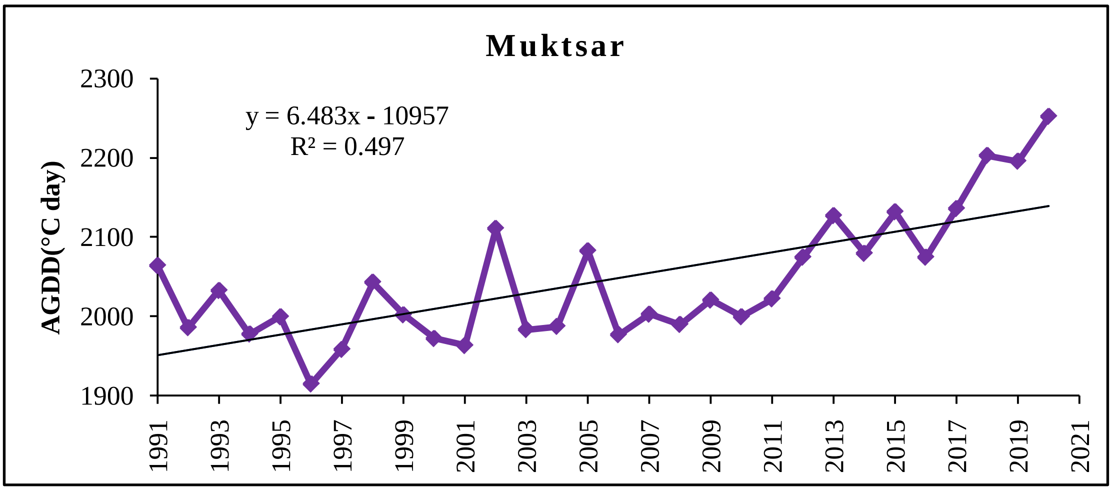

Fig. 4.33: Variability in accumulated growing degree days from 1991 to 2020 at Muktsar under sowing window II

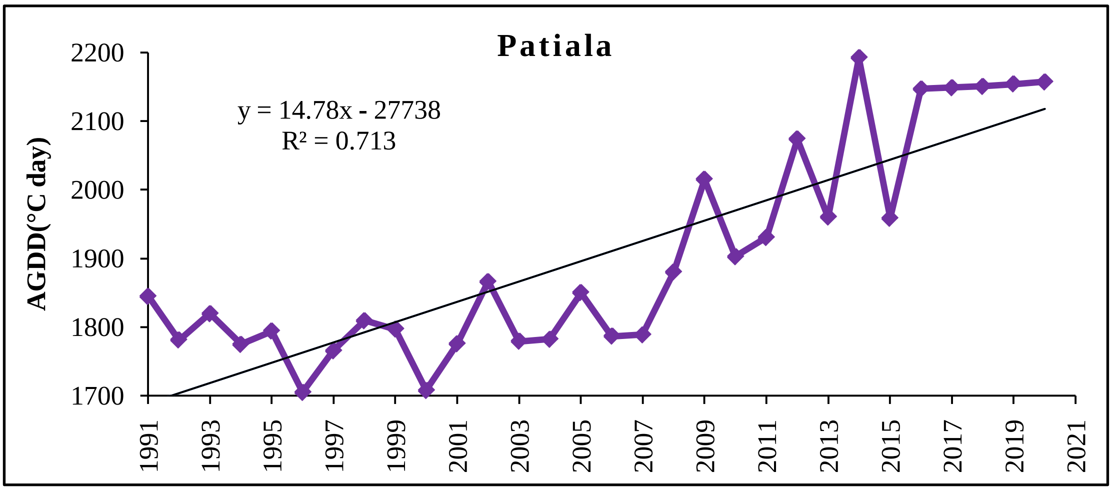

Fig. 4.34: Variability in accumulated growing degree days from 1991 to 2020 at Patiala under sowing window II

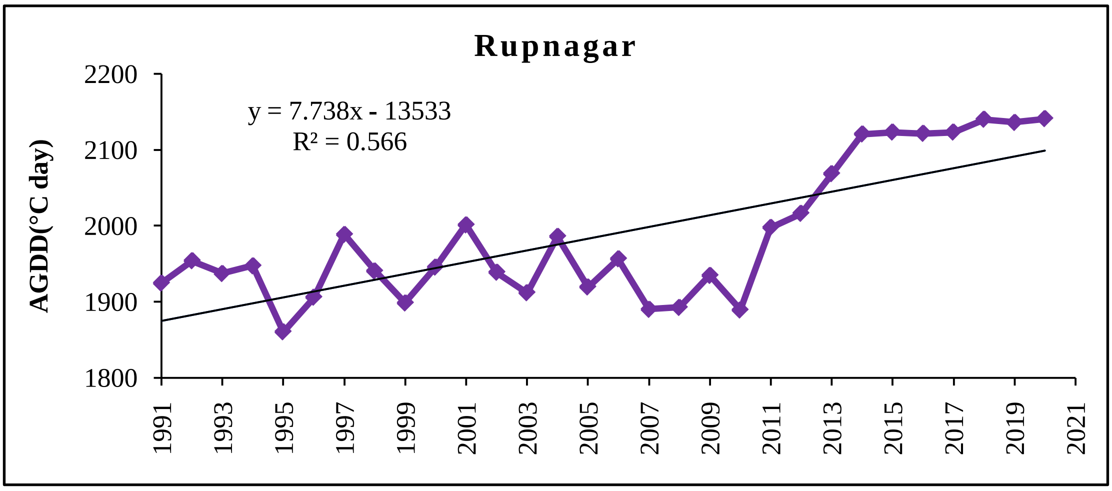

Fig. 4.35: Variability in accumulated growing degree days from 1991 to 2020 at Rupnagar under sowing window II

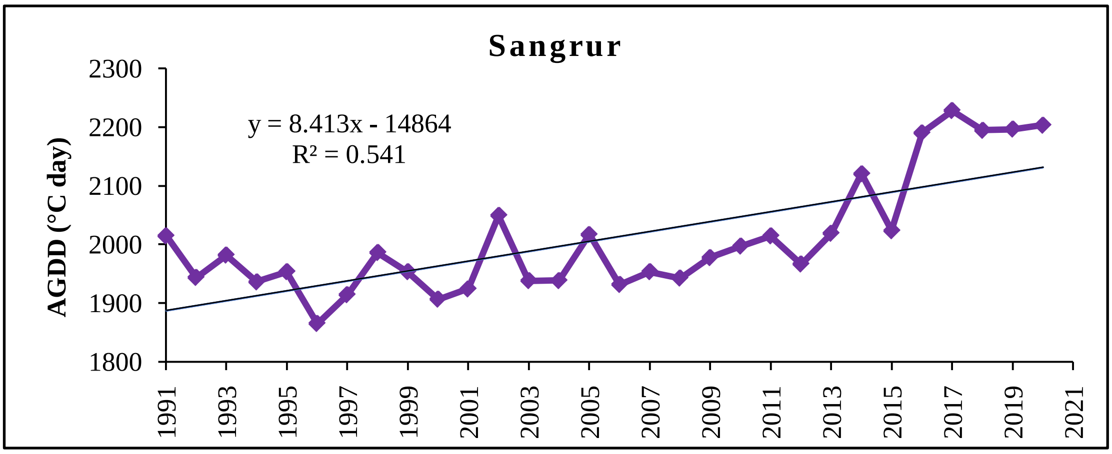

Fig. 4.36: Variability in accumulated growing degree days from 1991 to 2020 at Sangrur under sowing window II

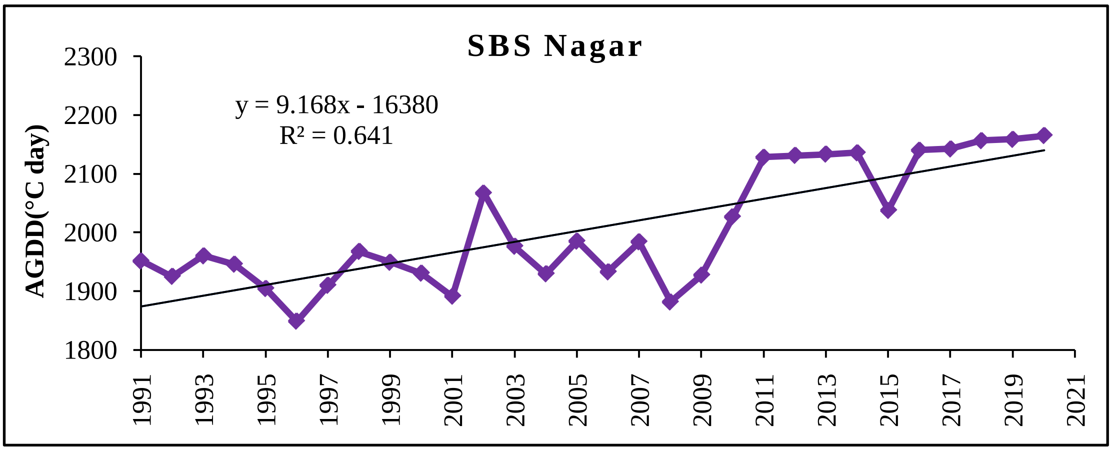

Fig. 4.37: Variability in accumulated growing degree days from 1991 to 2020 at SBS Nagar under sowing window II

4.2.3 Trend analysis of accumulated growing degree days from 1991-2020 under sowing window III

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under sowing window III and presented in Figures from 4.38 to 4.54. Variation in accumulated growing degree days was observed during different time periods but the trend increased in all the districts except Ludhiana and Bathinda. Among all, the highest R^2 value was found for Gurdaspur (0.75) and lowest for Bathinda (0.16). The rate of increase in AGDD was highest for Patiala (14.08 ˚C day year^{-1}) followed by Fatehgarh sahib (13.62 ˚C day year^{-1}) and lowest was for Bathinda (2.55 ˚C day year^{-1}**)** and Ludhiana (2.62 ˚C day year^{-1}**).** The rate of increase was 5.68 ˚C day year^{-1} in Amritsar, 5.29 ˚C day year^{-1} in Faridkot, 8.44 ˚C day year^{-1} in Ferozepur, 10.59 ˚C day year^{-1} in Gurdaspur, 10.67 ˚C day year^{-1} in Hoshiarpur, 8.04 ˚C day year^{-1} in Jalandhar, 10.71 ˚C day year^{-1} in Kapurthala, 7.21 ˚C day year^{-1} in Mansa, 6.22 ˚C day year^{-1} in Moga, 8.65 ˚C day year $^{-1}$ in Muktsar, 7.42 ˚C day year $^{-1}$ in Rupnagar, 8.413 ˚C day year $^{-1}$ in Sangrur and 7.68 ˚C day year $^{-1}$ in S.B.S. Nagar.

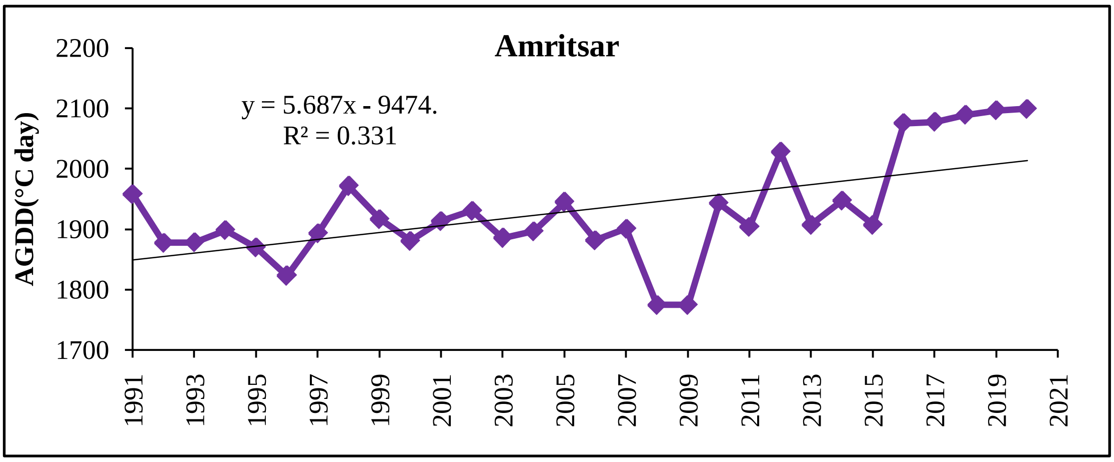

Fig. 4.38: Variability in accumulated growing degree days from 1991 to 2020 at Amritsar under sowing window III

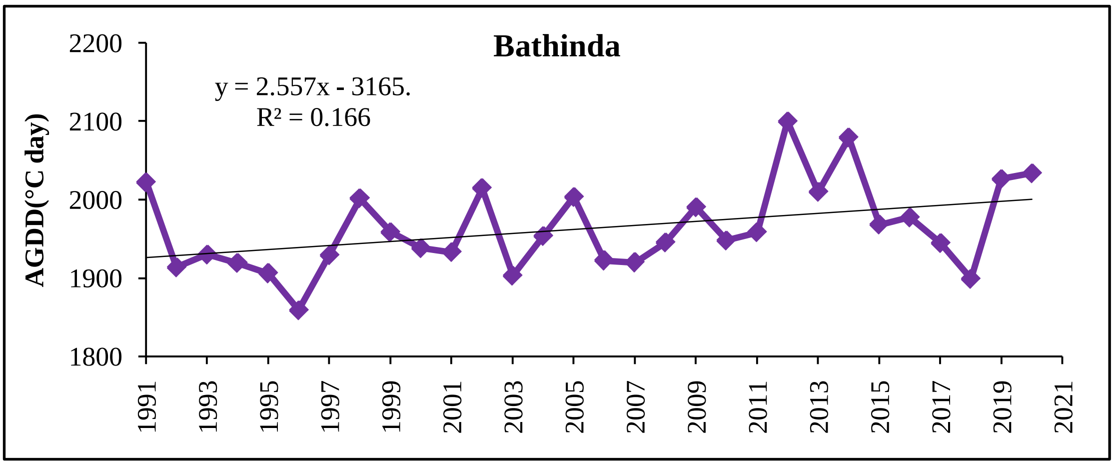

Fig. 4.39: Variability in accumulated growing degree days from 1991 to 2020 at Bathinda under sowing window III

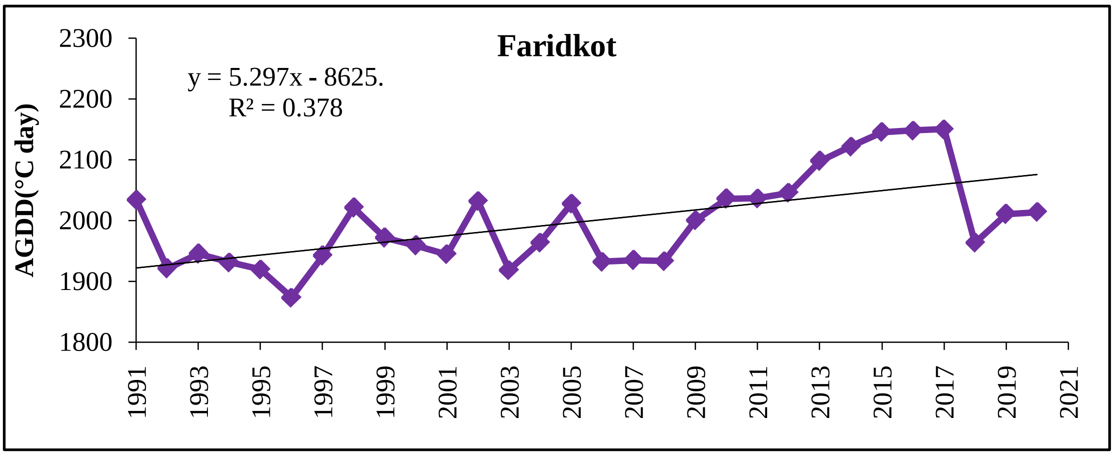

Fig. 4.40: Variability in accumulated growing degree days from 1991 to 2020 at Faridkot under sowing window III

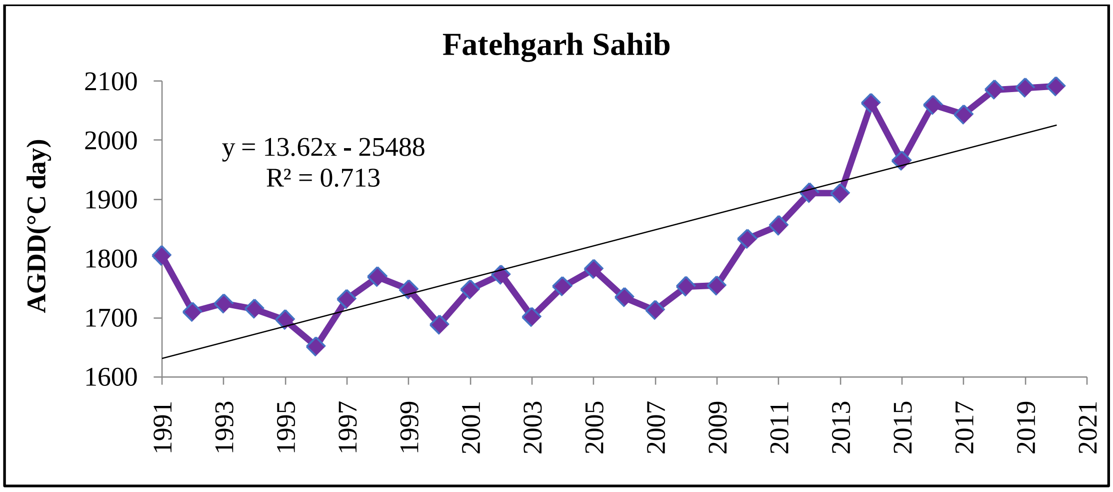

Fig. 4.41: Variability in accumulated growing degree days from 1991 to 2020 at Fatehgarh Sahib under sowing window III

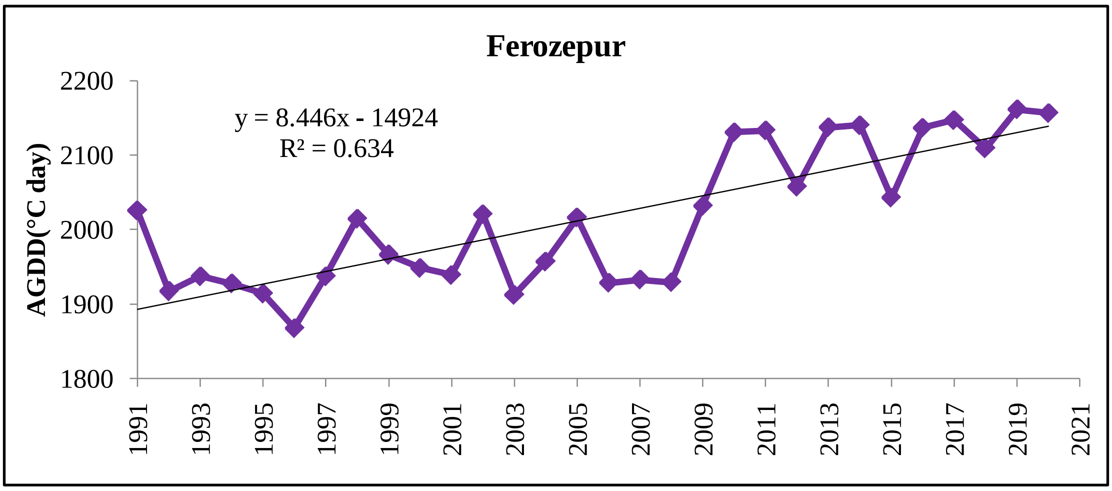

Fig. 4.42: Variability in accumulated growing degree days from 1991 to 2020 at Ferozepur under sowing window III

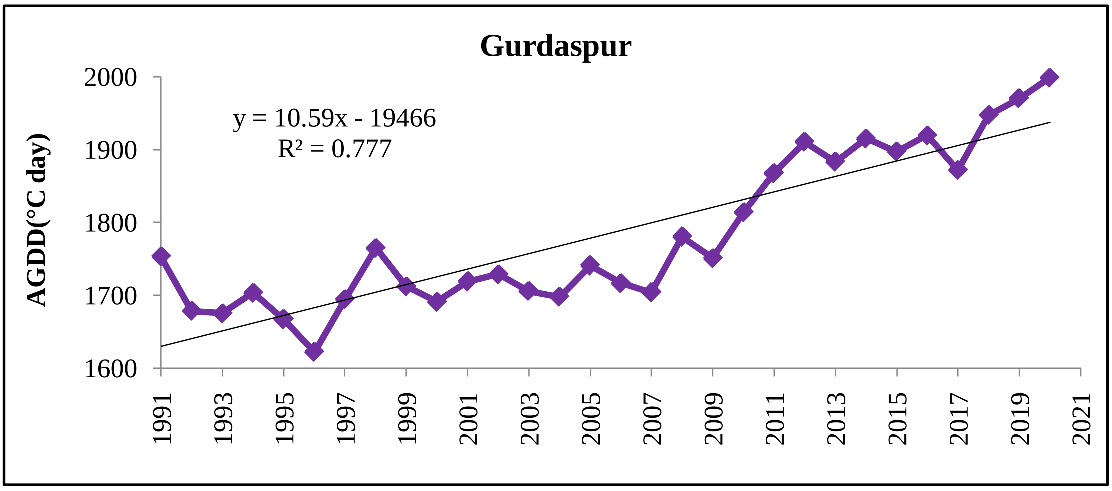

Fig. 4.43: Variability in accumulated growing degree days from 1991 to 2020 at Gurdaspur under sowing window III

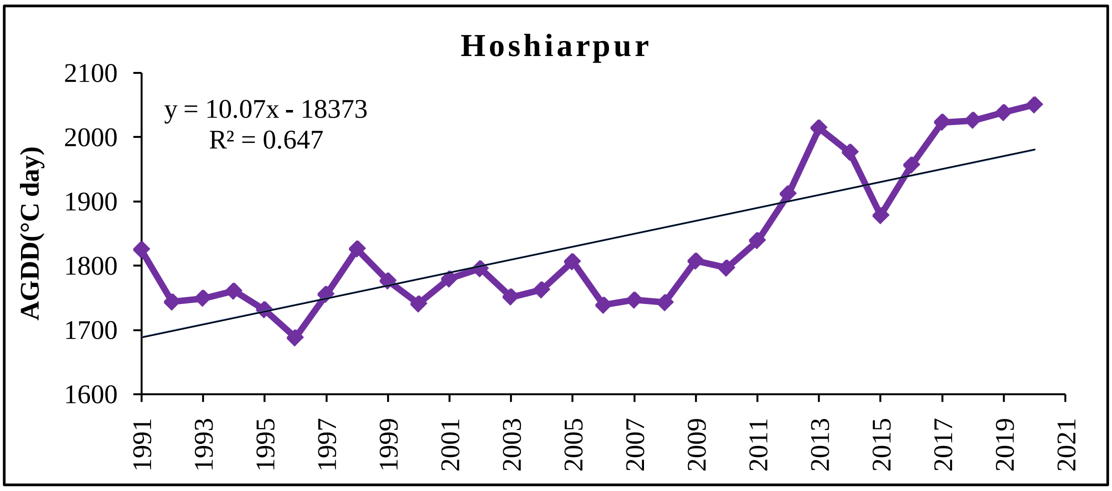

Fig. 4.44: Variability in accumulated growing degree days from 1991 to 2020 at Hoshiarpur under sowing window III

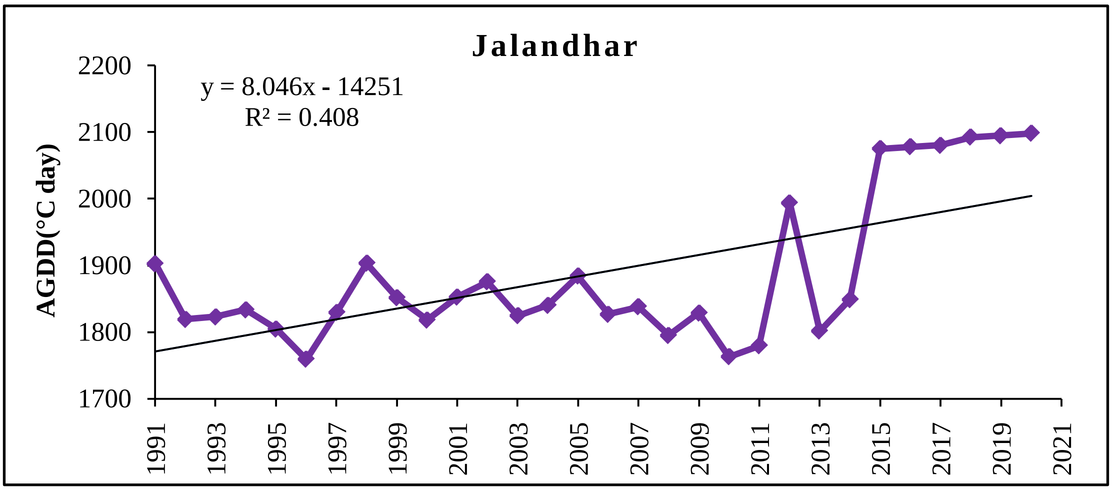

Fig. 4.45: Variability in accumulated growing degree days from 1991 to 2020 at Jalandhar under sowing window III

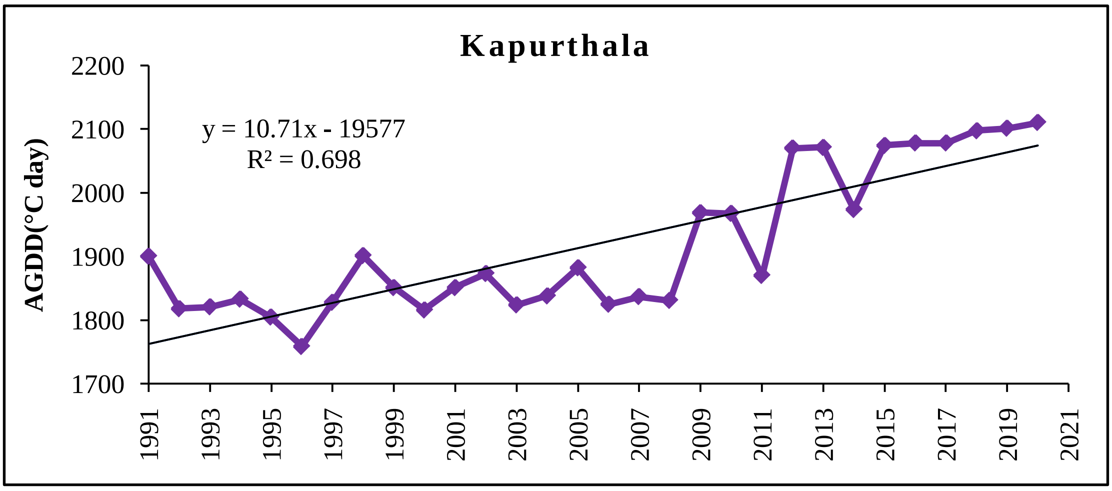

Fig. 4.46: Variability in accumulated growing degree days from 1991 to 2020 at Kapurthala under sowing window III

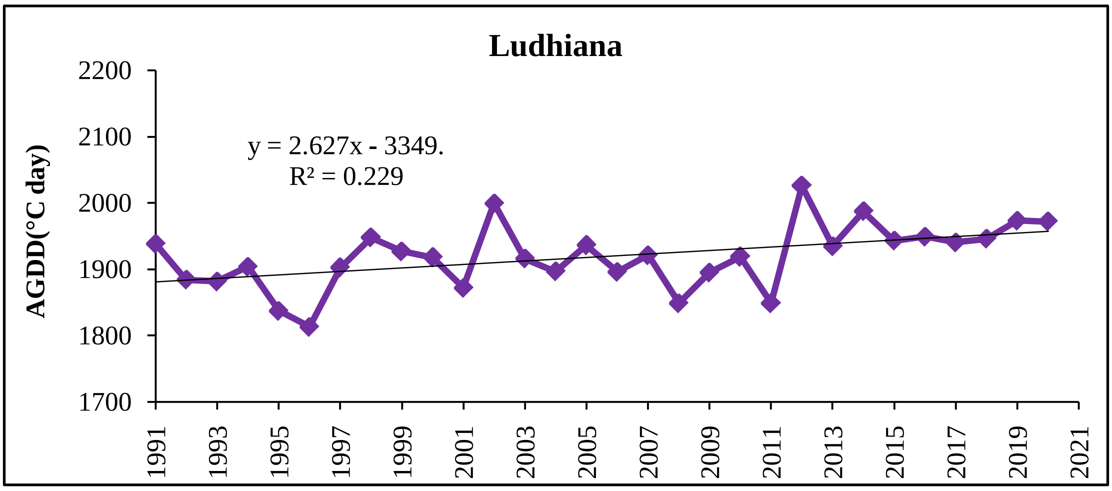

Fig. 4.47: Variability in accumulated growing degree days from 1991 to 2020 at Ludhiana under sowing window III

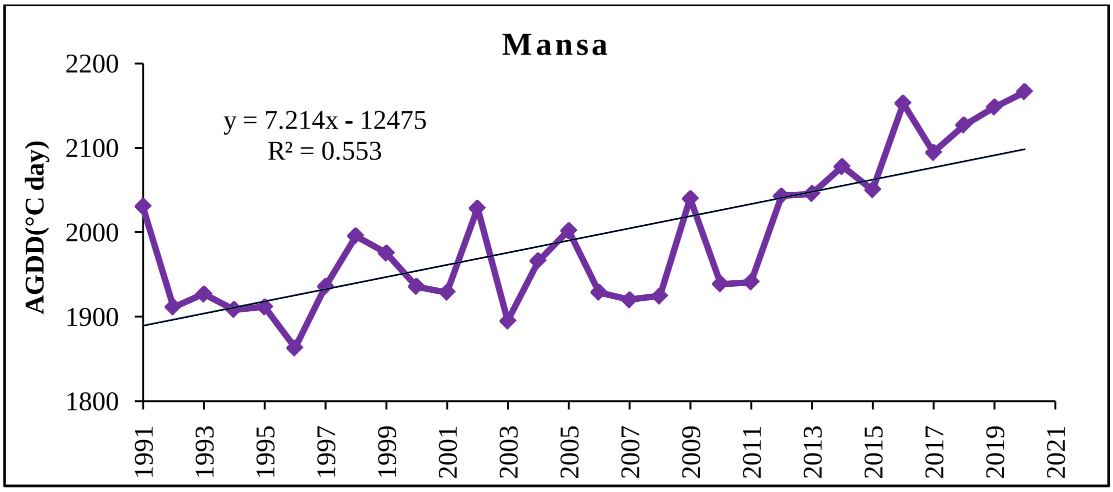

Fig. 4.48: Variability in accumulated growing degree days from 1991 to 2020 at Mansa under sowing window III

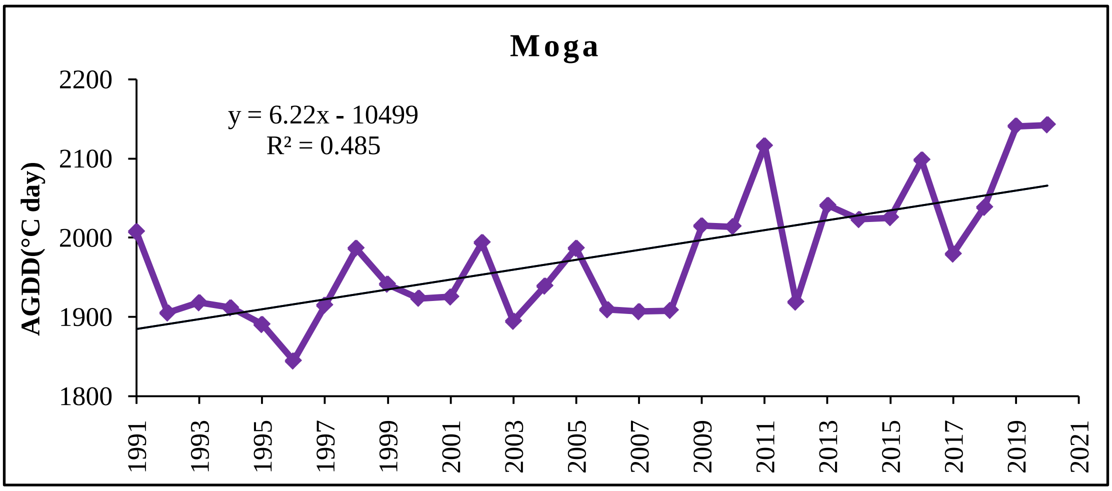

Fig. 4.49: Variability in accumulated growing degree days from 1991 to 2020 at Moga under sowing window III

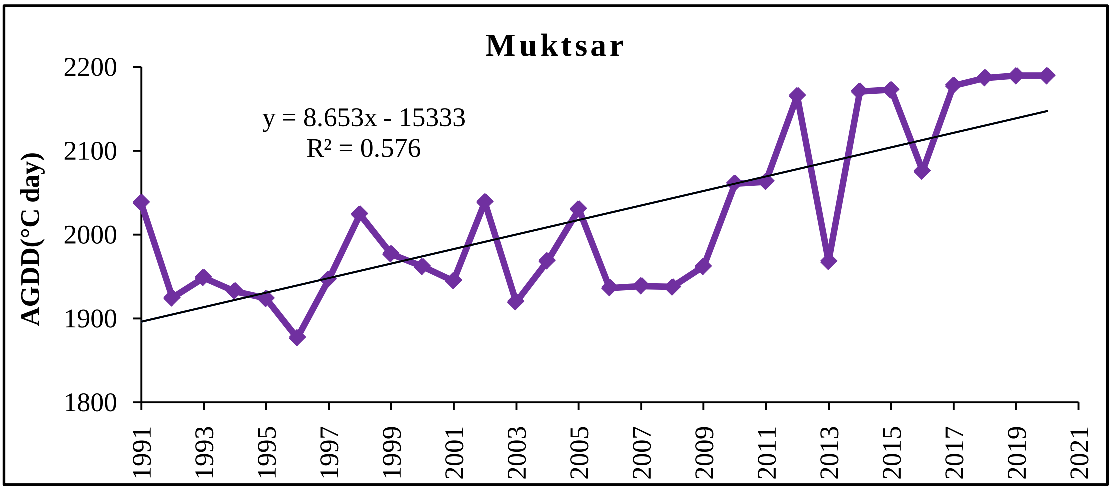

Fig. 4.50: Variability in accumulated growing degree days from 1991 to 2020 at Muktsar under sowing window III

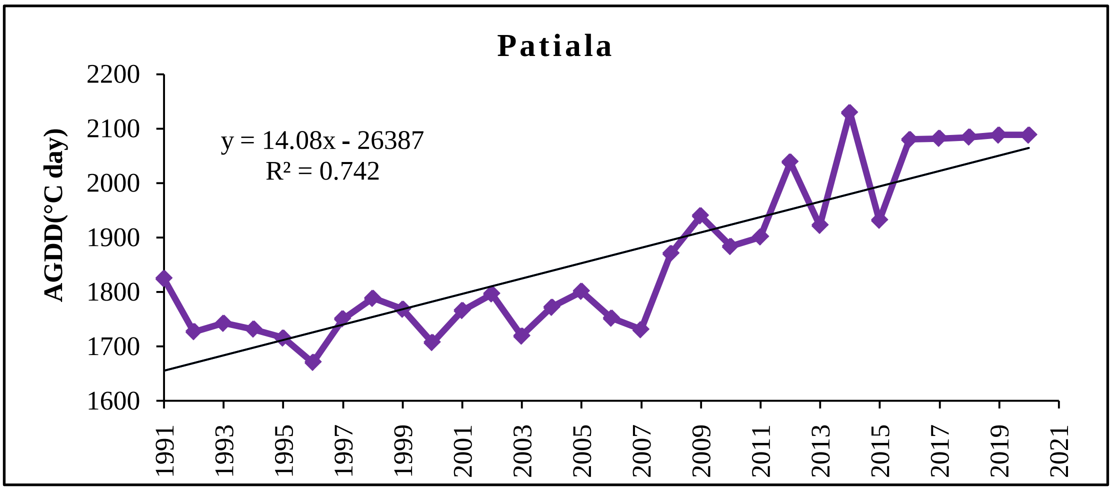

Fig. 4.51: Variability in accumulated growing degree days from 1991 to 2020 at Patiala under sowing window III

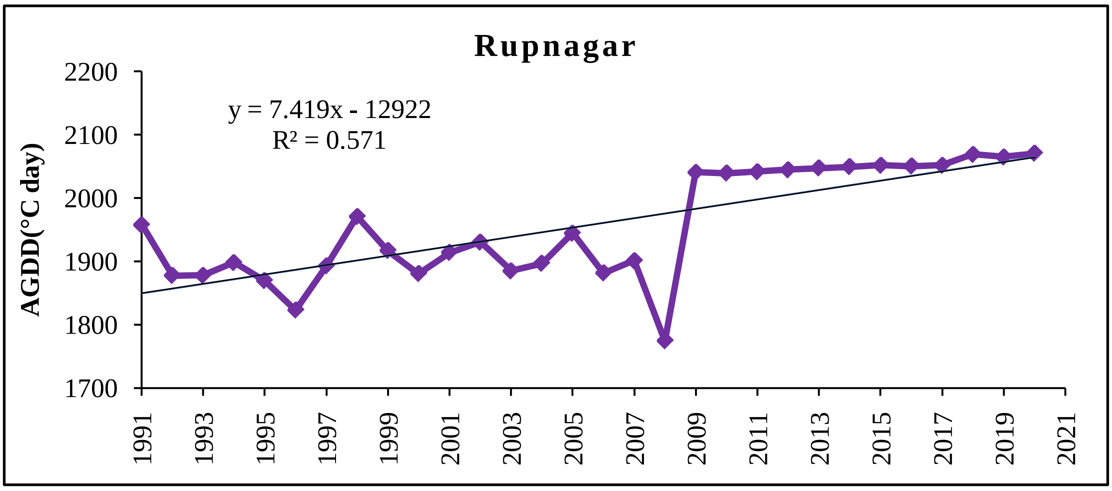

Fig. 4.52: Variability in accumulated growing degree days from 1991 to 2020 at Rupnagar under sowing window III

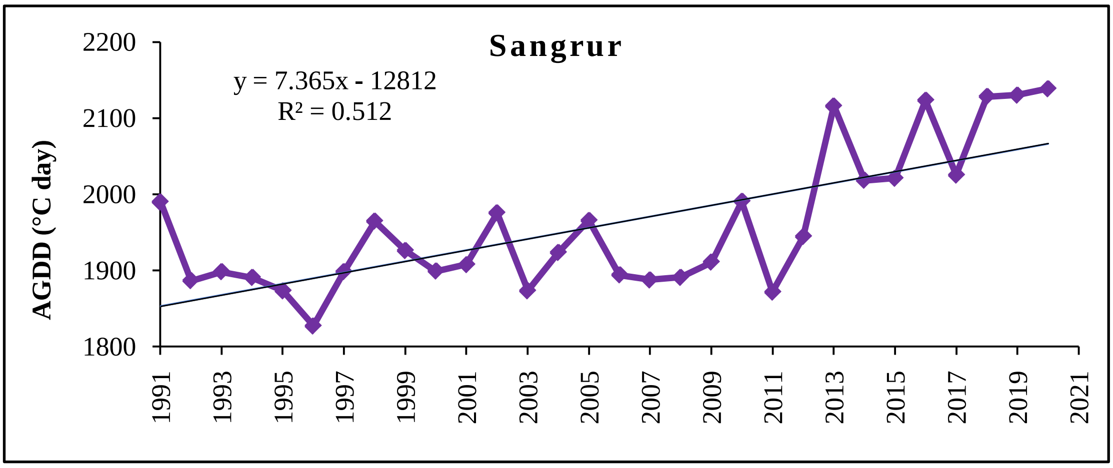

Fig. 4.53: Variability in accumulated growing degree days from 1991 to 2020 at Sangrur under sowing window III

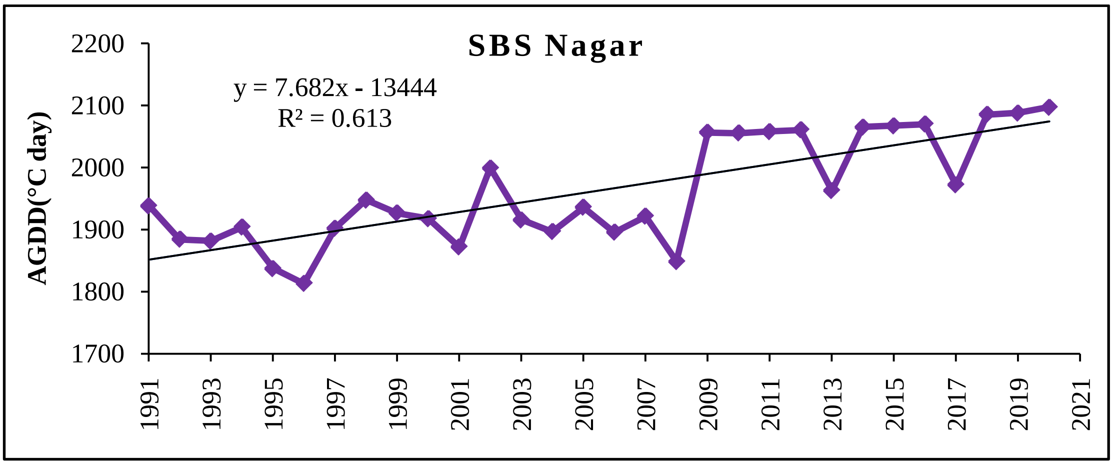

Fig. 4.54: Variability in accumulated growing degree days from 1991 to 2020 at SBS Nagar under sowing window III

4.2.4 Trend analysis of accumulated growing degree days from 1991-2020 under sowing window IV

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under sowing window IV and presented in Figures from 4.55 to 4.71. Variation in accumulated growing degree days was observed during different time periods but the trend increased in all the districts except Ludhiana and Bathinda. Among all, the highest R^2 value was found for Gurdaspur (0.76) and lowest for Bathinda (0.20). The rate of increase in AGDD was highest for Patiala (13.73 ˚C day year $^{-1}$) followed by Fatehgarh Sahib (11.88 ˚C day year $^{-1}$) and lowest was for Bathinda (2.74 ˚C day year $^{-1}$**)** and Ludhiana (2.76 ˚C day year $^{-1}$**).** The rate of increase was 5.56 ˚C day year $^{-1}$ in Amritsar, 5.29 ˚C day year $^{-1}$ in Faridkot, 8.21 ˚C day year $^{-1}$ in Ferozepur, 10.58 ˚C day year $^{-1}$ in Gurdaspur, 10.47 ˚C day year $^{-1}$ in Hoshiarpur, 7.67 ˚C day year $^{-1}$ in Jalandhar, 9.59 ˚C day year $^{-1}$ in Kapurthala, 7.86 ˚C day year $^{-1}$ in Mansa, 7.66 ˚C day year $^{-1}$ in Moga, 8.78 ˚C day year $^{-1}$ in Muktsar, 7.27 ˚C day year $^{-1}$ in Rupnagar, 8.97 ˚C day year $^{-1}$ in Sangrur and 7.79 ˚C day year $^{-1}$ in S.B.S. Nagar.

