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# Weather Variability during Wheat Growing Season in Central Plain Region of Punjab

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Wheat production data in relation to weather variability in central plain region of Punjab using the annual time series data were analyzed from 1990 to 2017. The analysis indicates maximum and minimum temperatures has increased by about 0.015 ºC year$^{-1}$ and 0.044 ºC year$^{-1}$ respectively and rainfall trend was negative (-0.028 mm year$^{-1}$) during the wheat growing season (October to March). Both maximum and minimum temperatures indicate increasing trend from late vegetative stage to maturity except for the maximum temperature which shows decreasing trend during the month of January. Deviation (positive or negative) in weather parameters from long term average at different phenological stages caused significantly reduction in wheat yield. The highest variability among weather parameters was observed in rainfall (-5.7 mm and +27.5 mm) especially during reproductive phase of wheat crop in high (2012) and low (2015) yield years respectively which might be the cause of low grain yield. During the period of study, maximum negative correlation was observed in minimum temperature during crop growing season of wheat crop. The climatic changes resulted in substantial loss in wheat production which might be due to shorter life cycle, pollen abortion and poor grain quality by rising temperature and rainfall variability.

*Keywords: Terminal heat stress; crop phenology; rainfall; pollen fertility; wheat yield.*

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## 1. INTRODUCTION

As the consequence of rise in temperature and uncertainty in rainfall distribution poses a serious threat to the wheat production in the era of climate change. Future projections about variable precipitation and rising temperature in climate change scenario will negatively impact the wheat productivity [1,2]. Wheat (*Triticum aestivum* L.) is an important cereal crop traditionally grown under irrigated conditions in the North-Western region of India. The major constraints in the yield potential in this region are uneven distribution of rainfall and high temperature stress during reproductive phase of wheat growing season. Temperature influences the yield of crops by controlling growth and development rates [3].

The problem of heat stress is likely to become even worse in future under global environmental change which has become one of the greatest challenges that humanity faces today. Day and night temperature found higher as compared to long -term averages, high night temperature and rainfall during milking stage to maturity stage is unfavorable for the good wheat yield [4]. Variability in rainfall and temperature affect crop growth and development by shortening the life cycle of crop [5], accelerated plant growth development, reduced grain filling period and negatively impact the movement of photosynthetic products towards the developing grains and inhibited starch synthesis [6]. To attain a phenological stage, crop requires certain amount of heat units accumulation [7], the temperature determines the time taken to complete its normal phenology [8] which affects tillering capacity, growth and final yield in shorter period of time to complete phenology under high temperature conditions [9]. The variation in crop yield largely depends upon the rainfall variability with climate change [10]. Water is not limiting in Punjab (*e.g.*, supplied by irrigation or canals) but heat stress that occurs during anthesis and grain filling periods [11] imposes negative effects on wheat and other crops. The amount of precipitation during grain filling period critically affects the wheat yield as a dominant factor [12]. In wheat crop the optimum temperature during heading, anthesis and grain filling stages are approximately 12℃, 23℃, and 21℃, respectively but damage may occur to these stages if maximum temperature goes above 22℃, 32℃, and 34℃, respectively [13]. Cloudiness/less sunshine hours have become major challenge to crop production in many areas of the world which not only reduce the amount of direct solar radiation but also increase the fraction of diffused light which is more efficiently utilized by plants, enhance leaf $CO_2$ uptake, photosynthesis and plant growth and affect total grain yield [14, 15]. Keeping all this in view, the analysis of different weather parameters during wheat growing season was done to study the effect of all the parameters on different phenological stages and yield of wheat.

## 2. MATERIALS AND METHODS

The study was conducted for district Ludhiana (Punjab) to assess the variability in weather parameters during last three decades. Historical weather data (daily maximum and minimum temperatures, sunshine hours and rainfall) during the period from 1984-85 to 2016-2017 were collected from the Agrometeorological Observatory, Punjab Agricultural University, Ludhiana. The data were divided into three decades viz. first decade (1984-85 to 1994-95), second decade (1995-96 to 2005-06) and third decade (2006-07 to 2016-17) for analysis. The wheat growing season was simply divided into two stages *i.e.* vegetative (sowing to flowering stages) and reproductive (flowering to maturity stages), corresponding to the periods of October to January and February to April, respectively. The time taken to complete different phenological stages of wheat was used as per the report given by CRIDA report [16].

The data on wheat yield of Ludhiana district were collected from the Statistical Abstracts of Punjab for the period from 1984-85 to 2016-17 [17]. The deviations in weather parameters were calculated for complete wheat growing seasons and for late flowering to maturity phase of crop. Decade wise comparison between different years for highest and the lowest grain yield with meteorological parameters was done. The correlation coefficients between different meteorological parameters and wheat yield (2001-02 to 2016-17) were worked out using excel.

The deviation of different weather parameters from normal at Ludhiana during wheat growing season from 1990-91 to 2016-17 was calculated using the following formula:

Deviation (%) = (Actual value–Normal value / Normal value) x 100

To quantify the climate variability, normal values of particular weather parameter were calculated by averaging long term weather data (40 years).

## 3. RESULTS AND DISCUSSION

### 3.1 Weather Variability Analysis of Different Meteorological Parameters at Ludhiana (1990-91 to 2016-17)

#### 3.1.1 Deviation in weather parameters from normal during wheat growing season (October to March)

Deviation in temperature (maximum and minimum) and rainfall from normal during wheat growing season from October to March was analyzed (Fig. 1) and the results indicate that from 1990-91 to 2016-17, the maximum temperature at Ludhiana has been increasing at the rate of 0.015ºC year$^{-1}$ during the wheat growing season. Terminal heat stress conditions are increasing and winter window gets reduced for wheat growing season in northern India [18].