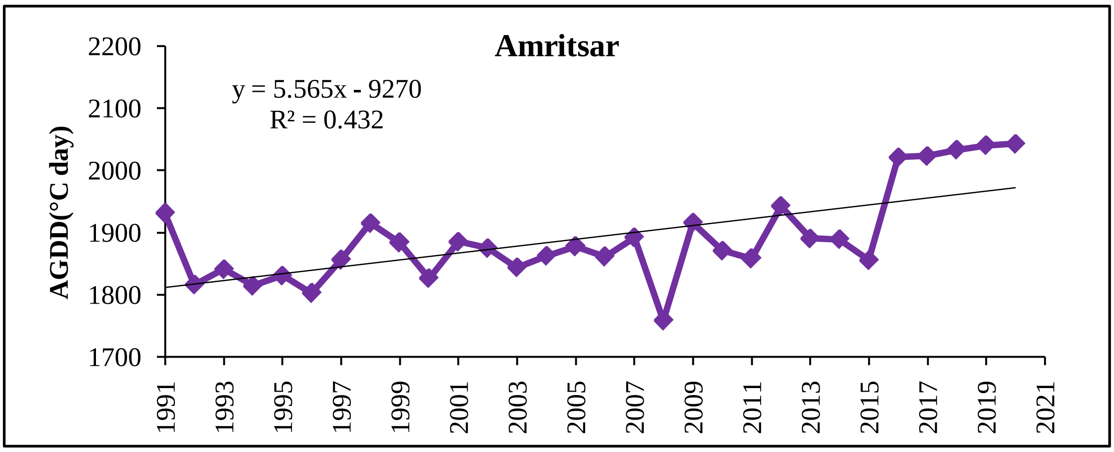

Fig. 4.55: Variability in accumulated growing degree days from 1991 to 2020 at Amritsar under sowing window IV

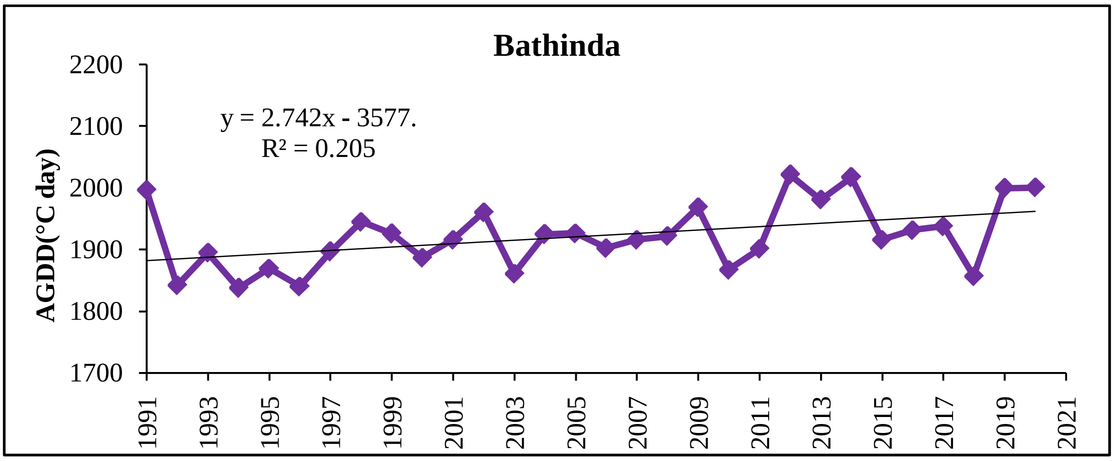

Fig. 4.56: Variability in accumulated growing degree days from 1991 to 2020 at Bathinda under sowing window IV

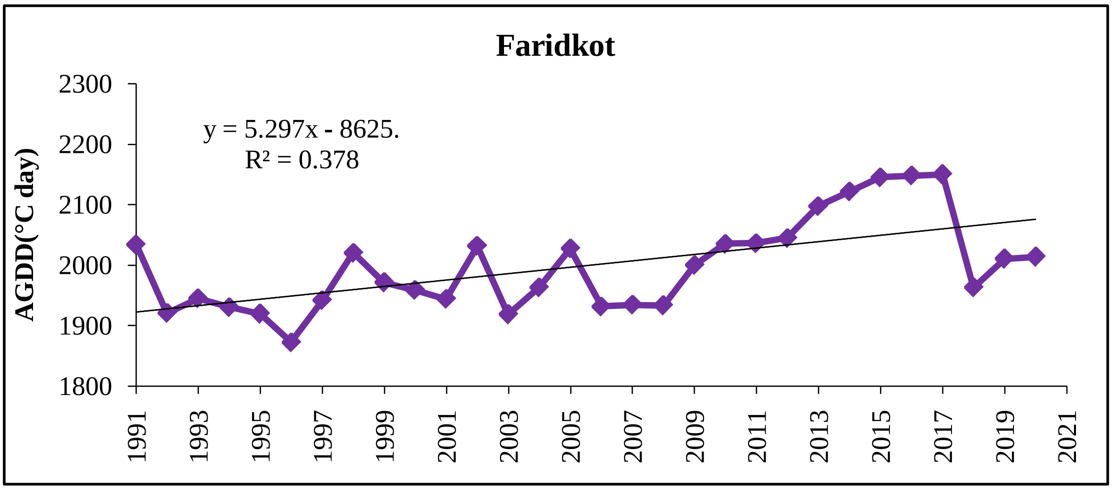

Fig. 4.57: Variability in accumulated growing degree days from 1991 to 2020 at Faridkot under sowing window IV

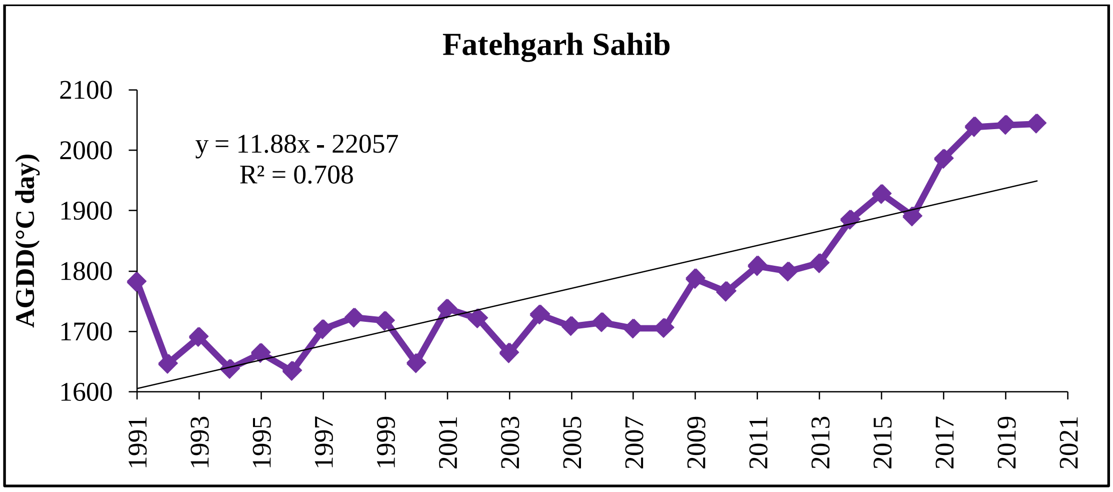

Fig. 4.58: Variability in accumulated growing degree days from 1991 to 2020 at Fatehgarh Sahib under sowing window IV

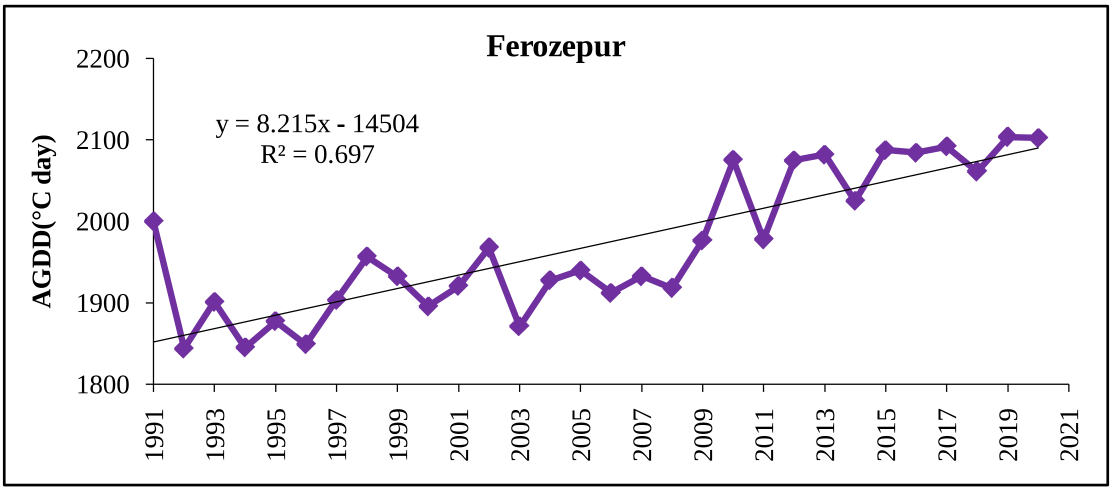

Fig. 4.59: Variability in accumulated growing degree days from 1991 to 2020 at Ferozepur under sowing window IV

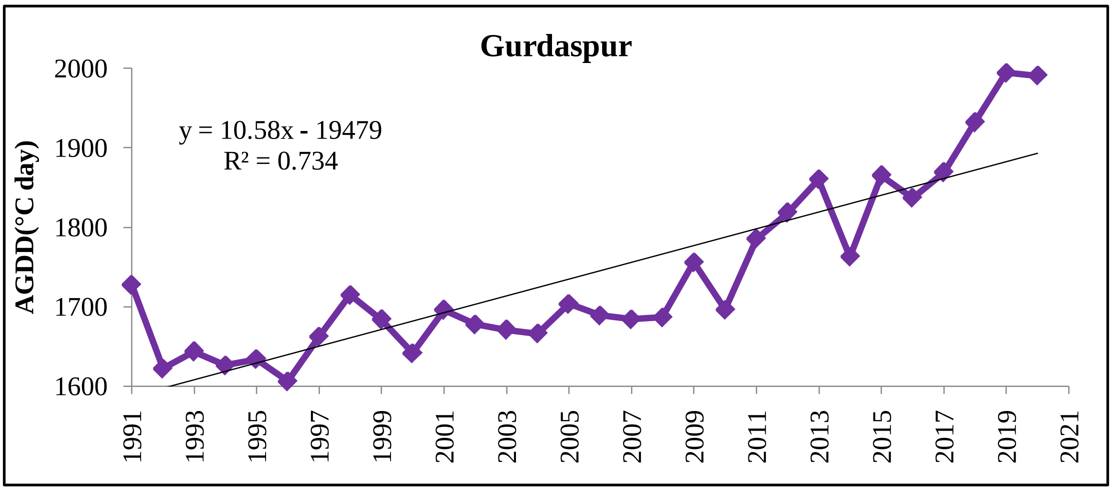

Fig. 4.60: Variability in accumulated growing degree days from 1991 to 2020 at Gurdaspur under sowing window IV

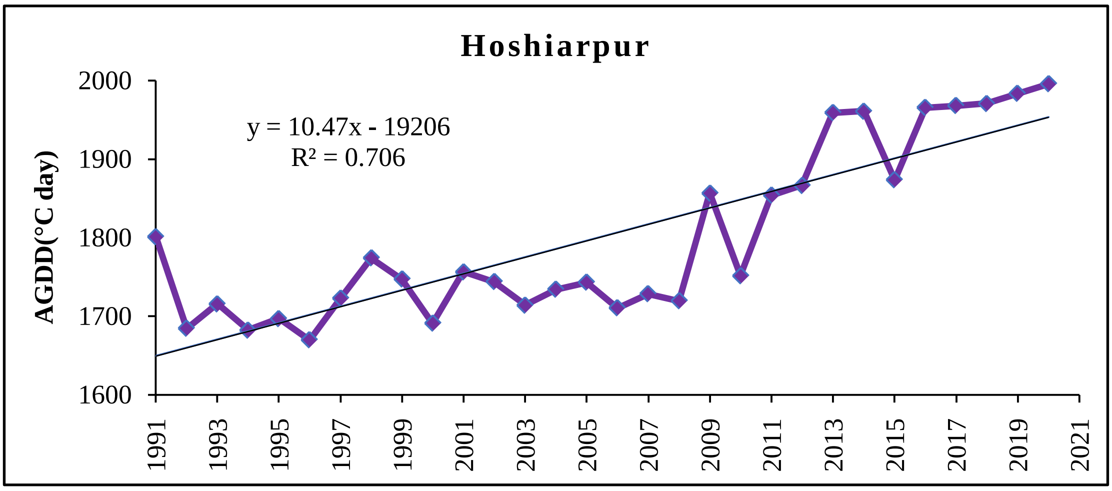

Fig. 4.61: Variability in accumulated growing degree days from 1991 to 2020 at Hoshiarpur under sowing window IV

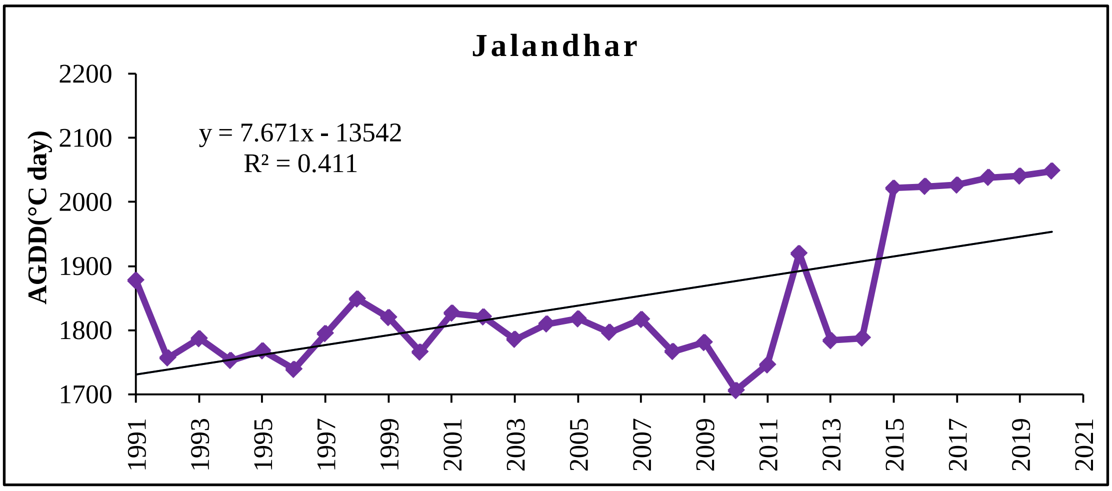

Fig. 4.62: Variability in accumulated growing degree days from 1991 to 2020 at Jalandhar under sowing window IV

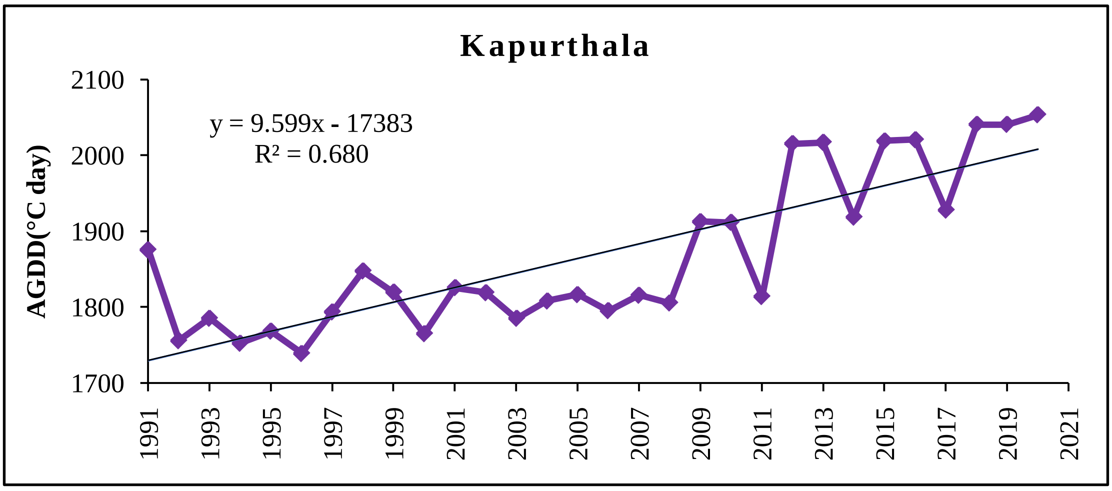

Fig. 4.63: Variability in accumulated growing degree days from 1991 to 2020 at Kapurthala under sowing window IV

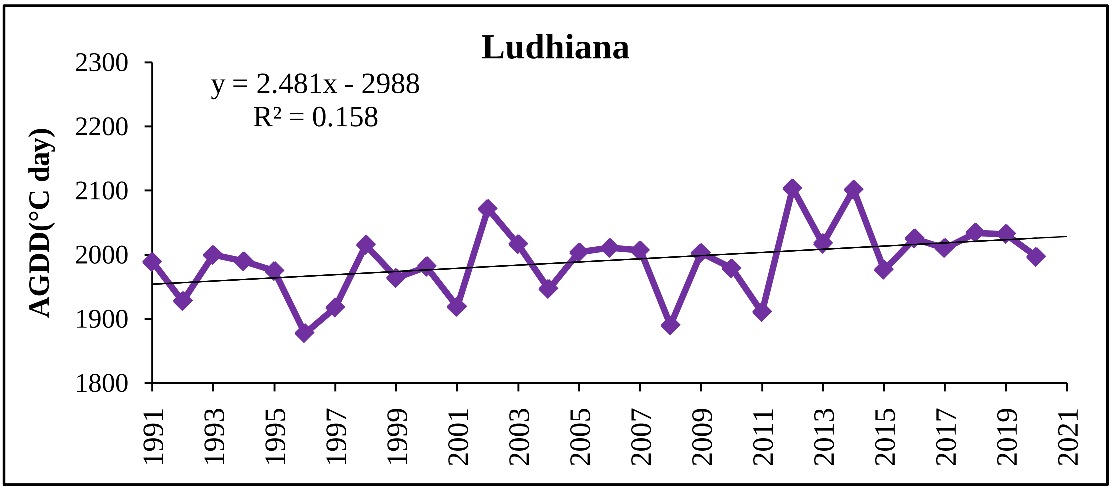

Fig. 4.64: **Variability in accumulated growing degree days from 1991 to 2020 at Ludhiana under sowing window IV**

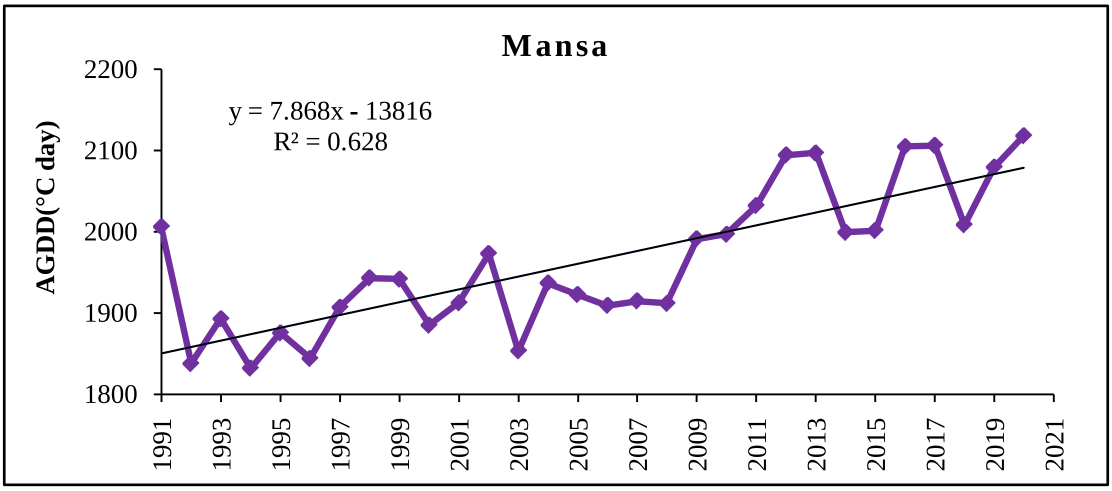

Fig. 4.65: **Variability in accumulated growing degree days from 1991 to 2020 at Mansa under sowing window IV**

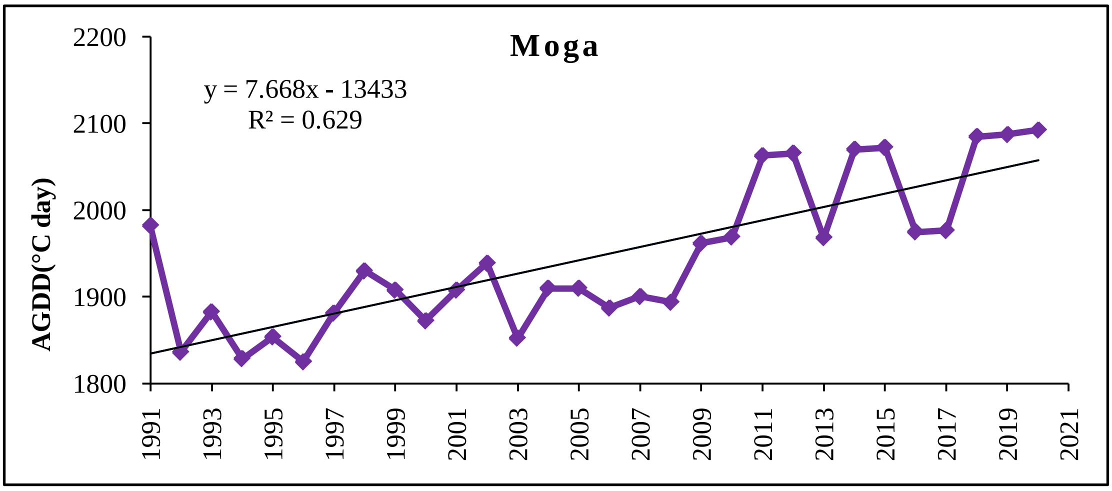

Fig. 4.66: **Variability in accumulated growing degree days from 1991 to 2020 at Moga under sowing window IV**

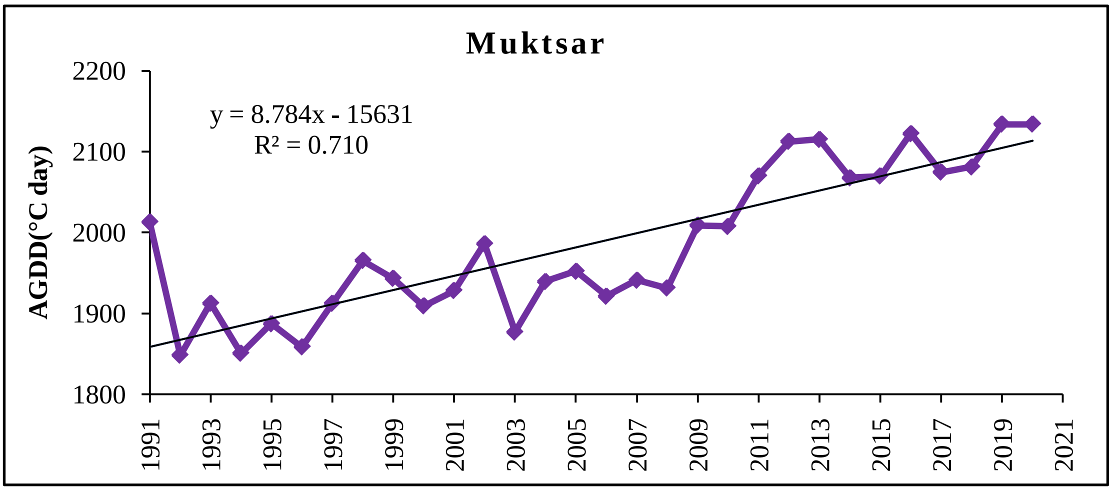

Fig. 4.67: **Variability in accumulated growing degree days from 1991 to 2020 at Muktsar under sowing window IV**

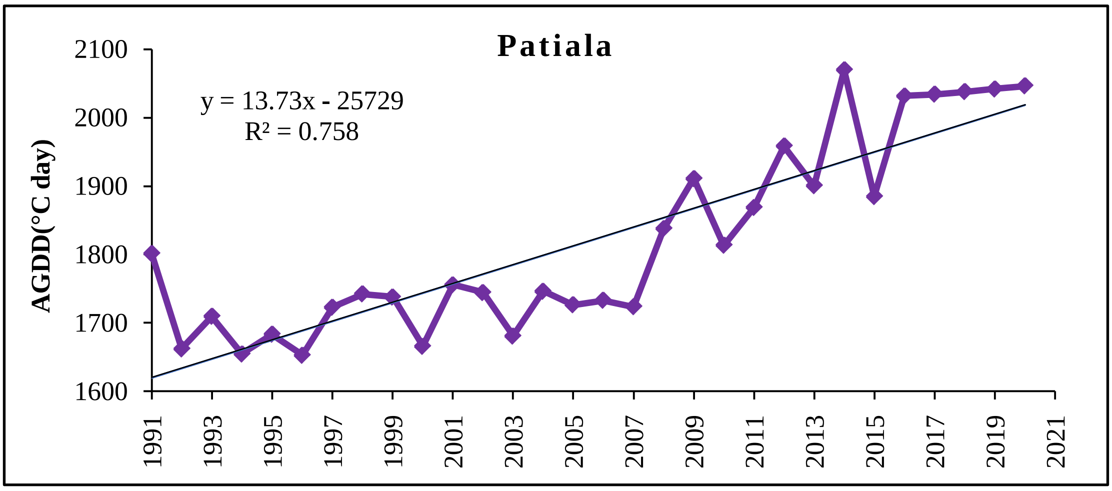

Fig. 4.68: **Variability in accumulated growing degree days from 1991 to 2020 at Patiala under sowing window IV**

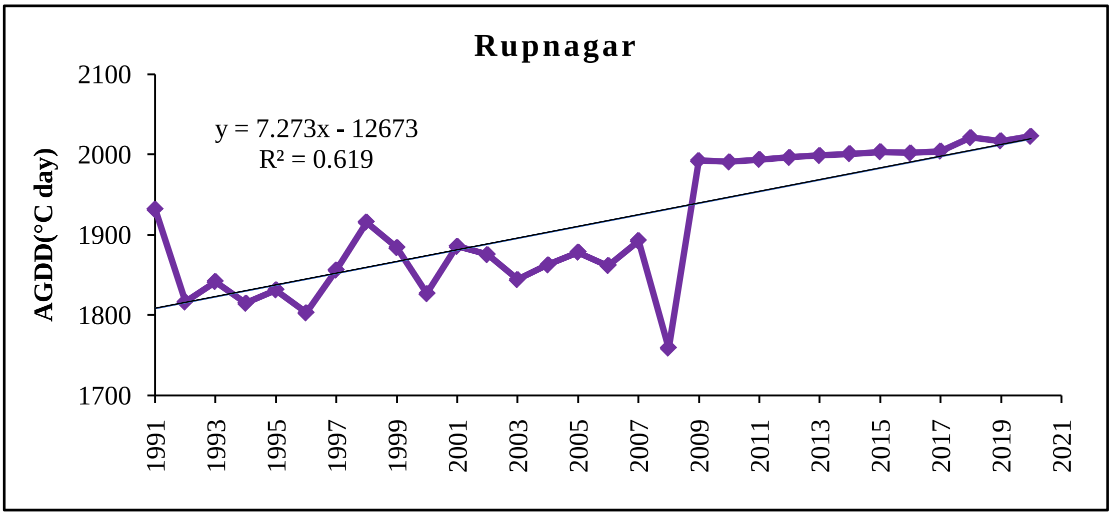

Fig. 4.69: **Variability in accumulated growing degree days from 1991 to 2020 at Rupnagar under sowing window IV**

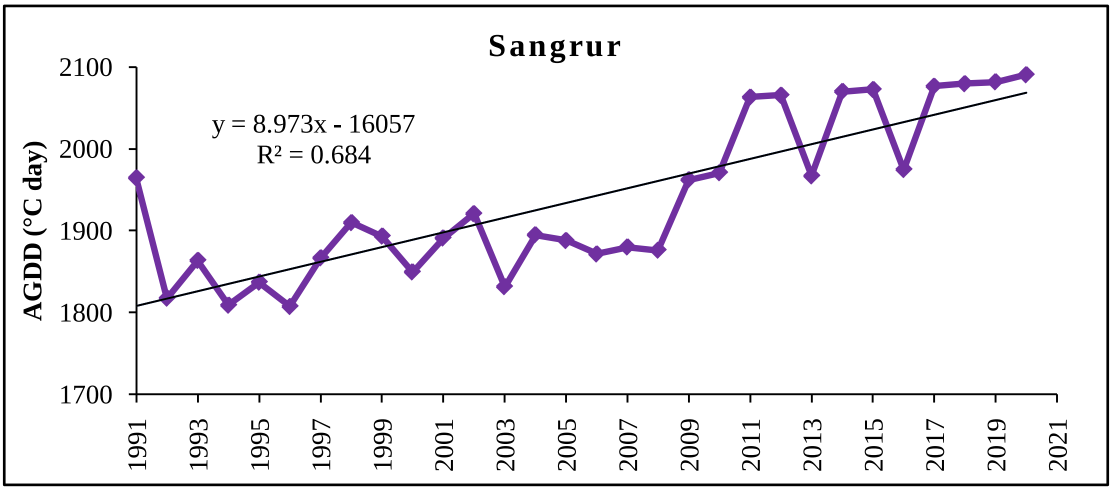

Fig. 4.70: Variability in accumulated growing degree days from 1991 to 2019 at Sangrur under sowing window IV

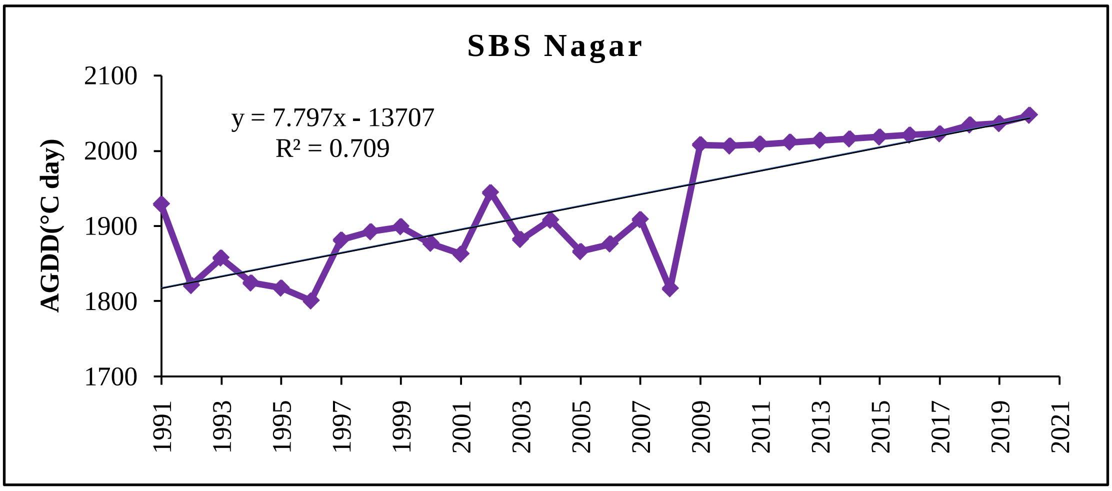

Fig. 4.71: Variability in accumulated growing degree days from 1991 to 2020 at SBS Nagar under sowing window IV

4.3 Decade-wise variability in Accumulated growing degree days of maize in different districts of Punjab

4.3.1 Decade-wise variability of accumulated growing degree days of maize in Amritsar

Amritsar district in sowing window I observed mean accumulated growing degree days of 1966.93±14.4 ˚C day year $^{-1}$ during 1991-2000, 1969.32±22.8 ˚C day year $^{-1}$ during 2001-2010, 2097.88±30.6 ˚C day year $^{-1}$ during 2011-2020 and 2011.38±17.26 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -6.64°C day year $^{-1}$) and significant increase was noticed during 2011-2020 (@ 24.27°C day year $^{-1}$). During sowing window II, the district had mean accumulated growing degree days of 1934.61±12.5 ˚C day year $^{-1}$ during 1991-2000, 1942.74±19.8 ˚C day year $^{-1}$ during 2001-2010, 2060.41±28.5 ˚C day year $^{-1}$ during 2011-2020 and 1979.25±15.96 ˚C day year $^{-1}$ during 1991-2020. During sowing window III, mean accumulated growing degree days of 1896.54±13.7

˚C day year $^{-1}$ was noticed during 1991-2000, 1884.52±19.6 ˚C day year $^{-1}$ during 2001-2010, 2013.09±27.3 ˚C day year $^{-1}$ during 2011-2020 and 1931.38±15.9 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1852.06±14.0 ˚C day year $^{-1}$ was noticed during 1991-2000, 1864.57±13.3 ˚C day year $^{-1}$ during 2001-2010, 1960.03±25.3 ˚C day year $^{-1}$ during 2011-2020 and 1892.22±13.6 ˚C day year $^{-1}$ during 1991-2020 (Table 4.4). Similar work was done by Yin *et al* (2020) in Huang-huai-hai River basin of China to detect significant trend in heat unit accumulation using Mann-Kendall statistical test and the results showed an increasing trend in heat unit accumulation during since 1960s.

Table 4.4: Decade-wise variability of accumulated growing degree days during maize growing season in Amritsar

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1966.93±14.4	1969.32±22.8	2097.88±30.6	2011.38±17.4
	Z	-0.36	0.00	2.86**	3.14**
	Q	-6.64	-0.77	24.27	6.77
Sowing Window II (5 June)	**Mean±SE**	1934.61±12.5	1942.74±19.8	2060.41±28.5	1979.25±15.9
	Z	-0.89	0.00	2.86**	3.35***
	Q	-3.83	0.82	21.76	5.81
Sowing Window III (15 June)	**Mean±SE**	1896.54±13.7	1884.52±19.6	2013.09±27.3	1931.38±15.9
	Z	0.18	-0.81	3.14**	3.39***
	Q	0.41	-5.87	14.39	4.86
Sowing Window IV (25 June)	**Mean±SE**	1852.06±14.0	1864.57±13.3	1960.03±25.3	1892.22±13.6
	Z	0.00	0.00	2.68**	3.60***
	Q	1.13	0.82	16.29	5.1

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.2 Decade-wise variability of accumulated growing degree days of maize in Bathinda

Bathinda district in sowing window I observed mean accumulated growing degree days of 2015.12±16.3 ˚C day year^{-1} during 1991-2000, 2025.95±15.2 ˚C day year^{-1} during 2001-2010, 2076.23±23.1 ˚C day year $^{-1}$ during 2011-2020 and 2039.10±11.4 ˚C day year^{-1} during 1991-2020. During sowing window II, the district had mean accumulated growing degree days of 1978.08±13.8 ˚C day year $^{-1}$ during 1991-2000, 1999.01±15.3 ˚C day year $^{-1}$ during 2001-2010, 2036.43±20.6 ˚C day year $^{-1}$ during 2011-2020 and 2004.50±10.4 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 2011-2020 (@ -9.48°C day year^{-1}). During sowing window III, mean accumulated growing degree days of

1937.76±14.9 ˚C day year $^{-1}$ was noticed during 1991-2000, 1953.31±11.9 ˚C day year^{-1} during 2001-2010, 1999.68±19.6 ˚C day year^{-1} during 2011-2020 and 1963.58±10.1 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1893.26±16.2 ˚C day year^{-1} was noticed during 1991-2000, 1916.29±10.8 ˚C day year $^{-1}$ during 2001-2010, 1956.04±17.6 ˚C day year $^{-1}$ during 2011-2020 and 1921.86±9.7 ˚C day year $^{-1}$ during 1991-2020 and significant increase was noticed during 1991-2000 (@ 3.55°C day year^{-1}) (Table 4.5).

Table 4.5: Decade-wise variability of accumulated growing degree days during maize growing season in Bathinda

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	Mean±SE	2015.12±16.3	2025.95±15.2	2076.23±23.1	2039.10±11.4
	Z	-0.89	0.54	-1.25	1.64
	Q	-8.65	1.63	-6.86	1.91
Sowing Window II (5 June)	Mean±SE	1978.08±13.8	1999.01±15.3	2036.43±20.6	2004.50±10.4
	Z	-0.89	0.63	-0.54	1.84+
	Q	-5.89	2.15	-9.48	2.04
Sowing Window III (15 June)	Mean±SE	1937.76±14.9	1953.31±11.9	1999.68±19.6	1963.58±10.1
	Z	0.18	0.00	-0.36	2.32*
	Q	2.77	1.4	-8.26	2.50
Sowing Window IV (25 June)	Mean±SE	1893.26±16.2	1916.29±10.8	1956.04±17.6	1921.86±9.7
	Z	0.36	0.00	0.00	2.6**
	Q	3.55	0.042	1.35	3.1

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.3 Decade-wise variability of accumulated growing degree days of maize in Faridkot

Faridkot district in sowing window I observed mean accumulated growing degree days of 2026.44±16.4 ˚C day year $^{-1}$ during 1991-2000, 2029.91±12.8 ˚C day year $^{-1}$ during 2001-2010, 2155.96±26.9 ˚C day year $^{-1}$ during 2011-2020 and 2070.8±15.7 ˚C day year $^{-1}$ during 1991-2020. During sowing window II, the district had mean accumulated growing degree days of 1990.93±13.8 ˚C day year $^{-1}$ during 1991-2000, 2017.55±17.1 ˚C day year $^{-1}$ during 2001-2010, 2137.57±26.2 ˚C day year $^{-1}$ during 2011-2020 and 2048.68±16.2 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 2011-2020 (@ -19.4°C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1951.48±15.2 ˚C day year $^{-1}$ was noticed during 1991-2000, 1972.03±14.8 ˚C day year $^{-}$

^{1} during 2001-2010, 2073.06±21.4 ˚C day year^{-1} during 2011-2020 and 1998.86±13.8 ˚C day year^{-1} during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1906.31±16.6 ˚C day year^{-1} was noticed during 1991-2000, 1954.62±15.5 ˚C day year^{-1} during 2001-2010, 2042.23±19.6 ˚C day year^{-1} during 2011-2020 and 1967.72±14.2 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2001-2010 (@ 8.65°C day year^{-1}) (Table 4.6).

Table 4.6: Decade-wise variability of accumulated growing degree days during maize growing season in Faridkot

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	Mean±SE	2026.44±16.4	2029.91±12.8	2155.96±26.9	2070.8±15.7
	Z	-0.72	0.09	-0.36	2.77**
	Q	-5.6	0.32	-6.59	4.05
Sowing Window II (5 June)	Mean±SE	1990.93±13.8	2017.55±17.1	2137.57±26.2	2048.68±16.2
	Z	-0.89	1.25	-1.07	3.28**
	Q	-5.39	5.33	-19.4	4.42
Sowing Window III (15 June)	Mean±SE	1951.48±15.2	1972.03±14.8	2073.06±21.4	1998.86±13.8
	Z	0.18	0.54	0.18	3.53***
	Q	3.7	2.7	2.27	5.42
Sowing Window IV (25 June)	Mean±SE	1906.31±16.6	1954.62±15.5	2042.23±19.6	1967.72±14.2
	Z	0.54	1.61	-0.54	4.17***
	Q	4.57	8.65	-9.23	7.48

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.4 Decade-wise variability of accumulated growing degree days of maize in Fatehgarh Sahib

Fatehgarh Sahib district in sowing window I observed mean accumulated growing degree days of 1796.75±16.4 ˚C day year^{-1} during 1991-2000, 1818.18±12.0 ˚C day year^{-1} during 2001-2010, 2036.01±27.2 ˚C day year^{-1} during 2011-2020 and 1883.64±22.9 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -9.32°C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1767.67±11.6 ˚C day year^{-1} during 1991-2000, 1784.46±9.6 ˚C day year^{-1} during 2001-2010, 1967.15±33.2 ˚C day year^{-1} during 2011-2020 and 1839.76±20.5 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2011-2020 (@ 33.05 °C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1723.51±13.7

˚C day year $^{-1}$ was noticed during 1991-2000, 1754.23±11.7 ˚C day year $^{-1}$ during 2001-2010, 2007.34±27.9 ˚C day year $^{-1}$ during 2011-2020 and 1828.36±25.9 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1684.66±15.1 ˚C day year^{-1} was noticed during 1991-2000, 1723.64±10.8 ˚C day year $^{-1}$ during 2001-2010, 1923.32±31.5 ˚C day year^{-1} during 2011-2020 and 1828.36±25.9 ˚C day year $^{-1}$ during 1991-2020 (Table 4.7).

Table 4.7: Decade-wise variability of accumulated growing degree days during maize growing season in Fatehgarh Sahib

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1796.75±16.4	1818.18±12.0	2036.01±27.2	1883.64±22.9
	Z	-1.61	1.07	3.94***	4.89***
	Q	-9.32	4.3	27.29	12.28
Sowing Window II (5 June)	**Mean±SE**	1767.67±11.6	1784.46±9.6	1967.15±33.2	1839.76±20.5
	Z	-0.89	1.07	3.22**	4.66***
	Q	-4.07	1.93	33.05	8.5
Sowing Window III (15 June)	**Mean±SE**	1723.51±13.7	1754.23±11.7	2007.34±27.9	1828.36±25.9
	Z	-0.36	0.89	3.04**	5.10***
	Q	-4.48	2.85	26.58	13.36
Sowing Window IV (25 June)	**Mean±SE**	1684.66±15.1	1723.64±10.8	1923.32±31.5	1777.21±22.7
	Z	0.00	0.18	3.58***	5.32***
	Q	0.18	3.09	30.6	11.49

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.5 Decade-wise variability of accumulated growing degree days of maize in Ferozepur

Ferozepur district in sowing window I observed mean accumulated growing degree days of 2020.54±16.0 ˚C day year $^{-1}$ during 1991-2000, 2040.53±16.0 ˚C day year $^{-1}$ during 2001-2010, 2191.63±19.8 ˚C day year $^{-1}$ during 2011-2020 and 2084.24±17.2 ˚C day year $^{-1}$ during 1991-2020 and significant increase was noticed during 2011-2020 (@ 14.46°C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1985.11±13.6 ˚C day year $^{-1}$ during 1991-2000, 2029.75±24.5 ˚C day year $^{-1}$ during 2001-2010, 2181.68±11.7 ˚C day year $^{-1}$ during 2011-2020 and 2065.51±18.4 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -5.26°C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1945.57±14.9 ˚C day year $^{-1}$ was noticed during 1991-2000, 1979.79±21.7 ˚C day year^{-1} during 2001-2010, 2122.1±12.9 ˚C day year $^{-1}$ during 2011-2020 and 2015.82±17.0 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1900.46±16.2 ˚C day year^{-1} was noticed during 1991-2000, 1944.05±17.3 ˚C day year^{-1} during 2001-2010, 2069.1±12.5 ˚C day year^{-1} during 2011-2020 and 1971.19±15.8 ˚C day year $^{-1}$ during 1991-2020 (Table 4.8).

Table 4.8: Decade-wise variability of accumulated growing degree days during maize growing season in Ferozepur

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	2020.54±16.0	2040.53±16.0	2191.63±19.8	2084.24±17.2
	Z	-0.89	0.89	2.33*	4.28***
	Q	-4.02	6.88	14.46	8.3
Sowing Window II (5 June)	**Mean±SE**	1985.11±13.6	2029.75±24.5	2181.68±11.7	2065.51±18.4
	Z	-0.89	1.79+	2.33*	4.57***
	Q	-5.26	6.74	5.63	9.17
Sowing Window III (15 June)	**Mean±SE**	1945.57±14.9	1979.79±21.7	2122.1±12.9	2015.82±17.0
	Z	0.36	0.89	1.61	4.57***
	Q	3.35	5.00	2.85	8.30
Sowing Window IV (25 June)	**Mean±SE**	1900.46±16.2	1944.05±17.3	2069.1±12.5	1971.19±15.8
	Z	0.72	1.25	2.33*	5.17***
	Q	3.70	9.25	4.15	8.58

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.6 Decade-wise variability of accumulated growing degree days of maize in Gurdaspur

Gurdaspur district in sowing window I observed mean accumulated growing degree days of 1751.46±13.6 ˚C day year $^{-1}$ during 1991-2000, 1779.90±10.4 ˚C day year $^{-1}$ during 2001-2010, 1938.30±21.2 ˚C day year $^{-1}$ during 2011-2020 and 1823.22±17.5 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -5.81°C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1728.36±11.7 ˚C day year $^{-1}$ during 1991-2000, 1766.27±10.1 ˚C day year $^{-1}$ during 2001-2010, 2045.24±27.2 ˚C day year $^{-1}$ during 2011-2020 and 1846.62±28.1 ˚C day year $^{-1}$ during 1991-2020. During sowing window III, mean accumulated growing degree days of 1696.50±13.1 ˚C day year $^{-1}$ was noticed during 1991-2000, 1735.92±11.7 ˚C day year $^{-1}$ during 2001-2010, 1918.40±13.5 ˚C day year $^{-1}$ during 2011-2020 and 1783.61±19.3 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1656.26±12.8 ˚C day year^{-1} was noticed during 1991-2000, 1692.69±7.9 ˚C day year^{-1} during 2001-2010, 1871.6±25.0 ˚C day year^{-1} during 2011-2020 and 1740.2±19.8 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2011-2020 (@ 22.82 °C day year^{-1}) (Table 4.9).

Table 4.9: Decade-wise variability of accumulated growing degree days during maize growing season in Gurdaspur

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1751.46±13.6	1779.90±10.4	1938.30±21.2	1823.22±17.5
	Z	-0.36	0.89	3.58***	5.03***
	Q	-5.81	2.73	21.22	9.51
Sowing Window II (5 June)	**Mean±SE**	1728.36±11.7	1766.27±10.1	2045.24±27.2	1846.62±28.1
	Z	-1.07	1.25	2.86**	5.32***
	Q	-3.62	4.42	21.1	13.9
Sowing Window III (15 June)	**Mean±SE**	1696.50±13.1	1735.92±11.7	1918.40±13.5	1783.61±19.3
	Z	0.00	1.43	2.50	5.46
	Q	1.62	8.57	12.12	10.77
Sowing Window IV (25 June)	**Mean±SE**	1656.26±12.8	1692.69±7.9	1871.6±25.0	1740.2±19.8
	Z	0.36	1.07	2.86**	5.50***
	Q	2.4	2.36	22.82	10.07

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.7 Decade-wise variability of accumulated growing degree days of maize in Hoshiarpur

Hoshiarpur district in sowing window I observed mean accumulated growing degree days of 1826.24±14.4 ˚C day year^{-1} during 1991-2000, 1837.65±10.4 ˚C day year^{-1} during 2001-2010, 1944.55±18.6 ˚C day year^{-1} during 2011-2020 and 1869.48±12.9 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -6.52 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1795.59±12.4 ˚C day year^{-1} during 1991-2000, 1804.28±9.7 ˚C day year^{-1} during 2001-2010, 1971.43±34.8 ˚C day year^{-1} during 2011-2020 and 1857.10±19.4 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2011-2020 (@ 32.43°C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1759.71±13.2 ˚C day year^{-1} was noticed during 1991-2000, 1772.87±8.7 ˚C day year^{-1} during 2001-2010, 1971.41±23.2

˚C day year $^{-1}$ during 2011-2020 and 1834.66±20.1 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1718.25±13.7 ˚C day year^{-1} was noticed during 1991-2000, 1745.62±13.3 ˚C day year^{-1} during 2001-2010, 1939.55±16.8 ˚C day year^{-1} during 2011-2020 and 1801.14±20.0 ˚C day year $^{-1}$ during 1991-2020 (Table 4.10).

Table 4.10: Decade-wise variability of accumulated growing degree days during maize growing season in Hoshiarpur

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1826.24±14.4	1837.65±10.4	1944.55±18.6	1869.48±12.9
	Z	-0.54	-0.36	1.79+	3.60***
	Q	-6.52	-1.3	10.72	5.22
Sowing Window II (5 June)	**Mean±SE**	1795.59±12.4	1804.28±9.7	1971.43±34.8	1857.10±19.4
	Z	-1.07	-1.07	2.68**	3.35***
	Q	-6.2	-3.87	32.43	6.95
Sowing Window III (15 June)	**Mean±SE**	1759.71±13.2	1772.87±8.7	1971.41±23.2	1834.66±20.1
	Z	0.00	0.00	2.86**	4.53***
	Q	-0.43	0.14	17.82	10.03
Sowing Window IV (25 June)	**Mean±SE**	1718.25±13.7	1745.62±13.3	1939.55±16.8	1801.14±20.0
	Z	0.00	0.00	3.58***	4.96***
	Q	0.85	-0.25	12.35	10.39

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.8 Decade-wise variability of accumulated growing degree days of maize in Jalandhar

Jalandhar district in sowing window I observed mean accumulated growing degree days of 1905.59±14.6 ˚C day year^{-1} during 1991-2000, 1900.17±14.9 ˚C day year^{-1} during 2001-2010, 2089.14±46.7 ˚C day year^{-1} during 2011-2020 and 1964.97±23.2 ˚C day year^{-1} during 1991-2020. During sowing window II, the district had mean accumulated growing degree days of 1872.38±12.8 ˚C day year^{-1} during 1991-2000, 1874.05±14.1 ˚C day year^{-1} during 2001-2010, 2052.31±44.0 ˚C day year^{-1} during 2011-2020 and 1932.91±22.0 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 2001-2010 (@ -9.8 °C day year^{-1}) and significant increase was noticed during 2011-2020 (@ 30.53 °C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1834.42±13.7 ˚C day year^{-1} was noticed during 1991-2000, 1832.79±11.2 ˚C day year^{-1} during 2001-2010, 1994.31±41.7 ˚C day year^{-1} during 2011-2020 and 1887.17±20.2 ˚C day year^{-1} during 1991-

2020. For sowing window IV, mean accumulated growing degree days of 1791.28±14.2 ˚C day year^{-1} was noticed during 1991-2000, 1793.11±11.5 ˚C day year^{-1} during 2001-2010, 1943.98±39.2 ˚C day year^{-1} during 2011-2020 and 1842.79±19.2 ˚C day year^{-1} during 1991-2020 (Table 4.11).