Deviation in average minimum temperature from normal during wheat growing season of Ludhiana indicates that there is an increasing trend of minimum temperature by 0.04$^0$ C year$^{-1}$ (Fig. 3). Significant increase in minimum temperature is unfavorable for wheat yield. The average minimum temperature (1990-91 to 2016-17) was above normal except during 1994-95, 1996-97 and 2007-08. Minimum temperature is rising rapidly than maximum temperature and mean daily temperature [19] and annually minimum (night) temperature turned to rising linearly which can causes grain yield losses [20].

Deviation in rainfall from normal during wheat season (October to March) indicates that during most of the years rainfall was deficit from normal whereas, from 2013-14 to 2016-17, the rainfall was above normal during wheat crop growing season as shown in Fig. 5. On an average the analysis from 1990-91 to 2016-17 revealed that at Ludhiana rainfall has been decreasing at the rate of 0.028 mm year$^{-1}$ during the wheat growing period.

#### 3.1.2 Maximum and minimum temperature variability during late vegetative stage to maturity of wheat crop

The analysis on maximum and minimum temperatures during January, February and March months at Ludhiana from 1990-91 to 2016-17 was conducted (Fig. 2). Variability in maximum temperature during January (1990-91 to 2016-17) indicates a decreasing trend at the rate of 0.039 $^0$ C year$^{-1}$ but increasing trend in maximum temperature by 0.029$^0$ C year$^{-1}$ and 0.07$^0$ C year$^{-1}$ during February and March respectively. There is continuous increase in maximum temperature during February month from 2014-15 to 2016-17 but it was seen that the maximum temperature during March from the year 2010-11 to 2016-17 remained below normal as compared to other years. Maximum temperature (1970 to 2010) has been decreased during January but shown an increasing trend during February and March at Ludhiana [21]. With every 1˚C increase in temperature, wheat yield decreased by 10 per cent [22].

Variability in minimum temperature (1990-91 to 2016-17) indicates an increasing trend during January by 0.023$^0$ C year$^{-1}$, during February by 0.038 $^0$ C and during March by 0.068 $^0$ C year-$^1$. There is a continuous increase in minimum temperature in January month from 2013-14 to 2016-17. An increase in minimum temperature during February is unfavorable for anthesis and high night time temperature decreases the spikelet fertility, grains per spike and grain size which is the major yield contributing factors. Increasing trend of minimum temperature had a negative correlation with wheat productivity. Minimum temperature is significantly increased and the average minimum temperature (1990-91 to 2016-17) was above normal except during 1994-95, 1996-97 and 2007-08 over the years at Ludhiana district [21, 23].

### 3.2 Relationship between Wheat Yield and Different Weather Parameters

#### 3.2.1 First decade (1984-85 to 1994-95)

Different weather parameters play an important role in crop production. The weather parameters during wheat growing season were analyzed from sowing to physiological maturity and presented in Fig. 3. During first decade, the lowest grain yield (39.32 q ha$^{-1}$) and the highest grain yield (45.56 q ha$^{-1}$) were recorded during 1984-85 and 1994-95 years, respectively. Maximum and minimum temperatures during both the years remained close to normal in the early vegetative growth whereas; in the late vegetative stage as well as from reproductive to physiological maturity, the maximum temperature during 1984-85 remained above normal but during 1994-95 it was below normal. The minimum temperature remained below the normal during both the years.

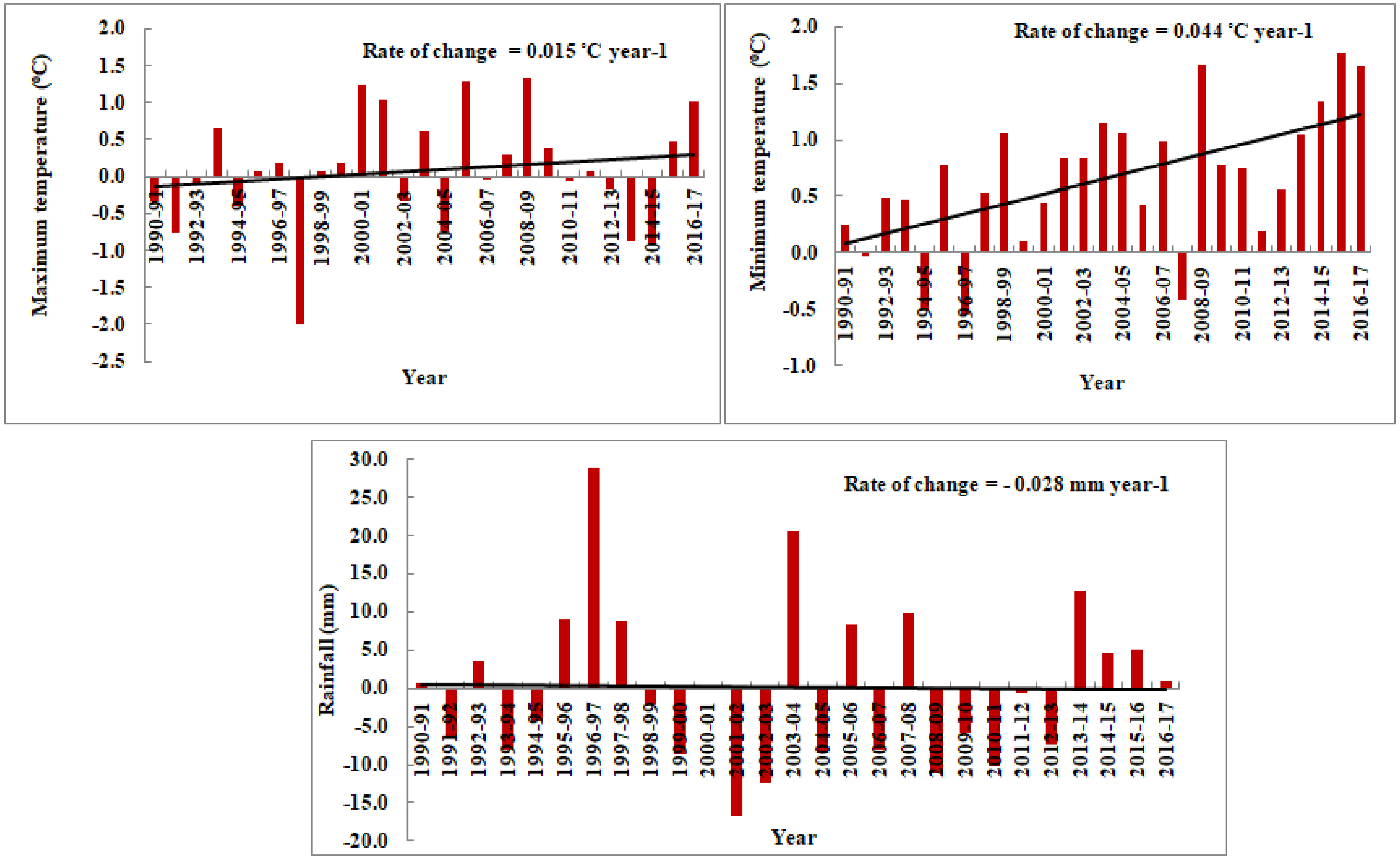


**Fig. 1. Deviation in maximum, minimum temperature and rainfall from normal at Ludhiana (1990-91 to 2016-17)**

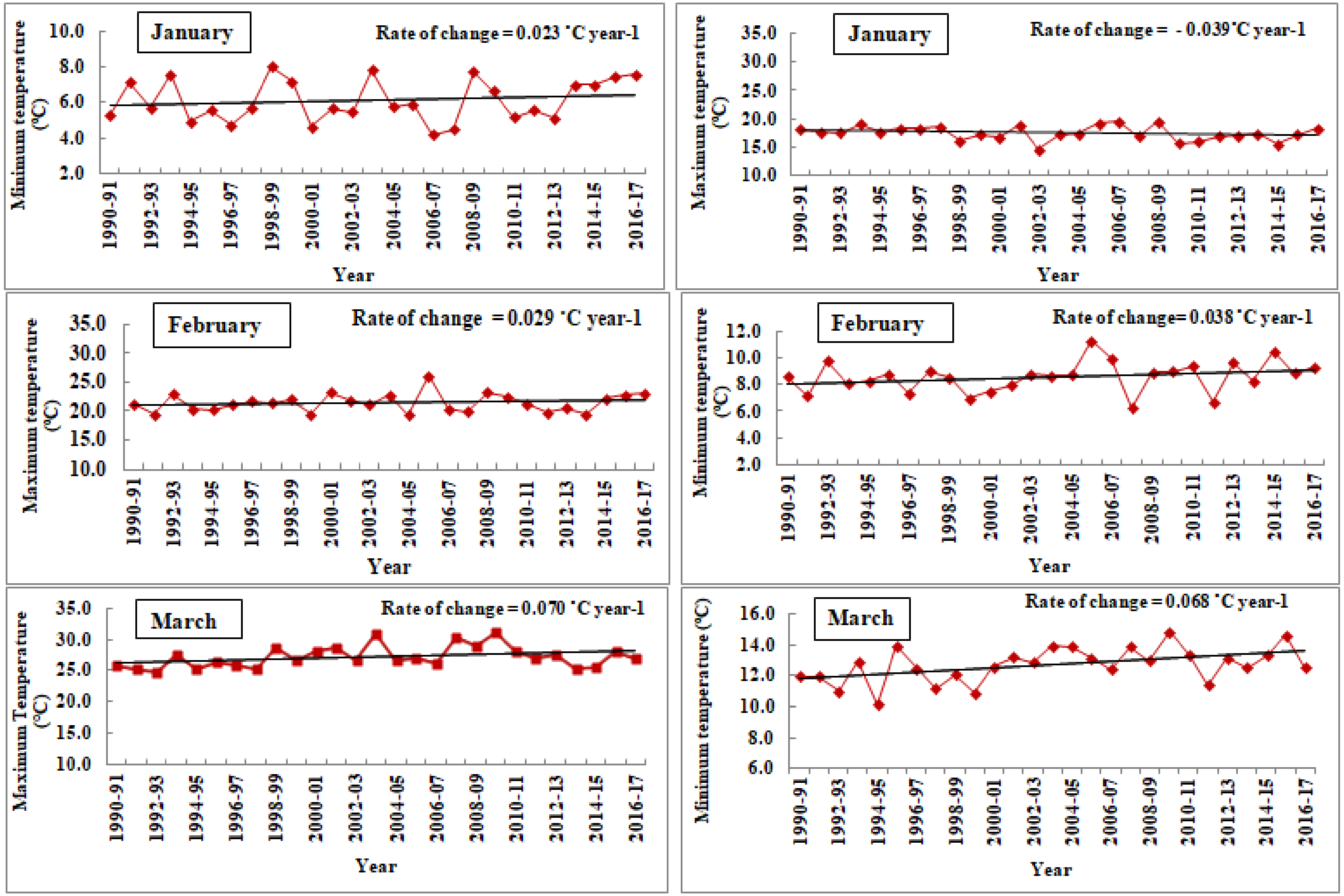


**Fig. 2. Variability in maximum and minimum temperatures from late vegetative to maturity phase in wheat at Ludhiana (1990-91 to 2016-17)**

The rainfall amount not only accounts for the higher yield but its distribution is also important. The results clearly demonstrated that the rainfall indirectly affects the sunshine hours from late vegetative phase to physiological maturity. During 1994-95, most of the rainfall received was during vegetative phase to early maturity phase but very little rainfall was received in 1984-85 during this growth period. The rainfall received at physiological maturity during the year 1984-85 causes loss in yield which may be due to crop lodging. The wheat crop faces above normal sunshine hours throughout the crop growing season during 1984-85, the reason behind this was the isolated or scattered cloudiness except during physiological maturity phase where the rainfall caused lower sunshine hours. The photosynthesis is effected by sunshine hours [14, 24] and duration of sunshine hours during grain filling stage was linearly correlated with grain yield and its quality [25, 26].