Table 4.11: Decade-wise variability of accumulated growing degree days during maize growing season in Jalandhar

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1905.59±14.6	1900.17±14.9	2089.14±46.7	1964.97±23.2
	Z	-0.54	-1.07	3.58***	2.53*
	Q	-6.87	-8.44	28.42	6.39
Sowing Window II (5 June)	**Mean±SE**	1872.38±12.8	1874.05±14.1	2052.31±44.0	1932.91±22.0
	Z	-1.07	-1.61	3.58***	2.5*
	Q	-6.45	-9.8	30.53	6.8
Sowing Window III (15 June)	**Mean±SE**	1834.42±13.7	1832.79±11.2	1994.31±41.7	1887.17±20.2
	Z	0.00	-1.79+	3.58***	2.6**
	Q	-0.16	-7.46	20.94	5.50
Sowing Window IV (25 June)	**Mean±SE**	1791.28±14.2	1793.11±11.5	1943.98±39.2	1842.79±19.2
	Z	0.00	-2.5*	3.58***	2.64**
	Q	1.17	-5.99	19.77	5.74

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.9 Decade-wise variability of accumulated growing degree days of maize in Kapurthala

Kapurthala district in sowing window I observed mean accumulated growing degree days of 1904.43±14.5 ˚C day year^{-1} during 1991-2000, 1948.50±23.0 ˚C day year^{-1} during 2001-2010, 2168.22±15.5 ˚C day year^{-1} during 2011-2020 and 2007.05±23.7 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -6.92 °C day year^{-1}) and significant increase was noticed during 1991-2020 (@ 12.14 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1871.34±12.7 ˚C day year^{-1} during 1991-2000, 1937.56±32.7 ˚C day year^{-1} during 2001-2010, 2142.08±4.4 ˚C day year^{-1} during 2011-2020 and 1983.66±24.2 ˚C day year^{-1} during 1991-2020. During sowing window III, mean accumulated growing degree days of 1833.47±13.6 ˚C day year^{-1} was noticed during 1991-2000, 1889.84±30.4 ˚C day year^{-1} during 2001-2010, 2082.66±4.7 ˚C day year^{-1} during 2011-2020 and 1935.32±22.6 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1790.35±14.1 ˚C day year^{-1} was noticed during 1991-2000, 1849.59±27.4 ˚C day year^{-1} during 2001-2010, 2026.76±4.3 ˚C day year^{-1} during 2011-2020 and 1888.90±21.2 ˚C day year $^{-1}$ during 1991-2020 (Table 4.12).

Table 4.12: Decade-wise variability of accumulated growing degree days during maize growing season in Kapurthala

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1904.43±14.5	1948.50±23.0	2168.22±15.5	2007.05±23.7
	Z	-0.54	0.89	2.78**	4.76***
	Q	-6.92	5.95	7.47	12.14
Sowing Window II (5 June)	**Mean±SE**	1871.34±12.7	1937.56±32.7	2142.08±4.4	1983.66±24.2
	Z	-1.07	0.89	3.76***	5.00***
	Q	-6.27	7.80	3.90	11.26
Sowing Window III (15 June)	**Mean±SE**	1833.47±13.6	1889.84±30.4	2082.66±4.70	1935.32±22.6
	Z	0.00	0.72	3.76***	5.28***
	Q	-0.22	3.27	3.89	10.72
Sowing Window IV (25 June)	**Mean±SE**	1790.35±14.1	1849.59±27.4	2026.76±4.3	1888.90±21.2
	Z	0.00	0.36	3.86***	5.34***
	Q	1.07	4.08	3.83	10.54

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.10 Decade-wise variability of accumulated growing degree days of maize in Ludhiana

Ludhiana district in sowing window I observed mean accumulated growing degree days of 1963.40±13.6 ˚C day year $^{-1}$ during 1991-2000, 1984.46±16.8 ˚C day year $^{-1}$ during 2001-2010, 2020.65±17.8 ˚C day year $^{-1}$ during 2011-2020 and 1989.50±10.0 ˚C day year^{-1} during 1991-2020. During sowing window II, the district had mean accumulated growing degree days of 1929.43±11.1 ˚C day year $^{-1}$ during 1991-2000, 1955.10±16.9 ˚C day year^{-1} during 2001-2010, 1988.83±14.1 ˚C day year $^{-1}$ during 2011-2020 and 1957.79±9.1 ˚C day year $^{-1}$ during 1991-2020. During sowing window III, mean accumulated growing degree days of 1895.29±13.6 ˚C day year $^{-1}$ was noticed during 1991-2000, 1909.91±12.8 ˚C day year^{-1} during 2001-2010, 1952.02±14.5 ˚C day year $^{-1}$ during 2011-2020 and 1919.07±8.8 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1860.04±13.4 ˚C day year^{-1} was noticed during 1991-2000, 1878.49±11.5 ˚C day year^{-}

[1] during 2001-2010, 1918.99±16.5 ˚C day year^{-1} during 2011-2020 and 1885.84±9.0 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 2001-2010 (@ -5.96 °C day year^{-1}) and significant increase was noticed during 1991-2000 (@ 6.04 °C day year^{-1}) (Table 4.13).

Table 4.13: Decade-wise variability of accumulated growing degree days during maize growing season in Ludhiana

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1963.40±13.6	1984.46±16.8	2020.65±17.8	1989.50±10.0
	Z	-0.18	-0.89	0.00	2.25*
	Q	-1.42	-2.67	-0.82	1.96
Sowing Window II (5 June)	**Mean±SE**	1929.43±11.1	1955.10±16.9	1988.83±14.1	1957.79±9.1
	Z	-0.18	-0.36	0.18	2.64**
	Q	-1.84	-2.90	3.29	2.37
Sowing Window III (15 June)	**Mean±SE**	1895.29±13.6	1909.91±12.8	1952.02±14.5	1919.07±8.8
	Z	0.36	-0.54	0.72	2.68**
	Q	3.63	-0.87	4.75	2.47
Sowing Window IV (25 June)	**Mean±SE**	1860.04±13.4	1878.49±11.5	1918.99±16.5	1885.84±9.0
	Z	0.36	-0.89	1.07	2.71**
	Q	6.04	-5.96	3.78	2.65

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.11 Decade-wise variability of accumulated growing degree days of maize in Mansa

Mansa district in sowing window I observed mean accumulated growing degree days of 2022.72±16.7 ˚C day year^{-1} during 1991-2000, 2038.47±17.1 ˚C day year^{-1} during 2001-2010, 2123.05±15.1 ˚C day year^{-1} during 2011-2020 and 2061.41±12.2 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -7.98 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1981.82±14.4 ˚C day year^{-1} during 1991-2000, 2004.03±17.8 ˚C day year^{-1} during 2001-2010, 2067.08±17.4 ˚C day year^{-1} during 2011-2020 and 2017.64±11.4 ˚C day year^{-1} during 1991-2020. During sowing window III, mean accumulated growing degree days of 1939.81±15.4 ˚C day year^{-1} was noticed during 1991-2000, 1957.57±15.7 ˚C day year^{-1} during 2001-2010, 2084.96±21.7 ˚C day year^{-1} during 2011-2020 and 1994.11±15.6 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2011-2020 (@ 19.69 °C day year^{-1}). For sowing window IV, mean accumulated growing degree days of 1896.59±17.4

˚C day year^{-1} was noticed during 1991-2000, 1932.32±13.9 ˚C day year^{-1} during 2001-2010, 2064.26±15.2 ˚C day year^{-1} during 2011-2020 and 1964.39±15.9 ˚C day year^{-1} during 1991-2020 (Table 4.14).

Table 4.14: Decade-wise variability of accumulated growing degree days during maize growing season in Mansa

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	2022.72±16.7	2038.47±17.1	2123.05±15.1	2061.41±12.2
	Z	-0.72	1.43	3.04**	3.93***
	Q	-7.98	5.68	9.57	5.04
Sowing Window II (5 June)	**Mean±SE**	1981.82±14.4	2004.03±17.8	2067.08±17.4	2017.64±11.4
	Z	-0.99	0.27	2.15*	3.11**
	Q	-5.5	2.32	6.26	3.85
Sowing Window III (15 June)	**Mean±SE**	1939.81±15.4	1957.57±15.7	2084.96±21.7	1994.11±15.6
	Z	0.54	0.18	3.22**	4.53***
	Q	2.22	1.11	19.69	7.54
Sowing Window IV (25 June)	**Mean±SE**	1896.59±17.4	1932.32±13.9	2064.26±15.2	1964.39±15.9
	Z	0.54	0.89	1.25	4.85***
	Q	5.91	5.40	2.67	8.26

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.12 Decade-wise variability of accumulated growing degree days of maize in Moga

Moga district in sowing window I observed mean accumulated growing degree days of 2000.82±16.2 ˚C day year^{-1} during 1991-2000, 2015.19±13.0 ˚C day year^{-1} during 2001-2010, 2091.35±19.9 ˚C day year^{-1} during 2011-2020 and 2035.78±11.8 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -7.5 °C day year^{-1}) and significant increase was noticed during 2011-2020 (@ 16.16 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1964.33±13.7 ˚C day year^{-1} during 1991-2000, 1989.10±16.0 ˚C day year^{-1} during 2001-2010, 2020.45±25.9 ˚C day year^{-1} during 2011-2020 and 2020.45±15.8 ˚C day year^{-1} during 1991-2020. During sowing window III, mean accumulated growing degree days of 1924.31±14.6 ˚C day year^{-1} was noticed during 1991-2000, 1949.22±15.1 ˚C day year^{-1} during 2001-2010, 2052.34±22.9 ˚C day year^{-1} during 2011-2020 and 1975.29±14.3 ˚C day year^{-1} during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1880.02±15.6 ˚C day year^{-1} was noticed during 1991-2000, 1913.12±11.1 ˚C day year^{-1} during 2001-2010, 2045.51±16.1

˚C day year^{-1} during 2011-2020 and 1946.22±15.5 ˚C day year $^{-1}$ during 1991-2020 (Table 4.15).

Table 4.15: Decade-wise variability of accumulated growing degree days during maize growing season in Moga

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	2000.82±16.2	2015.19±13.0	2091.35±19.9	2035.78±11.8
	Z	-0.89	0.54	1.79+	3.03**
	Q	-7.5	5.1	16.16	4.61
Sowing Window II (5 June)	**Mean±SE**	1964.33±13.7	1989.10±16.0	2020.45±25.9	2020.45±15.8
	Z	-1.07	1.25	2.15*	4.00***
	Q	-6.63	3.49	12.62	5.63
Sowing Window III (15 June)	**Mean±SE**	1924.31±14.6	1949.22±15.1	2052.34±22.9	1975.29±14.3
	Z	0.18	0.54	1.25	3.89***
	Q	0.90	3.06	12.20	5.90
Sowing Window IV (25 June)	**Mean±SE**	1880.02±15.6	1913.12±11.1	2045.51±16.1	1946.22±15.5
	Z	0.00	0.72	2.15*	4.89***
	Q	3.71	3.71	3.13	7.48

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.13 Decade-wise variability of accumulated growing degree days of maize in Muktsar

Muktsar district in sowing window I observed mean accumulated growing degree days of 2031.21±16.4 ˚C day year $^{-1}$ during 1991-2000, 2053.15±19.6 ˚C day year $^{-1}$ during 2001-2010, 2227.05±19.4 ˚C day year $^{-1}$ during 2011-2020 and 2103.80±19.3 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -5.65 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1995.20±13.9 ˚C day year $^{-1}$ during 1991-2000, 2011.77±15.1 ˚C day year $^{-1}$ during 2001-2010, 2129.54±22.3 ˚C day year $^{-1}$ during 2011-2020 and 2045.50±14.8 ˚C day year $^{-1}$ during 1991-2020 and significant increase was noticed during 2011-2020 (@ 21.71 °C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1955.49±15.2 ˚C day year^{-1} was noticed during 1991-2000, 1973.83±15.9 ˚C day year $^{-1}$ during 2001-2010, 2021.78±23.7 ˚C day year $^{-1}$ during 2011-2020 and 2021.78±18.3 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1910.28±16.8 ˚C day year^{-1} was noticed during 1991-2000, 1949.57±13.0 ˚C day year $^{-1}$ during 2001-2010, 2098.24±8.8 ˚C day year^{-1} during 2011-2020 and 1986.03±16.7 ˚C day year^{-1} during 1991-2020 (Table 4.16).

Table 4.16: Decade-wise variability of accumulated growing degree days during maize growing season in Muktsar

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	2031.21±16.4	2053.15±19.6	2227.05±19.4	2103.80±19.3
	Z	-0.72	0.89	2.50*	4.35***
	Q	-5.65	6.84	3.98	9.02
Sowing Window II (5 June)	**Mean±SE**	1995.20±13.9	2011.77±15.1	2129.54±22.3	2045.50±14.8
	Z	-0.89	0.72	2.86**	4.00***
	Q	-5.39	2.64	21.71	6.26
Sowing Window III (15 June)	**Mean±SE**	1955.49±15.2	1973.83±15.9	2021.78±23.7	2021.78±18.3
	Z	0.18	0.36	2.96**	4.41***
	Q	4.12	2.20	3.97	8.13
Sowing Window IV (25 June)	**Mean±SE**	1910.28±16.8	1949.57±13.0	2098.24±8.8	1986.03±16.7
	Z	0.72	1.25	1.71+	5.16***
	Q	4.35	6.10	2.75	9.55

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.14 Decade-wise variability of accumulated growing degree days of maize in Patiala

Patiala district in sowing window I observed mean accumulated growing degree days of 1817.22±16.5 ˚C day year^{-1} during 1991-2000, 1867.72±26.6 ˚C day year^{-1} during 2001-2010, 1936.48±32.9 ˚C day year^{-1} during 2011-2020 and 1951.71±34.8 ˚C day year^{-1} during 1991-2020 and significant increase was noticed during 2001-2010 (@ 18.47 °C day year^{-1}). During sowing window II, the district had mean accumulated growing degree days of 1780.22±14.2 ˚C day year^{-1} during 1991-2000, 1843.01±24.4 ˚C day year^{-1} during 2001-2010, 2087.58±31.5 ˚C day year^{-1} during 2011-2020 and 1903.60±28.1 ˚C day year^{-1} during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -9.16 °C day year^{-1}). During sowing window III, mean accumulated growing degree days of 1742.59±13.8 ˚C day year^{-1} was noticed during 1991-2000, 1802.90±22.8 ˚C day year^{-1} during 2001-2010, 2034.24±26.4 ˚C day year^{-1} during 2011-2020 and 1859.91±26.3 ˚C day year^{-1} during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1703.44±15.3 ˚C day year^{-1} was noticed during 1991-2000, 1767.28±21.3 ˚C day year^{-1} during 2001-2010, 1987.36±24.2 ˚C day year^{-1} during 2011-2020 and 1819.36±25.3 ˚C day year^{-1} during 1991-2020 (Table 4.17).

Table 4.17: Decade-wise variability of accumulated growing degree days during maize growing season in Patiala

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1817.22±16.5	1867.72±26.6	2124.52±32.9	1936.48±28.8
	Z	-1.61	1.97*	2.33*	4.75***
	Q	-9.06	18.47	8.85	14.21
Sowing Window II (5 June)	**Mean±SE**	1780.22±14.2	1843.01±24.4	2087.58±31.5	1903.60±28.1
	Z	-1.25	2.5*	2.33*	5.00***
	Q	-9.16	11.12	12.78	14.21
Sowing Window III (15 June)	**Mean±SE**	1742.59±13.8	1802.90±22.8	2034.24±26.4	1859.91±26.3
	Z	-0.36	1.61	2.33*	5.14***
	Q	-3.75	14.94	7.67	13.54
Sowing Window IV (25 June)	**Mean±SE**	1703.44±15.3	1767.28±21.3	1987.36±24.2	1819.36±25.3
	Z	0.00	0.89	2.33*	5.28***
	Q	0.47	11.17	13.21	14.01

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.15 Decade-wise variability of accumulated growing degree days of maize in Rupnagar

Rupnagar district in sowing window I observed mean accumulated growing degree days of 1963.01±13.5 ˚C day year $^{-1}$ during 1991-2000, 1951.23±16.9 ˚C day year $^{-1}$ during 2001-2010, 2041.18±30.4 ˚C day year $^{-1}$ during 2011-2020 and 1985.14±14.1 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 2001-2010 (@ -13.91 °C day year $^{-1}$) and significant increase was noticed during 2011-2020 (@ 28.83 °C day year $^{-1}$). During sowing window II, the district had mean accumulated growing degree days of 1930.36±11.2 ˚C day year $^{-1}$ during 1991-2000, 1932.0±12.5 ˚C day year $^{-1}$ during 2001-2010, 2098.8±16.7 ˚C day year $^{-1}$ during 2011-2020 and 1987.04+16.5 ˚C day year $^{-1}$ during 1991-2020. During sowing window III, mean accumulated growing degree days of 1896.54±13.7 ˚C day year $^{-1}$ was noticed during 1991-2000, 1920.82±24.6 ˚C day year $^{-1}$ during 2001-2010, 2054.28±3.2 ˚C day year $^{-1}$ during 2011-2020 and 1957.21±15.8 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1852.06±13.9 ˚C day year $^{-1}$ was noticed during 1991-2000, 1884.15±21.5 ˚C day year $^{-1}$ during 2001-2010, 2005.87±3.3 ˚C day year $^{-1}$ during 2011-2020 and 1914.03±14.8 ˚C day year $^{-1}$ during 1991-2020 (Table 4.18).

Table 4.18: Decade-wise variability of accumulated growing degree days during maize growing season in Rupnagar

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	Mean±SE	1963.01±13.5	1951.23±16.9	2041.18±30.4	1985.14±14.1
	Z	0.00	-2.15*	3.22**	2.18*
	Q	1.24	-13.91	28.83	3.85
Sowing Window II (5 June)	Mean±SE	1930.36±11.2	1932.0±12.5	2098.8±16.7	1987.04+16.5
	Z	0.00	-1.97*	3.50***	3.66***
	Q	-0.26	-7.66	13.72	7.55
Sowing Window III (15 June)	Mean±SE	1896.54±13.7	1920.82±24.6	2054.28±3.2	1957.21±15.8
	Z	0.18	0.36	3.58***	5.00***
	Q	0.41	4.73	2.80	7.13
Sowing Window IV (25 June)	Mean±SE	1852.06±13.9	1884.15±21.5	2005.87±3.3	1914.03±14.8
	Z	0.00	0.72	3.58***	5.17***
	Q	1.31	7.27	2.60	7.34

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.16 Decade-wise variability of accumulated growing degree days of maize in Sangrur

Sangrur district in sowing window I observed mean accumulated growing degree days of 1983.31±16.2 ˚C day year $^{-1}$ during 1991-2000, 1989.06±11.5 ˚C day year $^{-1}$ during 2001-2010, 2093.51±19.1 ˚C day year $^{-1}$ during 2011-2020 and 2021.96±12.9 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -7.95 °C day year $^{-1}$). During sowing window II, the district had mean accumulated growing degree days of 1945.72±13.7 ˚C day year $^{-1}$ during 1991-2000, 1967.21±13.2 ˚C day year $^{-1}$ during 2001-2010, 2009.62±31.5 ˚C day year $^{-1}$ during 2011-2020 and 2009.62±18.4 ˚C day year $^{-1}$ during 1991-2020 and significant increase was noticed during 2011-2020 (@ 29.59 °C day year $^{-1}$). During sowing window III, mean accumulated growing degree days of 1905.40±14.5 ˚C day year $^{-1}$ was noticed during 1991-2000, 1921.98±12.9 ˚C day year $^{-1}$ during 2001-2010, 2051.67±28.9 ˚C day year $^{-1}$ during 2011-2020 and 1959.68±15.5 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1861.95±15.7 ˚C day year $^{-1}$ was noticed during 1991-2000, 1898.78±13.3 ˚C day year $^{-1}$ during 2001-2010, 2054.22±14.1 ˚C day year $^{-1}$ during 2011-2020 and 1938.31±17.4 ˚C day year $^{-1}$ during 1991-2020 (Table 4.19).

Table 4.19: Decade-wise variability of accumulated growing degree days during maize growing season in Sangrur

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1983.31±16.2	1989.06±29.7	2093.51±15.8	2021.96±12.9
	Z	-1.07	0.18	2.86**	3.46***
	Q	-7.95	0.85	16.66	5.28
Sowing Window II (5 June)	**Mean±SE**	1945.72±13.7	1967.21±13.2	2009.62±31.5	2009.62±18.4
	Z	-1.07	1.07	3.04**	4.10***
	Q	-5.92	4.82	29.59	7.73
Sowing Window III (15 June)	**Mean±SE**	1905.40±14.5	1921.98±12.9	2051.67±28.9	1959.68±15.5
	Z	0.36	0.18	3.22**	3.93***
	Q	0.17	1.87	25.57	6.33
Sowing Window IV (25 June)	**Mean±SE**	1861.95±15.7	1898.78±13.3	2054.22±14.1	1938.31±17.4
	Z	0.18	0.54	2.86**	5.14***
	Q	2.49	6.23	2.35	9.07

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.3.17 Decade-wise variability of accumulated growing degree days of maize in SBS Nagar

SBS Nagar district in sowing window I observed mean accumulated growing degree days of 1963.4±13.6 ˚C day year $^{-1}$ during 1991-2000, 2019.78±29.7 ˚C day year $^{-1}$ during 2001-2010, 2164.40±15.8 ˚C day year $^{-1}$ during 2011-2020 and 2049.19±19.6 ˚C day year $^{-1}$ during 1991-2020 and significant increase was noticed during 1991-2020 (@ 9.15 °C day year $^{-1}$). During sowing window II, the district had mean accumulated growing degree days of 1929.43±11.1 ˚C day year $^{-1}$ during 1991-2000, 1960.29±18.6 ˚C day year $^{-1}$ during 2001-2010, 2133.00±11.3 ˚C day year $^{-1}$ during 2011-2020 and 2007.57±18.4 ˚C day year $^{-1}$ during 1991-2020 and significant decrease was noticed during 1991-2000 (@ -1.84 °C day year $^{-1}$). During sowing window III, mean accumulated growing degree days of 1895.29±13.6 ˚C day year $^{-1}$ was noticed during 1991-2000, 1939.8±23.2 ˚C day year $^{-1}$ during 2001-2010, 2052.71±14.8 ˚C day year $^{-1}$ during 2011-2020 and 1962.60±15.8 ˚C day year $^{-1}$ during 1991-2020. For sowing window IV, mean accumulated growing degree days of 1860.04±13.4 ˚C day year $^{-1}$ was noticed during 1991-2000, 1907.91±19.7 ˚C day year $^{-1}$ during 2001-2010, 2022.94±3.9 ˚C day year $^{-1}$ during 2011-2020 and 1930.29±14.9 ˚C day year $^{-1}$ during 1991-2020 (Table 4.20).

Table 4.20: Decade-wise variability of accumulated growing degree days during maize growing season in SBS Nagar

Period	Test	1991-2000	2001-2010	2011-2020	1991-2020
Sowing Window I (25 May)	**Mean±SE**	1963.40±13.6	2019.78±29.7	2164.40±15.8	2049.19±19.6
	Z	-0.18	0.72	3.58***	5.03***
	Q	-1.42	13.75	6.02	9.15
Sowing Window II (5 June)	**Mean±SE**	1929.43±11.1	1960.29±18.6	2133.00±11.3	2007.57±18.4
	Z	-0.18	0.00	3.22**	4.64***
	Q	-1.84	-0.42	4.07	8.44
Sowing Window III (15 June)	**Mean±SE**	1895.29±13.6	1939.80±23.2	2052.71±14.8	1962.60±15.8
	Z	0.36	0.72	2.68**	4.60***
	Q	3.63	8.18	4.14	7.06
Sowing Window IV (25 June)	**Mean±SE**	1860.04±13.4	1907.91±19.7	2022.94±3.9	1930.29±14.9
	Z	0.36	0.89	3.94***	5.39***
	Q	6.04	7.77	3.44	7.56

Z: Mann-Kendall test, Q: Sen's slope estimator.
* Statistically significant at the 5% significance level, *** Statistically significant at the 0.1% significance level, + Statistically significant at the 10% significance level

4.4 SPATIO-TEMPORAL VARIABILITY IN HEAT USE EFFICIENCY OF MAIZE UNDER DIFFERENT SOWING WINDOWS

4.4.1 Trend analysis of heat use efficiency (HUE) from 1991-2020 under sowing window I

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in heat use efficiency (HUE) under sowing window I and presented in Figures from 4.72 to 4.88. Variation in heat use efficiency was observed during different time periods but the trend increased in all the districts except S.B.S. Nagar. Among all, the highest R^2 value was observed for Gurdaspur (0.7608) and lowest for Moga (0.0104). The rate of increase in HUE was highest for Ludhiana (0.0435 kg ha^{-1} °C $days^{-1}$ $year^{-1}$) and lowest for S.B.S. Nagar (-0.0116 kg ha^{-1} °C $days^{-1}$ $year^{-1}$**).** While for Amritsar, Bathinda, Faridkot, Fatehgarh Sahib, Ferozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Mansa, Muktsar, Moga, Patiala, Rupnagar and Sangrur, HUE increased at the rate of 0.0264 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.041 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0156 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0093 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0092 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0362 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0292 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0363 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0287 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0043 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0018 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0226 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.0329 kg ha^{-1} °C $days^{-1}$ $year^{-1}$, 0.031 kg ha^{-1} °C $days^{-1}$ $year^{-1}$ and 0.0309 kg ha^{-1} °C $days^{-1}$ $year^{-1}$. Similar work was also done by Qing *et al* (2016) at 19 stations in Henan province to show tempo-spatial characteristics in radiation use efficiency (RUE) of maize increased from 4%-31% and 69%-96% during 1981 to 2007.

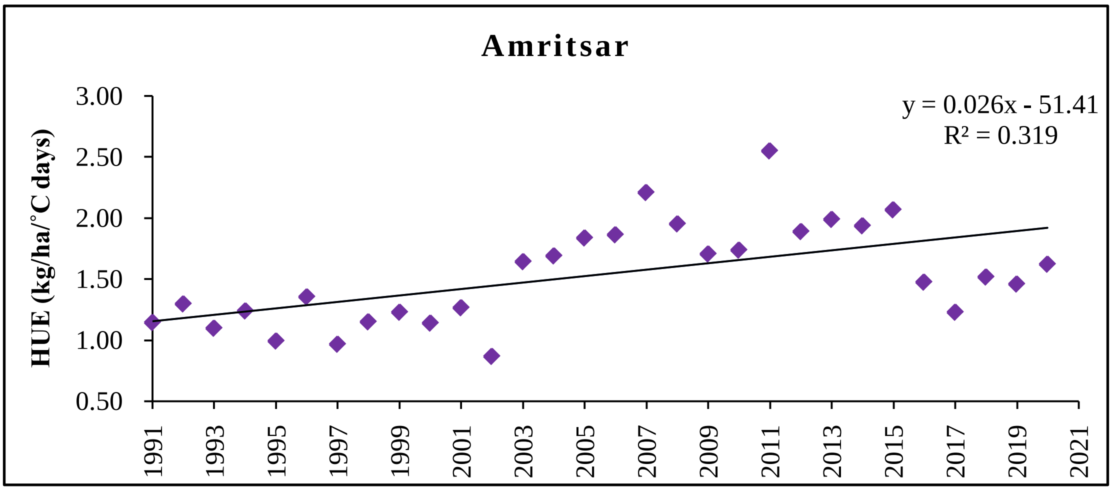

Fig. 4.72: Variability in heat use efficiency (HUE) from 1991 to 2020 at Amritsar under sowing window I

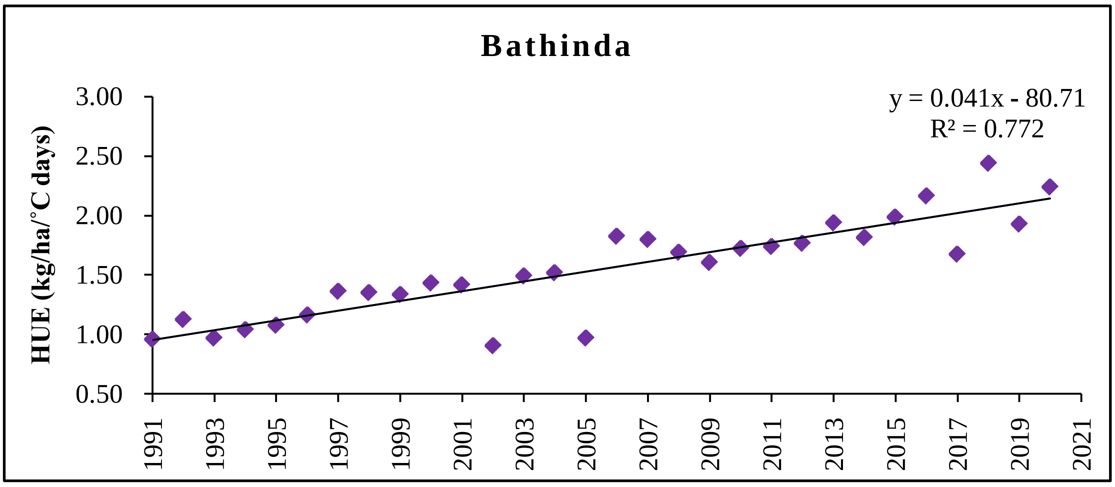

Fig. 4.73: Variability in heat use efficiency (HUE) from 1991 to 2020 at Bathinda under sowing window I

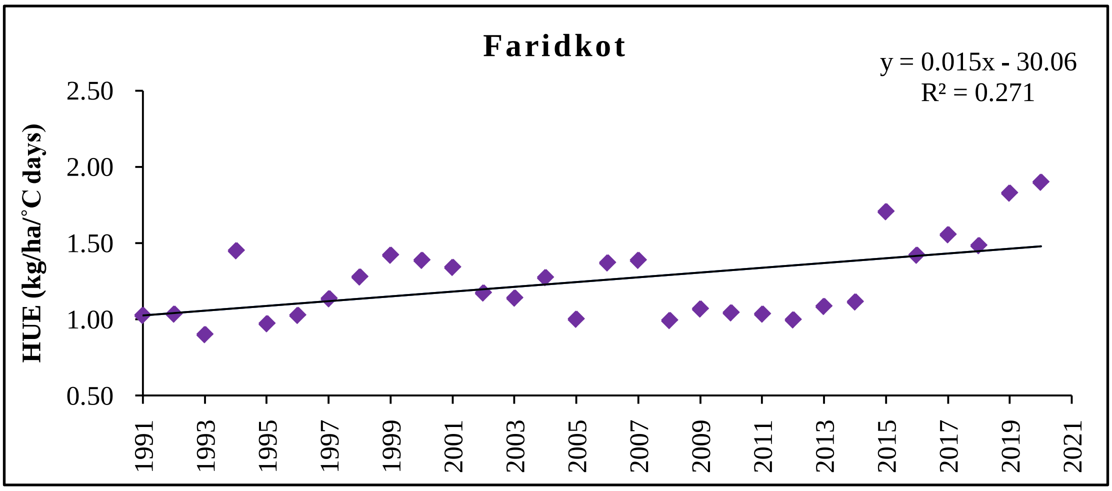

Fig. 4.74: Variability in heat use efficiency (HUE) from 1991 to 2020 at Faridkot under sowing window I

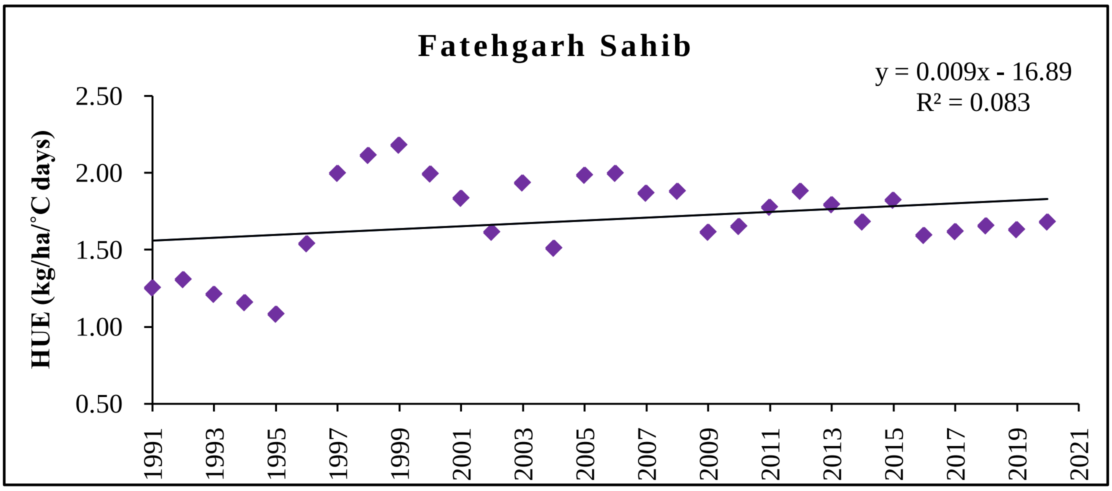

Fig. 4.75: Variability in heat use efficiency (HUE) from 1991 to 2020 at Fatehgarh Sahib under sowing window I

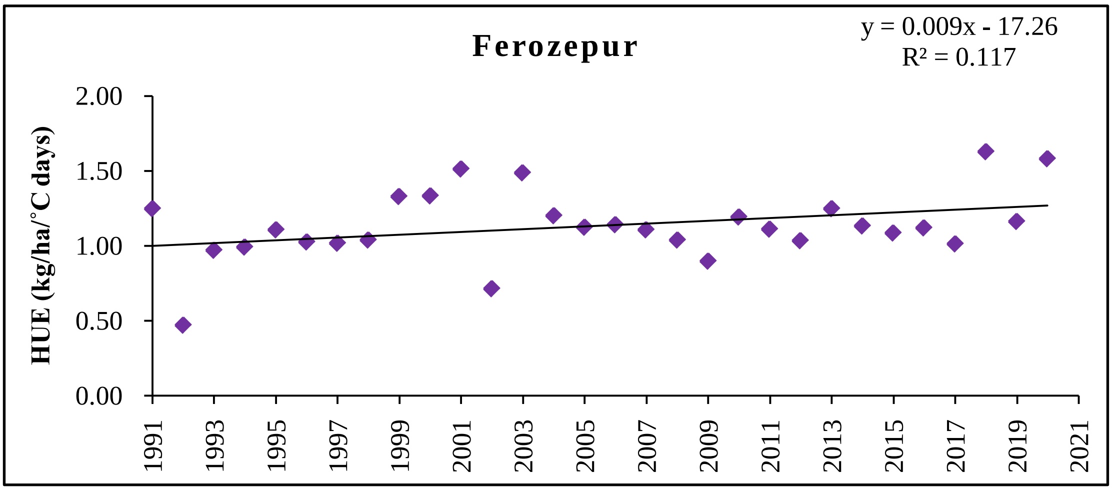

Fig. 4.76: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ferozepur under sowing window I

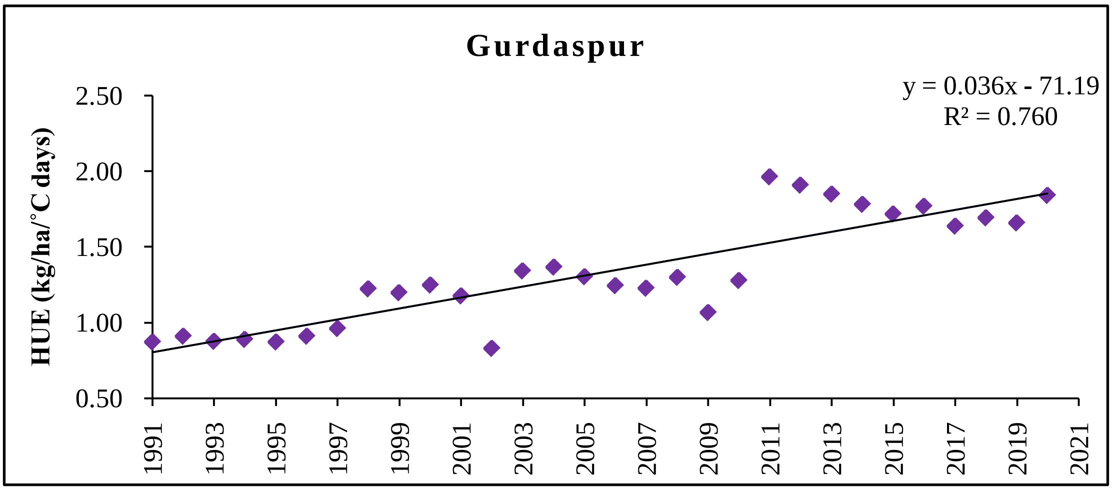

Fig. 4.77: Variability in heat use efficiency (HUE) from 1991 to 2020 at Gurdaspur under sowing window I

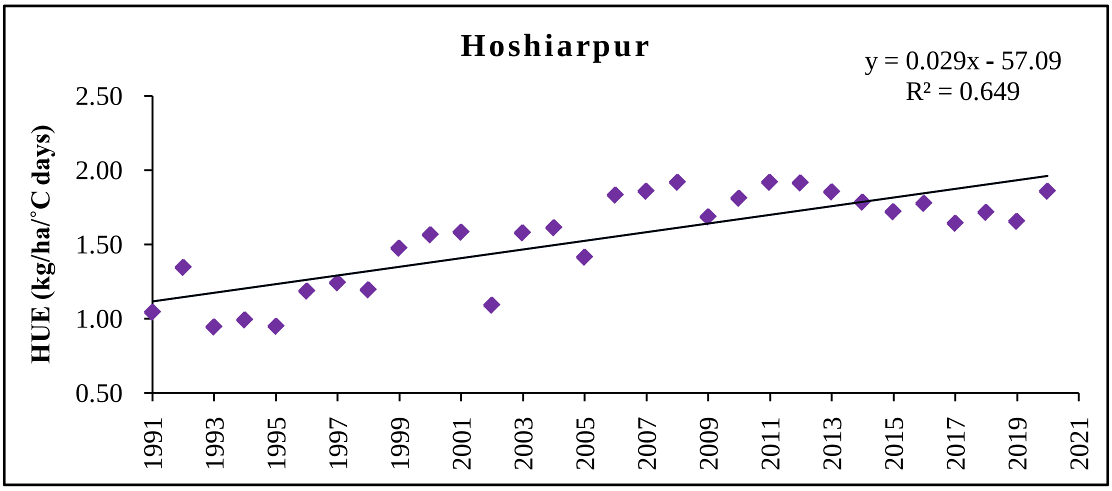

Fig. 4.78: Variability in heat use efficiency (HUE) from 1991 to 2020 at Hoshiarpur under sowing window I

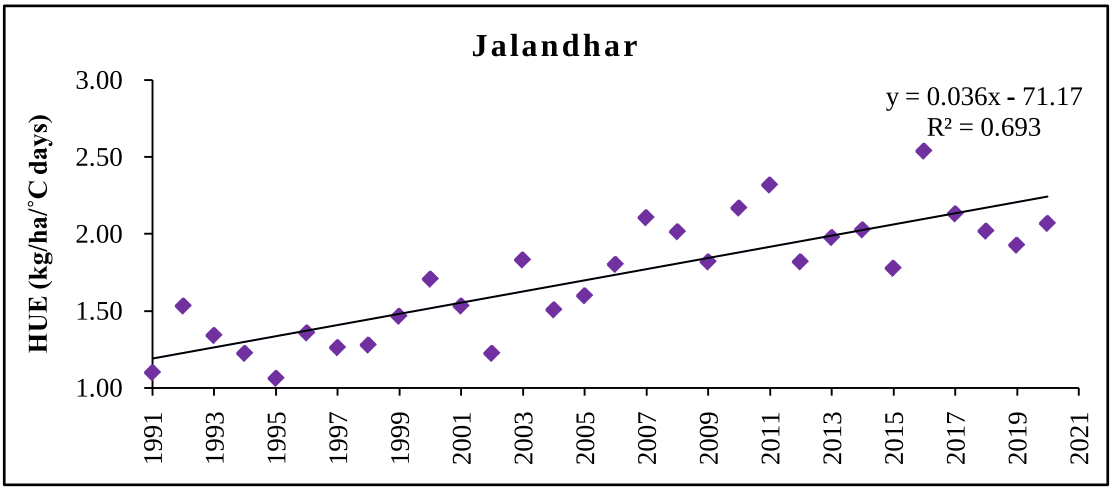

Fig. 4.79: Variability in heat use efficiency (HUE) from 1991 to 2020 at Jalandhar under sowing window I

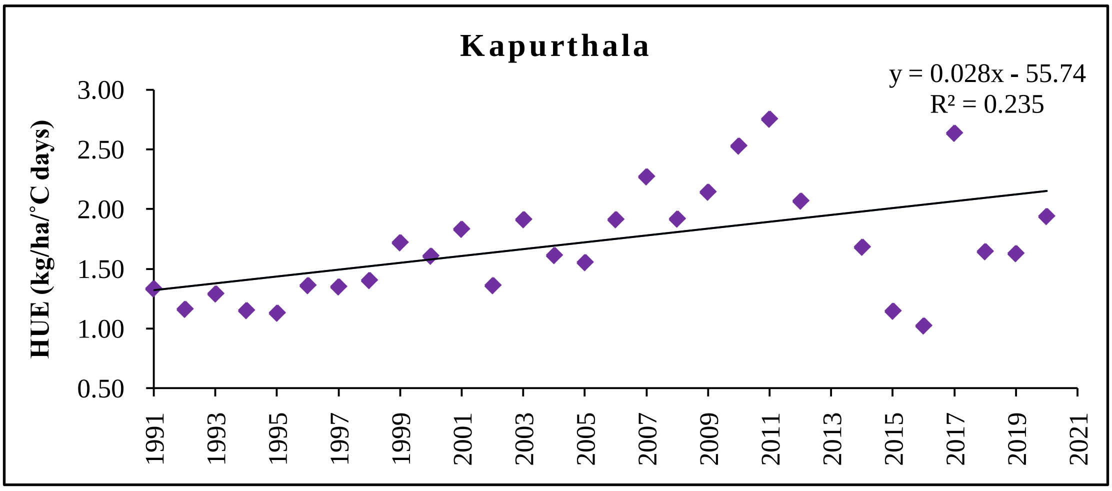

Fig. 4.80: Variability in heat use efficiency (HUE) from 1991 to 2020 at Kapurthala under sowing window I

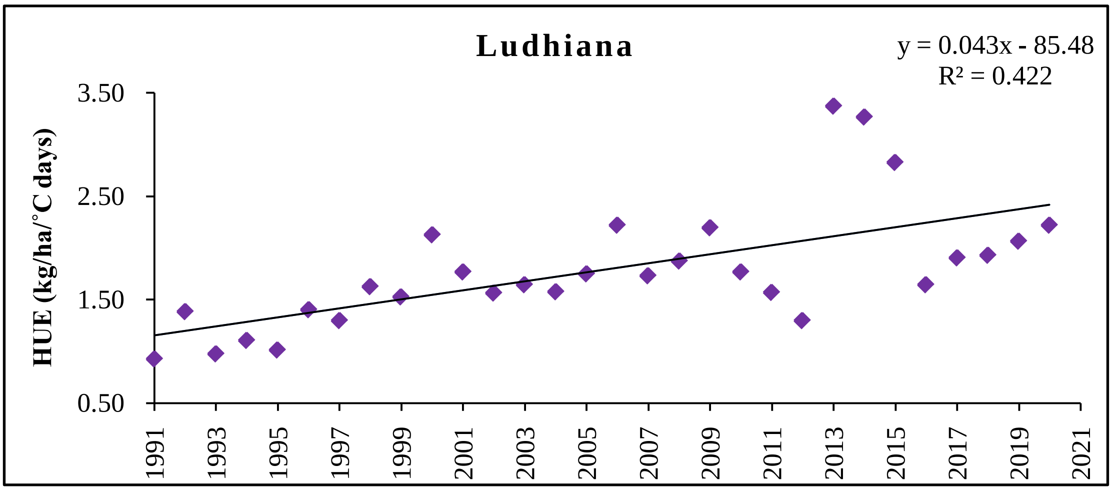

Fig. 4.81: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ludhiana under sowing window I

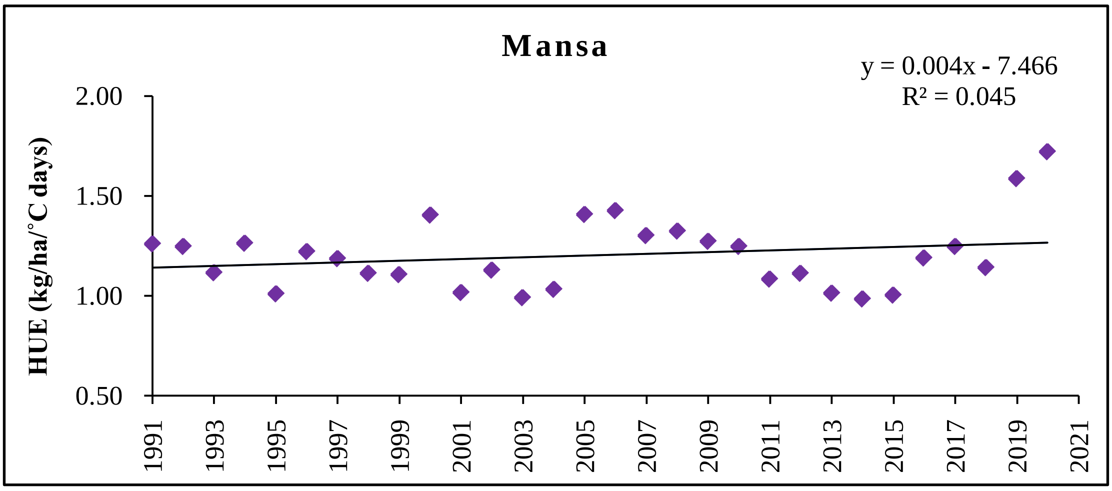

Fig. 4.82: Variability in heat use efficiency (HUE) from 1991 to 2020 at Mansa under sowing window I