The total rainfall received during the lowest wheat yield year (1984-85) was very low (19 mm) throughout the growing period, this amount of rainfall was not well distributed because most part of this rainfall was received during late maturity stage of wheat crop. The high yield year (1994-95) received well distributed rainfall of amount 130.3 during crop growing period. The rainfall received during December, January, February and March had a major effect on grain yield and higher rainfall at the reproductive stage was not favourable for higher yield [27].

### 3.2.2 Second decade (1995-96 to 2005-06)

During second decade, the years 1995-96 and 2000-01 were identified as low and high yield years with productivity of 41.92 q $ha^{-1}$ and 51.69 q $ha^{-1}$ respectively. The low yield year had maximum temperature very close to normal but during high grain yield year; it remained above normal throughout the wheat growing season. During low yield year (1995-96), above normal minimum temperature was recorded during vegetative stage (from $43^{rd}$ to $4^{th}$ standard meteorological week) otherwise, it remained below normal as in year 2000-01 throughout the life cycle of crop. High temperature at reproductive stage causes the production of non-viable pollen and deteriorates grain quality [28].

The sunshine hours showed variations from early vegetative phase to end maturity phase during both high and low yield years. During year 1995-96, for the first few weeks; the sunshine hours remained above normal but during 2000-01, it was below normal but after vegetative stage it varies with precipitation. Excess precipitation during early seedling stage inhibited the increase in tiller numbers and lower sunshine hours at stem elongation stage nullify the increase in grains number per square meter by 61-63% [29]. Cloudiness reduces grain yield by impairing net photosynthesis in wheat leaves [30-32].

During the low yield year (1995-96), 135.6 mm rainfall was received which was not well distributed but during the year 2000-01, only 8.8 mm of well distributed rainfall was received during peak demand of water and high terminal heat stress at reproductive stage of wheat crop. Biomass and grain yield is reduced by 39.2 and 51.7 per cent respectively under high temperature and low rainfall conditions [33].

### 3.2.3 Third decade (2006-07 to 2016-17)

During third decade, the years 2011-12 and 2014-15 were the high (53.75 q $ha^{-1}$) and the low (42.09 q $ha^{-1}$) yield years (Fig. 5). The fluctuations in maximum temperature from normal throughout the crop growing season during the low yield year (2014-15) were observed. The maximum temperature remained close to normal during $43^{rd}$ to $47^{th}$ SMW and it remained above normal during $48^{th}$ to $49^{th}$ SMW. The maximum temperature was below normal during $50^{th}$ to $6^{th}$ SMW and above normal during $7^{th}$ and $8^{th}$ SMW. At soft dough and hard dough stages, the maximum temperature was below normal. The high yield year (2011-12) had maximum temperature very close to normal from sowing to physiological maturity except during $3^{rd}$ and $14^{th}$ SMW where it was below normal. Increase in mean temperature by 1˚C resulted in reduction of vegetative period by 3 days [34].

The minimum temperature during third decade (2006-07 to 2016-17) remained mostly above normal during the low grain yield year (2014-15) but during $46^{th}$, $47^{th}$ and $6^{th}$ SMW it was below normal. The high yield year (2011-12) had above normal temperature during early growth period ($43^{rd}$ to $50^{th}$ SMW) and minimum temperature remains below normal during later stages up to physiological maturity ($51^{st}$ to $14^{th}$ SMW) except in $52^{nd}$ and $4^{th}$ SMW. Increase in minimum temperature during second fortnight of February decreased the grain yield under Punjab conditions and negatively correlated with grain yield. Night time temperature (>14°C) decreased photosynthesis, high night time temperature

(≥20°C) decrease grain filling duration by 7 days, spikelet fertility, grains per spike, and grain size were linearly decreased in grain yield by about 5 per cent per degree rise in temperature [35].

During the low yield year (2014-15) 197.9 mm rainfall was received from 43rd to 14th SMW. During the 50th SMW the highest amount of rainfall (42 mm) was received. It was above normal throughout the crop growing period and continuously rainfall was received from 1st to 14th SMW except in 6th and 12th SMW. The high yield year had experienced rainfall during January (Fig. 5). The rainfall received during December, January, February and March had a major effect on grain yield. The low yield was recorded in the years having higher rainfall during crop season and vice versa. Higher rainfall during the reproductive stage was not favorable for higher yield. Excessive rainfall during post-anthesis stage creates anaerobic conditions and significantly reduced the root respiratory activity, stomata conductance, grain number per spike and grain yield [36].

The low grain yield year (2014-15) during the third decade had received below normal sunshine hours throughout the crop growing period from sowing to physiological maturity. The high yield year (2011-12) had also experienced below normal sunshine hours from sowing to physiological maturity except in 2nd, 4th and 11th SMW but received comparatively higher sunshine hours during the low yield year (2014-15). Number of sunshine hours affects both photosynthetic light and carbon use efficiency and ultimately affect total grain yield [37]. The total number of sunshine hours during grain filling stage was linearly correlated with grain production and quality [38].

## 3.3 Deviations in Weather Parameters at Different Phenological Stages of Wheat Crop at Ludhiana (2011 to 2017)

### 3.3.1 Maximum temperature deviations from normal (2011-2017)

During late vegetative stage, the maximum temperature remained mostly below normal during 2011 to 2016 except in 2017 where it was slightly above normal (Table 1). From heading to anthesis stage, the maximum temperature was below normal during 2011 to 2014 and above normal during 2015 (+0.4˚C), 2016 (+2.3 ˚C) and 2017 (+2.4˚C) respectively. The maximum temperature remained above normal during 2012 (+0.3 ˚C), 2013 (+1.1 ˚C), 2016 (+2.7˚C) and 2017 (+0.3˚C) and below normal during 2011 (-2.5˚C) and 2015 (-3.7˚C) from anthesis to milking stage. During milking to dough stage the temperature remained below normal (2014 to 2017) except 2011 and 2013. High temperature reduces crop duration and has a detrimental effect on photosynthesis, fertilization and post fertilization processes which may decrease the crop yield [39]. Mean temperature has negative relationship with post heading phase; 1°C rise in temperature reduces the reproductive period by about 4 days and decreased the grain yield [34].

### 3.3.2 Minimum temperature deviations from normal

The minimum temperature was below normal at late vegetative stage during 2012 (-0.9˚C) and 2013 (-0.1˚C) where as it remained above normal during 2011 and 2014 to 2017 (Table 1). From heading to anthesis stage, during 2011, 2012 and 2014 the minimum temperature was below normal and above normal during 2013 and 2015 to 2017 respectively. The minimum temperature remained above normal during anthesis to milking stage from 2011 to 2017 except in 2014 where it remained below normal (-0.7˚C). During the year 2013, the minimum temperature was equal to normal. From milking to dough stage it remained above normal during 2011 to 2017 except in 2016 (+1.2˚C). During the high yield year (2012), the temperature during reproductive period remained mostly below normal or close to normal and it was 3°C below normal during milking to dough stage and might be favorable for higher yield. Rise in night time temperature up to 23°C decreased duration to flowering by 2 days, seed-set by 4 days and physiological maturity by 10 days. The wheat crop coincides with high night time temperature increases dark respiration, utilized sugar mostly for plant growth and maintenance rather than into grain production which results in potential yield loss for the plant [40].

### 3.3.3 Deviation in sunshine hours from normal at different phenological stages

During late vegetative stage sunshine hours were remained below normal during 2011 to 2017 (Table 2). From heading to anthesis stage, it also remained below normal from 2011 to 2016 and during 2017 (+1.2 hrs) it remained above normal. The sunshine hours remained below normal during anthesis to milking stage from

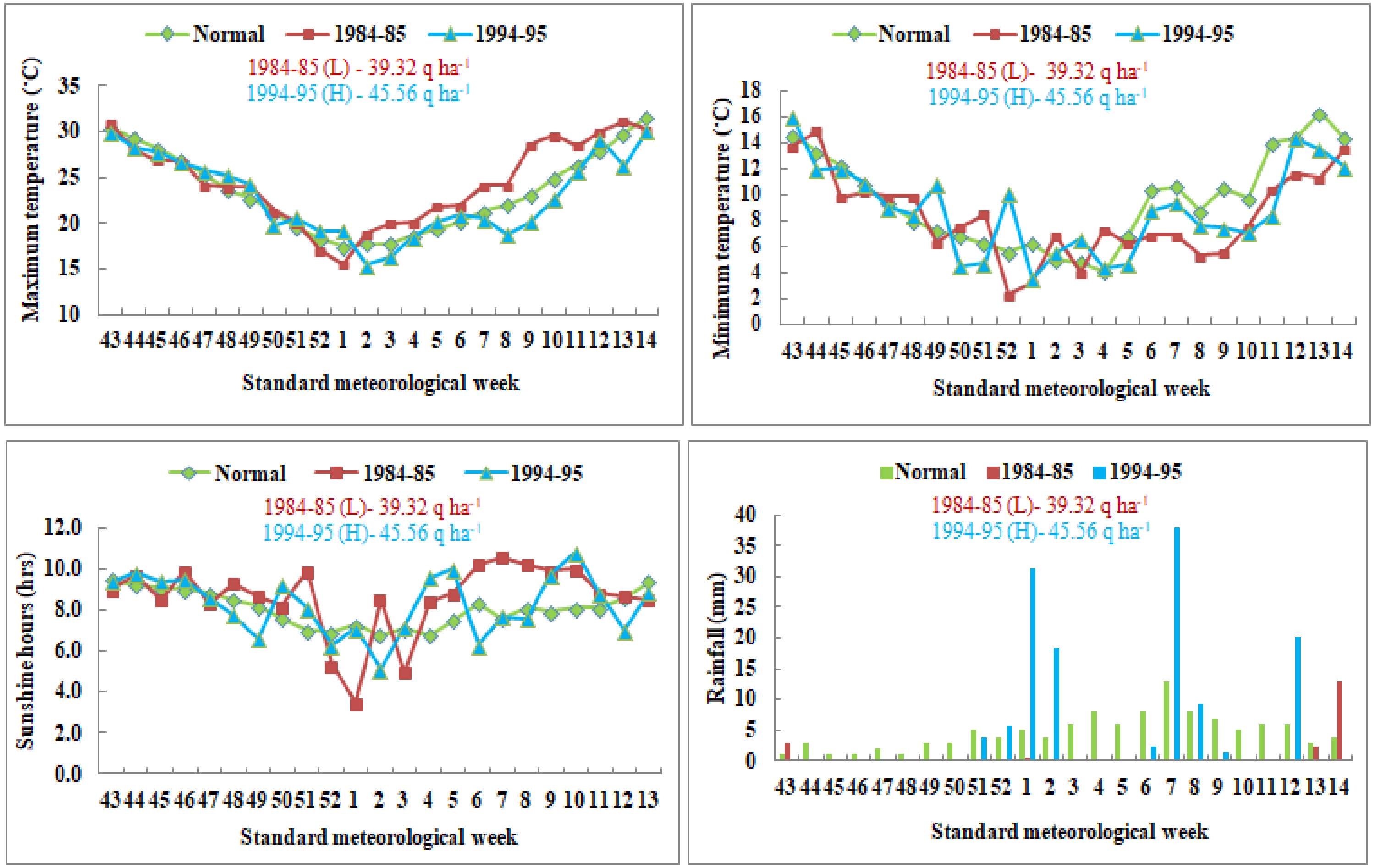


**Fig. 3. Weather parameters maximum and minimum temperature, sunshine hours and rainfall during high and low yield years at Ludhiana during first decade (1984-85 to 1994-95)**