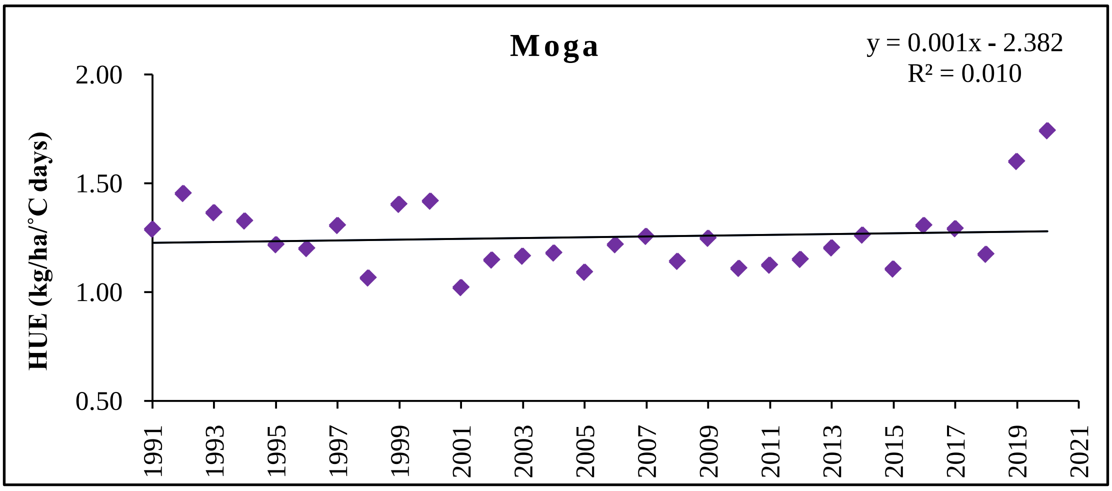

Fig. 4.83: Variability in heat use efficiency (HUE) from 1991 to 2020 at Moga under sowing window I

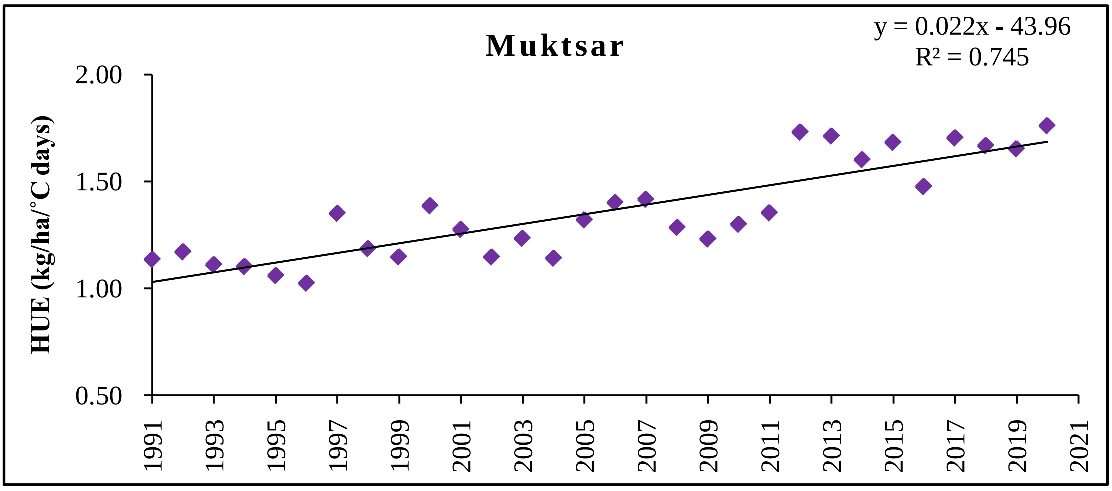

Fig. 4.84: Variability in heat use efficiency (HUE) from 1991 to 2020 at Muktsar under sowing window I

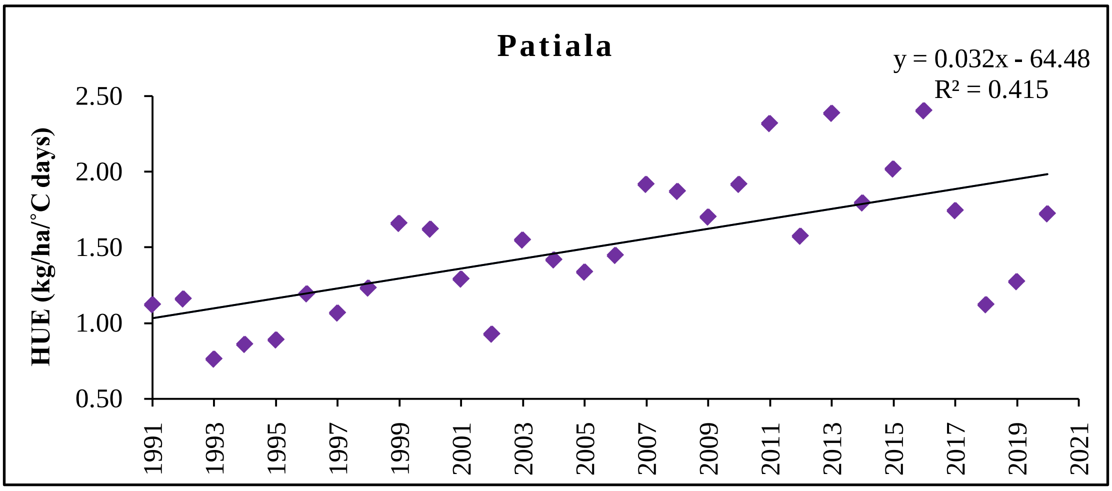

Fig. 4.85: Variability in heat use efficiency (HUE) from 1991 to 2020 at Patiala under sowing window I

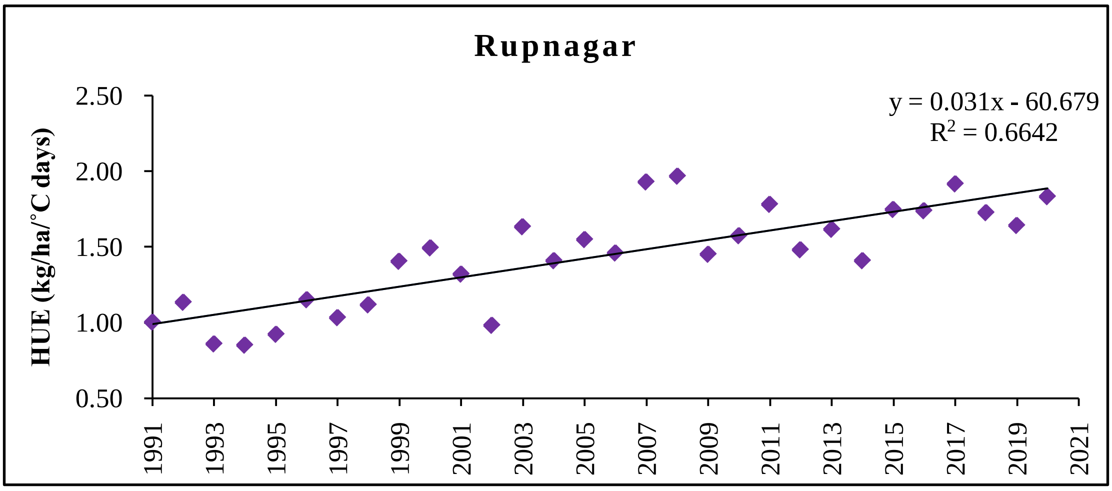

Fig. 4.86: Variability in heat use efficiency (HUE) from 1991 to 2020 at Rupnagar under sowing window I

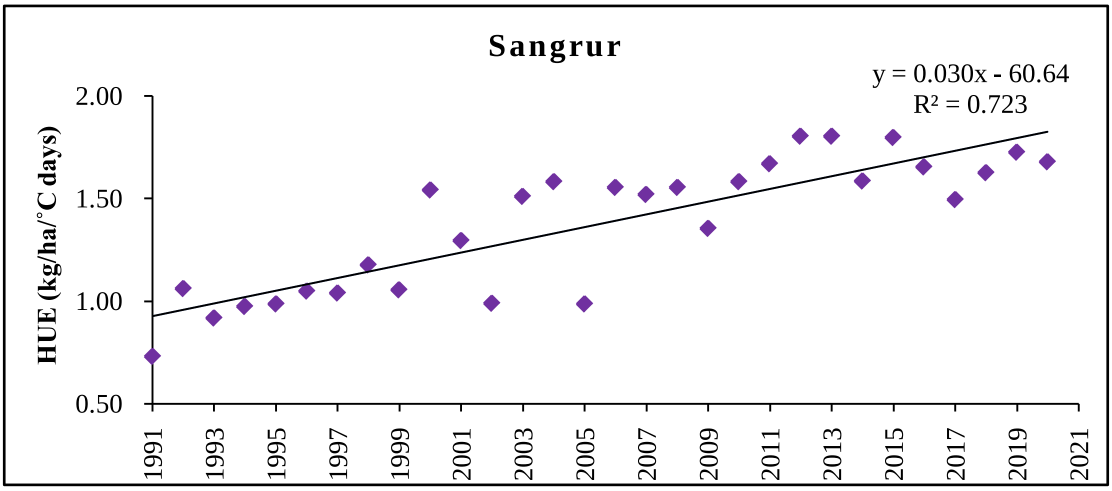

Fig. 4.87: Variability in heat use efficiency (HUE) from 1991 to 2020 at Sangrur under sowing window I

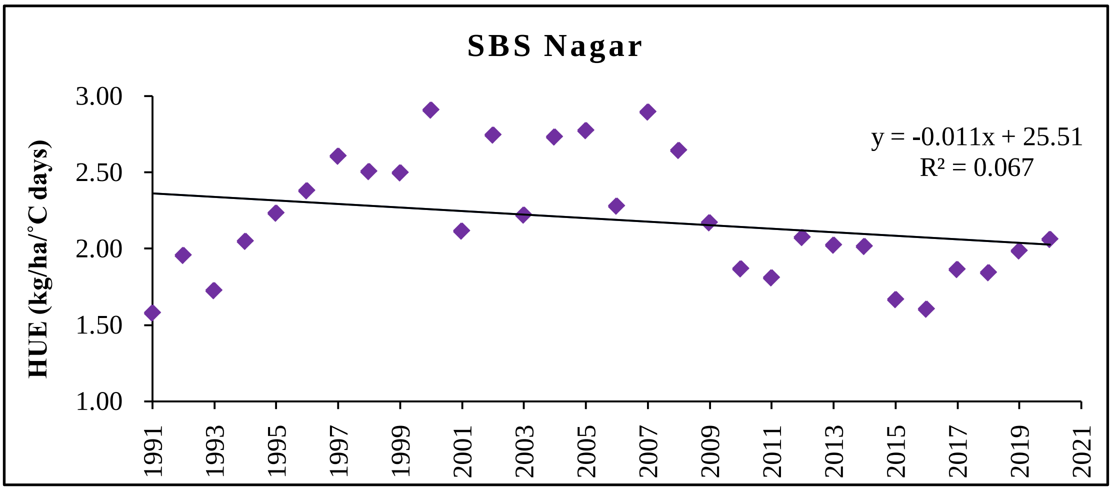

Fig. 4.88: Variability in heat use efficiency (HUE) from 1991 to 2020 at SBS Nagar under sowing window I

4.4.2 Trend analysis of heat use efficiency (HUE) from 1991-2020 under sowing window II

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in heat use efficiency (HUE) under sowing window II and presented in Figures from 4.89 to 4.105. An increasing trend in heat use efficiency was observed for all districts except S.B.S. Nagar. The highest R^2 value was observed for Gurdaspur (0.7725) and lowest for Moga (0.0101). Highest rate of increase in HUE was observed for Ludhiana (0.0428 kg ha^{-1} °C days^{-1} year^{-1}) and lowest for S.B.S. Nagar (-0.0115 kg ha^{-1} °C days^{-1} year^{-1}).

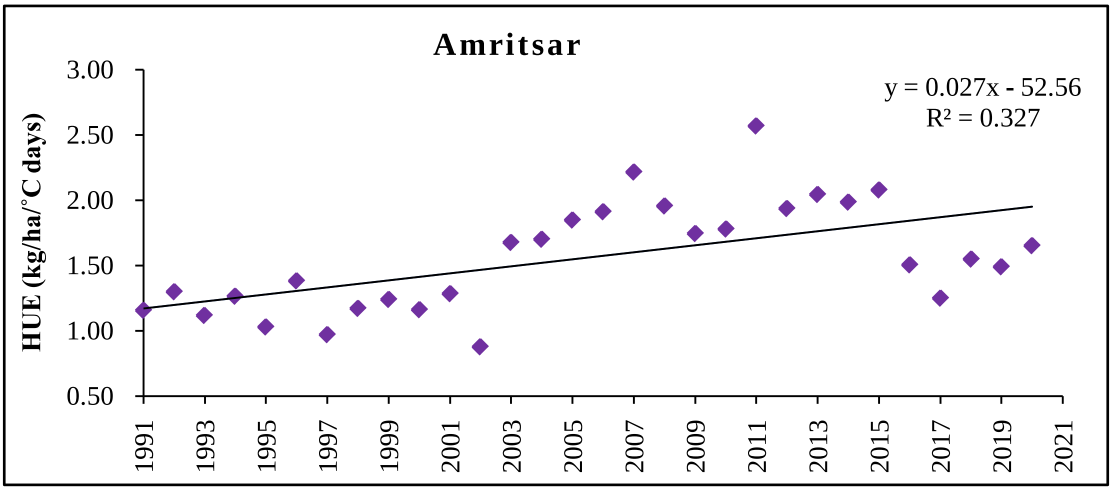

Fig. 4.89: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Amritsar under sowing window II**

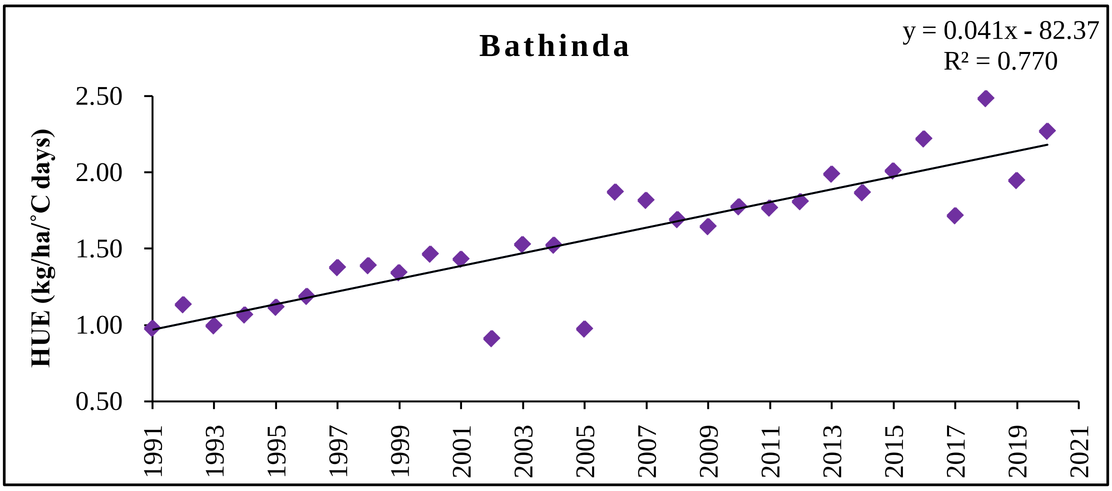

Fig. 4.90: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Bathinda under sowing window II**

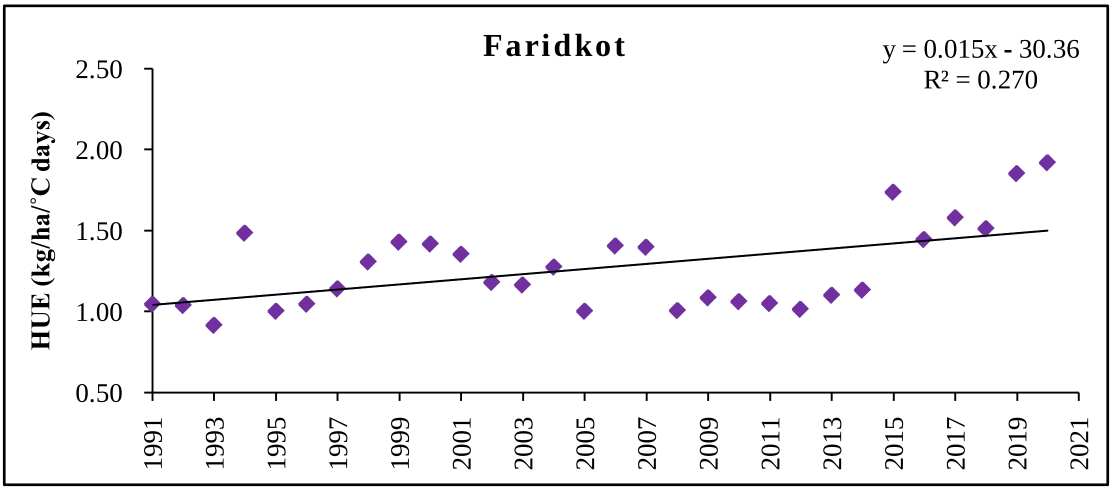

Fig. 4.91: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Faridkot under sowing window II**

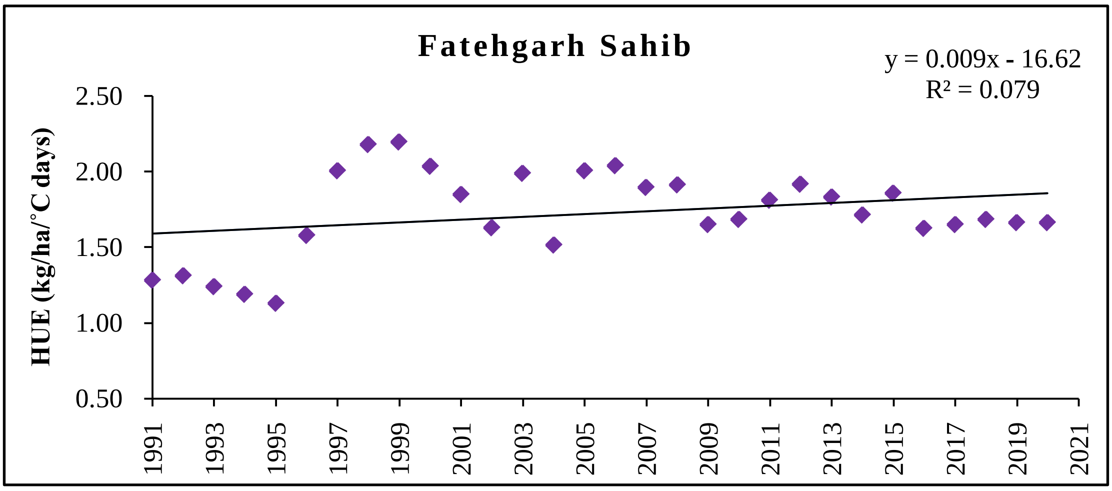

Fig. 4.92: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Fatehgarh Sahib under sowing window II**

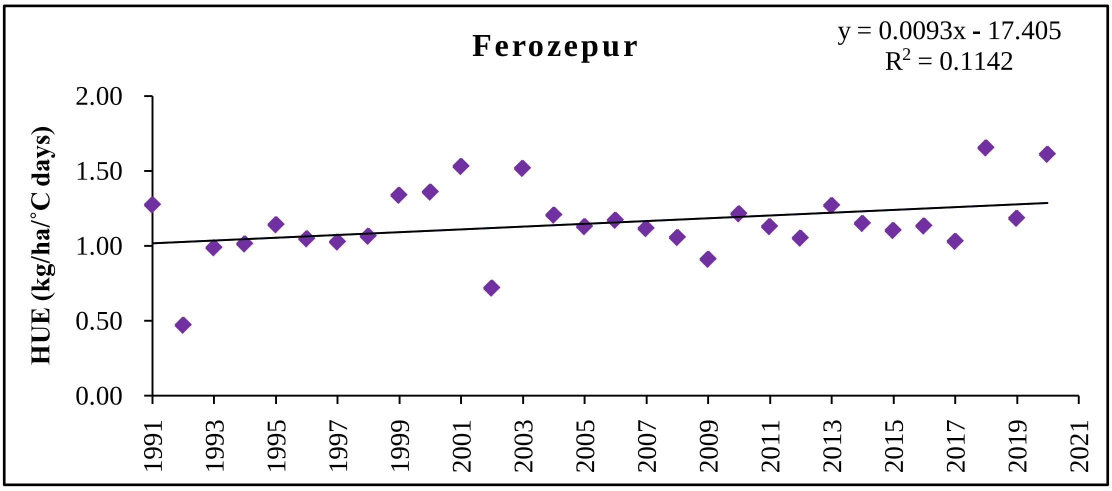

Fig. 4.93: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Ferozepur under sowing window II**

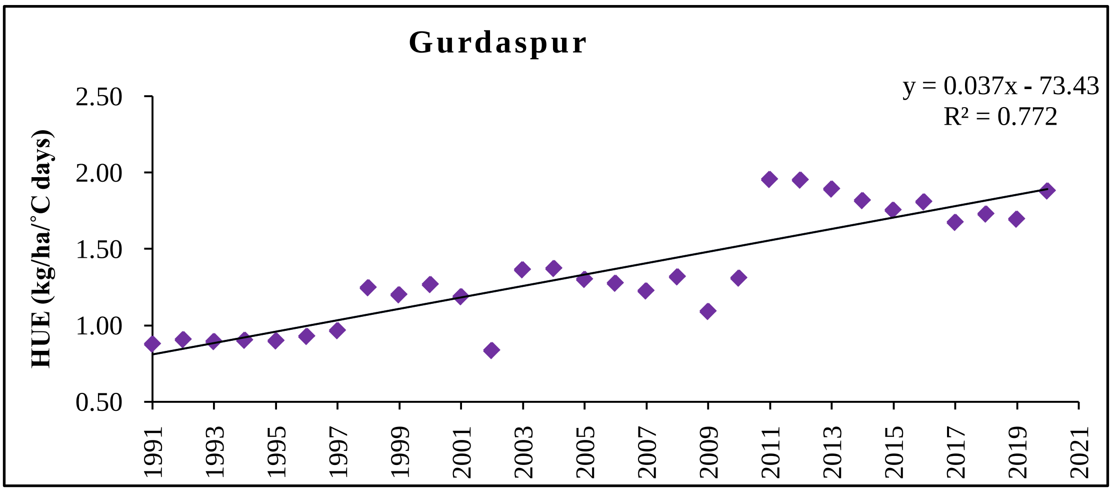

Fig. 4.94: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Gurdaspur under sowing window II**

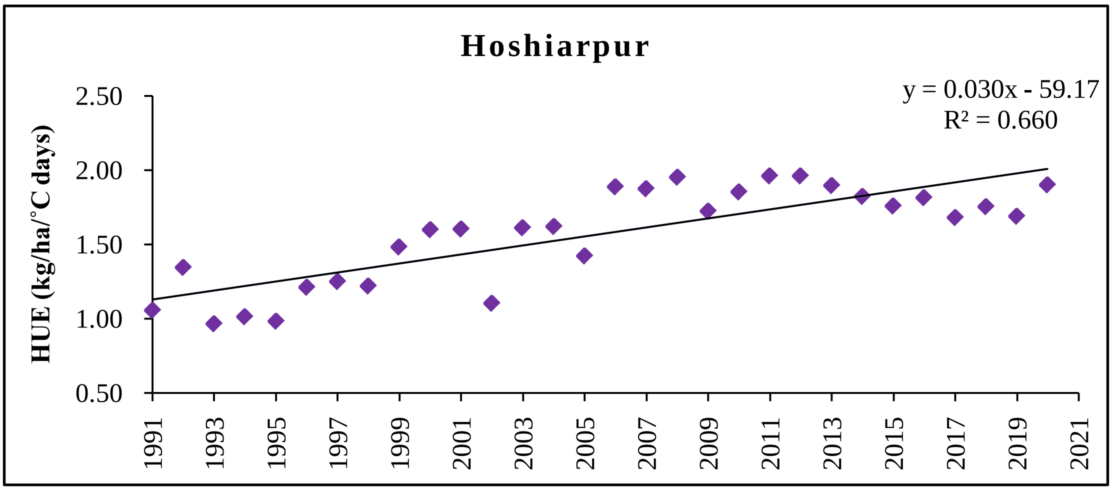

Fig. 4.95: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Hoshiarpur under sowing window II**

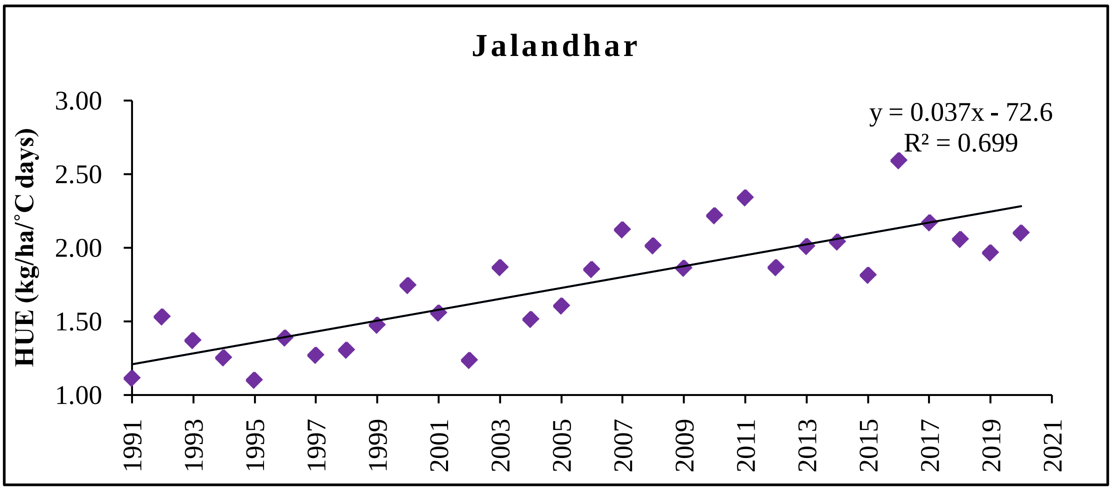

Fig. 4.96: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Jalandhar under sowing window II**

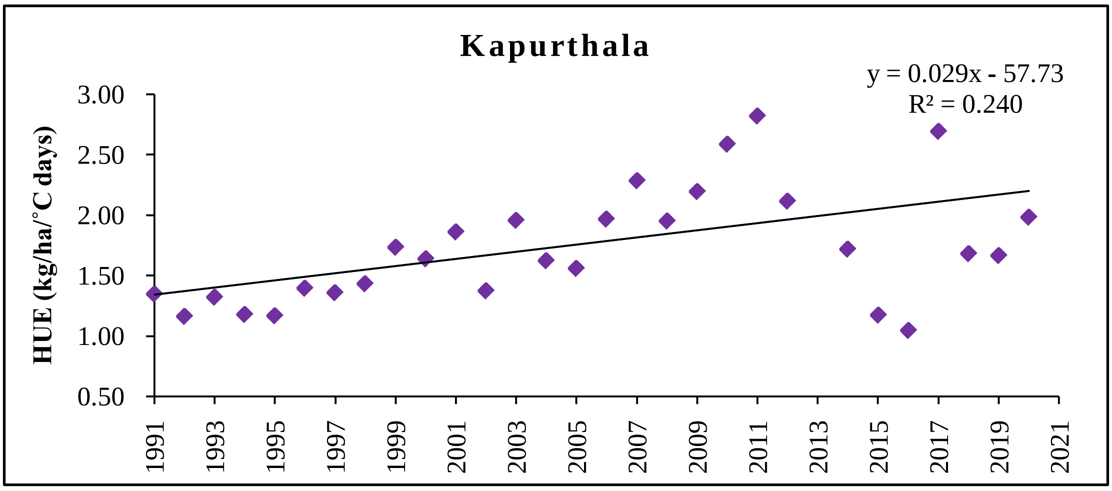

Fig. 4.97: **Variability in heat use efficiency (HUE) from 1991 to 2020 at Kapurthala under sowing window II**

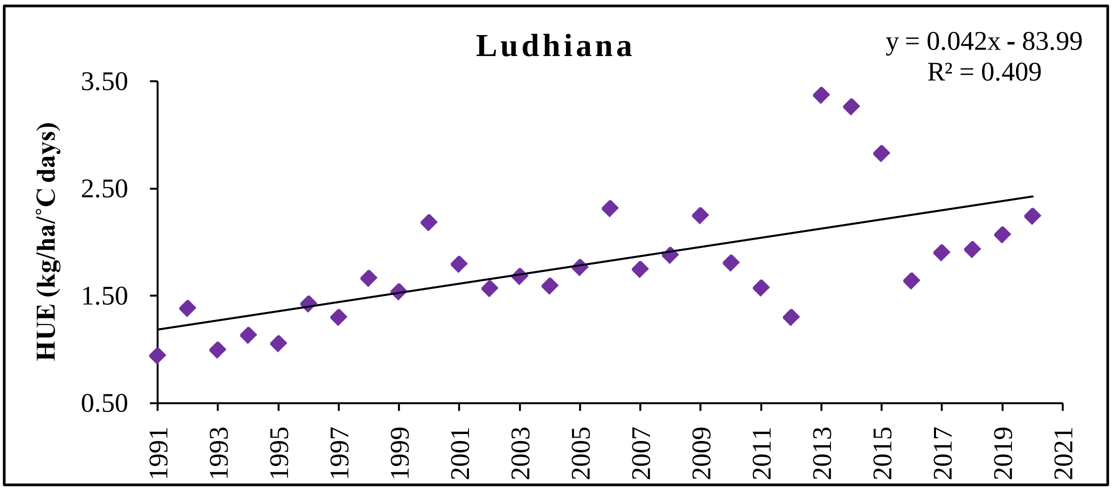

Fig. 4.98: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ludhiana under sowing window II

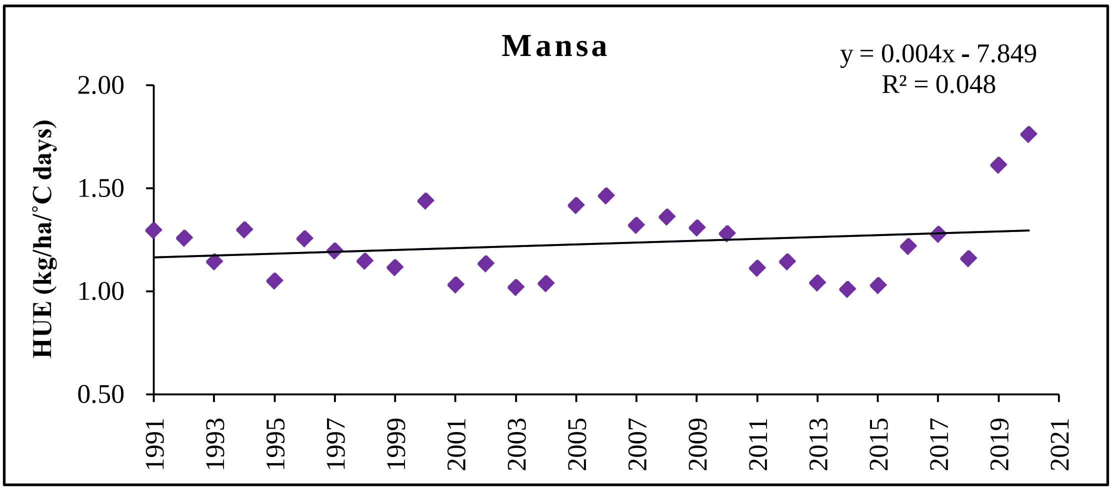

Fig. 4.99: Variability in heat use efficiency (HUE) from 1991 to 2020 at Mansa under sowing window II

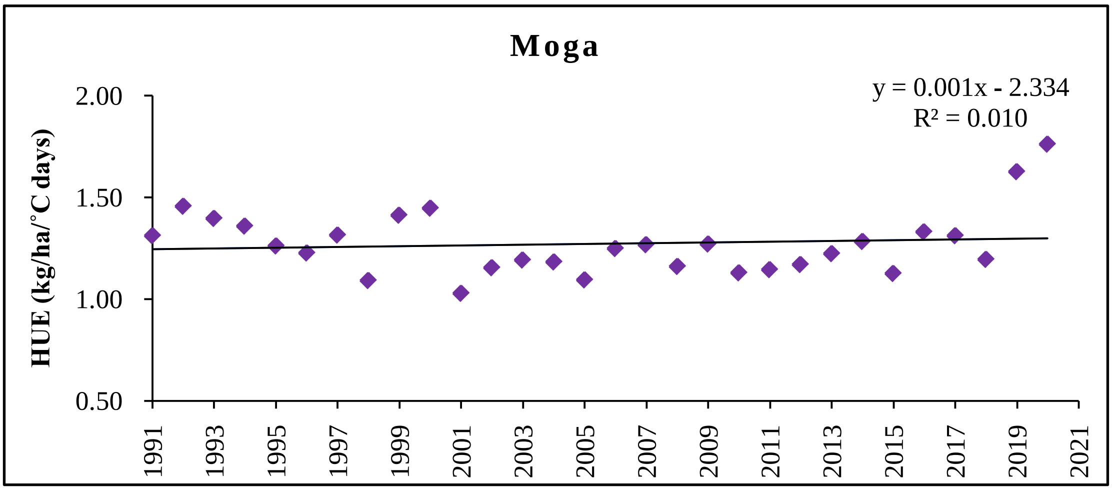

Fig. 4.100: Variability in heat use efficiency (HUE) from 1991 to 2020 at Moga under sowing window II

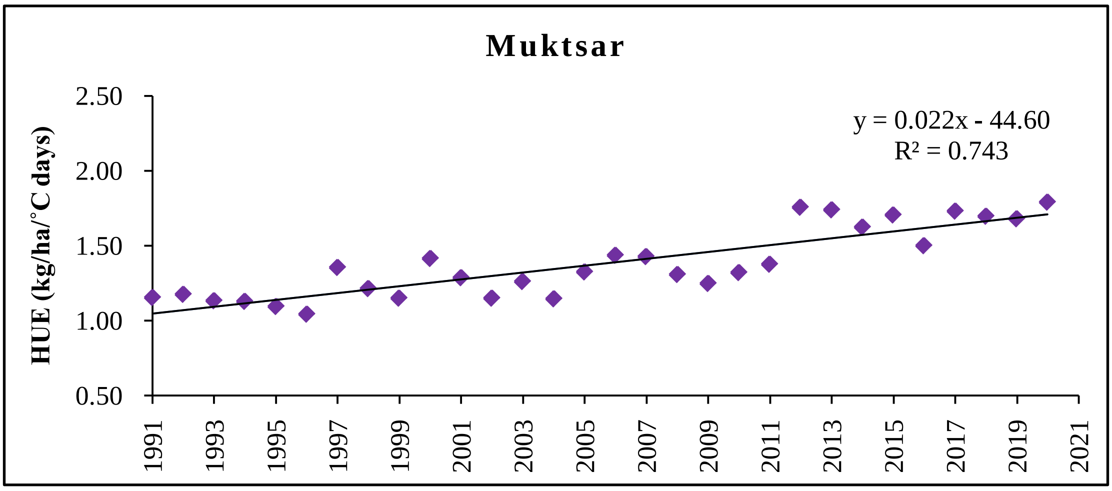

Fig. 4.101: Variability in heat use efficiency (HUE) from 1991 to 2020 at Muktsar under sowing window II

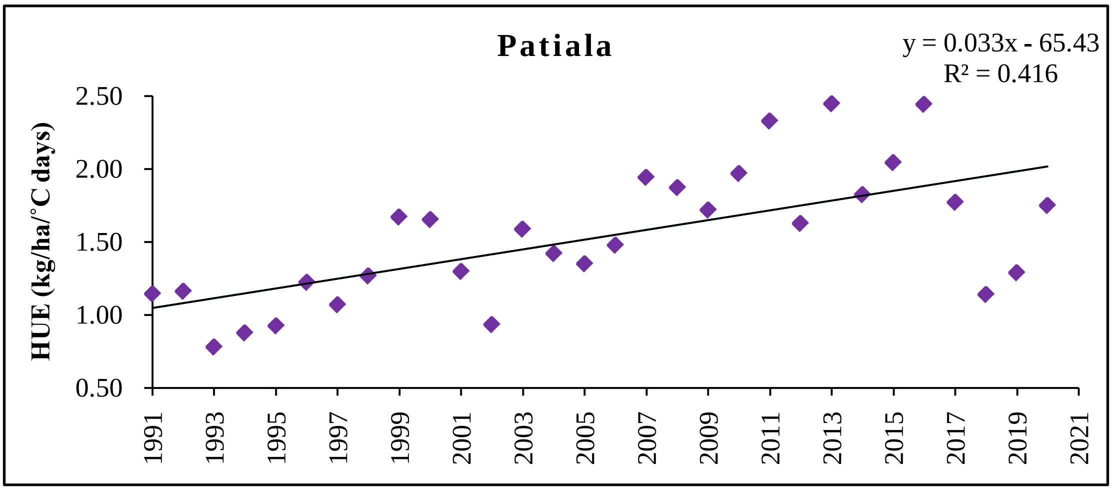

Fig. 4.102: Variability in heat use efficiency (HUE) from 1991 to 2020 at Patiala under sowing window II

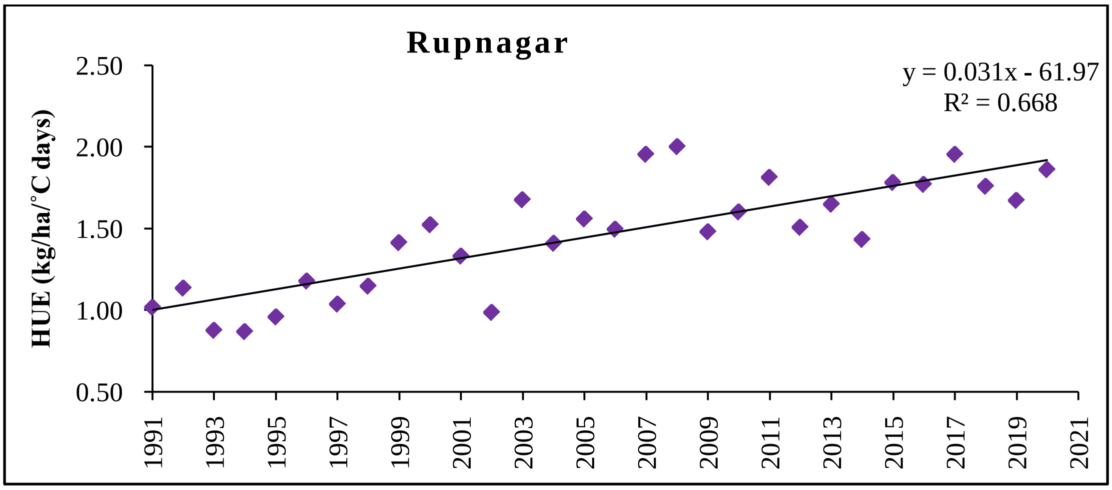

Fig. 4.103: Variability in heat use efficiency (HUE) from 1991 to 2020 at Rupnagar under sowing window II

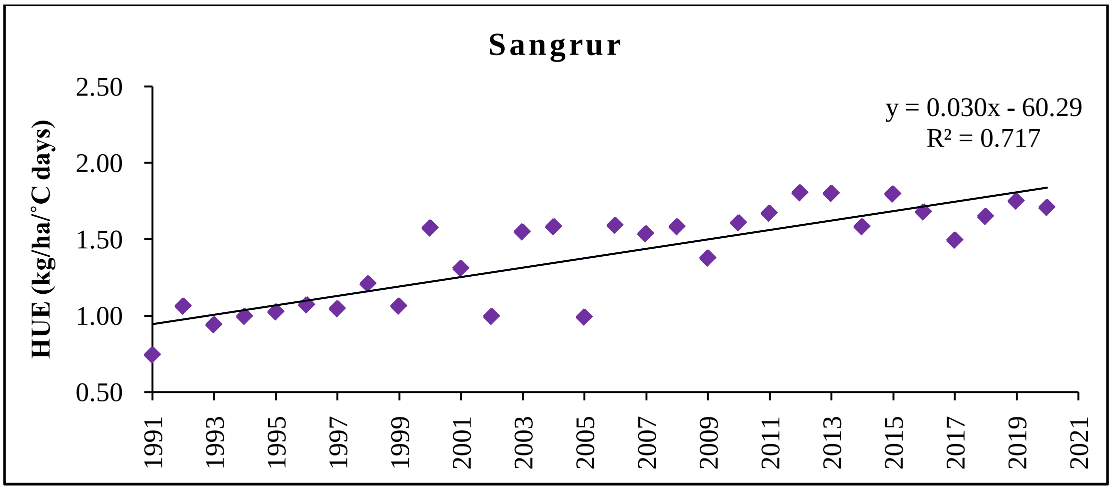

Fig. 4.104: Variability in heat use efficiency (HUE) from 1991 to 2020 at Sangrur under sowing window II

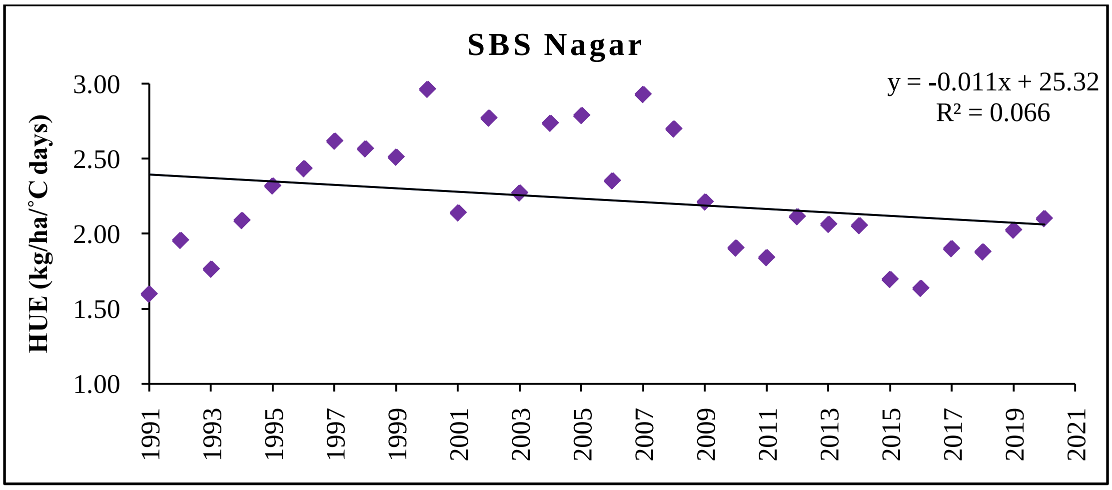

Fig. 4.105: Variability in heat use efficiency (HUE) from 1991 to 2020 at SBS Nagar under sowing window II

4.4.3 Trend analysis of heat use efficiency (HUE) from 1991-2020 under sowing window III

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in heat use efficiency (HUE) under sowing window II and presented in Figures from 4.106 to 4.122. An increasing trend in heat use efficiency was observed for all districts except S.B.S. Nagar. The highest R^2 value was observed for Gurdaspur (0.7823) and lowest for Moga (0.015). Highest rate of increase in HUE was observed for Ludhiana (0.0457 kg ha^{-1} °C days^{-1} year^{-1}) and lowest for S.B.S. Nagar (-0.0111 kg ha^{-1} °C days^{-1} year^{-1}).

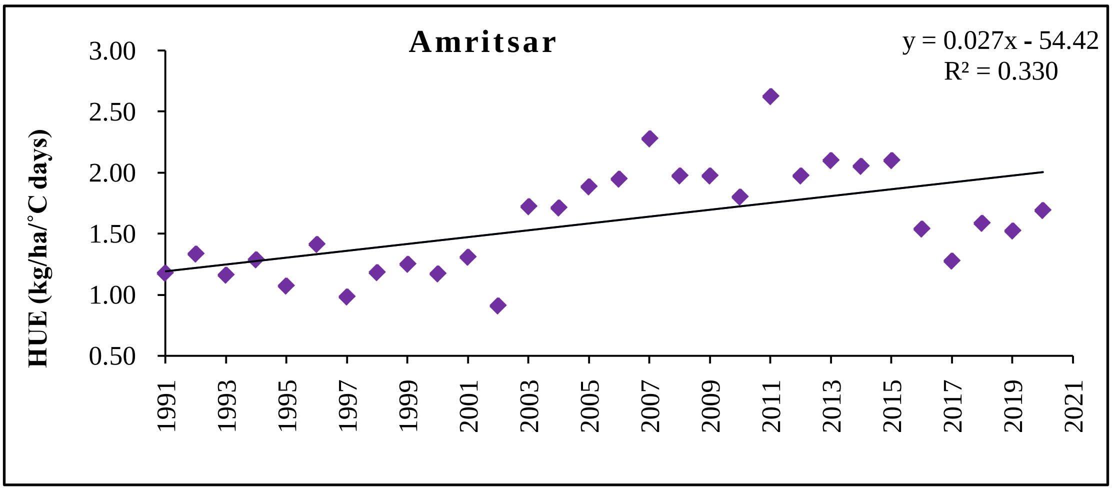

Fig. 4.106: Variability in heat use efficiency (HUE) from 1991 to 2020 at Amritsar under sowing window III

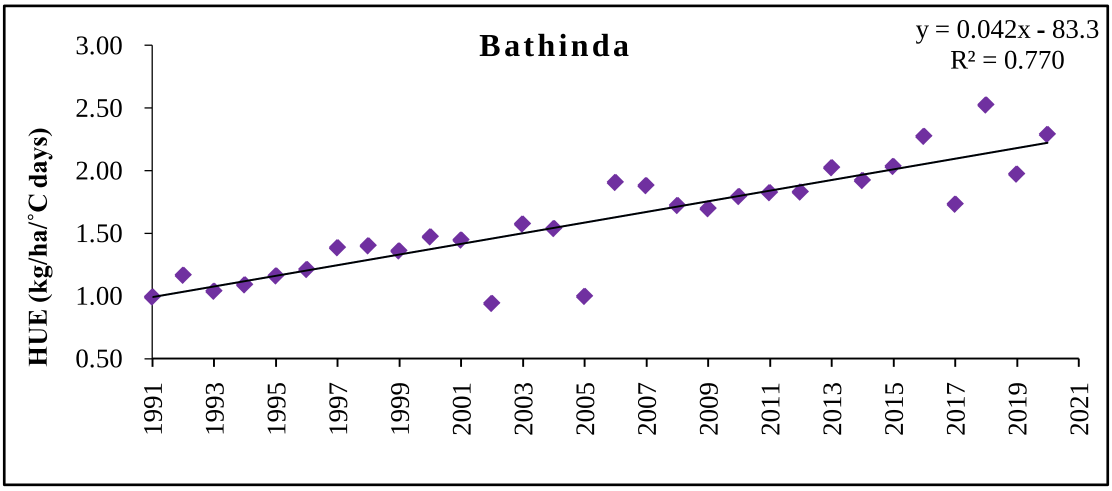

Fig. 4.107: Variability in heat use efficiency (HUE) from 1991 to 2020 at Bathinda under sowing window III

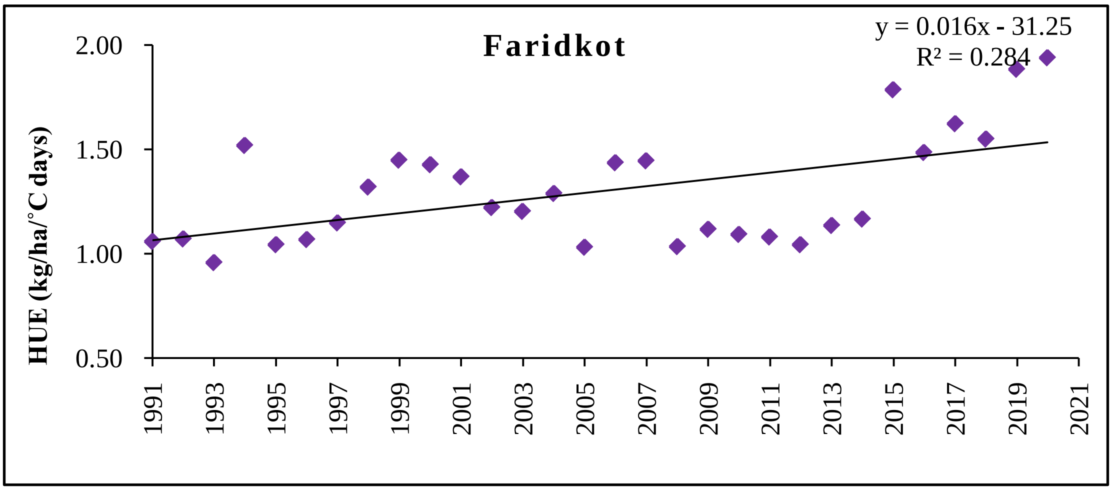

Fig. 4.108: Variability in heat use efficiency (HUE) from 1991 to 2020 at Faridkot under sowing window III

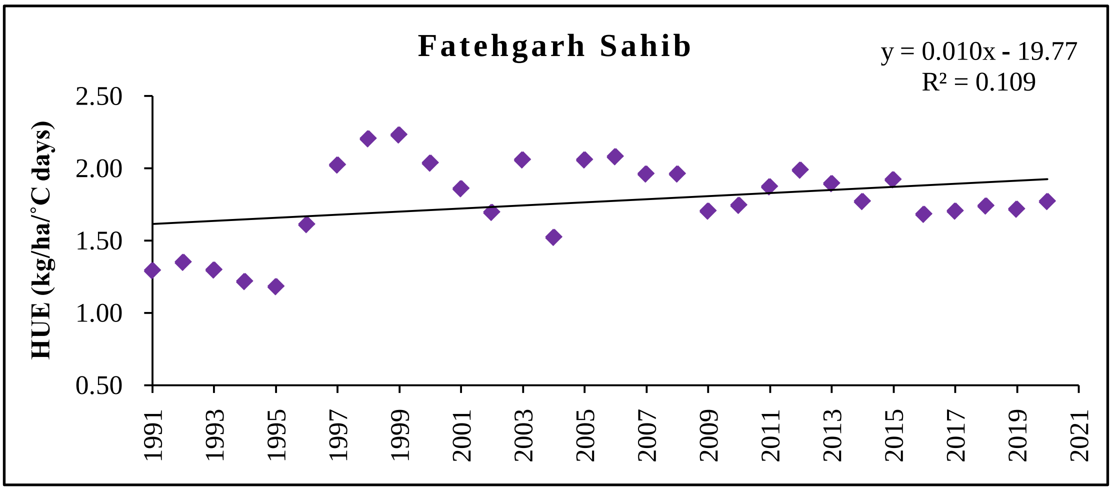

Fig. 4.109: Variability in heat use efficiency (HUE) from 1991 to 2020 at Fatehgarh Sahib under sowing window III

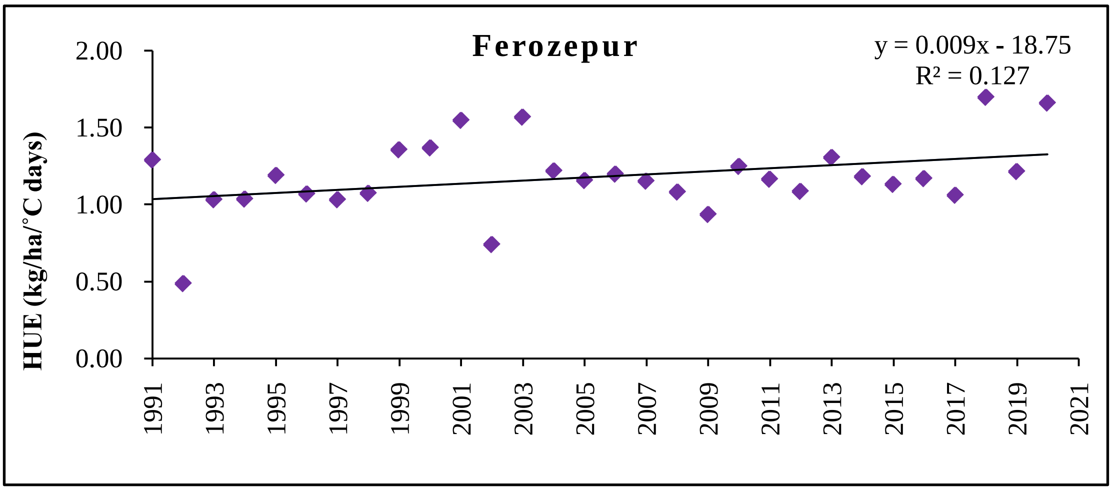

Fig. 4.110: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ferozepur under sowing window III

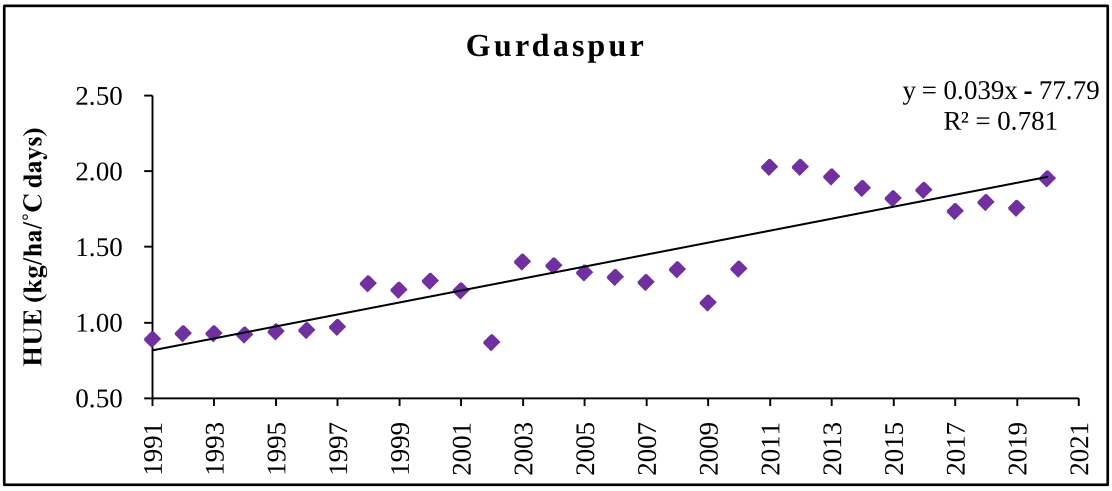

Fig. 4.111: Variability in heat use efficiency (HUE) from 1991 to 2020 at Gurdaspur under sowing window III

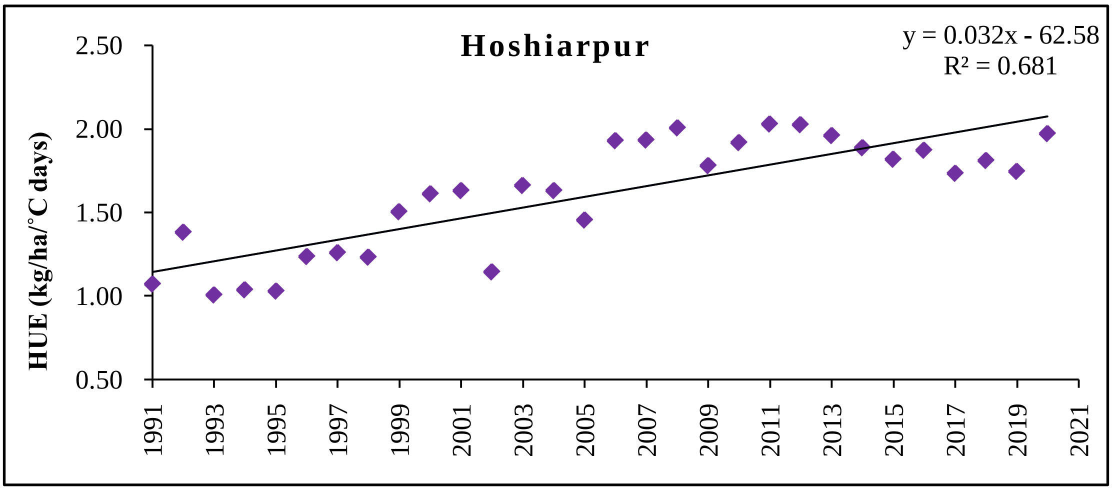

Fig. 4.112: Variability in heat use efficiency (HUE) from 1991 to 2020 at Hoshiarpur under sowing window III

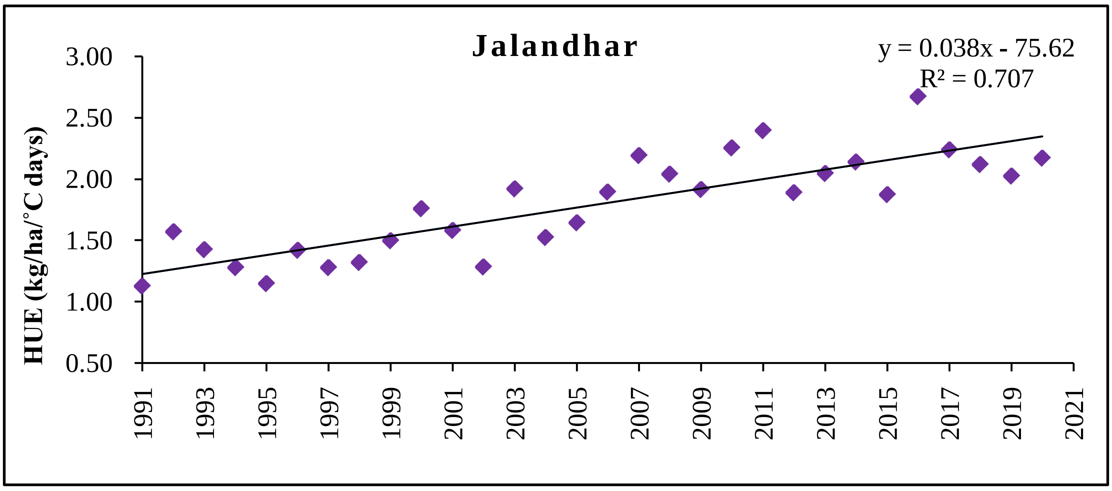

Fig. 4.113: Variability in heat use efficiency (HUE) from 1991 to 2020 at Jalandhar under sowing window III

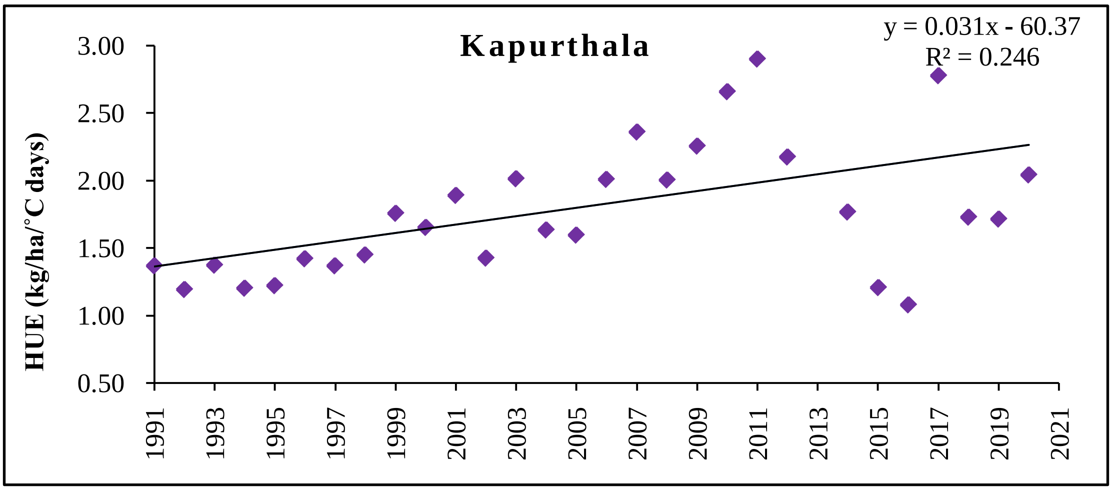

Fig. 4.114: Variability in heat use efficiency (HUE) from 1991 to 2020 at Kapurthala under sowing window III

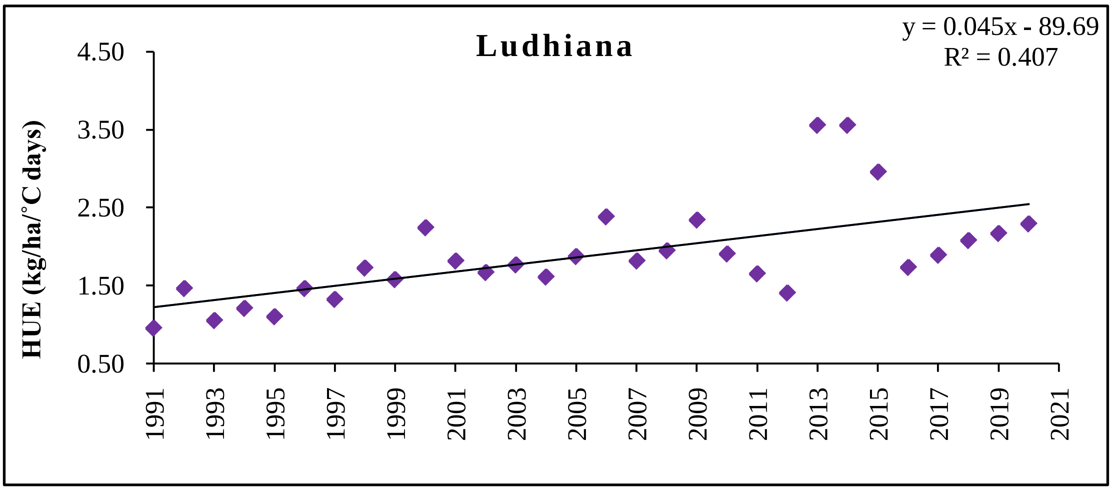

Fig. 4.115: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ludhiana under sowing window III

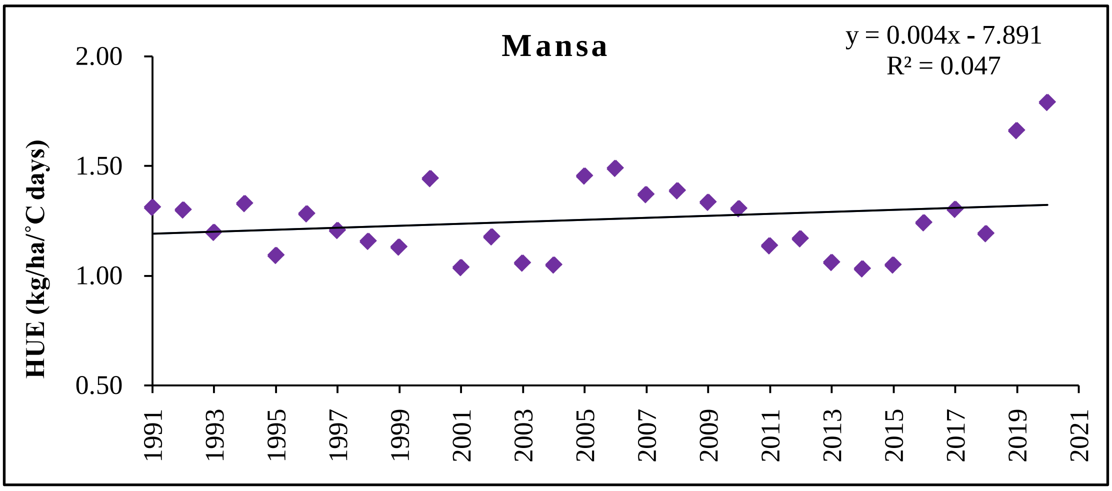

Fig. 4.116: Variability in heat use efficiency (HUE) from 1991 to 2020 at Mansa under sowing window III

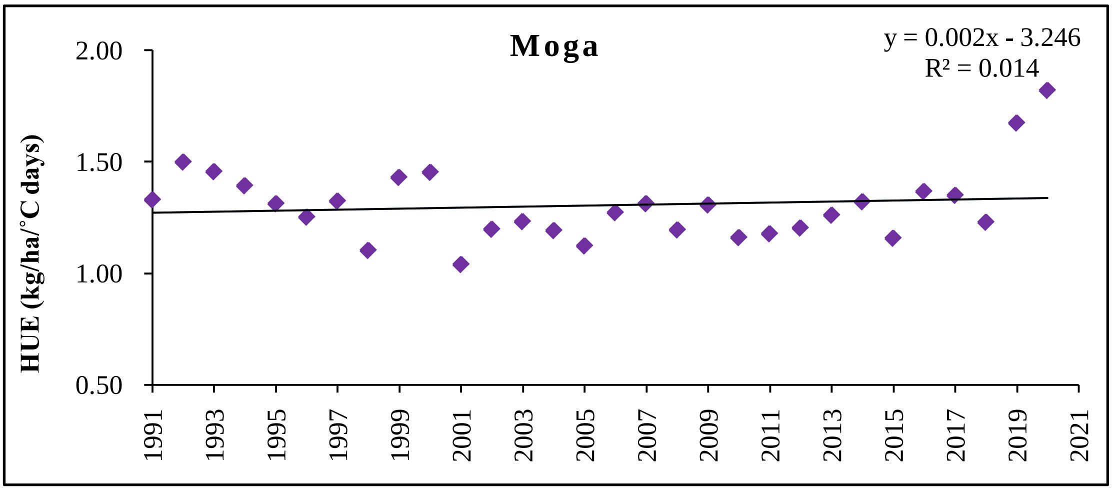

Fig. 4.117: Variability in heat use efficiency (HUE) from 1991 to 2020 at Moga under sowing window III

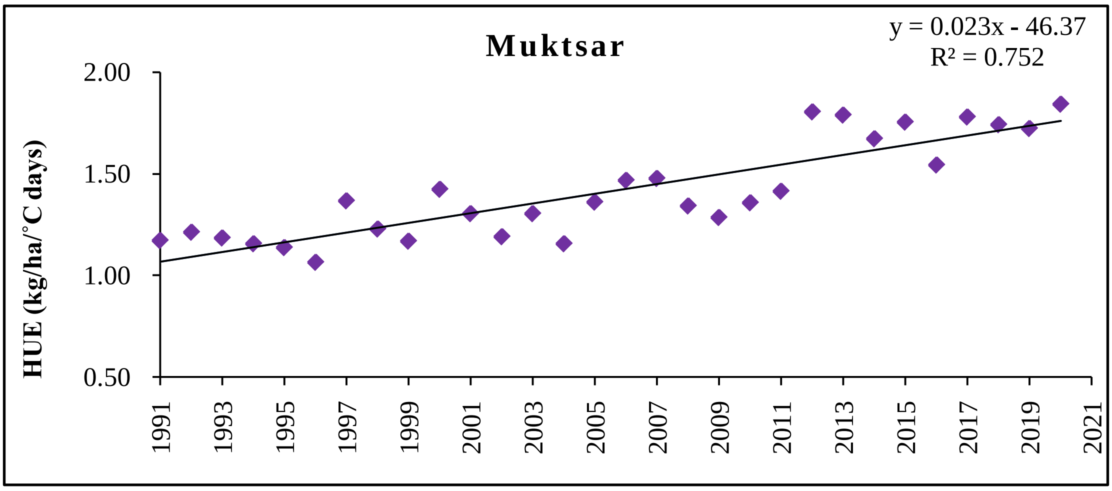

Fig. 4.118: Variability in heat use efficiency (HUE) from 1991 to 2020 at Muktsar under sowing window III

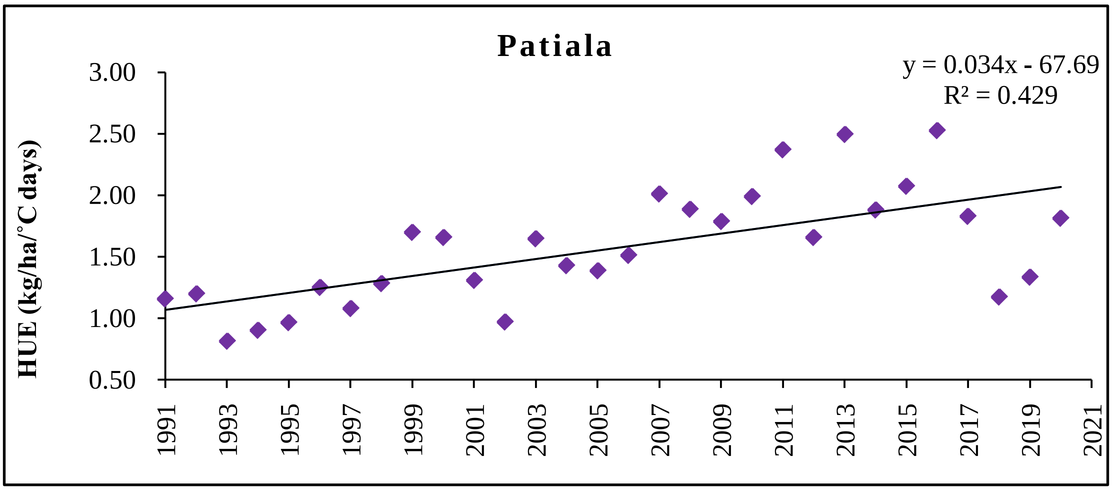

Fig. 4.119: Variability in heat use efficiency (HUE) from 1991 to 2020 at Patiala under sowing window III

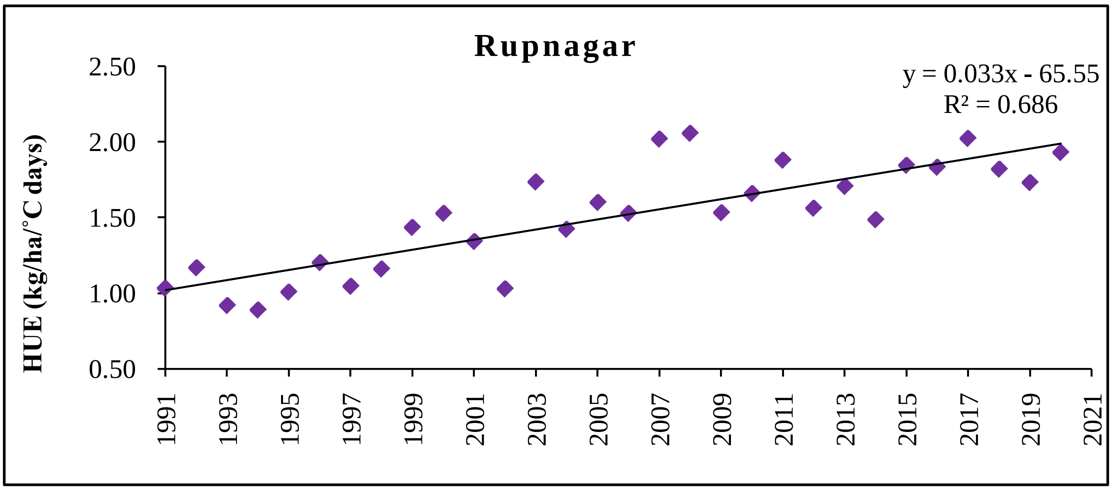

Fig. 4.120: Variability in heat use efficiency (HUE) from 1991 to 2020 at Rupnagar under sowing window III

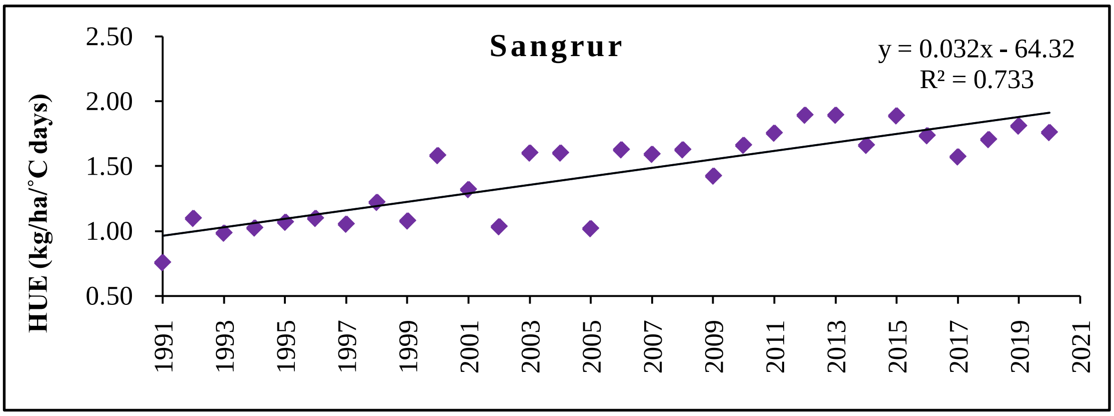

Fig. 4.121: Variability in heat use efficiency (HUE) from 1991 to 2020 at Sangrur under sowing window III

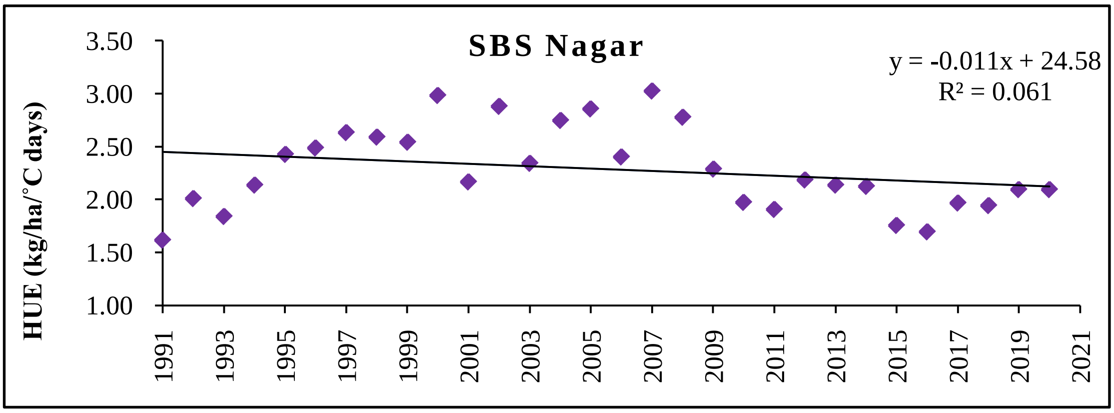

Fig. 4.122: Variability in heat use efficiency (HUE) from 1991 to 2020 at SBS Nagar under sowing window III

4.4.4 Trend analysis of heat use efficiency (HUE) from 1991-2020 under sowing window IV

The data from 1991-2020 was analyzed for trends (increasing or decreasing) in heat use efficiency (HUE) under sowing window III and presented in Figures from 4.123 to 4.139. Variation in heat use efficiency was observed during different time periods but the trend increased in all the districts except SBS Nagar. Among all, the highest R^2 value was observed for Gurdaspur (0.7818) and lowest for Moga (0.0148). The rate of increase was highest for Ludhiana (0.045 kg ha^{-1} °C days^{-1} year^{-1}) and lowest for S.B.S. Nagar (-0.011 kg ha^{-1} °C days^{-1} year^{-1}). While for Amritsar, Bathinda, Faridkot, Fatehgarh Sahib, Ferozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Mansa, Moga, Muktsar, Patiala, Rupnagar and Sangrur, HUE increased at the rate of 0.0285 kg ha^{-1} °C days^{-1} year^{-1}, 0.043 kg ha^{-1} °C days^{-1} year^{-1}, 0.0168 kg ha^{-1} °C days^{-1} year^{-1}, 0.011 kg ha^{-1} °C days^{-1} year^{-1}, 0.0104 kg ha^{-1} °C days^{-1} year^{-1}, 0.0408 kg ha^{-1} °C days^{-1} year^{-1}, 0.0331 kg ha^{-1} °C days^{-1} year^{-1}, 0.0397 kg ha^{-1} °C days^{-1} year^{-1}, 0.0321 kg ha^{-1} °C days^{-1} year^{-1}, 0.0046 kg ha^{-1} °C days^{-1} year^{-1}, 0.0024 kg ha^{-1} °C days^{-1} year^{-1}, 0.0244 kg ha^{-1} °C days^{-1} year^{-1}, 0.0353 kg ha^{-1} °C days^{-1} year^{-1}, 0.0342 kg ha^{-1} °C days^{-1} year^{-1} and 0.0336 kg ha^{-1} °C days^{-1} year^{-1} respectively.

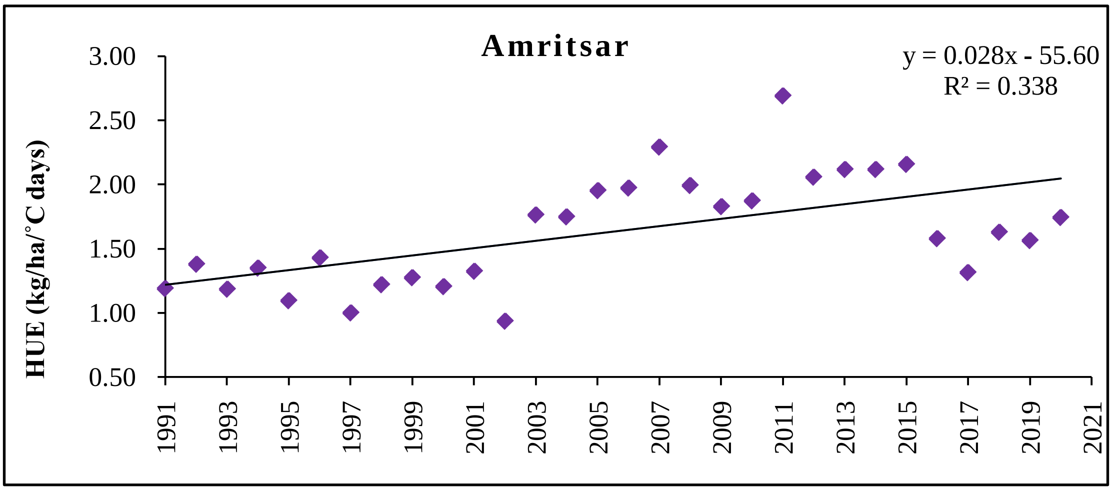

Fig. 4.123: Variability in heat use efficiency (HUE) from 1991 to 2020 at Amritsar under sowing window IV

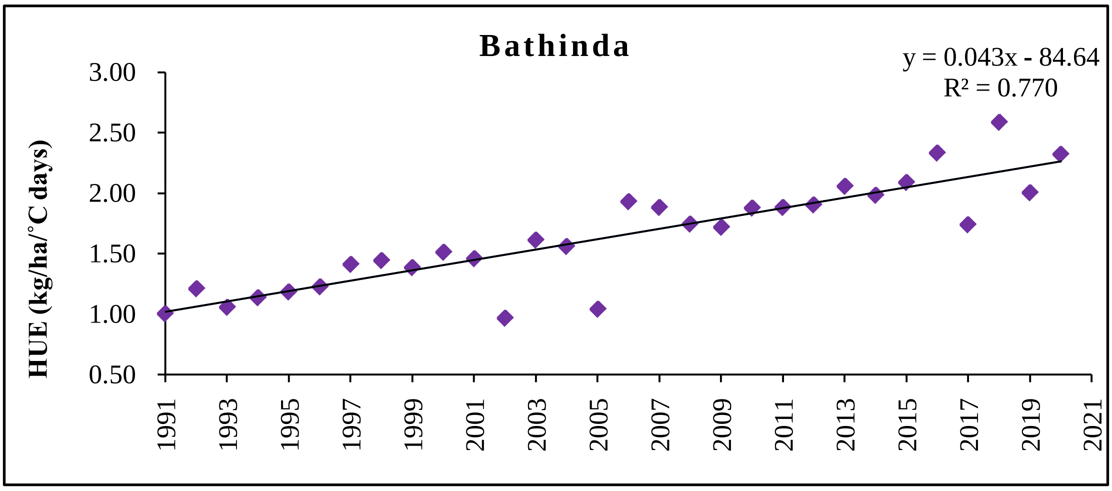

Fig. 4.124: Variability in heat use efficiency (HUE) from 1991 to 2020 at Bathinda under sowing window IV

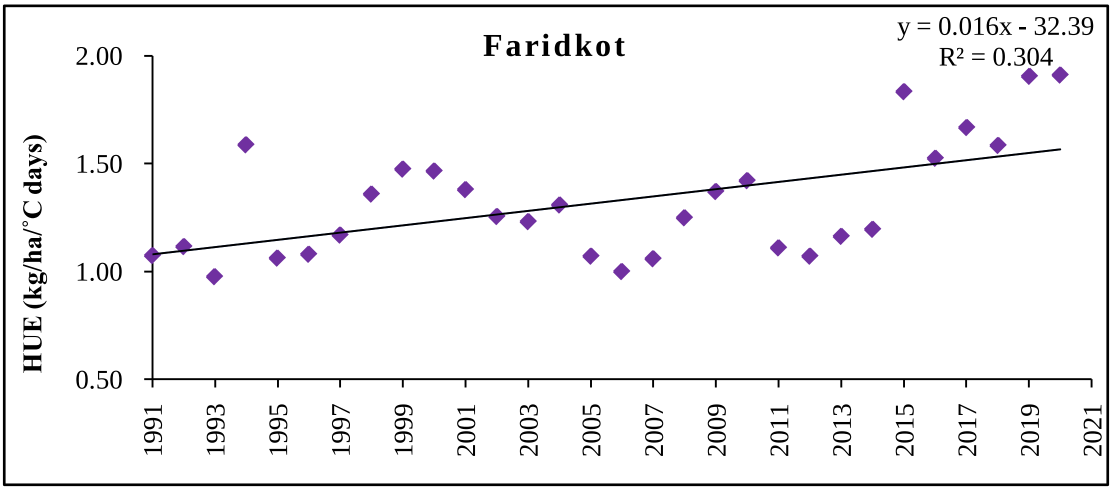

Fig. 4.125: Variability in heat use efficiency (HUE) from 1991 to 2020 at Faridkot under sowing window IV

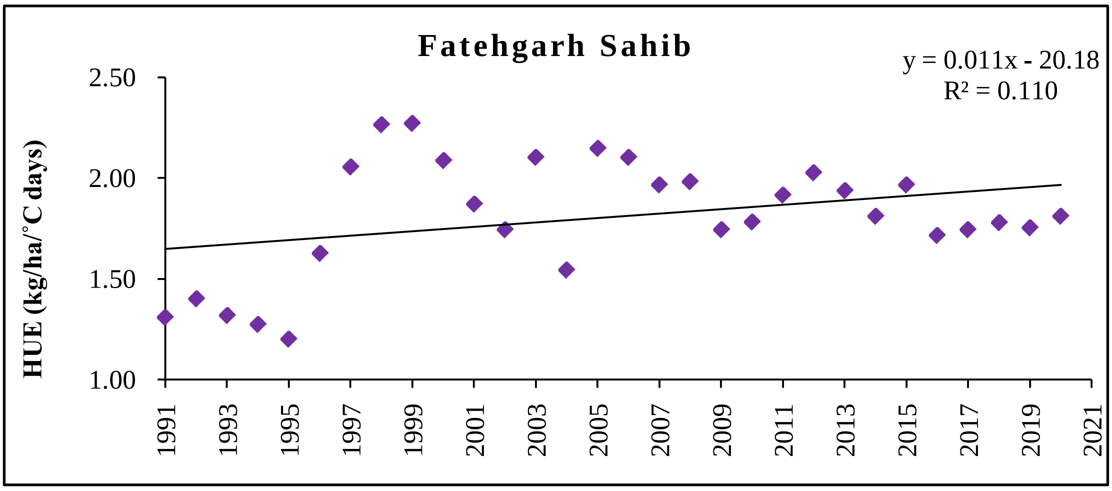

Fig. 4.126: Variability in heat use efficiency (HUE) from 1991 to 2020 at Fatehgarh Sahib under sowing window IV

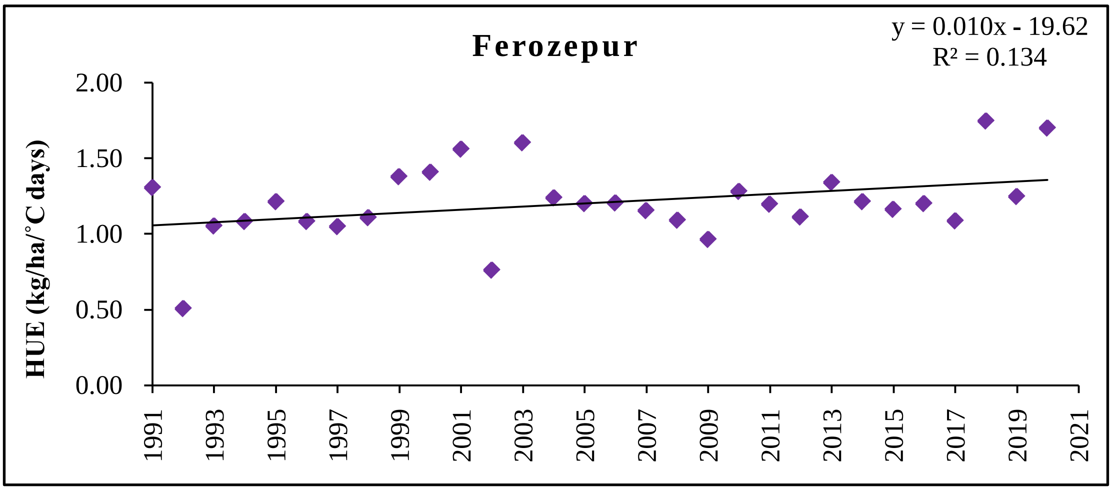

Fig. 4.127: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ferozepur under sowing window IV

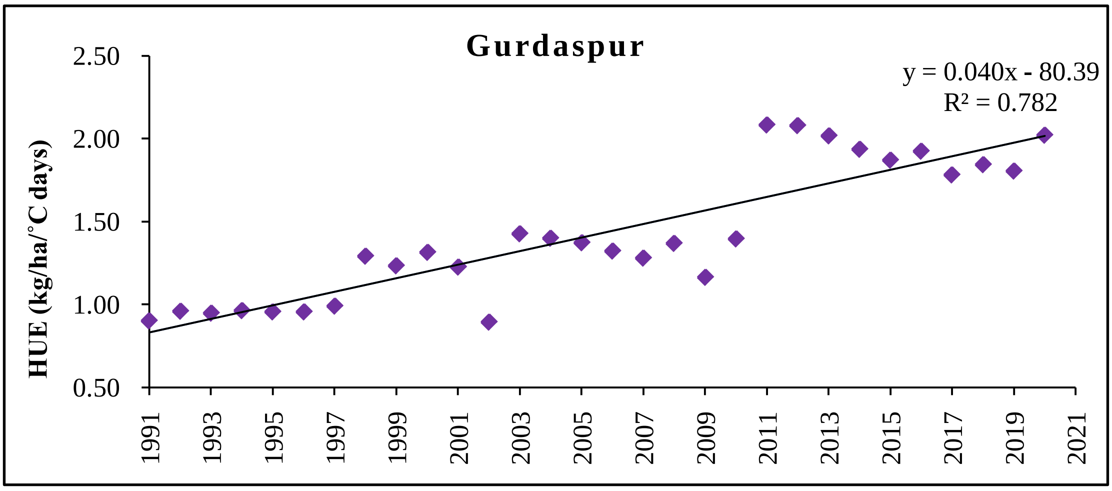

Fig. 4.128: Variability in heat use efficiency (HUE) from 1991 to 2020 at Gurdaspur under sowing window IV

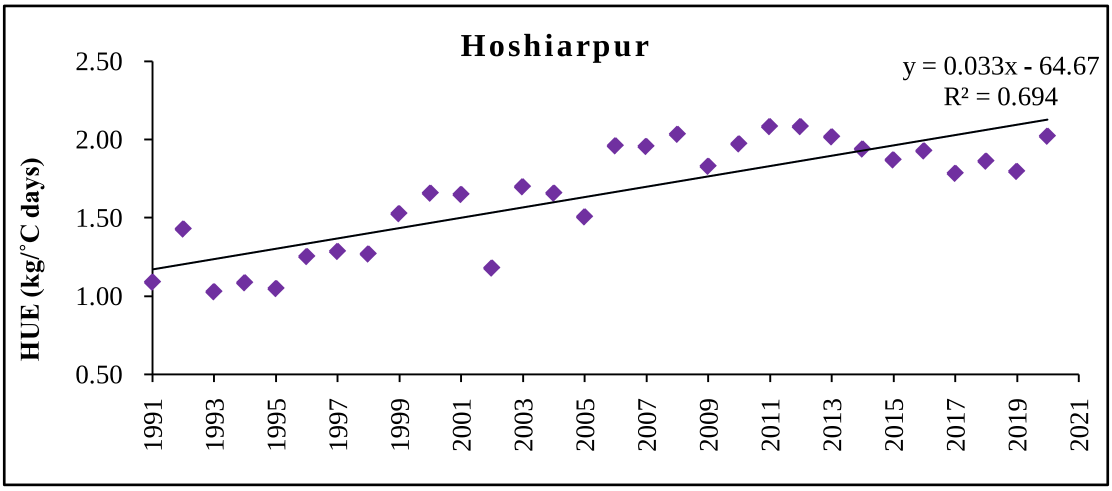

Fig. 4.129: Variability in heat use efficiency (HUE) from 1991 to 2020 at Hoshiarpur under sowing window IV

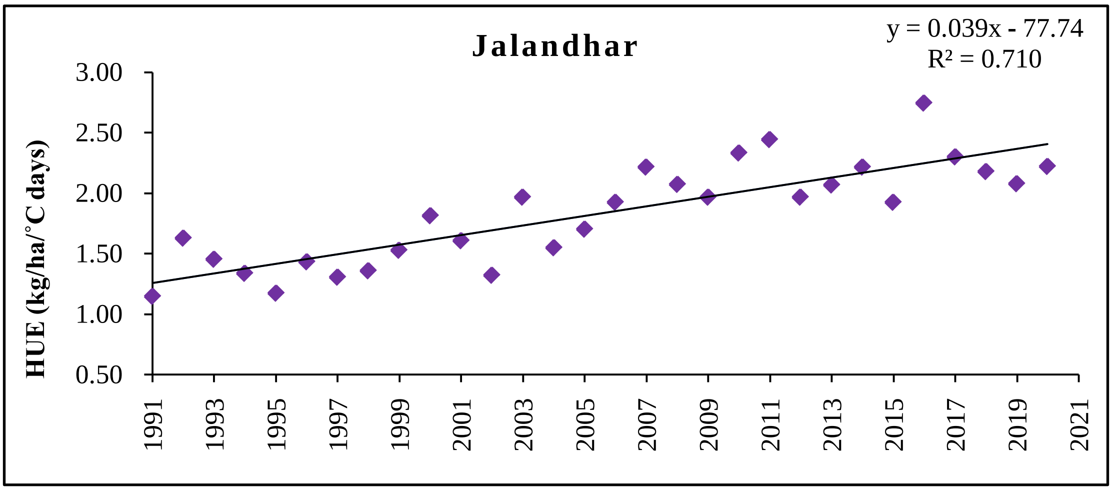

Fig. 4.130: Variability in heat use efficiency (HUE) from 1991 to 2020 at Jalandhar under sowing window IV