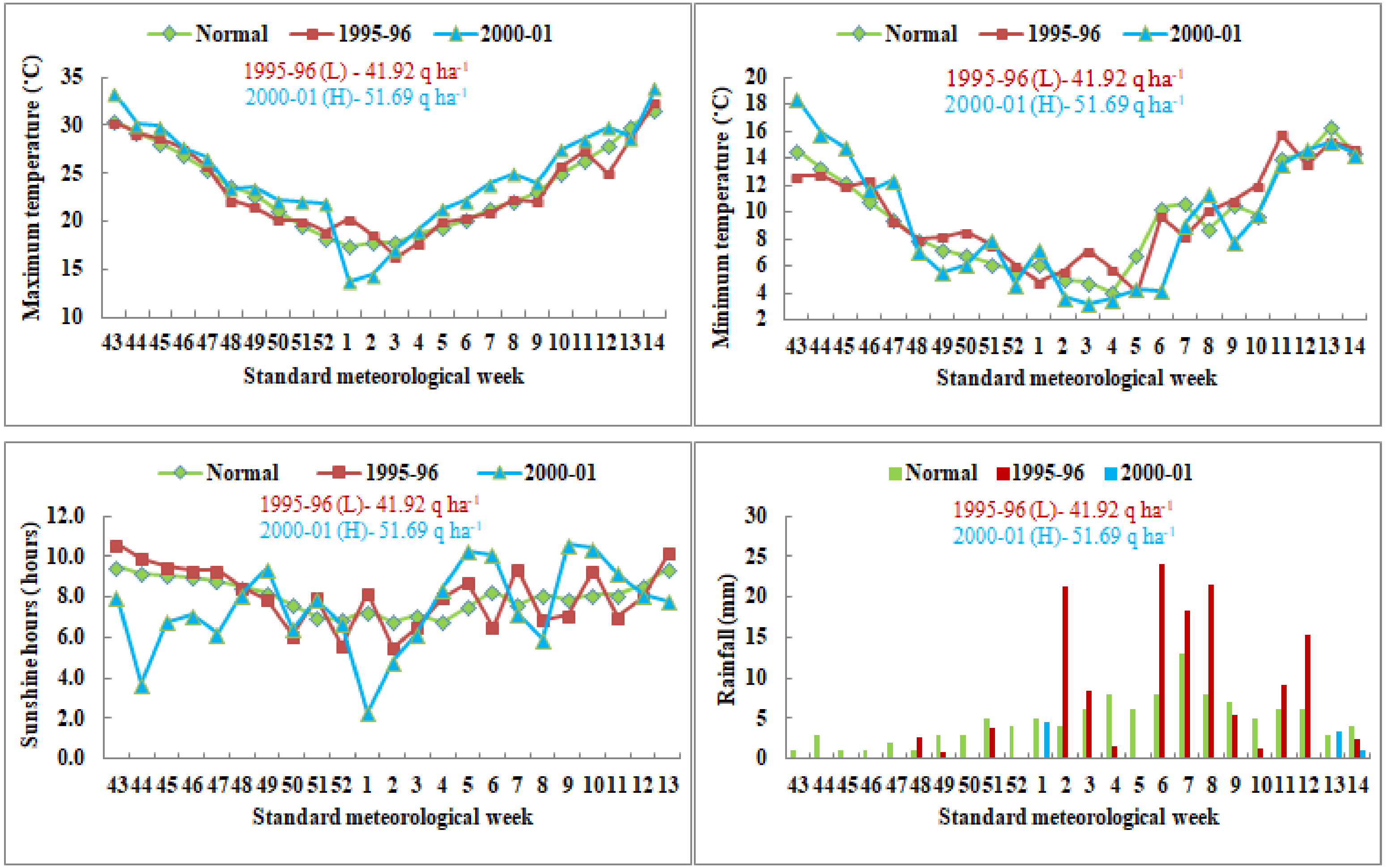


**Fig. 4. Weather parameters maximum and minimum temperature, sunshine hours and rainfall during high and low yield years at Ludhiana during second decade (1995-96 to 2005-06**