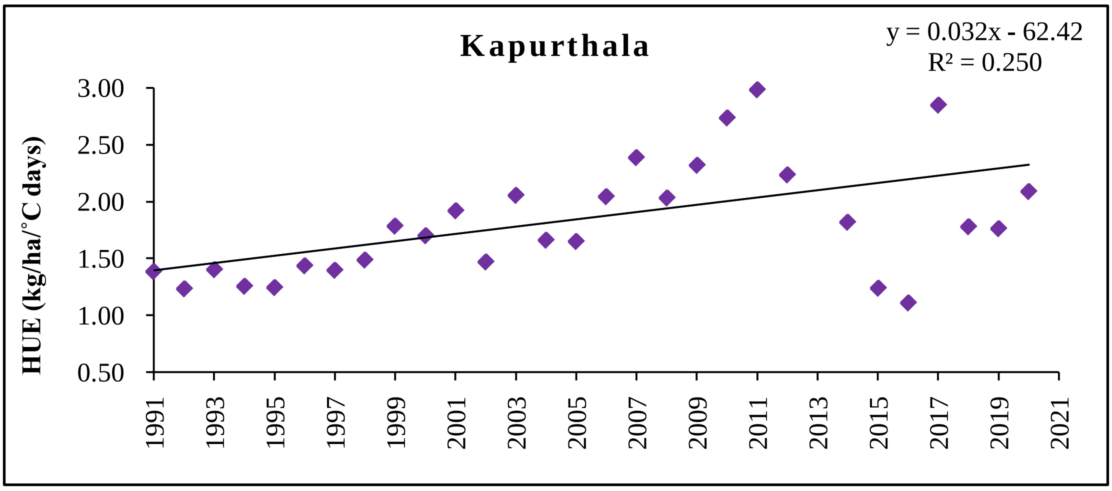

Fig. 4.131: Variability in heat use efficiency (HUE) from 1991 to 2020 at Kapurthala under sowing window IV

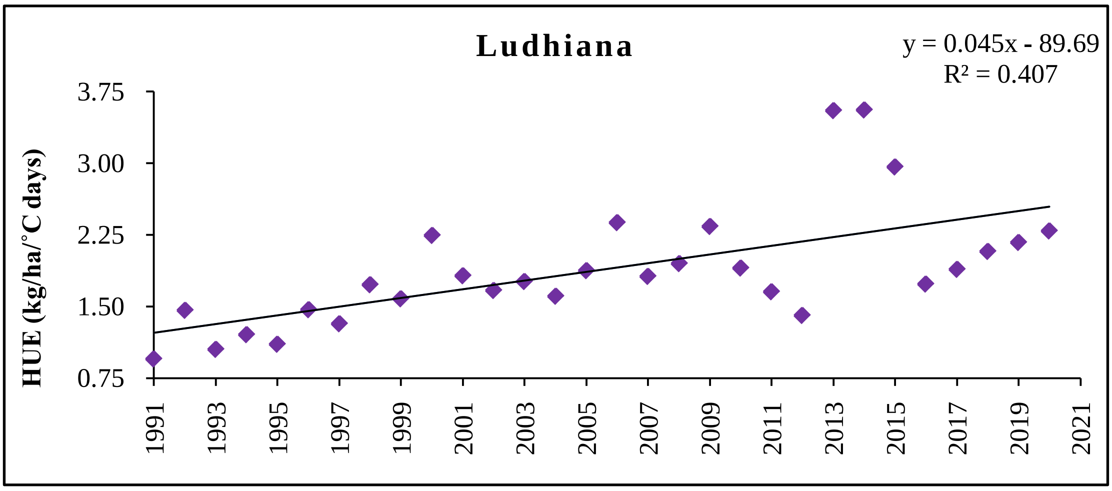

Fig. 4.132: Variability in heat use efficiency (HUE) from 1991 to 2020 at Ludhiana under sowing window IV

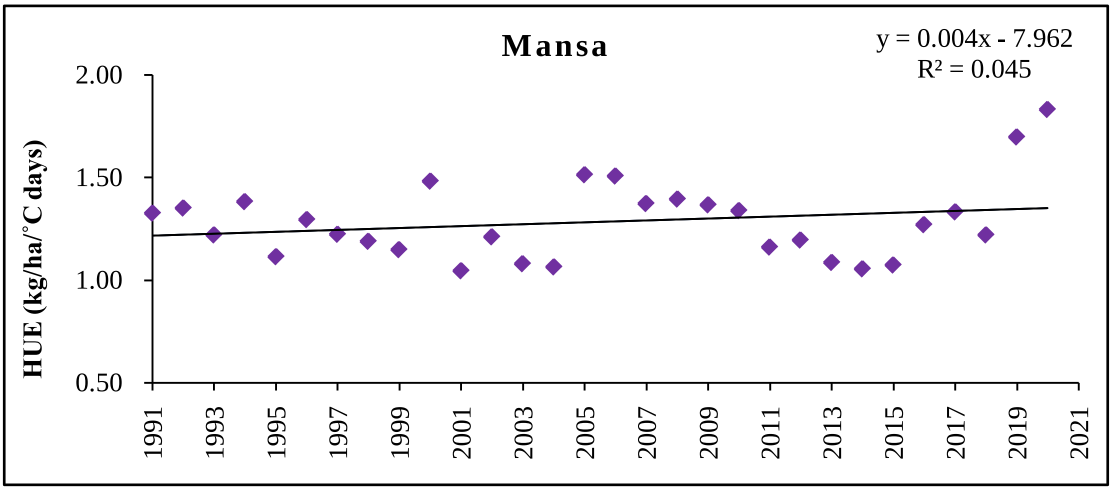

Fig. 4.133: Variability in heat use efficiency (HUE) from 1991 to 2020 at Mansa under sowing window IV

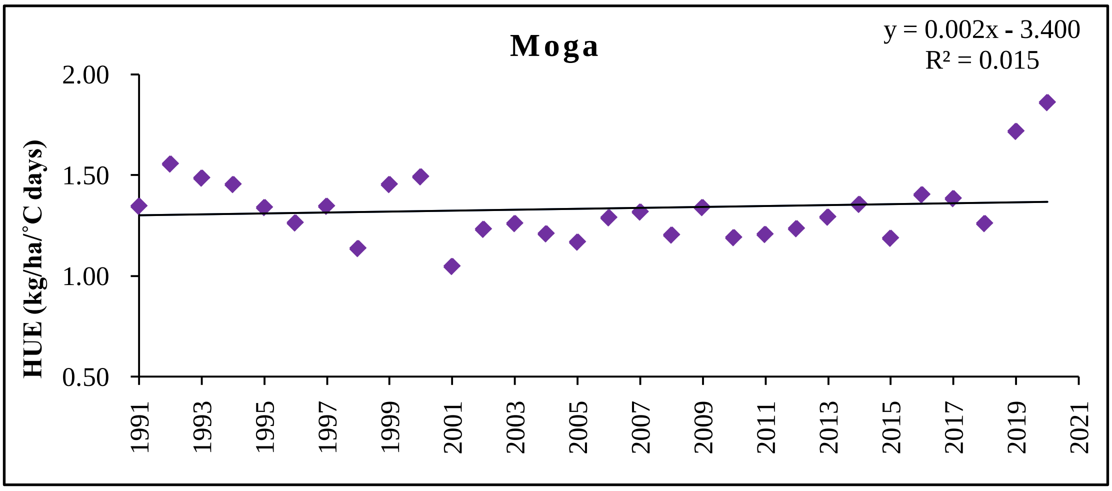

Fig. 4.134: Variability in heat use efficiency (HUE) from 1991 to 2020 at Moga under sowing window IV

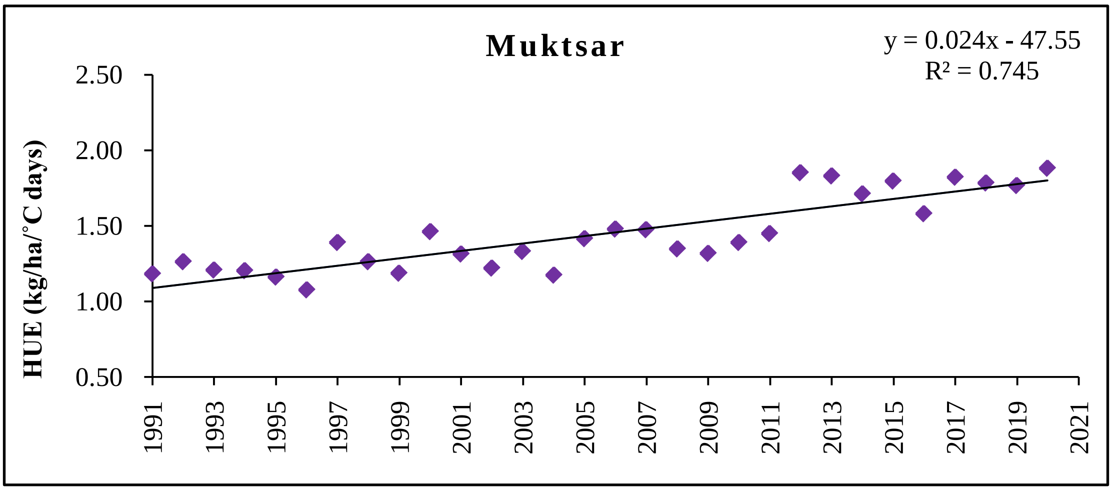

Fig. 4.135: Variability in heat use efficiency (HUE) from 1991 to 2020 at Muktsar under sowing window IV

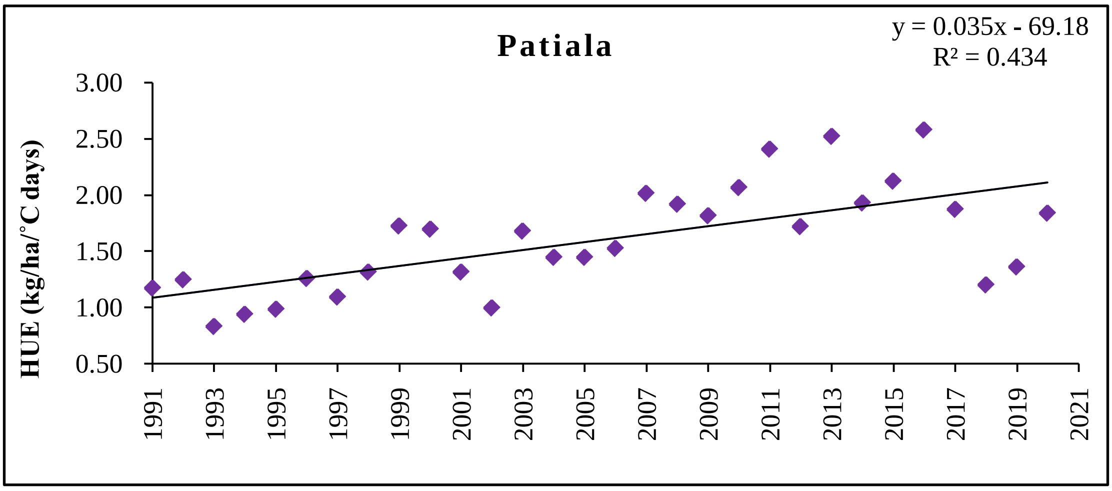

Fig. 4.136: Variability in heat use efficiency (HUE) from 1991 to 2020 at Patiala under sowing window IV

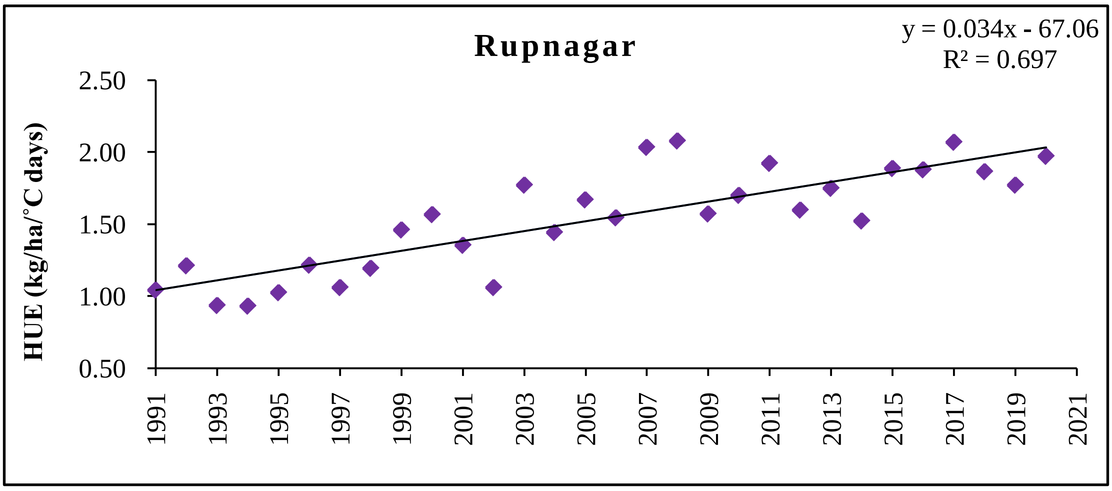

Fig. 4.137: Variability in heat use efficiency (HUE) from 1991 to 2020 at Rupnagar under sowing window IV

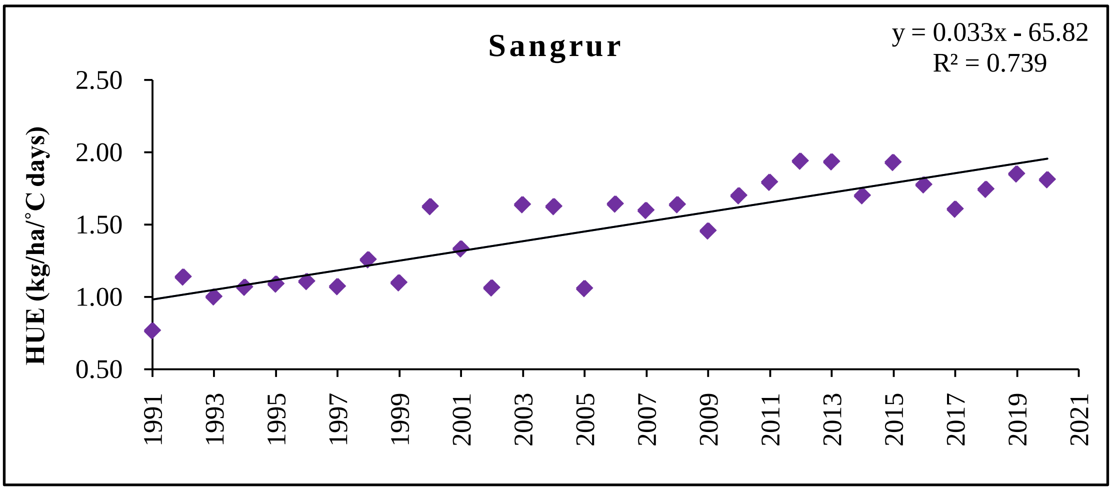

Fig. 4.138: Variability in heat use efficiency (HUE) from 1991 to 2020 at Sangrur under sowing window IV

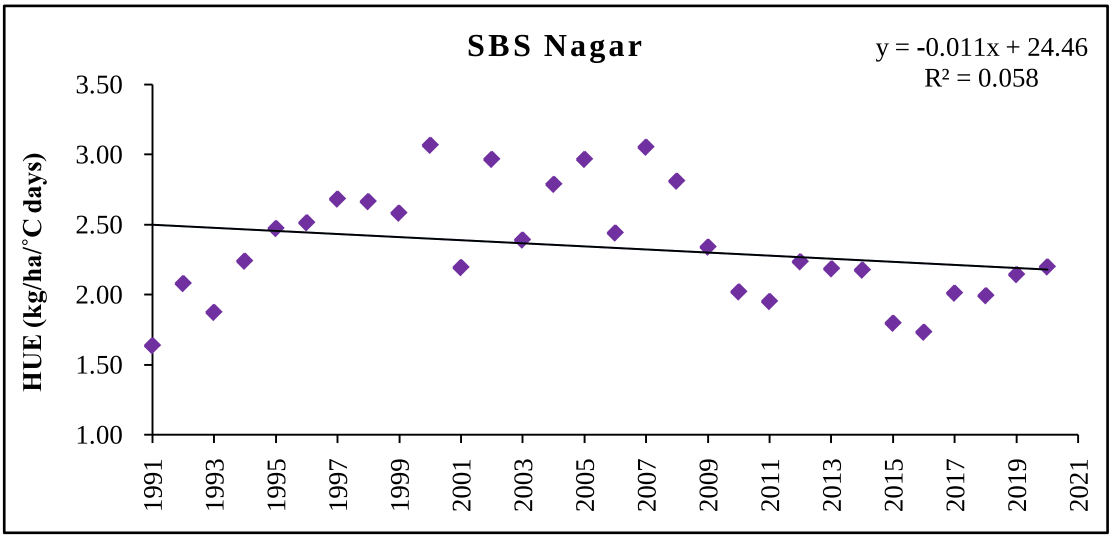

Fig. 4.139: Variability in heat use efficiency (HUE) from 1991 to 2020 at SBS Nagar under sowing window IV

4.4.5 Variation of heat use efficiency (HUE) during different Pentads under different Sowing windows

Variability in the heat use efficiency (HUE) of maize in different districts of Punjab was calculated for different pentads from 1991 to 2020 for different sowing windows and presented in Figures 1.140, 1.141, 1.142 and 1.143. It was found that maximum variability in HUE was found during P_5 (2011-2015) period and minimum variability was found during P_1 (1991-1995) pentadal period under all sowing windows.

Under sowing window I, the value of HUE was 1.4 kg/˚C days during P_2 (1996-2000) and P_3 (2001-2005) and 1.7 kg/ha/˚C days during P_5 (2011-2015) and P_6 (2016-2020). It was 1.1 and 1.6 kg/˚C days during P_1 (1991-1995) and P_4 (2006-2011). Under sowing window II, the value of HUE was 1.7 kg/ha/˚C days during P_4 (2006-2011) and P_6 (2016-2020). It was 1.2 kg/ha/˚C days during P_1 (1991-1995), 1.4 kg/ha/˚C days during P_2 (1996-2000), 1.5 kg/ha/˚C days during P_3 (2001-2005) and 1.8 kg/ha/˚C days during P_5 (2011-2015). Under sowing window III, the value of HUE was 1.7 kg/ha/˚C days during P_4 (2006-2011) and P_6 (2016-2020). It was 1.2 kg/ha/˚C days during P_1 (1991-1995), 1.4 kg/ha/˚C days during P_2 (1996-2000), 1.5 kg/ha/˚C days during P_3 (2001-2005) and 1.8 kg/ha/˚C days during P_5 (2011-2015). Under sowing window IV, the value of HUE was 1.5 kg/ha/˚C days during P_2 (1996-2000) and P_3 (2001-2005). It was 1.2 kg/ha/˚C days during P_1 (1991-1995), 1.7 kg/ha/˚C days during P_4 (2006-2011), 1.9 kg/ha/˚C days during P_5 (2011-2015) and 1.8 kg/ha/˚C days during P_6 (2016-2020).

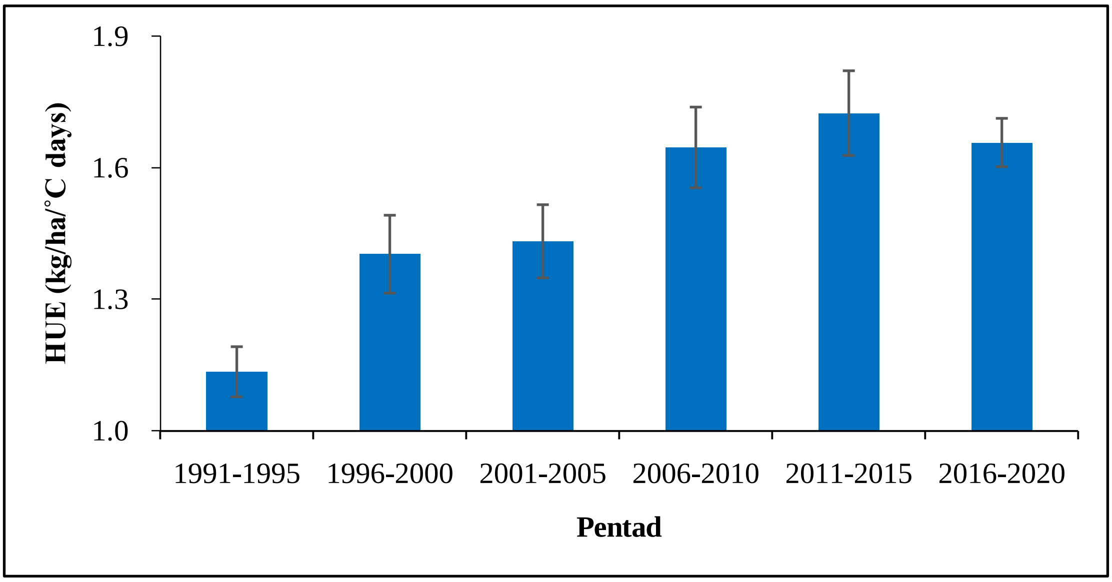

Fig. 4.140: Variation of Heat Use Efficiency in maize in Punjab under sowing window I

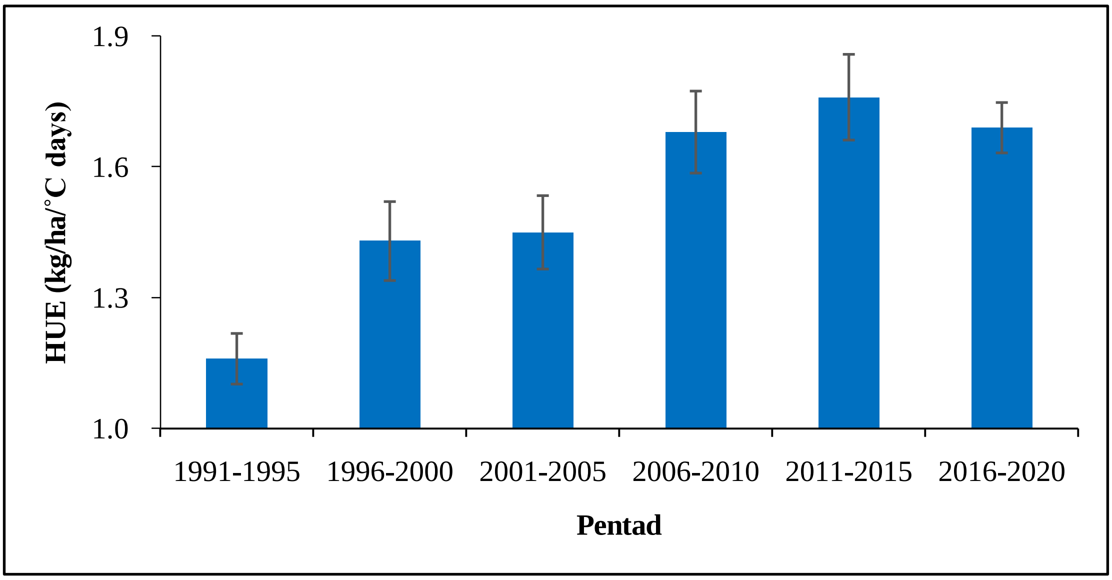

Fig. 4.141: Variation of Heat Use Efficiency in maize in Punjab under sowing window II

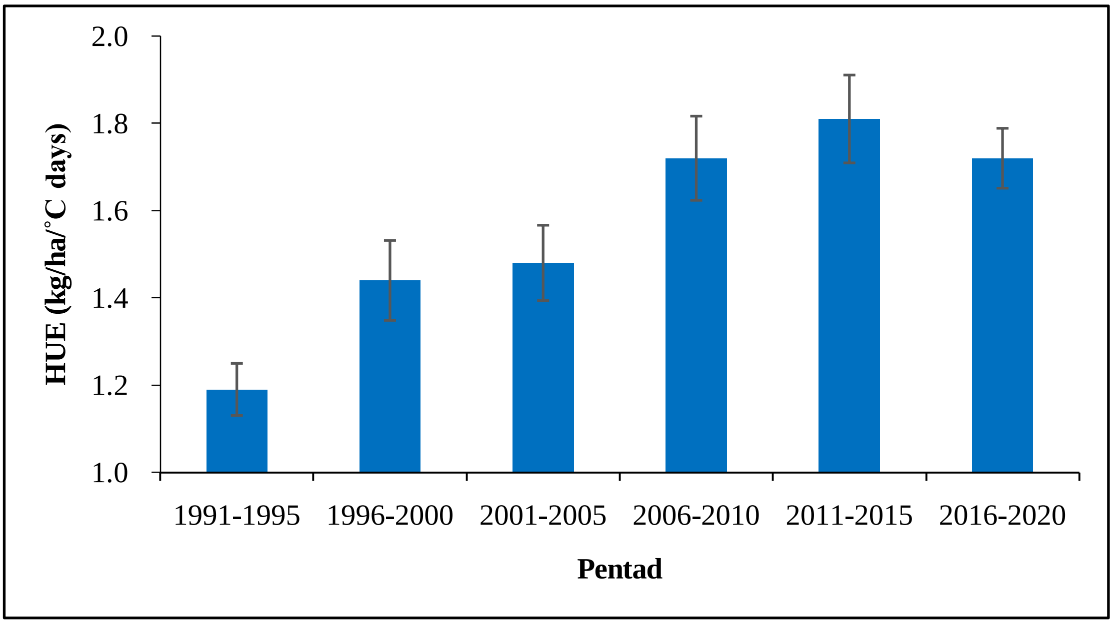

Fig. 4.142: Variation of Heat Use Efficiency in maize in Punjab under sowing window III

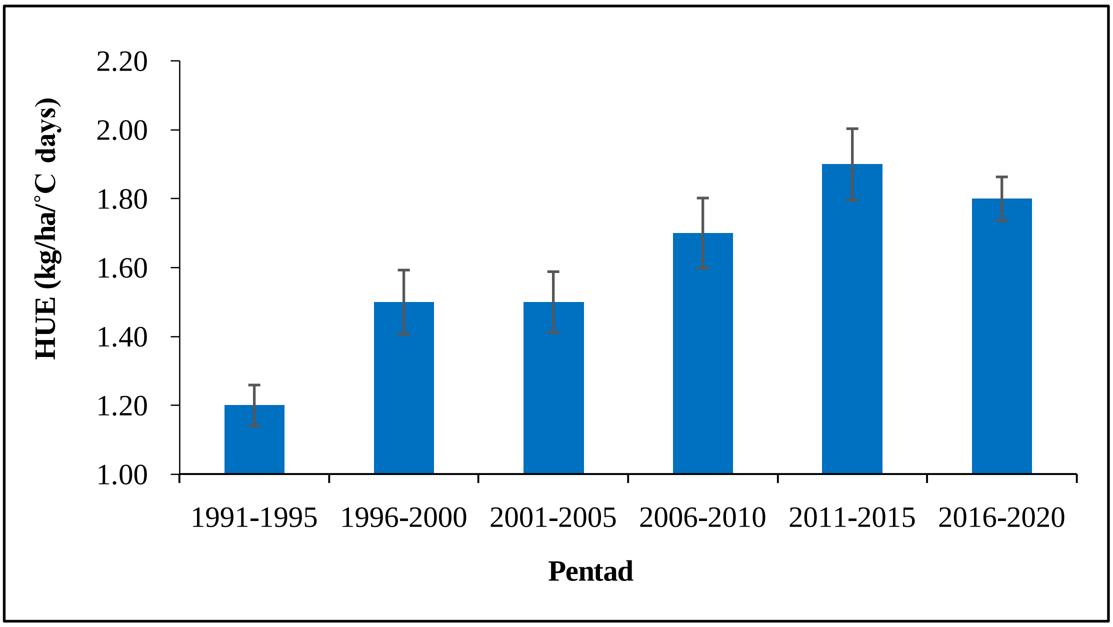

Fig. 4.143: Variation of Heat Use Efficiency in maize in Punjab under sowing window IV

4.5 SPATIO-TEMPORAL VARIABILITY IN THERMAL REQUIREMENT OF MAIZE IN PUNJAB USING GEOSPATIAL TECHNOLOGY

The Spatio-temporal variation in thermal requirement of maize from 1991-2020 in Punjab under different sowing windows was delineated by using Arc GIS 10.4 and has been presented in fig. 4.144 - 4.147. However, data for Barnala, Fazilka, Pathankot, SAS Nagar and Tarn Taran was not available (N/A) from 1991 to 2010.

4. 5.1 Spatio-temporal variability in thermal requirements of maize under sowing window I

The data from 1991-2020 was analysed pentad wise. In north-east region of Punjab during the period from 1991-1995 to 2016-2020, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Patiala and Fatehgarh Sahib district. Where, AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Amritsar, Moga, Sangrur, Jalandhar, Kapurthala, Ludhiana district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Pathankot, Barnala, SAS Nagar, Fazilka and Tarn taran, AGDD was 2100-2300 °C day. Similar work was also done by Dong *et al* (2009) in China to show spatiotemporal changes in heat unit accumulation of maize from 1980 to 2000 and the result showed increasing trend in heat unit accumulation from 1980s (Fig. 4. 144).

4.5.2 Spatio-temporal variability in thermal requirements of maize under sowing window II

The data from 1991-2020 was analysed pentad wise. In north-east region of Punjab during the period from 1991-1995 to 2016-2020, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, S.B.S. Nagar, and Rupnagar district. In the central region of Punjab AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Patiala and Fatehgarh Sahib district. While AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Amritsar, Moga, Sangrur, Jalandhar, Kapurthala, and Ludhiana district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Barnala, Fazilka and Tarn taran AGDD was 2100-2300 °C day. While AGDD was 1900-2100 °C day in Pathankot and heat unit accumulation was changed from 1900-2100 °C day to 2100-2300 °C day in SAS Nagar district (Fig 4. 145).

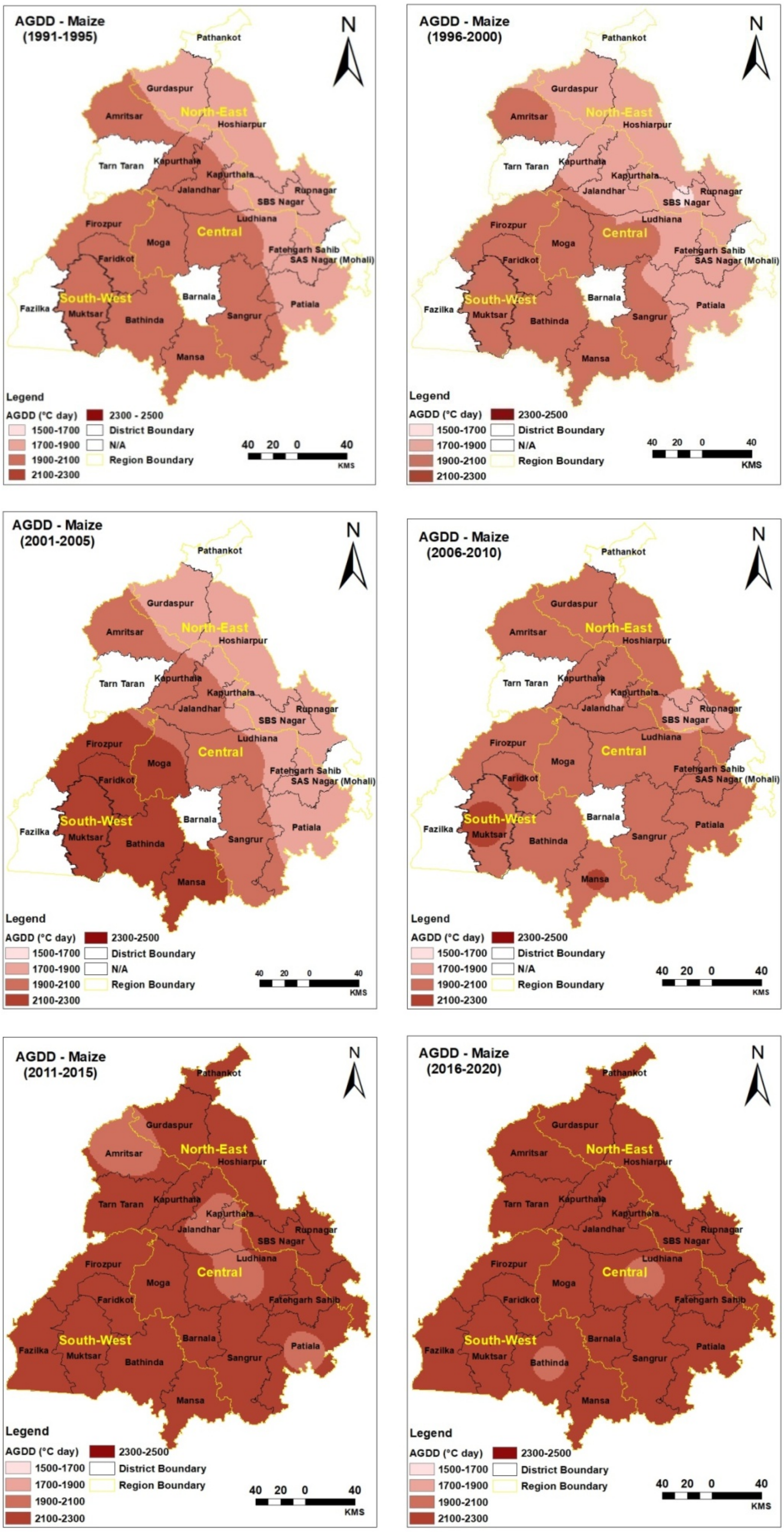

Fig. 4.144: Spatio-temporal variability in AGDD of maize under sowing window I

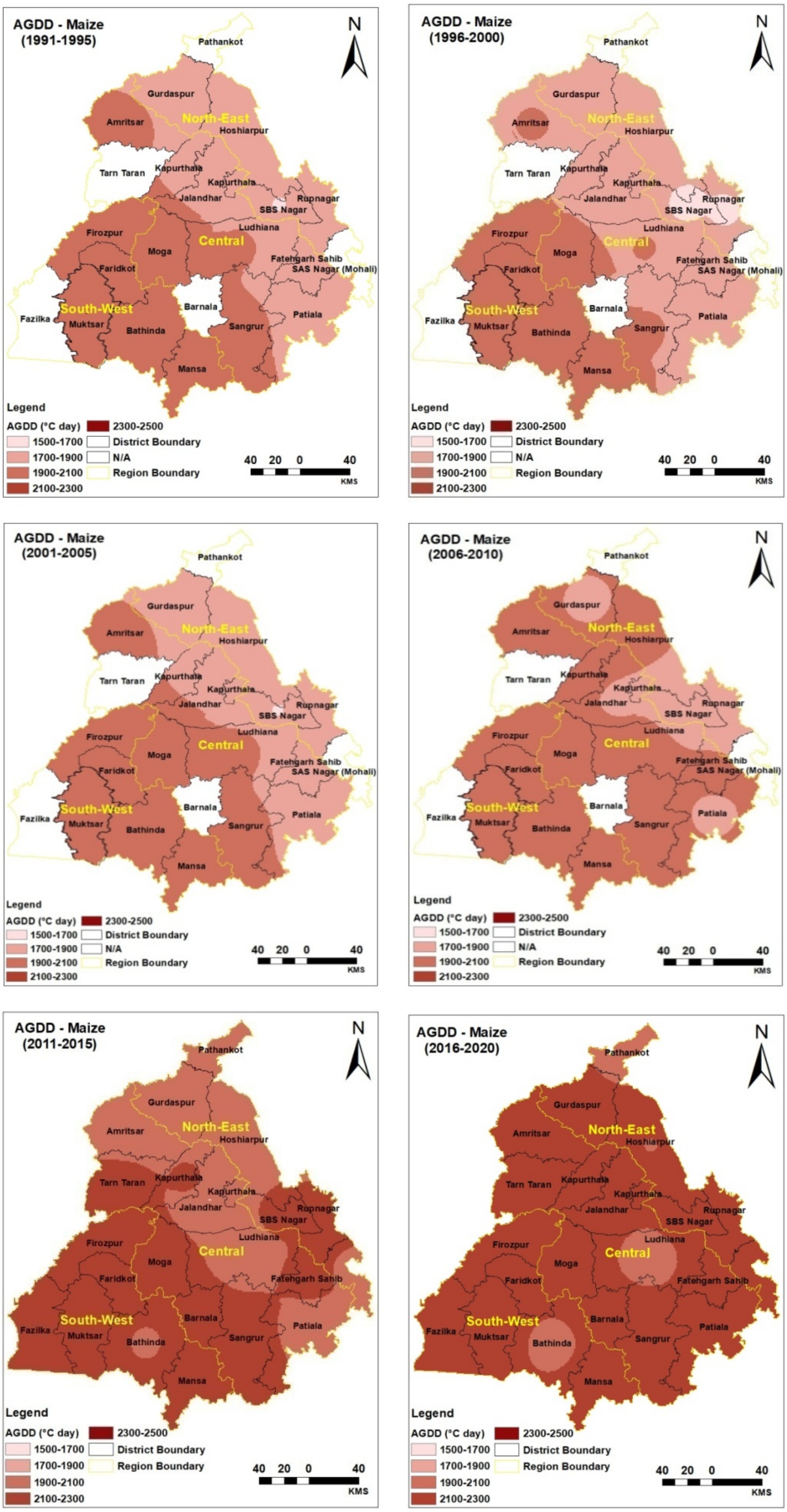

Fig. 4.145: Spatio-temporal variability in AGDD of maize under sowing window II

4.5.3 Spatio-temporal variability in thermal requirements of maize under sowing window III

Under sowing window III, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Gurdaspur, and Hoshiarpur district and from 1500-1700 °C day to 1900-2100 in S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Patiala, Fatehgarh Sahib, Amritsar, Sangrur, Jalandhar, Kapurthala, and Ludhiana district. Where, AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Moga district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Tarn Taran AGDD was changed from 1700-1900 °C day to 2100-2300 °C day. While AGDD was 1900-2100 °C day in Pathankot and SAS Nagar district and 2100-2300 °C day in Barnala and Fazilka district (Fig 4. 146).

4.5.3 Spatio-temporal variability in thermal requirements of maize under sowing window IV

Under sowing window IV, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Gurdaspur, and Hoshiarpur district and from 1500-1700 °C day to 1900-2100 °C day in S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Patiala, Amritsar, Sangrur, Jalandhar, Kapurthala, Moga and Ludhiana district. Where, AGDD changed from 1500-1700 °C day to 1900-2100 °C day in Fatehgarh Sahib district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1700-1900 °C day to 1900-2100 °C day at the same time period. While AGDD was 1900-2100 °C day in Pathankot, SAS Nagar, Barnala, Tarn Taran and Fazilka district. Similar work was also done by Dai *et al* (2015) in Southern China to show spatiotemporal variations of thermal requirement from 1960 to 2011 and the results showed that heat unit accumulation increased with an average of 7.54°C/decade in Southern China since 1960 (Fig 4. 147).

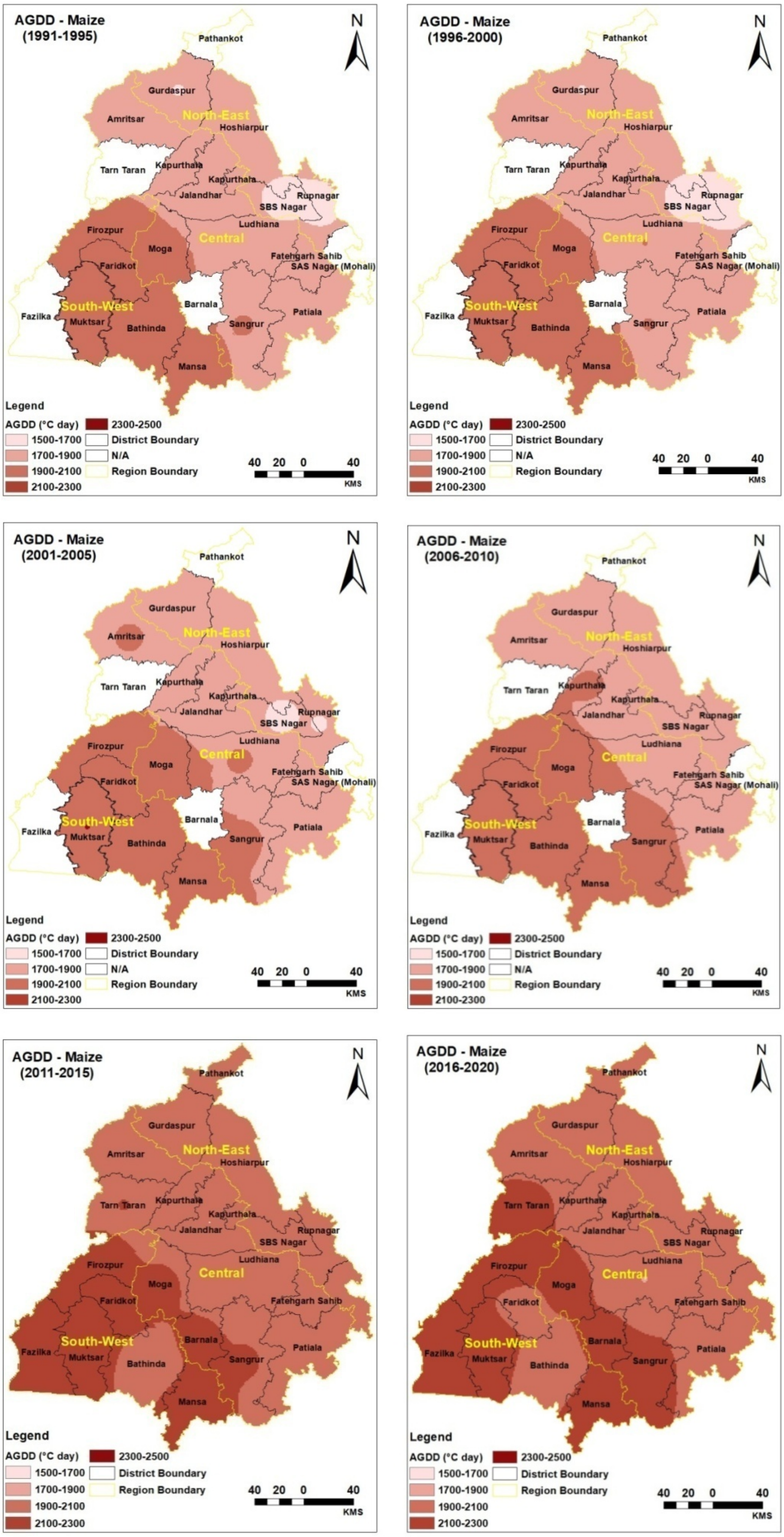

Fig. 4.146: Spatio-temporal variability in AGDD of maize under sowing window III

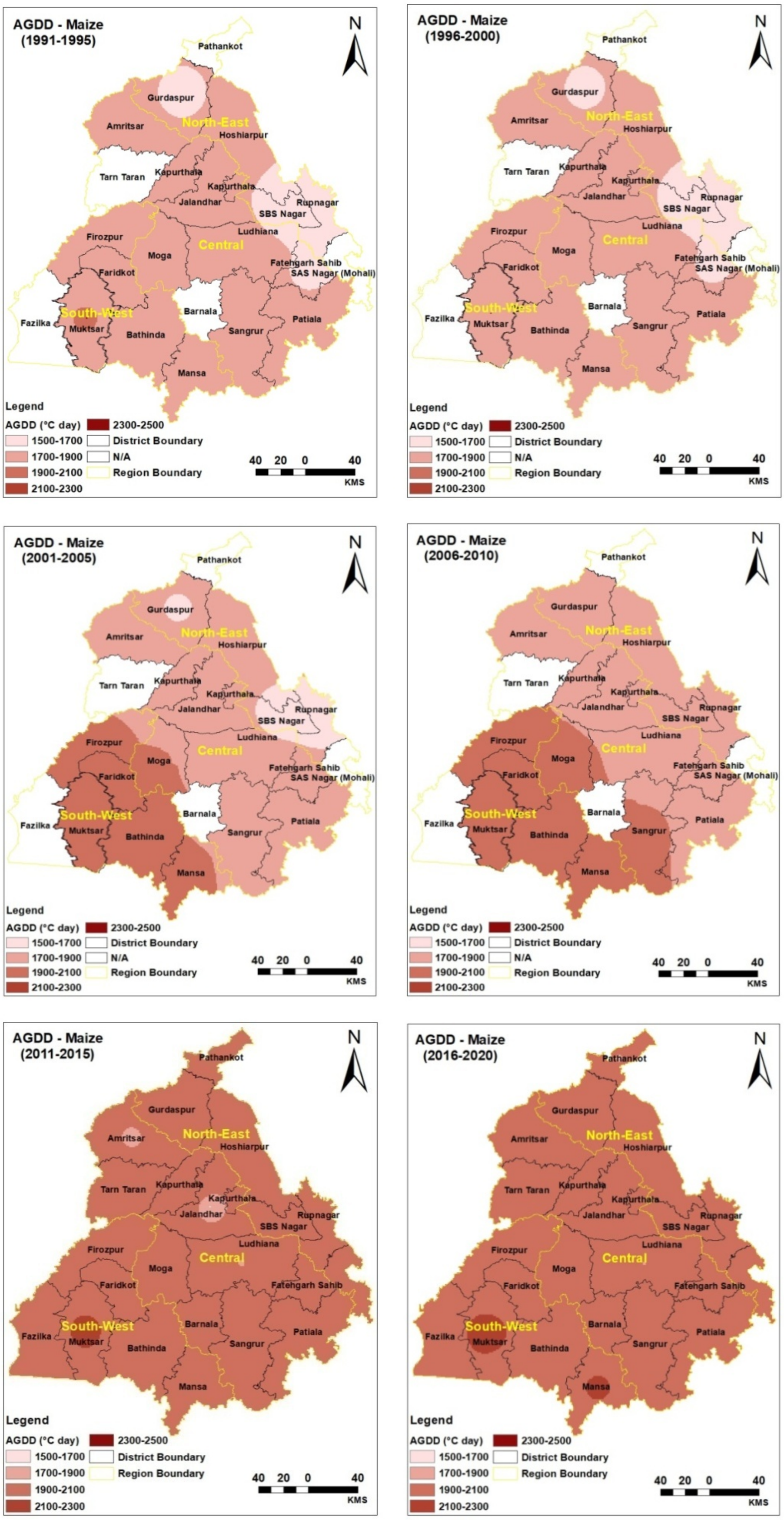

Fig. 4.147: Spatio-temporal variability in AGDD of maize under sowing window IV

4.6 SPATIO-TEMPORAL VARIABILITY IN PREDICTED THERMAL REQUIREMENT OF MAIZE IN PUNJAB USING GEOSPATIAL TECHNOLOGY

The predicted Spatio-temporal variation in thermal requirement of maize from 2021-2050 in Punjab under different sowing windows was delineated by using Arc GIS 10.4 and has been presented in Fig. 4.148-4.151.

4.6.1 Spatio-temporal variability in predicted thermal requirements of maize under sowing window I

The data from 2021-2050 is analyzed pentad wise. In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Gurdaspur, Rupnagar, S.B.S. Nagar. Where, AGDD will be remained 2100-2300 °C day in Hoshiarpur and Pathankot district. In the central region of Punjab, heat unit accumulation will be changed from 2100-2300 °C day to 2300-2500 °C day in Amritsar, Barnala, Moga, Sangrur, Ludhiana, Jalandhar, Kapurthala, Fatehgarh Sahib, Tarn Taran and Patiala district. Where, AGDD will be remained 2100-2300 °C day in SAS Nagar district. In South-west region, in Ferozepur, Faridkot, Muktsar, Bathinda and Mansa heat unit accumulation will be changed from 2100-2300 °C day to 2300-2500 °C day at the same time period. In AGDD will be remained 2300-2500 °C day in Fazilka district (Fig 4. 148).

4.6.2 Spatio-temporal variability in predicted thermal requirements of maize under sowing window II

The data from 2021-2050 is analyzed pentad wise. In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be remained 2100-2300 °C day in Gurdaspur, Hoshiarpur, Rupnagar, Pathankot and S.B.S. Nagar district. In the central region of Punjab, AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Barnala, Ludhiana, Sangrur and Moga district. While it will be remained 2100-2300 °C day in Amritsar, Jalandhar, Kapurthala, Fatehgarh Sahib, Tarn Taran, SAS Nagar and Patiala district. In South-west region, in Fazilka, Faridkot, Muktsar Bathinda, Ferozepur, and Mansa AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day (Fig 4. 149).

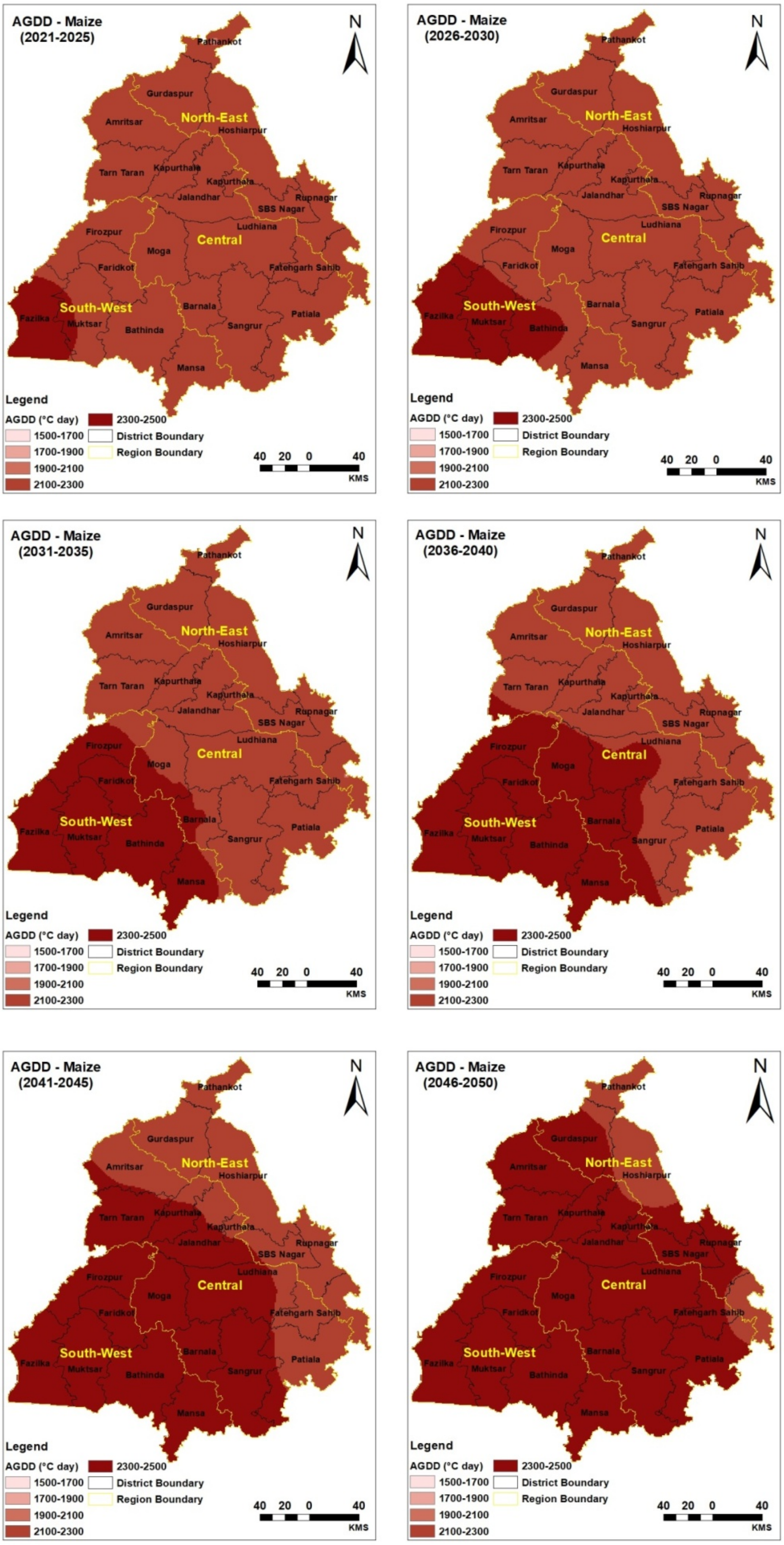

Fig. 4.148: Spatio-temporal variability in predicted AGDD of maize under sowing window I

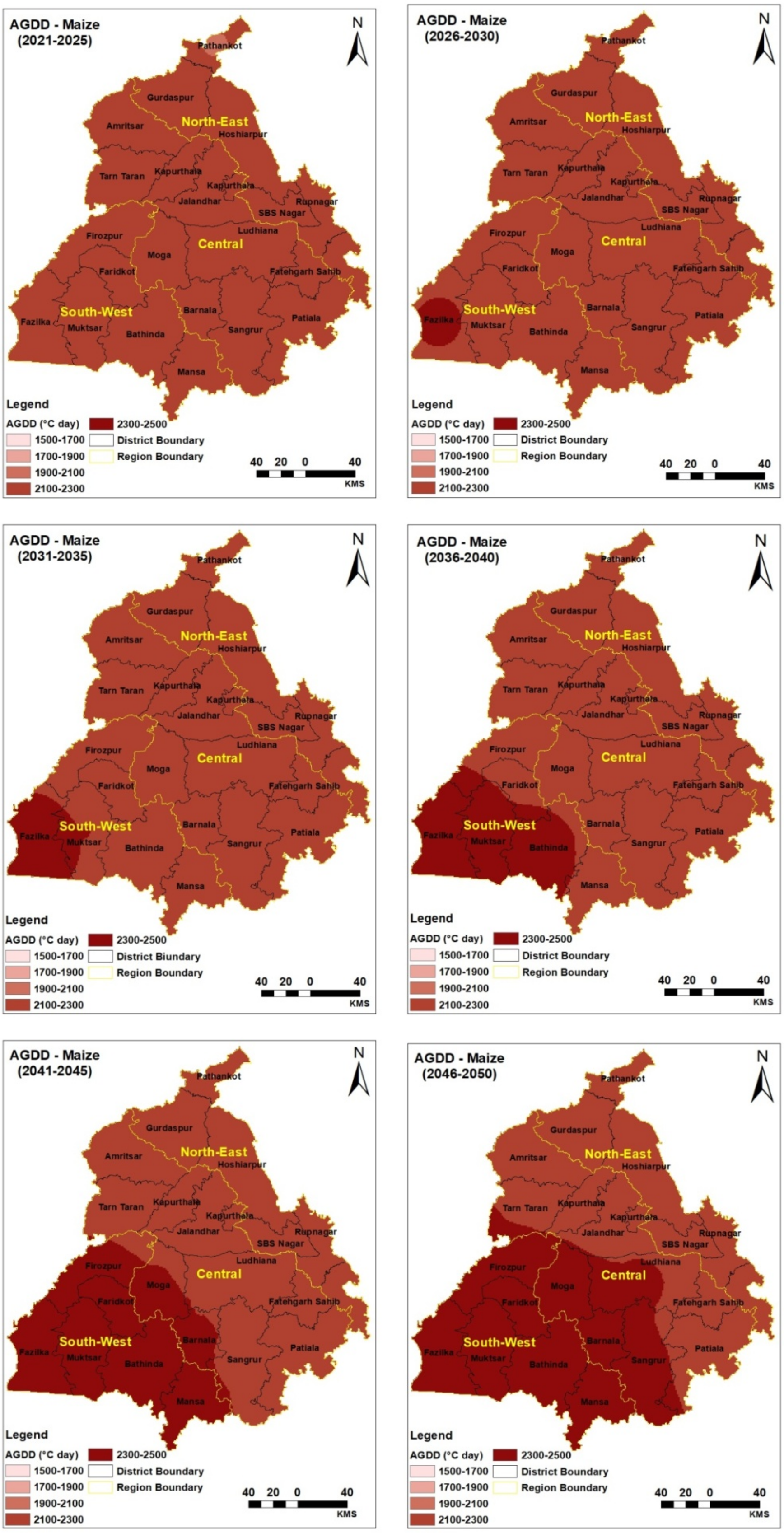

Fig. 4.149: Spatio-temporal variability in predicted AGDD of maize under sowing window II

4.6.3 Spatio-temporal variability in predicted thermal requirements of maize under sowing window III

In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be remained 2100-2300 °C day in S.B.S. Nagar district. While AGDD will be changed from 1900-2100 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, Pathankot and Rupnagar. In the central region of Punjab, in Amritsar, Barnala, Ludhiana, Jalandhar, Kapurthala, Moga, Sangrur heat unit accumulation will be remained 2100-2300 °C day. Whereas, in Fatehgarh sahib, Patiala, Tarn Taran and SAS Nagar heat unit accumulation will be changed from 1900-2100 °C day to 2100-2300 °C day. In South-west region, in Mansa, Ferozepur, Faridkot, and Bathinda AGDD will be remained 2100-2300 °C day in most of the time period. Where, AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Muktsar and Fazilka district (Fig 4. 150).

4.6.4 Spatio-temporal variability in predicted thermal requirements of maize under sowing window IV

In north-east region of Punjab during the period from 2021-2025 to 2046-2050, Gurdaspur, Hoshiarpur, S.B.S. Nagar, Pathankot and Rupnagar AGDD will be changed from 1900-2100 °C day to 2100-2300 °C day. In the central region of Punjab, in Amritsar, Ludhiana, Sangrur, Jalandhar, Kapurthala, Fatehgarh Sahib, Patiala, Tarn Taran and SAS Nagar heat unit accumulation will be changed from 1900-2100 °C day to 2100-2300 °C day. Where, AGDD will be remained 2100-2300 °C day in Barnala and Moga in most of the time period. In South-west region, in Mansa, Ferozepur, Faridkot, Fazilka, Muktsar and Bathinda AGDD will be remained 2100-2300 °C day in most of the time period (Fig 4. 151).

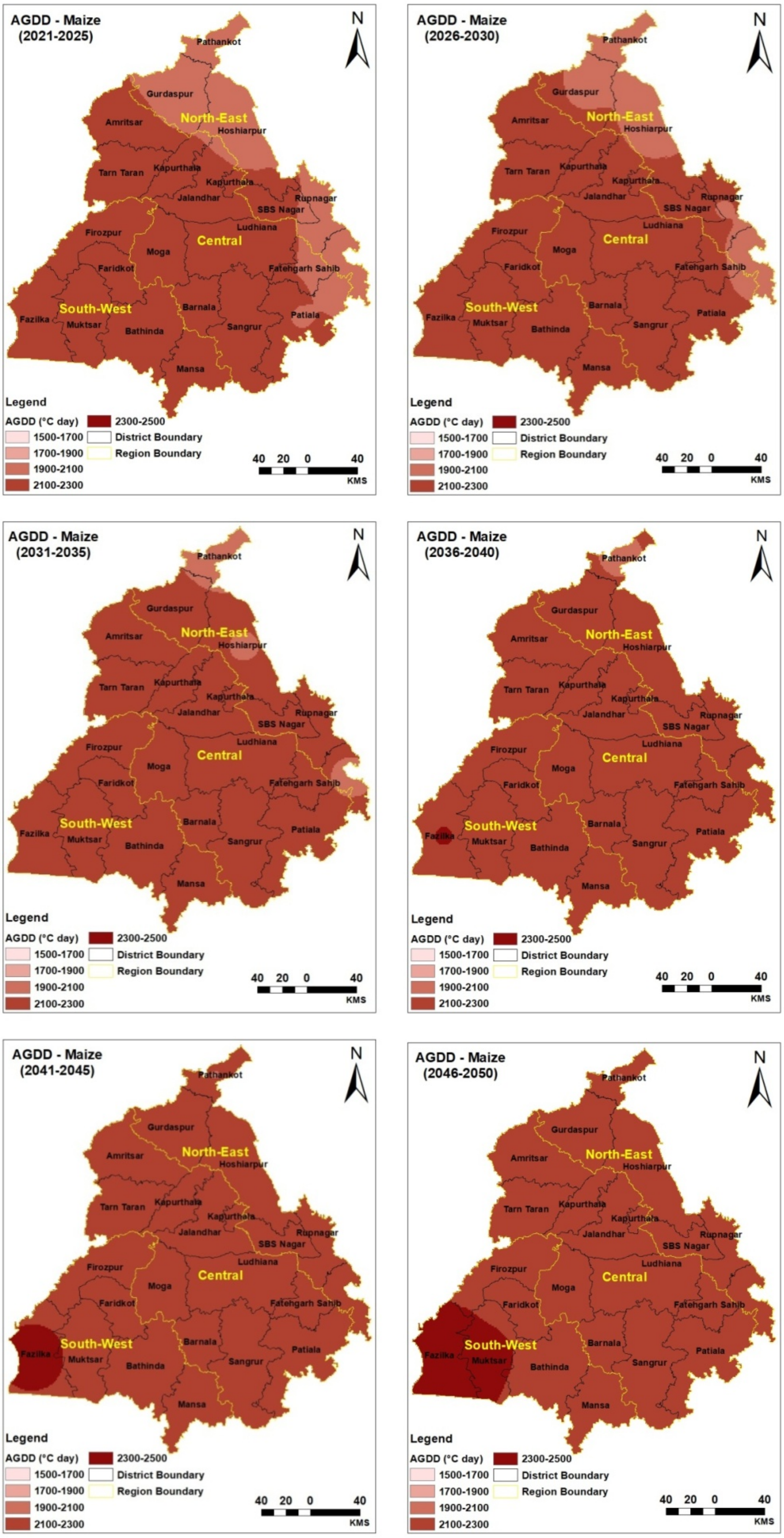

Fig. 4.150: Spatio-temporal variability in thermal requirement of maize under sowing window III

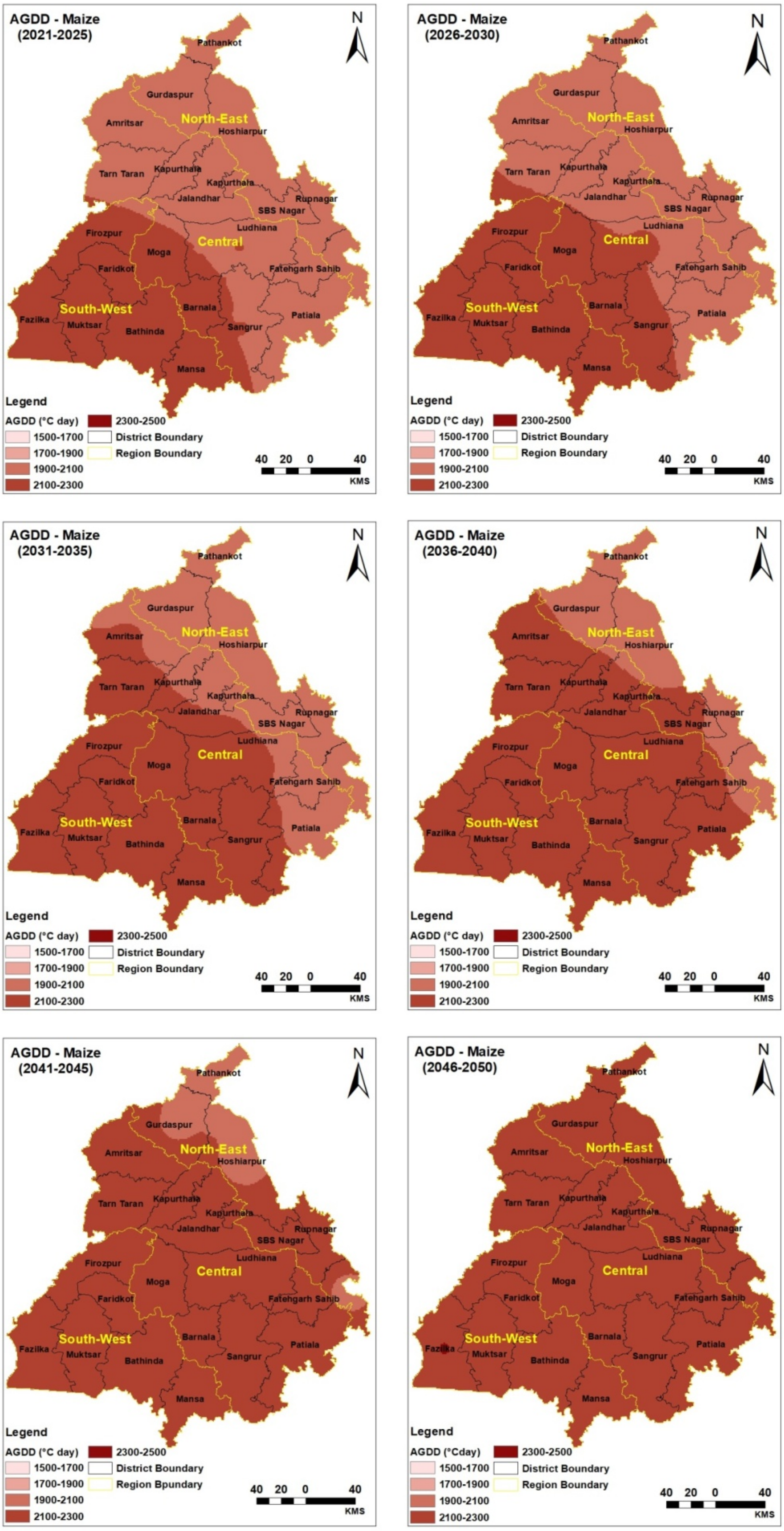

Fig. 4.151: Spatio-temporal variability in thermal requirement of maize under sowing window IV

4.7 VARIABILITY IN ACCUMULATED GROWING DEGREE DAYS IN DIFFERENT PHENOLOGICAL STAGES OF MAIZE DURING DIFFERENT PENTADS UNDER FOUR SOWING WINDOWS

For depicting the spatio-temporal variability in thermal requirements of maize under staggered planting, we divide the whole state into three agroclimatic regions:

1. North-East Region
2. Central Region
3. South-West Region

In North-east region, under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Hoshiarpur and minimum accumulation of GDD was observed in SBS Nagar districts at all the stages during all pentads. For the next three sowing windows the pattern of heat accumulation in all the phenological stages remained the same for the same two districts and for the same period.

In the central, region under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Moga at all the stages during all pentads. The lowest GDD was accumulated by Fatehgarh Sahib from P_1 (1991-1995) to P_4 (2006-2010) followed by Jalandhar in P_5 (2011-2015) and Ludhiana in P_6 (2016-2020). This same pattern of heat unit accumulation was observed in sowing window II, III & IV.

In the south-west region, under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Muktsar at all the stages during all pentads. The lowest GDD was accumulated by Bathinda to complete different phenological stages from P_1 to P_6. This same pattern of GDD accumulation was observed in sowing window II, III & IV (Table 4.21 to 4.37).

Kukal and Irmak (2018) showed that GDD has been increasing by 50°C century^{-1} due to signifcant air temperature changes have occurred globally during the 20th century that results in the crops responding negatively to increase in GDD.

Table 4.21: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Amritsar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	21.4	23.7	22.7	21.7	879.6	808.0	772.4	760.2	1069.9	987.5	886.9	916.0
1996-2000	21.8	19.5	21.8	21.9	837.4	767.9	761.0	759.2	1030.1	950.1	878.2	913.3
2001-2005	21.5	22.9	22.1	21.4	855.1	782.5	762.8	764.8	1040.0	965.8	885.2	922.6
2006-2010	22.3	21.3	19.3	22.3	836.8	769.0	728.7	763.5	1027.9	952.3	848.5	919.2
2011-2015	23.6	22.8	22.2	22.7	882.1	804.6	778.9	776.9	1073.7	991.4	903.4	935.9
2016-2020	25.4	22.4	24.6	24.8	952.0	861.3	838.7	815.9	1147.1	1062.0	964.5	981.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1403.6	1377.2	1352.2	1339.9	1985.3	1950.4	1896.2	1847.0
1996-2000	1369.1	1339.8	1345.2	1337.5	1948.6	1918.8	1896.9	1857.1
2001-2005	1386.7	1367.7	1361.5	1356.3	1978.8	1956.7	1914.2	1869.2
2006-2010	1370.3	1347.8	1307.9	1352.6	1959.8	1928.8	1854.9	1859.9
2011-2015	1426.0	1398.5	1378.3	1366.4	2019.4	1983.6	1938.7	1887.6
2016-2020	1517.4	1484.6	1491.1	1465.8	2176.3	2137.2	2087.5	2032.4

Table 4.22: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Bathinda

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	22.8	24.6	23.2	22.3	904.1	828.8	793.3	761.2	1100.4	1015.1	910.5	920.6
1996-2000	22.2	20.0	22.2	22.3	855.6	780.5	774.2	754.4	1050.2	965.8	893.9	913.5
2001-2005	22.3	23.3	22.4	21.2	867.9	794.9	776.0	763.1	1055.8	983.7	904.1	925.8
2006-2010	22.0	22.5	20.9	22.5	863.7	789.2	770.0	766.5	1057.7	979.4	896.8	929.6
2011-2015	24.9	24.5	22.5	24.1	919.5	839.2	820.3	794.5	1121.9	1039.1	947.2	962.3
2016-2020	21.6	24.8	23.5	23.4	881.5	798.0	773.3	756.5	1073.6	985.3	897.5	921.4

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1443.3	1412.7	1388.2	1354.4	2038.9	1997.1	1938.2	1887.8
1996-2000	1396.2	1368.1	1374.3	1347.9	1991.3	1959.1	1937.4	1898.7
2001-2005	1415.8	1401.0	1394.2	1371.8	2025.4	2006.5	1961.5	1917.5
2006-2010	1415.6	1392.4	1387.8	1376.9	2026.5	1991.5	1945.1	1915.1
2011-2015	1491.6	1463.4	1444.1	1411.6	2110.8	2066.8	2023.1	1967.0
2016-2020	1423.3	1398.2	1395.0	1371.5	2041.6	2006.0	1976.3	1945.1

Table 4.23: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Faridkot

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	22.9	24.7	23.3	22.5	907.5	832.7	798.1	765.5	1104.3	1019.9	915.6	925.9
1996-2000	22.3	20.1	22.3	22.5	859.8	785.2	779.7	760.0	1055.8	971.9	900.3	920.7
2001-2005	22.4	23.8	22.6	21.4	874.1	799.9	780.7	767.6	1063.1	990.2	909.6	932.1
2006-2010	24.0	22.9	24.5	23.8	913.4	829.8	797.5	787.6	1108.2	1024.7	922.9	951.8
2011-2015	25.2	23.9	28.7	25.2	985.5	891.8	865.3	817.0	1185.1	1099.7	992.0	987.5
2016-2020	22.4	23.9	26.0	23.0	929.7	844.9	814.7	784.2	1127.5	1038.8	938.6	954.7

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1448.9	1419.8	1396.2	1362.4	2048.2	2008.1	1949.9	1898.9
1996-2000	1404.2	1377.6	1385.0	1358.9	2004.7	1973.8	1952.9	1913.6
2001-2005	1425.1	1410.8	1404.3	1382.2	2040.5	2021.9	1977.1	1933.5
2006-2010	1469.9	1439.2	1430.6	1421.8	2103.9	2069.4	2013.7	2003.8
2011-2015	1563.1	1529.6	1537.1	1487.5	2239.7	2201.9	2141.0	2087.3
2016-2020	1486.2	1461.5	1459.1	1428.2	2133.5	2100.2	2056.9	2013.2

Table 4.24: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Fatehgarh Sahib

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	20.5	22.3	21.3	19.7	812.7	742.7	708.0	677.9	988.4	908.2	813.4	819.8
1996-2000	19.8	17.9	20.0	19.8	759.6	689.3	683.9	667.7	931.1	854.1	791.5	808.9
2001-2005	19.9	20.7	20.2	18.8	777.6	710.1	692.5	680.6	946.5	878.4	806.5	825.5
2006-2010	21.8	22.1	21.7	20.9	853.2	772.8	737.0	717.2	1032.9	952.7	852.3	864.8
2011-2015	24.1	24.9	26.7	23.4	980.2	878.7	833.6	786.3	1173.3	1076.8	957.5	943.6
2016-2020	24.3	25.2	26.9	22.6	987.5	886.9	841.4	792.9	1182.6	1086.6	966.0	950.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1294.6	1262.9	1239.6	1206.7	1825.4	1783.9	1729.7	1684.1
1996-2000	1240.2	1212.0	1217.6	1194.6	1768.1	1737.2	1717.3	1685.2
2001-2005	1267.1	1250.2	1243.5	1223.2	1810.3	1791.1	1751.1	1711.8
2006-2010	1365.1	1329.9	1322.2	1296.9	1946.0	1910.3	1855.3	1827.5
2011-2015	1535.3	1481.5	1479.2	1423.1	2171.3	2129.5	2058.9	2012.6
2016-2020	1547.1	1493.3	1490.1	1436.1	2189.2	2149.3	2079.8	2033.7

Table 4.25: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Ferozepur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	22.8	24.6	23.2	22.4	905.2	830.4	795.4	762.9	1101.4	1016.8	912.7	922.9
1996-2000	22.3	20.1	22.4	22.5	857.8	783.9	778.0	758.0	1053.6	970.1	898.2	917.6
2001-2005	22.3	23.7	22.6	21.5	871.9	798.1	778.7	764.9	1060.7	987.4	906.8	928.6
2006-2010	23.8	22.9	23.9	23.5	910.0	828.1	797.2	779.1	1104.9	1023.2	922.3	942.1
2011-2015	24.6	23.8	28.3	24.7	980.3	889.5	862.2	816.3	1179.5	1097.1	989.6	986.9
2016-2020	24.6	23.9	27.8	24.7	986.0	895.2	867.8	821.8	1186.8	1103.7	996.5	993.4

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1444.8	1415.7	1391.6	1357.9	2042.2	2002.3	1944.3	1893.4
1996-2000	1400.9	1373.7	1380.7	1354.4	1998.8	1967.9	1946.9	1907.5
2001-2005	1420.7	1405.6	1398.9	1376.4	2032.9	2013.7	1969.0	1925.2
2006-2010	1466.4	1437.4	1430.1	1409.7	2100.2	2065.8	2010.6	1982.9
2011-2015	1557.9	1527.4	1536.6	1487.7	2234.4	2199.4	2136.1	2081.5
2016-2020	1567.9	1537.3	1546.1	1498.1	2248.9	2213.9	2152.1	2096.7

Table 4.26: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Gurdaspur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	18.8	20.9	20.0	19.3	775.5	717.3	688.7	662.9	946.2	878.0	791.3	803.6
1996-2000	18.8	16.7	19.2	19.4	734.7	678.9	679.3	664.3	907.9	843.0	784.8	801.6
2001-2005	18.6	20.2	19.6	19.0	754.9	695.8	682.0	669.9	921.2	860.4	792.6	812.5
2006-2010	21.7	20.5	22.7	21.7	837.4	765.4	733.9	709.8	1017.9	940.9	847.2	857.5
2011-2015	23.8	24.7	26.9	21.2	963.9	871.1	826.1	774.7	1155.1	1066.8	946.7	928.0
2016-2020	24.2	24.9	27.3	22.0	979.3	880.2	835.2	783.5	1173.3	1077.6	957.5	938.8

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1245.4	1228.5	1209.8	1184.9	1768.6	1743.2	1695.6	1650.8
1996-2000	1213.5	1193.9	1205.5	1183.9	1734.3	1713.5	1697.4	1661.7
2001-2005	1233.7	1223.3	1223.0	1203.3	1767.5	1753.8	1718.6	1678.8
2006-2010	1343.3	1315.2	1311.3	1284.7	1920.3	1884.7	1831.3	1794.5
2011-2015	1510.7	1461.4	1455.2	1392.7	2123.9	2089.1	2013.1	1960.4
2016-2020	1532.7	1477.9	1471.0	1408.1	2158.6	2111.3	2035.7	1982.7

Table 4.27: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Hoshiarpur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	20.2	22.2	21.1	20.1	817.7	750.8	717.6	688.5	995.0	918.0	824.3	833.8
1996-2000	20.1	17.9	20.2	20.2	774.5	710.0	704.7	686.2	953.2	879.0	813.9	828.1
2001-2005	19.8	21.2	20.5	19.8	792.5	724.9	707.5	692.7	964.1	895.7	821.9	839.6
2006-2010	22.6	21.3	22.9	22.9	855.4	777.1	742.9	717.7	1036.8	955.4	856.7	865.1
2011-2015	25.2	23.7	28.2	23.1	959.6	860.4	823.3	767.7	1149.4	1054.1	941.2	923.8
2016-2020	25.5	23.9	28.5	23.3	966.8	869.2	831.2	774.8	1158.5	1064.3	950.2	931.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1305.6	1280.5	1257.4	1228.5	1847.2	1813.7	1762.0	1715.9
1996-2000	1268.2	1241.2	1247.0	1222.2	1805.3	1777.4	1757.4	1720.6
2001-2005	1287.5	1270.2	1265.1	1243.2	1838.5	1818.9	1779.2	1738.1
2006-2010	1366.2	1331.7	1320.5	1290.9	1942.8	1903.6	1848.5	1813.1
2011-2015	1502.0	1452.4	1449.4	1387.8	2128.4	2080.3	2013.8	1958.6
2016-2020	1514.1	1465.9	1461.5	1399.3	2144.7	2098.6	2031.8	1976.5

Table 4.28: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Jalandhar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	21.3	23.2	22.1	21.0	855.4	784.0	748.4	716.9	1039.9	958.2	859.3	867.9
1996-2000	21.1	18.9	21.1	21.1	812.1	743.2	735.5	714.7	998.1	918.9	848.9	862.4
2001-2005	20.8	22.2	21.4	20.6	829.9	757.9	738.2	721.7	1008.6	935.9	857.4	874.6
2006-2010	20.6	21.8	20.8	21.9	814.0	741.3	715.7	701.1	992.7	913.8	828.5	850.7
2011-2015	22.2	22.5	22.0	21.6	857.0	782.4	751.8	726.9	1040.7	963.2	869.4	905.7
2016-2020	25.3	24.3	28.4	24.4	982.2	885.4	849.9	798.3	1178.4	1086.7	973.5	961.2

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1363.2	1335.0	1309.8	1278.7	1926.5	1890.6	1836.6	1788.7
1996-2000	1325.6	1295.7	1299.6	1272.5	1884.6	1854.2	1832.2	1793.9
2001-2005	1345.4	1325.7	1318.6	1294.9	1919.1	1897.4	1855.3	1812.5
2006-2010	1316.0	1290.1	1281.99	1268.2	1881.2	1850.7	1810.3	1773.7
2011-2015	1379.7	1379.3	1359.8	1327.1	1982.8	1950.8	1899.8	1852.1
2016-2020	1545.5	1501.7	1501.9	1443.4	2195.4	2153.8	2088.8	2035.9

Table 4.29: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Kapurthala

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	21.2	23.2	22.1	21.0	854.7	783.4	747.8	716.4	1039.1	957.4	858.7	867.3
1996-2000	21.1	18.4	21.1	21.1	811.6	742.9	735.2	714.4	997.7	918.6	848.6	861.9
2001-2005	20.8	22.2	21.4	20.6	829.4	757.4	737.7	720.9	1007.9	935.2	856.6	873.7
2006-2010	23.6	21.4	22.4	23.2	882.6	801.7	766.7	741.9	1070.3	984.7	885.5	898.3
2011-2015	26.2	22.5	25.3	24.7	972.2	873.3	837.2	788.2	1166.7	1068.7	960.9	952.5
2016-2020	26.2	22.9	25.7	25.0	982.1	882.3	846.6	796.4	1178.8	1080.3	971.4	962.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1362.2	1334.1	1308.9	1277.8	1925.2	1889.4	1835.6	1787.7
1996-2000	1325.0	1295	1298.9	1271.9	1883.7	1853.3	1831.4	1793.0
2001-2005	1344.2	1324.4	1317.5	1293.6	1917.5	1895.7	1853.7	1810.9
2006-2010	1411.2	1379.9	1369.8	1347.4	2019.5	1979.4	1925.9	1888.2
2011-2015	1529.2	1486.7	1481.1	1433.3	2180.6	2131.5	2072.1	2016.8
2016-2020	1544.8	1501.6	1495.3	1446.1	2201.8	2152.7	2093.2	2036.7

Table 4.30: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Ludhiana

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	21.5	22.9	21.2	22.3	864.8	791.4	760.5	731.7	1053.6	971.2	875.8	893.6
1996-2000	22.5	21.0	22.6	22.7	836.9	762.2	752.1	736.5	1027.5	939.9	871.6	892.1
2001-2005	21.9	22.8	22.2	21.0	849.0	775.6	760.5	749.5	1033.9	962.6	883.2	911.0
2006-2010	21.9	21.8	19.3	21.6	843.6	767.1	745.2	738.9	1030.9	949.8	867.8	898.3
2011-2015	24.2	23.6	20.6	21.6	874.1	797.1	776.7	760.9	1066.8	985.5	902.7	923.4
2016-2020	21.9	25.2	23.3	23.3	878.4	800.6	767.6	757.3	1067.3	979.7	891.4	921.4

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1388.2	1362.7	1347.4	1321.9	1975.9	1937.6	1889.1	1849.9
1996-2000	1366.5	1337.4	1345.5	1320.7	1950.9	1921.2	1901.5	1870.2
2001-2005	1388.4	1372.9	1367.5	1353.2	1991.2	1970.1	1923.9	1892.7
2006-2010	1373.8	1351.4	1351.1	1341.7	1977.7	1940.1	1895.9	1864.3
2011-2015	1423.8	1399.0	1383.7	1356.2	2021.6	1987.8	1947.9	1898.2
2016-2020	1410.8	1389.1	1381.3	1371.4	2019.7	1989.9	1956.1	1939.7

Table 4.31: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Mansa

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	23.0	24.7	23.5	22.2	910.2	833.5	796.0	762.2	1108.8	1019.7	912.6	921.4
1996-2000	22.5	20.2	22.4	22.3	861.1	784.1	777.8	756.9	1057.1	969.9	897.2	916.7
2001-2005	22.6	23.4	22.7	20.9	870.8	799.0	778.4	765.6	1061.7	987.5	907.4	928.6
2006-2010	23.5	23.4	24.0	23.0	915.7	829.6	798.7	782.7	111.8	1025.3	925.6	944.4
2011-2015	24.1	25.2	27.4	23.4	994.0	895.7	867.4	822.1	1195.1	1103.9	996.5	989.2
2016-2020	24.3	24.8	27.6	23.6	996.5	905.2	872.6	826.6	1198.8	1115.1	1002.2	994.6

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1450.6	1415.9	1390.6	1354.9	2046.1	1999.3	1938.1	1888.9
1996-2000	1403.3	1372.8	1378.2	1351.5	1999.3	1964.3	1941.5	1904.3
2001-2005	1422.0	1406.8	1397.6	1373.9	2031.4	2011.2	1964.4	1919.7
2006-2010	1476.0	1440.8	1432.5	1412.4	2105.6	2056.8	2010.7	1983.5
2011-2015	1575.9	1538.4	1541.8	1490.8	2244.8	2189.0	2145.8	2097.0
2016-2020	1581.5	1546.4	1549.7	1498.4	2253.3	2215.1	2158.1	2109.6

Table 4.32: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Moga

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	22.6	24.4	23.1	22.1	897.5	822.5	787.3	756.2	1092.0	1007.6	904.2	914.9
1996-2000	22.0	19.8	22.1	22.2	849.3	774.4	767.5	748.0	1041.9	958.2	886.7	905.7
2001-2005	22.0	23.0	22.2	21.1	860.6	789.0	770.79	758.1	1048.7	976.6	898.0	919.3
2006-2010	23.7	22.6	23.9	23.5	902.8	821.0	789.4	771.2	1096.0	1014.2	913.3	932.0
2011-2015	25.2	23.9	28.6	24.9	981.5	886.4	858. 1	808.3	1179.2	1091.8	982.9	976.0
2016-2020	25.2	24.2	28.5	24.8	990.2	894.5	863. 5	813.7	1189.3	1101.2	989.5	981.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1433.5	1403.6	1379.2	1346.2	2025.8	1984.8	1926.7	1876.7
1996-2000	1385.4	1357.4	1363.1	1336.9	1975.8	1943.9	1921.9	1883.3
2001-2005	1405.6	1390.6	1384.2	1362.3	2010.6	1992.2	1947.8	1903.7
2006-2010	1454.0	1424.0	1415.9	1396.5	2081.7	2046.0	1990.6	1960.9
2011-2015	1552.4	1515.4	1520.8	1470.5	2220.6	2181.6	2120.8	2067.8
2016-2020	1564.9	1526.5	1530.9	1480.4	2236.1	2198.3	2135.8	2083.3

Table 4.33: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Muktsar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	23.0	24.7	23.3	22.6	909.9	834.8	800.1	767.2	1107.4	1022.5	917.8	927.9
1996-2000	22.4	20.2	22.3	22.5	862.0	787.4	782.0	762.1	1058.7	974.7	902.8	923.1
2001-2005	22.5	23.9	22.7	21.5	875.8	801.6	782.2	769.1	1065.4	992.2	911.3	933.8
2006-2010	24.1	22.9	24.6	24.0	917.4	834.2	803.2	785.5	1113.8	1030.9	929.6	949.7
2011-2015	25.3	24.1	28.8	25.4	992.1	900.1	876.0	828.5	1194.6	1111.2	1004.6	1001.2
2016-2020	25.2	24.1	28.2	25.7	1000.0	907.2	881.9	834.0	1204.0	1119.1	1011.7	1007.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1452.6	1423.0	1399.1	1365.1	2052.9	2012.2	1953.7	1902.6
1996-2000	1407.9	1381.1	1388.4	1362.1	2009.5	1978.2	1957.3	1918.0
2001-2005	1427.9	1413.5	1406.8	1384.5	2044.2	2025.5	1980.5	1936.9
2006-2010	1478.5	1448.2	1440.1	1420.5	2116.0	2082.1	2027.2	2002.3
2011-2015	1578.2	1546.7	1555.5	1506.7	2262.3	2226.9	2168.2	2115.2
2016-2020	1590.1	1557.2	1564.1	1516.5	2277.8	2242.2	2183.9	2129.3

Table 4.34: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Patiala

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	20.7	22.6	21.5	19.9	821.9	751.2	716.1	685.5	999.9	918.5	822.5	828.8
1996-2000	20.1	18.1	20.3	20.0	769.2	697.8	692.2	675.4	942.8	864.5	800.8	818.2
2001-2005	20.2	20.9	20.5	18.9	786.4	718.4	700.4	688.3	957.5	888.5	815.7	834.9
2006-2010	21.0	21.8	19.9	20.7	813.4	741.2	725.8	717.6	994.7	921.9	843.6	869.5
2011-2015	24.7	24.2	22.7	22.5	897.3	813.0	794.5	775.8	1094.5	1005.3	921.3	943.3
2016-2020	24.0	24.9	26.8	22.7	983.5	888.7	847.4	799.9	1180.5	1091.1	973.2	957.7

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1309.2	1276.7	1253.1	1219.7	1845.6	1803.3	1748.3	1702.5
1996-2000	1255.1	1226.3	1231.7	1208.0	1788.8	1757.2	1736.9	1704.4
2001-2005	1281.6	1264.6	1257.5	1236.6	1830.6	1811.0	1770.5	1730.9
2006-2010	1330.6	1307.7	1306.2	1292.2	1904.8	1875.0	1835.3	1803.7
2011-2015	1456.4	1424.9	1408.9	1379.9	2061.4	2023.3	1984.2	1936.3
2016-2020	1548.9	1499.3	1497.2	1439.7	2187.6	2151.8	2084.2	2038.4

Table 4.35: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Rupnagar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	19.6	21.5	20.4	19.1	783.8	717.9	685.3	657.3	953.9	878.0	787.6	795.3
1996-2000	19.1	17.1	19.3	19.2	733.5	667.9	663.9	648.9	900.7	828.0	786.5	785.4
2001-2005	19.1	19.9	19.5	18.3	751.5	687.0	671.1	659.7	915.1	850.0	781.3	800.2
2006-2010	21.5	21.5	21.7	20.7	836.5	758.4	722.1	701.6	1012.9	933.9	834.8	843.4
2011-2015	24.0	24.7	26.9	22.2	977.3	874.9	828.9	779.3	1168.8	1071.5	950.7	935.5
2016-2020	24.3	24.9	27.1	22.5	985.8	881.5	834.2	781.9	1177.5	1074.4	955.8	938.6

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1250.7	1222.9	1201.1	1170.9	1766.3	1728.5	1676.6	1632.2
1996-2000	1200.7	1174.9	1181.7	1159.7	1712.6	1684.2	1665.7	1633.5
2001-2005	1225.3	1209.8	1204.7	1185.3	1751.6	1733.5	1695.1	1656.4
2006-2010	1337.1	1299.4	1287.5	1258.9	1896.2	1860.0	1804.8	1776.4
2011-2015	1526.8	1471.8	1468.7	1413.0	2159.9	2118.3	2047.1	1998.5
2016-2020	1536.7	1480.1	1475.6	1419.9	2173.7	2132.3	2061.4	2013.2

Table 4.36: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Sangrur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	22.4	24.3	22.9	21.9	891.1	816.2	780.4	749.0	1084.5	999.4	896.2	905.9
1996-2000	21.9	19.7	21.9	21.9	842.3	767.2	760.3	740.9	1033.2	949.3	878.4	897.2
2001-2005	21.8	22.8	22.1	20.8	853.6	782.6	763.9	751.3	1040.3	968.2	890.0	910.9
2006-2010	23.1	22.8	23.4	22.5	901.5	819.7	784.4	767.1	1093.7	1012.2	908.4	926.2
2011-2015	24.0	24.0	27.2	23.0	988.3	912.6	854.7	807.7	1185.8	1115.4	981.2	971.8
2016-2020	24.5	24.6	27.4	23.2	995.2	902.1	860.0	812.3	1194.1	1107.9	987.2	977.1

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1422.4	1391.1	1366.4	1332.9	2008.6	1966.2	1907.7	1858.4
1996-2000	1373.5	1344.7	1350.1	1324.0	1958.0	1925.3	1903.1	1865.5
2001-2005	1393.9	1378.5	1371.4	1349.2	1992.7	1973.7	1929.2	1885.4
2006-2010	1450.1	1417.5	1408.6	1388.4	2071.4	2036.7	1978.5	1950.2
2011-2015	1559.3	1559.3	1518.7	1467.6	2219.0	2219.0	2116.3	2067.8
2016-2020	1569.2	1533.0	1527.0	1475.3	2231.9	2202.8	2129.1	2080.6

Table 4.37: Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in SBS Nagar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1991-1995	18.7	20.8	19.6	18.7	759.6	698.4	668.3	642.6	925.1	854.4	768.2	778.3
1996-2000	18.5	16.5	18.7	18.7	715.0	655.8	653.1	638.3	880.9	813.0	755.3	770.8
2001-2005	18.4	19.6	18.9	18.3	733.1	671.2	656.9	645.0	892.9	830.3	763.8	782.3
2006-2010	21.1	21.0	21.5	20.3	826.6	751.8	717.7	695.9	1002.3	926.2	828.8	833.4
2011-2015	24.0	24.9	27.1	21.3	978.6	878.4	836.1	787.1	1172.5	1078.4	959.2	945.0
2016-2020	24.3	25.1	27.1	21.6	988.5	887.4	845.7	795.8	1184.8	1089.3	970.0	955.3

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
1991-1995	1215.3	1193.2	1172.9	1146.7	1720.9	1689.4	1640.3	1596.9
1996-2000	1174.8	1151.6	1159.4	1137.9	1675.7	1650.5	1632.9	1599.2
2001-2005	1194.6	1180.4	1177.2	1158.3	1708.4	1691.4	1654.7	1616.1
2006-2010	1323.2	1284.4	1268.6	1235.1	1865.0	1828.3	1773.8	1742.5
2011-2015	1535.7	1483.0	1481.6	1425.6	2173.9	2133.2	2062.9	2013.7
2016-2020	1551.5	1497.9	1496.7	1439.5	2194.9	2152.8	2082.5	2032.1

4.8 VARIABILITY IN PREDICTED ACCUMULATED GROWING DEGREE DAYS IN DIFFERENT PHENOLOGICAL STAGES OF MAIZE DURING DIFFERENT PENTADS UNDER FOUR SOWING WINDOWS

For depicting the spatio-temporal variability in predicted thermal requirements of maize under staggered planting, we divide the whole state into three agroclimatic regions:

1. North-East Region
2. Central Region
3. South-West Region

In North-east region, under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units will be accumulated in district SBS Nagar and minimum accumulation of GDD will be observed in Hoshiarpur district at all the stages during all pentads. For the next three sowing windows the pattern of heat accumulation in all the phenological stages will be remained the same for the same two districts and for the same period.