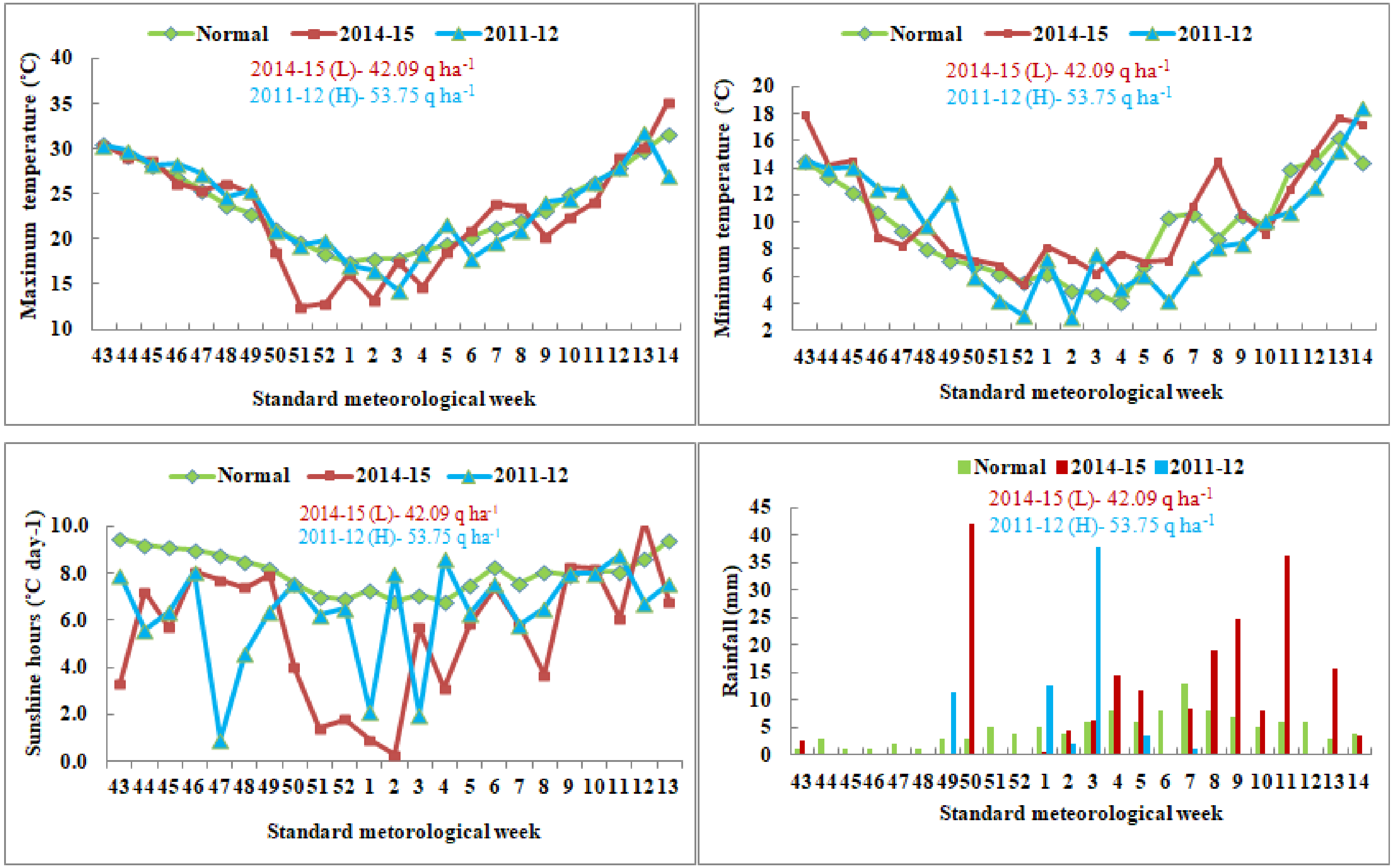


**Fig. 5. Weather parameters maximum and minimum temperature, sunshine hours and rainfall during high and low yield years at Ludhiana during third decade (2006-07 to 2016-17)**

2011 to 2017 except in 2014. From milking to dough stage it remained above normal during 2011 to 2014 and below normal during 2015 to 2017. Comparatively sunshine hours were higher during the highest yield year (2011-12) than the lowest yield year (2014-15). Changes in radiation influence both photosynthetic light and carbon-use efficiency and affect total grain yield [41].

#### 3.3.4 Deviation in rainfall from normal at different phenological stages

During late vegetative stage the rainfall remained below normal in 2012, 2015 and 2016 where as it remained above normal during 2011 (+2.9 mm), 2013 (+18.9 mm) and 2014 (+18.1mm) (Table 2). From heading to anthesis stage, the years 2013, 2014 and 2015 had received above normal rainfall except for years 2011, 2012, 2016 and 2017 where it was below normal. The rainfall was below normal during 2012 (-5.7 mm), 2013 (-5.7 mm) and 2014 (-3.9 mm) from anthesis to milking stage but the years 2011, 2015, 2016 and 2017 received above normal rainfall. During milking to dough stage rainfall remained above normal in the years 2014 to 2016 and below normal during 2011 (-8.8 mm), 2012 (-8.8 mm), 2013 (-3.4 mm) and 2017 (-0.2 mm). During the high yield year (2011-12), the rainfall was below normal from vegetative stage to dough stage which proved favourable for higher grain yield of wheat. But during the low yield year (2014-15), the rainfall was above normal from heading to dough stage. From anthesis to milking and milking to dough stage above normal rainfall of 27.3 mm and 27.4 mm was recorded during low yield year which caused the decline in yield. High rainfall received during reproductive phase was unfavorable for higher yield [27].

### 3.4 Correlation Coefficients between Different Meteorological Parameters and Wheat Yield (1990-91 to 2000-01)

Correlation coefficients were worked out during wheat growing period from 1990-91 to 2000-01 for Ludhiana. The maximum temperature was negatively correlated with wheat yield during January and February and positively correlated during November, December, March and April months (Table 3). A significant positive correlation was observed during November month. The minimum temperature was positively correlated with yield during October and November and negatively correlated with wheat yield from December to March. Increasing trend of minimum temperature with wheat productivity had a negative correlation with wheat productivity [23]. A negative correlation of rainfall with wheat yield was observed during January and February and positive correlation was observed during November, December, March and April months. The rainfall showed a negative relationship with wheat yield in all the months except during October and December (Table. 3). Grain yield was positively correlated when cumulative post-anthesis precipitation is less than 50 mm whereas; the relationship found negative when cumulative post-anthesis rainfall is more than 50 mm [25].

### 3.5 Correlation Coefficients between Different Meteorological Parameters and Wheat Yield of Ludhiana (2001-02 to 2016-17)

The correlation coefficients (2001-02 to 2016-17) between different meteorological parameters (maximum temperature, minimum temperature and rainfall) and grain yield were worked out. Maximum temperature was negatively correlated (-0.05) with grain yield in February and positively correlated in all other months (October, November, December, January and March). The maximum temperature in December month was significantly and positively correlated with wheat yield. Whereas minimum temperature was negatively correlated with wheat yield throughout the crop growing period except during November (Table 3). Most manifested effect of high temperature is to shorten the duration of grain filling [42]. Increasing minimum temperature during 4$^{th}$ to 12$^{th}$ SMW was negatively correlated with wheat productivity at Ludhiana [23]. Negative correlation of wheat yield with rainfall was observed during October (-0.12), November (-0.06), December (-0.25) and March (-0.30) and positive during January (+0.30) and February (+0.10) (Table 3). Excessive high temperature and rainfall (above 30 mm per day) during grain filling stage causes grain shrinkage and ultimately exerts deleterious effects on wheat quality [43].