In the central region, under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units will be accumulated in district Ludhiana at all the stages during all pentads. The lowest GDD will be accumulated by Amritsar. This same pattern of heat unit accumulation was observed in sowing window II, III & IV.

In the south-west region, under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units will be accumulated in district Muktsar at all the stages during all pentads. The lowest GDD will be accumulated by Barnala to complete different phenological stages from F_1 to F_6. This same pattern of GDD accumulation will be observed in sowing window II, III & IV (Table 4. 38 to 4.59).

Paparrizos and Matzarakis (2017) indicated that for all the future periods and scenarios, the GDD are expected to increase.

Table 4.38: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Amritsar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.1	22.7	25.7	25.2	969.4	875.7	851.3	803.7	1166.6	1079.5	978.3	972.1
2026-2030	25.3	22.9	25.9	25.4	978.2	883.5	858.9	810.9	1177.3	1089.2	987.0	981.0
2031-2035	25.6	23.3	26.1	25.7	988.3	892.6	867.1	819.0	1189.6	1099.9	996.6	990.7
2036-2040	25.8	23.6	26.4	25.9	998.4	901.7	873.1	823.9	1201.9	1108.4	1003.7	998.8
2041-2045	26.0	23.9	26.7	26.2	1010.1	912.3	881.7	831.3	1215.9	1119.9	1013.3	1010.0
2046-2050	26.3	24.4	27.1	26.4	1022.6	923.7	894.2	842.5	1231.4	1135.6	1026.9	1023.2

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1541.9	1507.9	1510.7	1465.4	2210.8	2170.8	2119.8	2063.9
2026-2030	1556.0	1521.4	1523.7	1478.2	2230.3	2189.7	2138.4	2082.4
2031-2035	1571.8	1536.5	1538.2	1492.3	2252.1	2210.9	2159.3	2103.2
2036-2040	1584.5	1549.9	1551.7	1504.8	2272.3	2230.4	2178.9	2122.9
2041-2045	1600.9	1567.1	1568.3	1520.7	2296.8	2254.5	2203.1	2147.5
2046-2050	1621.9	1586.8	1586.1	1538.9	2324.5	2281.7	2229.9	2174.4

Table 4.39: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Barnala

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.5	25.0	27.8	23.6	1010.7	911.9	872.9	824.3	1212.8	1121.3	1001.8	991.6
2026-2030	24.8	25.3	27.9	23.9	1017.4	919.0	872.7	830.9	1221.1	1129.9	1009.7	999.8
2031-2035	25.0	25.5	28.1	24.1	1026.1	926.7	886.6	837.7	1231.7	1138.8	1017.8	1008.1
2036-2040	25.3	25.8	28.4	24.3	1035.9	935.2	893.8	844.7	1243.6	1148.2	1026.3	1016.8
2041-2045	25.7	26.0	28.6	24.6	1046.7	944.5	902.7	853.1	1256.5	1159.6	1036.5	1027.1
2046-2050	26.0	26.4	28.9	24.9	1058.4	954.8	912.3	862.1	1270.6	1171.9	1047.5	1037.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1593.2	1547.2	1548.5	1496.6	2265.2	2228.1	2160.5	2111.3
2026-2030	1604.7	1559.5	1560.5	1508.5	2281.7	2245.5	2177.8	2128.6
2031-2035	1618.0	1572.4	1572.9	1520.7	2300.7	2263.8	2196.1	2146.9
2036-2040	1632.6	1586.1	1586.1	1533.8	2321.3	2283.6	2216.0	2166.8
2041-2045	1649.3	1601.9	1601.3	1548.9	2344.5	2306.1	2238.5	2189.3
2046-2050	1667.3	1618.9	1617.5	1564.8	2369.4	2330.3	2262.6	2213.3

Table 4.40: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Bathinda

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	26.05	24.7	29.2	25.7	1010.1	912.9	886.4	837.9	1215.3	1126.1	1016.4	1011.6
2026-2030	25.7	25.3	28.8	25.1	1018.3	924.1	889.8	842.1	1224.5	1138.0	1021.2	1016.0
2031-2035	25.0	25.4	28.2	25.3	1030.2	930.9	894.4	848.1	1237.6	1146.5	1027.8	1022.1
2036-2040	25.3	25.6	27.9	25.3	1039.9	943.7	909.9	865.2	1249.4	1160.6	1046.9	1042.3
2041-2045	25.6	25.9	28.7	24.8	1050.8	948.9	911.5	864.4	1262.5	1168.4	1047.4	1041.9
2046-2050	26.0	26.3	29.0	25.1	1062.7	959.2	921.1	873.4	1276.7	1180.7	1058.4	1052.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1602.8	1565.2	1570.1	1519.6	2290.3	2250.4	2191.7	2141.3
2026-2030	1614.1	1582.4	1579.5	1529.3	2304.7	2274.596	2204.9	2154.9
2031-2035	1630.4	1588.3	1592.4	1542.8	2324.8	2289.3	2223.2	2174.1
2036-2040	1645.7	1611.6	1610.5	1566.8	2346.3	2317.5	2257.3	2204.9
2041-2045	1662.6	1618.9	1621.9	1571.9	2369.7	2332.9	2266.8	2217.8
2046-2050	1680.8	1635.9	1638.2	1587.9	2394.9	2357.3	2291.2	2242.1

Table 4.41: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Faridkot

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.9	24.7	29.2	25.7	1007.9	912.5	885.4	837.2	1212.8	1125.3	1015.5	1011.6
2026-2030	26.0	24.7	29.2	25.7	1009.1	913.6	886.6	838.5	1214.4	1126.7	1016.9	1013.3
2031-2035	26.0	24.9	29.4	25.9	1018.3	921.6	894.3	846.2	1225.4	1136.6	1025.9	1022.8
2036-2040	26.5	25.3	29.6	26.2	1018.3	921.6	894.3	846.2	1237.8	1147.4	1035.6	1032.2
2041-2045	26.8	25.6	29.8	26.5	1039.6	940.3	911.8	862.9	1251.3	1159.3	1046.1	1042.8
2046-2050	27.1	26.0	30.1	26.8	1051.7	950.8	921.5	871.9	1265.7	1171.9	1057.2	1053.8

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1600.2	1565.4	1571.3	1521.5	2290.4	2252.5	2192.7	2140.7
2026-2030	1602.4	1567.7	1573.6	1523.9	2293.6	2255.6	2195.9	2143.9
2031-2035	1617.1	1581.6	1587.1	1537.6	2313.9	2275.3	2215.5	2163.7
2036-2040	1632.9	1596.7	1601.6	1551.6	2335.9	2296.8	2236.9	2185.1
2041-2045	1650.2	1613.1	1617.2	1567.1	2359.9	2320.1	2260.1	2208.2
2046-2050	1668.6	1630.3	1633.8	1583.4	2385.4	2344.9	2284.7	2232.8

Table 4.42: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Fatehgarh Sahib

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.8	26.4	26.8	22.8	998.6	898.3	898.3	801.6	1196.7	1098.8	976.2	959.8
2026-2030	24.2	27.5	26.6	22.6	1000.7	901.8	901.8	802.8	1198.8	1102.1	977.4	961.6
2031-2035	24.1	27.8	26.9	22.9	1008.9	910.4	910.4	808.3	1208.7	1112.3	985.5	968.1
2036-2040	24.4	28.0	27.1	23.1	1019.1	919.8	919.8	816.9	1221.3	1123.8	995.9	978.5
2041-2045	24.7	28.3	27.4	23.5	1030.1	929.7	929.7	826.5	1234.8	1136.0	1007.4	990.2
2046-2050	25.1	28.5	27.7	23.8	1041.9	940.1	940.1	836.5	1249.2	1148.9	1019.2	1002.4

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1564.8	1509.4	1509.4	1447.6	2208.4	2169.5	2169.5	2055.6
2026-2030	1568.4	1515.6	1515.6	1455.2	2217.2	2182.2	2182.2	2069.2
2031-2035	1580.1	1527.0	1527.0	1466.9	2234.9	2200.8	2200.8	2088.5
2036-2040	1596.3	1542.7	1542.7	1482.2	2257.8	2223.0	2223.0	2110.5
2041-2045	1614.2	1560.1	1560.1	1498.8	2282.8	2247.3	2247.3	2134.4
2046-2050	1633.1	1578.2	1578.2	1516.3	2309.1	2272.8	2272.8	2159.7

Table 4.43: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Fazilka

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	26.1	24.9	29.4	26.1	1020.6	926.0	902.6	856.0	1230.1	1144.1	1036.0	1034.9
2026-2030	26.4	25.1	29.6	26.3	1029.6	933.8	910.3	863.7	1241.1	1153.8	1044.9	1044.2
2031-2035	26.6	25.4	29.8	26.6	1039.3	942.3	918.4	871.7	1252.8	1164.2	1054.4	1054.0
2036-2040	26.9	25.78	30.0	26.8	1049.4	951.2	926.9	879.8	1265.1	1175.1	1064.2	1063.9
2041-2045	27.2	26.1	30.3	27.1	1060.8	961.0	935.9	888.4	1278.7	1186.9	1074.5	1074.4
2046-2050	27.5	26.5	30.5	27.4	1072.9	971.6	945.6	897.6	1293.3	1199.5	1085.7	1085.5

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1626.9	1594.9	1603.9	1556.2	2332.7	2297.3	2240.5	2188.7
2026-2030	1641.4	1608.8	1617.5	1569.8	2353.1	2317.2	2260.7	2209.3
2031-2035	1656.9	1623.6	1631.9	1584.2	2374.8	2338.5	2282.0	2230.8
2036-2040	1672.8	1638.8	1646.7	1599.0	2397.2	2360.4	2303.9	2252.9
2041-2045	1690.2	1655.2	1662.4	1614.6	2421.5	2384.1	2327.5	2276.5
2046-2050	1708.8	1672.6	1679.1	1631.1	2447.3	2409.2	2352.5	2301.6

Table 4.44: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Ferozepur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.5	24.4	29.0	25.6	995.9	903.2	878.9	831.1	1199.7	1114.5	1008.4	1004.8
2026-2030	25.8	24.6	29.2	25.8	1004.7	910.9	886.5	838.5	1210.3	1124.0	1017.1	1013.8
2031-2035	26.0	24.9	29.4	26.0	1015.2	920.4	895.6	847.5	1222.8	1135.3	1027.5	1024.5
2036-2040	26.3	25.2	29.6	26.2	1025.7	929.6	904.3	855.8	1235.5	1146.5	1037.5	1034.6
2041-2045	26.6	25.6	29.9	26.5	1036.9	939.4	913.4	864.5	1248.9	1158.3	1048.0	1045.0
2046-2050	26.9	25.9	30.2	26.8	1049.1	950.1	923.2	873.8	1263.7	1171.1	1059.3	1056.3

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1584.8	1552.9	1562.4	1512.4	2272.2	2235.4	2176.4	2121.7
2026-2030	1598.7	1566.2	1575.4	1525.3	2291.5	2254.1	2195.1	2140.6
2031-2035	1614.8	1581.7	1590.4	1540.1	2313.4	2275.4	2216.3	2161.8
2036-2040	1631.2	1597.2	1605.4	1554.8	2336.1	2297.4	2238.2	2183.7
2041-2045	1648.5	1613.6	1620.9	1570.3	2360.1	2320.8	2261.4	2206.9
2046-2050	1667.2	1631.2	1637.8	1586.9	2385.9	2345.9	2286.4	2231.8

Table 4.45: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Gurdaspur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.3	25.4	27.6	21.9	997.4	896.1	850.7	797.9	1194.9	1098.2	974.8	955.8
2026-2030	24.6	25.7	27.8	22.2	1006.1	904.0	858.4	805.4	1205.8	1107.8	983.7	964.9
2031-2035	24.9	25.9	28.0	23.1	1014.7	912.0	865.0	810.4	1215.2	1116.7	990.9	971.4
2036-2040	25.2	26.1	28.3	23.1	1025.7	919.8	872.4	816.1	1227.6	1125.9	998.8	978.3
2041-2045	25.5	26.4	28.5	22.8	1035.1	928.1	879.8	823.0	1239.4	1136.0	1007.3	986.7
2046-2050	25.9	26.7	28.9	23.2	1049.2	940.7	892.2	835.2	1256.7	1151.6	1021.6	1001.6

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1561.2	1504.1	1496.0	1432.4	2196.1	2148.4	2071.8	2018.4
2026-2030	1575.5	1517.7	1509.2	1445.3	2215.8	2167.3	2090.5	2036.9
2031-2035	1586.8	1529.7	1520.8	1456.6	2233.1	2186.0	2109.1	2054.9
2036-2040	1601.7	1541.6	1531.1	1466.2	2251.5	2202.5	2126.1	2072.3
2041-2045	1616.1	1554.7	1543.1	1477.7	2270.4	2220.4	2144.4	2090.9
2046-2050	1639.0	1576.9	1564.6	1499.2	2302.6	2251.7	2175.5	2121.8

Table 4.46: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Hoshiarpur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.9	24.5	28.3	24.3	979.6	879.0	841.8	784.9	1173.5	1076.9	961.9	943.8
2026-2030	26.2	24.8	28.5	24.5	987.9	886.2	848.4	790.0	1183.2	1085.6	969.0	950.1
2031-2035	26.4	25.0	29.2	24.0	999.4	897.3	857.3	796.6	1197.1	1098.8	978.9	958.0
2036-2040	25.5	25.7	28.3	22.5	1008.8	905.7	859.2	803.0	1207.5	1109.0	983.5	964.5
2041-2045	25.5	26.1	28.2	22.4	1019.9	915.6	867.4	812.4	1220.9	1121.2	993.6	975.4
2046-2050	25.9	26.2	28.6	23.0	1025.3	920.5	873.7	817.5	1227.8	1127.2	1000.4	982.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1532.9	1482.2	1478.4	1416.8	2170.6	2123.3	2058.4	2004.5
2026-2030	1544.7	1492.9	1487.9	1425.4	2185.7	2138.1	2073.5	2019.6
2031-2035	1561.8	1509.1	1500.4	1435.2	2205.8	2157.7	2091.2	2036.3
2036-2040	1575.9	1520.4	1511.9	1450.2	2223.5	2179.7	2108.0	2056.8
2041-2045	1593.7	1537.1	1528.3	1467.4	2247.9	2204.5	2131.4	2080.9
2046-2050	1602.7	1546.4	1537.3	1475.4	2261.1	2216.1	2144.2	2092.7

Table 4.47: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Jalandhar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	26.0	24.6	29.0	25.2	991.9	896.1	862.5	809.1	1191.4	1100.1	987.4	974.3
2026-2030	26.2	24.9	29.2	25.4	1000.3	903.6	869.8	816.3	1201.8	1109.3	995.8	982.9
2031-2035	26.5	25.1	29.4	25.7	1009.7	911.9	877.7	823.9	1213.1	1119.4	1004.9	992.1
2036-2040	26.8	25.5	29.6	25.8	1019.9	919.1	883.5	828.4	1223.7	1128.0	1011.2	997.9
2041-2045	27.1	25.8	29.8	26.1	1031.1	929.1	892.9	836.4	1237.0	1140.1	1021.5	1007.4
2046-2050	27.4	26.2	30.1	26.5	1042.9	940.3	903.8	845.6	1251.6	1153.5	1033.4	1018.2

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1563.2	1520.8	1520.5	1460.3	2220.3	2178.8	2116.0	2062.5
2026-2030	1576.8	1533.7	1532.9	1472.5	2238.9	2196.8	2133.9	2080.3
2031-2035	1591.6	1547.8	1546.4	1485.6	2259.2	2216.4	2153.3	2099.5
2036-2040	1604.1	1558.6	1556.9	1496.8	2277.9	2234.8	2171.6	2118.1
2041-2045	1620.4	1573.8	1570.6	1511.7	2300.9	2257.5	2194.5	2141.2
2046-2050	1638.6	1590.7	1585.6	1528.4	2326.4	2282.4	2219.9	2166.8

Table 4.48: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Kapurthala

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.7	23.4	26.0	25.4	994.2	893.3	856.7	805.1	1194.1	1091.8	983.1	972.4
2026-2030	26.0	24.0	27.3	25.5	1002.7	900.5	862.9	810.9	1203.4	1101.1	989.8	979.3
2031-2035	26.3	24.9	29.2	25.5	1011.3	907.7	868.3	815.6	1211.9	1110.2	995.1	984.7
2036-2040	26.6	25.3	29.4	25.7	1021.1	915.1	873.2	819.3	1222.2	1117.9	1000.4	989.7
2041-2045	26.9	25.6	29.7	25.9	1032.7	925.3	882.9	828.4	1236.3	1130.3	1011.5	1000.3
2046-2050	27.2	25.9	29.9	26.3	1046.8	937.7	893.9	837.6	1253.3	1145.0	1023.5	1010.1

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1563.2	1517.9	1512.2	1463.1	2228.4	2177.8	2120.6	2063.6
2026-2030	1575.4	1528.9	1524.7	1473.6	2244.5	2195.0	2135.5	2080.7
2031-2035	1586.0	1538.4	1536.8	1483.1	2259.1	2212.2	2149.5	2097.9
2036-2040	1597.3	1548.7	1546.6	1493.8	2277.1	2230.4	2167.5	2116.3
2041-2045	1615.3	1565.0	1562.4	1508.8	2300.9	2253.0	2189.9	2138.8
2046-2050	1635.6	1581.8	1579.0	1523.6	2326.6	2276.9	2213.6	2162.9

Table 4.49: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Ludhiana

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.0	25.6	27.9	23.3	1006.8	903.5	860.6	820.5	1207.4	1109.9	987.4	989.4
2026-2030	25.2	25.8	28.1	22.3	1015.2	910.8	867.7	817.6	1217.7	1118.9	995.7	987.4
2031-2035	25.5	26.0	28.3	22.6	1024.4	918.8	875.5	825.2	1228.8	1128.8	1004.8	996.8
2036-2040	25.8	26.3	28.6	22.7	1036.1	927.6	883.3	833.9	1241.2	1138.4	1014.1	1007.2
2041-2045	26.2	26.6	28.8	22.9	1048.2	937.5	892.5	842.9	1254.9	1149.6	1024.6	1018.2
2046-2050	26.5	26.9	29.1	23.3	1059.9	947.9	902.6	850.7	1269.2	1162.5	1035.2	1028.2

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1581.9	1533.6	1534.9	1491.9	2253.4	2211.2	2141.2	2100.9
2026-2030	1595.6	1546.7	1547.8	1493.9	2272.6	2229.6	2159.4	2108.9
2031-2035	1610.2	1560.9	1561.7	1507.6	2293.4	2249.7	2179.3	2128.6
2036-2040	1626.1	1576.3	1575.5	1522.3	2315.7	2271.3	2200.6	2150.0
2041-2045	1643.4	1592.9	1590.8	1537.9	2339.8	2294.6	2223.7	2173.1
2046-2050	1661.1	1608.9	1606.3	1553.3	2364.0	2318.1	2247.1	2196.3

Table 4.50: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Mansa

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.7	25.0	27.8	23.8	1005.9	916.0	879.9	833.3	1210.1	1128.2	1010.7	1002.4
2026-2030	24.9	25.2	28.0	24.0	1013.6	922.7	886.5	839.9	1219.4	1136.5	1018.3	1010.4
2031-2035	25.2	25.5	28.2	24.2	1022.2	930.2	893.9	847.1	1229.9	1145.8	1026.8	1019.3
2036-2040	25.5	25.7	28.4	24.5	1032.1	938.8	902.0	854.9	1241.8	1156.1	1036.2	1028.8
2041-2045	25.8	26.0	28.7	24.8	1042.8	948.1	910.9	863.4	1254.7	1167.5	1046.4	1039.1
2046-2050	26.1	26.3	29.0	25.1	1054.6	958.4	920.5	872.3	1268.9	1179.8	1057.3	1049.9

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1595.7	1559.0	1561.2	1509.2	2271.5	2242.1	2175.9	2127.9
2026-2030	1608.1	1570.9	1572.9	1520.9	2289.0	2259.2	2193.0	2145.0
2031-2035	1621.9	1584.3	1585.8	1533.7	2308.5	2277.9	2211.8	2164.0
2036-2040	1637.3	1598.9	1599.9	1547.6	2329.9	2298.7	2232.5	2184.7
2041-2045	1654.0	1614.7	1615.1	1562.7	2353.2	2321.2	2255.0	2207.1
2046-2050	1672.1	1631.72	1631.3	1578.6	2378.1	2345.4	2279.2	2231.2

Table 4.51: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Moga

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.8	24.6	29.1	25.5	1002.03	905.25	875.03	823.65	1204.0	1114.2	1002.2	993.9
2026-2030	26.1	24.8	29.2	25.7	1010.19	912.45	882.05	830.61	1214.0	1123.1	1010.4	1002.4
2031-2035	26.3	25.1	29.4	25.9	1019.43	920.6	889.83	838.19	1225.2	1133.1	1019.4	1011.5
2036-2040	26.6	25.4	29.7	26.2	1029.46	929.41	898.16	846.21	1237.3	1143.8	1029.0	1021.3
2041-2045	26.9	25.7	29.9	26.4	1040.37	938.99	907.1	854.76	1250.5	1155.4	1039.3	1031.6
2046-2050	27.2	26.1	30.1	26.7	1052.25	949.37	916.68	863.8	1264.8	1167.9	1050.28	1042.5

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1583.6	1544.5	1547.2	1495.5	2261.2	2221.5	2160.4	2107.6
2026-2030	1596.8	1557.1	1559.4	1507.6	2279.4	2239.2	2178.1	2125.3
2031-2035	1611.4	1571.0	1572.8	1520.9	2299.7	2258.8	2197.5	2144.7
2036-2040	1627.2	1585.9	1587.1	1535.0	2321.4	2279.9	2218.6	2165.8
2041-2045	1644.1	1602.0	1602.5	1550.1	2344.8	2302.7	2241.2	2188.4
2046-2050	1662.3	1619.1	1618.8	1566.3	2370.0	2327.2	2265.4	2212.6

Table 4.52: Variability in predicted accumulated growing degree days of maize in different phenological stages of rice during different pentads under four sowing windows in Muktsar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.9	24.7	29.3	25.9	1010.7	916.1	890.6	842.0	1217.1	1130.4	1021.3	1017.0
2026-2030	26.1	24.9	29.4	26.1	1018.8	923.4	897.7	849.1	1227.0	1139.4	1029.6	1025.7
2031-2035	26.3	25.2	29.6	26.3	1028.0	931.4	905.4	856.6	1238.2	1149.2	1038.5	1034.8
2036-2040	26.6	25.5	29.8	26.5	1038.2	940.3	913.8	864.7	1250.5	1160.1	1048.2	1044.7
2041-2045	26.9	25.8	30.1	26.8	1049.3	950.0	922.8	873.4	1263.8	1171.7	1058.6	1055.2
2046-2050	27.3	26.2	30.4	27.1	1061.4	960.6	932.5	882.5	1278.3	1184.4	1069.8	1066.3

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1606.3	1572.0	1578.8	1529.1	2299.1	2262.3	2204.0	2151.7
2026-2030	1619.6	1584.8	1591.3	1541.6	2317.7	2280.6	2222.3	2170.1
2031-2035	1634.1	1598.7	1604.8	1555.0	2338.1	2300.3	2242.0	2190.0
2036-2040	1650.1	1613.8	1619.5	1569.5	2360.3	2322.0	2263.7	2211.7
2041-2045	1667.3	1630.1	1635.0	1585.0	2384.2	2345.3	2286.8	2235.0
2046-2050	1685.8	1647.6	1651.6	1601.4	2409.8	2370.2	2311.5	2259.7

Table 4.53: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Pathankot

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	26.2	23.4	25.9	24.9	983.9	879.5	837.0	778.6	1178.0	1072.3	957.6	936.4
2026-2030	26.4	23.7	26.1	25.1	992.0	887.6	845.5	786.1	1187.1	1083.2	966.8	945.1
2031-2035	26.6	24.0	26.4	25.4	1000.5	895.5	853.5	794.2	1198.1	1093.5	976.2	955.0
2036-2040	26.9	24.3	26.6	25.6	1010.9	905.1	862.8	803.4	1211.2	1105.3	987.1	966.1
2041-2045	27.1	24.7	27.0	26.0	1024.4	916.2	873.1	813.0	1227.4	1118.3	998.9	977.4
2046-2050	27.4	25.0	27.2	26.3	1037.8	927.3	882.3	821.4	1243.6	1130.2	1009.5	987.8

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1533.6	1475.9	1458.7	1395.5	2158.7	2094.5	2023.9	1957.3
2026-2030	1546.3	1489.5	1472.1	1408.9	2177.1	2114.7	2043.8	1977.2
2031-2035	1561.7	1504.4	1486.5	1422.8	2198.4	2135.3	2064.1	1997.3
2036-2040	1579.0	1521.1	1502.5	1438.4	2221.9	2158.2	2086.8	2019.9
2041-2045	1599.0	1538.9	1519.0	1453.6	2247.5	2181.5	2110.2	2043.4
2046-2050	1617.8	1556.1	1535.0	1468.7	2273.0	2205.2	2134.2	2067.6

Table 4.54: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Patiala

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	23.5	25.9	26.4	22.6	987.7	895.9	849.2	805.8	1187.0	1097.7	979.0	963.3
2026-2030	24.3	25.6	26.5	23.3	995.0	900.0	854.2	806.8	1194.9	1101.8	982.8	965.7
2031-2035	23.9	26.2	26.8	23.0	1004.0	911.0	863.8	817.9	1206.9	1115.8	994.9	978.0
2036-2040	24.2	26.5	27.1	23.3	1015.0	920.7	873.2	826.4	1220.3	1127.7	1005.5	988.5
2041-2045	24.5	26.8	27.4	23.6	1025.9	930.0	882.2	835.1	1233.3	1139.1	1015.8	999.2
2046-2050	24.9	27.1	27.7	23.9	1037.1	939.2	890.4	842.8	1246.4	1150.0	1025.2	1009.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1558.3	1510.0	1506.8	1450.0	2199.6	2166.8	2097.4	2055.5
2026-2030	1565.8	1515.2	1508.8	1451.0	2209.2	2170.0	2100.6	2053.7
2031-2035	1582.9	1533.1	1528.4	1473.1	2234.9	2201.3	2132.6	2090.5
2036-2040	1599.9	1549.3	1544.1	1489.0	2259.2	2224.9	2156.3	2114.0
2041-2045	1616.9	1565.6	1559.9	1504.7	2283.4	2248.2	2179.4	2136.9
2046-2050	1633.4	1581.1	1574.8	1519.0	2306.4	2270.5	2201.7	2159.1

Table 4.55: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Rupnagar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.7	25.2	27.4	22.8	997.3	891.6	843.4	788.8	1191.4	1091.3	965.5	946.3
2026-2030	25.0	25.4	27.6	23.1	1006.2	899.7	851.5	797.0	1202.4	1101.4	975.0	956.4
2031-2035	25.2	25.7	27.8	23.4	1015.7	908.4	860.2	805.7	1214.2	1112.1	985.2	966.9
2036-2040	25.9	27.6	27.3	23.2	1023.6	915.8	861.1	812.4	1224.3	1118.9	990.7	973.9
2041-2045	26.3	28.3	27.4	23.5	1034.2	925.5	868.1	820.6	1237.5	1129.2	1000.1	983.9
2046-2050	26.6	28.6	27.7	23.8	1046.5	936.6	878.9	831.1	1252.6	1142.7	1012.6	996.2

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1552.7	1493.4	1485.9	1431.1	2193.7	2150.9	2080.4	2032.5
2026-2030	1567.6	1508.0	1499.9	1443.8	2213.2	2169.5	2098.6	2050.4
2031-2035	1583.4	1523.5	1515.0	1456.5	2233.1	2188.6	2117.6	2069.1
2036-2040	1597.4	1536.3	1526.8	1469.9	2251.8	2207.3	2133.2	2089.1
2041-2045	1614.0	1552.2	1542.2	1485.5	2275.3	2230.2	2155.1	2111.7
2046-2050	1633.8	1571.0	1560.5	1503.8	2302.8	2257.0	2181.9	2138.2

Table 4.56: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Sangrur

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.6	25.0	27.7	23.5	1004.0	905.4	868.6	820.0	1205.0	1113.8	996.8	986.1
2026-2030	24.9	25.2	27.8	23.7	1005.7	911.9	874.4	825.8	1208.3	1121.4	1003.8	993.3
2031-2035	24.7	25.9	27.7	23.6	1014.1	919.5	877.5	831.4	1218.9	1128.5	1009.6	999.9
2036-2040	24.4	26.7	27.3	23.4	1022.9	927.5	880.2	837.8	1229.9	1136.4	1015.9	1006.9
2041-2045	24.7	27.0	27.6	23.7	1033.2	936.5	888.8	845.8	1242.3	1147.3	1025.7	1016.7
2046-2050	24.9	27.2	27.9	24.0	1045.3	947.9	899.4	853.7	1257.1	1160.7	1036.9	1025.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1583.5	1536.8	1539.7	1487.2	2250.4	2213.1	2148.3	2100.4
2026-2030	1589.3	1548.0	1550.5	1498.0	2261.2	2229.1	2164.2	2116.3
2031-2035	1602.1	1559.8	1561.4	1509.6	2279.2	2246.6	2180.0	2134.2
2036-2040	1616.4	1572.7	1573.1	1522.5	2298.6	2265.9	2196.7	2153.8
2041-2045	1632.3	1587.8	1587.7	1536.8	2320.8	2287.3	2218.3	2175.2
2046-2050	1649.6	1603.7	1603.3	1550.5	2343.6	2309.9	2241.7	2198.6

Table 4.57: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in SAS Nagar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.4	25.1	27.3	22.7	983.8	885.0	838.3	783.7	1177.9	1082.6	959.7	938.2
2026-2030	24.2	26.2	26.5	22.4	989.4	888.1	832.0	782.0	1183.3	1083.1	956.9	934.9
2031-2035	24.2	26.4	26.7	22.7	998.2	896.6	840.0	789.2	1194.0	1093.3	966.1	943.8
2036-2040	24.5	26.7	27.0	23.0	1008.5	905.8	849.2	798.2	1206.6	1104.7	976.7	954.9
2041-2045	24.8	27.0	27.2	23.3	1019.6	915.7	859.0	807.9	1220.3	1117.0	988.1	966.7
2046-2050	25.1	27.3	27.5	23.6	1031.6	926.4	869.5	818.0	1234.9	1130.1	1000.1	979.1

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1536.2	1480.0	1473.6	1414.2	2165.5	2127.5	2058.7	2010.0
2026-2030	1541.5	1481.6	1472.7	1416.5	2171.6	2133.6	2062.1	2020.0
2031-2035	1555.4	1495.9	1486.5	1429.0	2190.8	2153.2	2081.4	2038.6
2036-2040	1572.2	1512.2	1502.4	1444.7	2214.3	2175.8	2103.8	2060.7
2041-2045	1590.3	1529.7	1519.4	1461.5	2239.6	2200.2	2128.1	2084.7
2046-2050	1609.5	1548.3	1537.5	1479.3	2266.5	2226.4	2154.2	2110.4

Table 4.58: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in SBS Nagar

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	24.6	25.3	27.1	22.6	1001.0	900.0	861.7	812.0	1201.0	1106.1	988.5	975.3
2026-2030	24.9	25.7	26.9	22.2	1007.0	903.3	864.0	811.7	1207.8	1109.1	990.1	974.0
2031-2035	25.3	25.9	27.1	22.3	1015.3	908.7	868.6	814.5	1216.4	1114.8	994.8	978.0
2036-2040	25.6	26.2	27.3	22.6	1025.1	918.0	877.7	823.6	1228.5	1126.2	1005.4	988.9
2041-2045	25.9	26.5	27.8	22.9	1037.9	929.1	887.2	832.7	1243.9	1139.6	1016.5	1000.1
2046-2050	26.2	26.8	29.0	23.2	1054.9	945.0	897.7	842.0	1263.6	1157.9	1028.6	1011.6

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1575.2	1523.3	1524.6	1468.8	2231.6	2190.3	2123.6	2074.2
2026-2030	1581.0	1524.3	1523.2	1464.0	2232.6	2188.2	2121.1	2070.8
2031-2035	1591.1	1532.5	1530.6	1471.4	2246.9	2201.9	2135.2	2085.3
2036-2040	1607.1	1548.8	1546.4	1487.1	2269.4	2224.5	2157.7	2107.57
2041-2045	1626.5	1566.9	1563.2	1503.4	2296.2	2249.6	2181.7	2131.1
2046-2050	1649.9	1589.7	1581.2	1520.2	2327.2	2280.0	2207.7	2155.9

Table 4.59: Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows in Tarn Taran

Pentad	Sowing				Tasseling				50% Silking			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2021-2025	25.1	22.8	25.8	25.4	973.8	882.9	859.6	811.3	1174.5	1088.1	987.0	980.1
2026-2030	25.3	23.1	26.0	25.6	982.5	890.6	866.9	818.5	1185.1	1097.7	995.6	988.9
2031-2035	25.6	23.4	26.2	25.8	992.0	899.1	874.9	826.3	1196.6	1107.9	1004.9	998.3
2036-2040	25.8	23.7	26.5	26.1	1002.4	908.3	883.6	834.6	1209.2	1119.2	1014.8	1008.3
2041-2045	26.1	24.0	26.8	26.3	1013.7	918.2	892.9	843.5	1222.8	1131.2	1025.5	1019.0
2046-2050	26.4	24.5	27.1	26.6	1028.4	929.8	901.6	850.3	1238.2	1143.2	1034.8	1028.0

Pentad	Dent				Physiological Maturity			
	I	II	III	IV	I	II	III	IV
2021-2025	1551.8	1517.8	1520.4	1474.7	2222.3	2182.7	2132.6	2076.7
2026-2030	1565.7	1531.1	1533.2	1487.4	2241.5	2201.4	2151.0	2095.1
2031-2035	1580.7	1545.4	1547.1	1500.9	2262.2	2221.6	2170.9	2115.1
2036-2040	1597.0	1561.0	1562.1	1515.6	2284.8	2243.6	2192.7	2136.7
2041-2045	1614.5	1577.5	1577.9	1531.1	2308.8	2267.1	2215.9	2160.0
2046-2050	1631.2	1593.0	1592.5	1546.1	2333.1	2290.9	2239.6	2184.0

CHAPTER V

SUMMARY

Weather and climate majorly affect the agricultural productivity in any region. The main determinant of agricultural production is climate and is regulated by prevailing climatic factors including light intensity, sunshine duration, rainfall, temperature, air pressure and humidity level across the region. On global scale both, climate change and agriculture are interrelated processes. To study the crop responses to ambient air temperature cardinal temperatures are considered which include optimum temperature (T_{opt}), maximum temperature (T_{max}) and minimum temperature (T_{min}). Cool environmental conditions are responsible for the delay in achieving maturity stage for maize plant while high temperature tends to achieve all maize plant development stages earlier, so a crop sown at the same time in large region is not ready to harvest at the expected time. Temperature increment of 4°C during the growth period of maize plant will cause five to six days early maturation in both wet and dry seasons. This alarming situation demands for analysis of the spatio-temporal variability in climatic patterns at regional scale to adopt mitigation strategies on regional basis. Plants require definite temperature for attainment of certain phenological stages. Thermo and photoperiod is influenced by shifting of the sowing dates. So, study of these effects may help in the deciding the right time of sowing and match phenology of crop in specific environment to achieve higher heat use efficiency. The estimation of occurrence of various phenological events during the crop growth period in relation to temperature can be done by computing accumulated growing degree days. Heat unit in terms of dry matter is known as Heat use efficiency (HUE) which depends on genetic factors, crop type and sowing time. There is good interaction of maize with the existing environment. Under changing climatic scenario for getting full potential performance of maize under given agro-climatic conditions the choice of correct variety and right time of sowing play a deciding role. The present study entitled "Delineation of thermal requirements of maize (*Zea mays* L.) in different sowing windows" was undertaken to accomplish the following objectives:

1. To study the spatio-temporal variations in maize productivity in maize growing area in Punjab.
2. To study the thermal requirements with actual experimental data under staggered planting.
3. To study the shifting of thermal requirements of maize under future climate change scenario.

The present investigation was conducted at Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. Long term climatic data on maximum temperature, minimum temperature during the maize growing period has been collected from the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, India Meteorological Department, Chandigarh and MarksimGCM software.

The above reported data was analysed using appropriate software and Spatio-temporal variability of thermal requirements of maize during different time has been assessed by using spatial interpolation techniques in built in Arc GIS 10.4.

The salient findings of the study have been summarized as follows:

- Under the four sowing windows the crop sown on 25th May (D_1) took greater number of days to reach maturity stage as compared to 5th June (D_2), 15th June (D_3) and 25th June (D_4). The early sown crop takes greater number of days to each phenological stage as compared. In all the varieties the highest Growing Degree Days (GDD) was accumulated under first date of sowing i.e., 25th May by variety PMH1 (1936.2) at maturity stage. Highest PAR interception of 85.0% was recoded at tasseling stage and minimum of 68.2% was at dent stage for 25th May (D_1) sown crop. Sowing dates and Varieties had significant effect on grain yield. Among the dates of sowing, D_1 resulted in maximum grain yield, but it was significantly at par with the grain yield produced by D_2 which in turn significantly at par with the grain yield produced by D_3 and which in turn significantly at par with the grain yield produced by D_4. The grain yield of cultivar PMH1 was significantly higher than the cultivar PMH2.
- **Trend analysis of accumulated growing degree days of maize under sowing window I, II, III and IV**

  a) It was observed that there is increasing trend of accumulated growing degree days (AGDD) in all districts except Bathinda and Ludhiana where no such prominent increasing trend was found.

  b) Among all the districts, the highest rate of AGDD increase was in Patiala followed by Kapurthala under sowing window I & II and the highest rate of AGDD increase was in Patiala followed by Fatehgarh Sahib under sowing window III & IV. The lowest rate of increase in Bathinda and Ludhiana.
- **Trend analysis of heat use efficiency (HUE) of maize from 1991-2019**

  a) Sowing window I - among all the districts the highest rate of increase in HUE was observed in Ludhiana (0.7488) and lowest for Moga (0.0018). The decreasing rate was found in S.B.S. Nagar.

  b) Sowing window II, III & IV - highest rate of HUE increase was observed in Ludhiana and decreasing rate was found in S.B.S Nagar.
- **Variability in heat use efficiency (HUE) of maize in Punjab during different pentadal period -** it was found that maximum variability was found during P_5 (2011-

2015) period and minimum variability was found during P_1 (1991-1995) pentadal period under all sowing windows.

- **Spatio-temporal interpolation of variability of thermal requirements of maize from 1991-2020 in different districts of Punjab have been demarcated using geospatial technology:**

a) **Sowing window I - from 1991-1995 to 2016-2020:** In north-east region of Punjab during the period from1991-1995 to 2016-2020, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Patiala and Fatehgarh Sahib district. While AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Amritsar, Moga, Sangrur, Jalandhar, Kapurthala, Ludhiana district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Pathankot, Barnala, SAS Nagar, Fazilka and Tarn taran, AGDD was 2100-2300 °C day.

b) **Sowing window II - from 1991-1995 to 2016-2020:** In north-east region of Punjab during the period from 1991-1995 to 2016-2020, AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, S.B.S. Nagar, and Rupnagar district. In the central region of Punjab AGDD changed from 1700-1900 °C day to 2100-2300 °C day in Patiala and Fatehgarh Sahib district. While AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Amritsar, Moga, Sangrur, Jalandhar, Kapurthala, and Ludhiana district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Barnala, Fazilka and Tarn taran AGDD was 2100-2300 °C day. While AGDD was 1900-2100 °C day in Pathankot and heat unit accumulation was changed from 1900-2100 °C day to 2100-2300 °C day in SAS Nagar district.

c) **Sowing window III - from 1991-1995 to 2016-2020:** In north-east region, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Gurdaspur, and Hoshiarpur district and from 1500-1700 °C day to 1900-2100 in S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Patiala, Fatehgarh Sahib, Amritsar, Sangrur, Jalandhar, Kapurthala, and Ludhiana district. While AGDD changed from 1900-2100 °C day to 2100-2300 °C day in Moga district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1900-2100 °C day to 2100-2300 °C day at the same time period. In case of Tarn Taran AGDD was changed from 1700-1900 °C day to 2100-2300

°C day. While AGDD was 1900-2100 °C day in Pathankot and SAS Nagar district and 2100-2300 °C day in Barnala and Fazilka district.

d) Sowing window IV - from 1991-1995 to 2016-2020: In north-east region AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Gurdaspur, and Hoshiarpur district and from 1500-1700 °C day to 1900-2100 °C day in S.B.S. Nagar, and Rupnagar district. In the central region of Punjab, AGDD changed from 1700-1900 °C day to 1900-2100 °C day in Patiala, Amritsar, Sangrur, Jalandhar, Kapurthala, Moga and Ludhiana district. While AGDD changed from 1500-1700 °C day to 1900-2100 °C day in Fatehgarh Sahib district. In South-west region, in Faridkot, Ferozepur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 1700-1900 °C day to 1900-2100 °C day at the same time period. While AGDD was 1900-2100 °C day in Pathankot, SAS Nagar, Barnala, Tarn Taran and Fazilka district.

❖ **Spatio-temporal interpolation of variability of thermal requirements of maize from 2021-2050 in different districts of Punjab have been demarcated using geospatial technology:**

a) Sowing window I - from 2021-2025 to 2046-2050: In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Gurdaspur, Rupnagar, S.B.S. Nagar. While AGDD will be remained 2100-2300 °C day in Hoshiarpur and Pathankot district. In the central region of Punjab, heat unit accumulation will be changed from 2100-2300 °C day to 2300-2500 °C day in Amritsar, Barnala, Moga, Sangrur, Ludhiana, Jalandhar, Kapurthala, Fatehgarh Sahib, Tarn Taran and Patiala district. While AGDD will be remained 2100-2300 °C day in SAS Nagar district. In South-west region, in Ferozepur, Faridkot, Muktsar, Bathinda and Mansa heat unit accumulation will be changed from 2100-2300 °C day to 2300-2500 °C day at the same time period. In AGDD will be remained 2300-2500 °C day in Fazilka district.

b) **Sowing window II - from 2021-2025 to 2046-2050:** In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be remained 2100-2300 °C day in Gurdaspur, Hoshiarpur, Rupnagar, Pathankot and S.B.S. Nagar district. In the central region of Punjab, AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Barnala, Ludhiana, Sangrur and Moga district. While it will be remained 2100-2300 °C day in Amritsar, Jalandhar, Kapurthala, Fatehgarh Sahib, Tarn Taran, SAS Nagar and Patiala district. In South-west region, in Fazilka, Faridkot, Muktsar Bathinda, Ferozepur, and Mansa AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day.

c) **Sowing window III - from 2021-2025 to 2046-2050:** In north-east region of Punjab during the period from 2021-2025 to 2046-2050, AGDD will be remained 2100-2300 °C day in S.B.S. Nagar district. While AGDD will be changed from 1900-2100 °C day to 2100-2300 °C day in Gurdaspur, Hoshiarpur, Pathankot and Rupnagar. In the central region of Punjab, in Amritsar, Barnala, Ludhiana, Jalandhar, Kapurthala, Moga, Sangrur heat unit accumulation will be remained 2100-2300 °C day. Whereas, in Fatehgarh sahib, Patiala, Tarn Taran and SAS Nagar heat unit accumulation will be changed from 1900-2100 °C day to 2100-2300 °C day. In South-west region, in Mansa, Ferozepur, Faridkot, and Bathinda AGDD will be remained 2100-2300 °C day in most of the time period. While AGDD will be changed from 2100-2300 °C day to 2300-2500 °C day in Muktsar and Fazilka district.

d) **Sowing window IV - from 2021-2025 to 2046-2050:** In north-east region of Punjab during the period from 2021-2025 to 2046-2050, Gurdaspur, Hoshiarpur, S.B.S. Nagar, Pathankot and Rupnagar AGDD will be changed from 1900-2100 °C day to 2100-2300 °C day. In the central region of Punjab, in Amritsar, Ludhiana, Sangrur, Jalandhar, Kapurthala, Fatehgarh Sahib, Patiala, Tarn Taran and SAS Nagar heat unit accumulation will be changed from 1900-2100 °C day to 2100-2300 °C day. While AGDD will be remained 2100-2300 °C day in Barnala and Moga in most of the time period. In South-west region, in Mansa, Ferozepur, Faridkot, Fazilka, Muktsar and Bathinda AGDD will be remained 2100-2300 °C day in most of the time period.

- **Variability in accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows.**

a) North-east region: Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Hoshiarpur and minimum accumulation of GDD was observed in SBS Nagar districts at all the stages during all pentads. For the next three sowing windows the pattern of heat accumulation in all the phenological stages remained the same for the same two districts and for the same period.

b) Central region: Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Moga at all the stages during all pentads. The lowest GDD was accumulated by Fatehgarh Sahib from P_1 (1991-1995) to P_4 (2006-2010) followed by Jalandhar in P_5 (2011-2015) and Ludhiana in P_6 (2016-2020). This same pattern of heat unit accumulation was observed in sowing window II, III & IV.

c) South-west region: Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Muktsar at all the stages during all pentads. The lowest GDD was accumulated by Bathinda to complete different phenological stages from P_1 to P_6. This same pattern of GDD accumulation was observed in sowing window II, III & IV.

- **Variability in predicted accumulated growing degree days in different phenological stages of maize during different pentads under four sowing windows.**

a. **North-east region:** Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district SBS Nagar and minimum accumulation of GDD was observed in Hoshiarpur district at all the stages during all pentads. For the next three sowing windows the pattern of heat accumulation in all the phenological stages remained the same for the same two districts and for the same period.

b. **Central region:** Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Ludhiana at all the stages during all pentads. The lowest GDD was accumulated by Amritsar. This same pattern of heat unit accumulation was observed in sowing window II, III & IV.

c. **South-west region:** Under sowing window I to complete different phenological stages namely sowing, tasseling, 50% silking, dent and physiological maturity maximum heat units were accumulated in district Muktsar at all the stages during all pentads. The lowest GDD was accumulated by Barnala to complete different phenological stages from P_1 to P_6. This same pattern of GDD accumulation was observed in sowing window II, III & IV.

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