### 3.6 Correlation Coefficients between Different Meteorological Parameters and Wheat Yield (1990-91 to 2016-17)

The correlation coefficients between different meteorological parameters and wheat yield of Ludhiana during 1990-91 to 2016-17 were worked out (Table 3). The analysis indicates that maximum temperature showed a significant positive relationship with wheat yield during crop

**Table 1. Deviation in maximum temperature from normal at different phenological stages**

| Phenological stages | Normal maximum temperature | Deviation of maximum temperature from normal | | | | | | | Normal minimum temperature | Deviation of minimum temperature from normal | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | 2012(H) | 2013 | 2014 | 2015(L) | 2016 | 2017 | | 2011 | 2012(H) | 2013 | 2014 | 2015(L) | 2016 | 2017 |
| Late vegetative (1 January – 18 February) | 19.1 | -1.1 | -1.5 | -0.9 | -1.4 | -1.2 | -0.3 | +0.5 | 6.6 | +0.2 | -0.9 | -0.1 | +0.7 | +1.2 | +0.8 | +1.4 |
| Heading to Anthesis (19 February- 27 February) | 22.6 | -1.7 | -1.5 | -1.8 | -0.6 | +0.4 | +2.3 | +2.4 | 9.4 | -0.6 | -1.6 | +1.8 | -0.7 | +3.7 | +2.3 | +0.6 |
| Anthesis to Milking 28 February-8 March | 24.7 | -2.5 | +0.3 | +1.1 | -2.5 | -3.7 | +2.7 | +0.3 | 10.2 | +0.2 | +0.3 | 0.0 | -0.7 | +0.6 | +3.3 | +0.2 |
| Milking to dough 9 March- 18 March | 26.2 | +1.8 | -1.0 | +1.7 | -0.6 | -2.7 | -1.5 | -5.8 | 10.1 | -1.7 | -3.0 | -0.5 | -1.9 | -0.4 | +1.2 | -2.3 |

*H- High yield year, L- Low yield year*

**Table 2. Deviation in sunshine hours and rainfall from normal at different phenological stages**

| Phenological stages | Normal rainfall | Deviation of rainfall from normal | | | | | | | Normal sunshine hours | Deviation of sunshine hours from normal | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | 2012 (H) | 2013 | 2014 | 2015(L) | 2016 | 2017 | | 2011 | 2012(H) | 2013 | 2014 | 2015(L) | 2016 | 2017 |
| Late vegetative (1 January - 18 February) | 46.3 | +2.9 | -46.3 | +18.9 | +18.1 | -2.1 | -25.5 | -38.1 | 6.4 | -1.6 | -0.6 | -0.8 | -1.7 | -2.2 | -2.1 | -1.3 |
| Heading to Anthesis (19 February- 27 February) | 9.7 | -9.3 | -9.7 | +27.7 | +18.1 | +9.3 | -2.3 | -9.7 | 8.8 | -2.1 | -0.6 | -2.0 | -0.6 | -3.1 | -0.3 | +1.2 |
| Anthesis to Milking 28 February-8 March | 5.7 | +0.8 | -5.7 | -5.7 | -3.9 | +27.3 | +2.1 | +26.5 | 8.0 | -2.9 | -1.2 | +1.4 | -1.5 | -2.7 | -0.1 | -0.8 |
| Milking to dough 9 March- 18 March | 8.8 | -8.8 | -8.8 | -3.4 | +11.2 | +27.4 | +17.9 | -0.2 | 8.4 | +0.5 | +0.7 | +0.9 | +0.5 | -1.3 | -2.1 | -0.1 |

*H- High yield year, L- Low yield year*

**Table 3. Correlation coefficients between different meteorological parameters and wheat yield at Ludhiana**

| Month | 1990-91 to 2000-01 | | | 2001-02 to 2016-17 | | | 1990-91 to 2016-17 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tmax | Tmin | RF | Tmax | Tmin | RF | Tmax | Tmin | RF |
| October | 0.40 | 0.51* | 0.20 | 0.47 | -0.21 | -0.12 | 0.48* | 0.17 | -0.05 |
| November | 0.63* | 0.32 | 0.05 | 0.47 | 0.31 | -0.06 | 0.53* | 0.27 | -0.03 |
| December | 0.49 | -0.70* | -0.46 | 0.50* | -0.16 | -0.25 | 0.47* | -0.16* | -0.23 |
| January | -0.34 | -0.11 | -0.40 | 0.08 | -0.33 | 0.30 | -0.11 | -0.16 | -0.10 |
| February | -0.37 | -0.65* | 0.10 | -0.05 | -0.47 | 0.10 | 0.00 | -0.33* | 0.00 |
| March | 0.32 | -0.11 | 0.20 | 0.17 | -0.34 | -0.30 | 0.38* | 0.04 | -0.10 |

**(P= 0.05)*

growing season except during January and February. Whereas minimum temperature was negatively correlated during December, January and February at Ludhiana but a significant negative correlation during December and February was observed. Rainfall showed a negative relationship with wheat yield during the crop season.

## 4. CONCLUSION

Variability among weather parameters *i.e.* maximum temperature, minimum temperature and rainfall becomes a dominant issue in crop production. The findings of this study indicate that maximum temperature and minimum temperature has been increasing at the rate of 0.015ºC and $0.04^0$ C per year respectively. The rainfall analysis revealed that most of the years were deficit and it has been decreasing at the rate of 0.028 mm $year^{-1}$ during the wheat growing period. It is found that during the highest yield year (2011-12), the sunshine hours were also higher in comparison to lower sunshine hours during the lowest yield year (2014-15). The findings of this study suggest that weather variability due to climate change has negative effect on wheat production. Climate change causing ill effects to the staple food (wheat) of country hence there is a need to aware the people about climate change signals, techniques to mitigate these change by adopting suitable practices like in situ management of straw and tackle negative impacts of climate change to cope up with the production losses on priority basis. The emphasis of climate change and weather variability challenges on wheat production presented in this paper will benefits the breeders to develop suitable varieties for this location in the era of climate change for sustainable yield production.

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### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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