



## Weather conditions favoring wheat (*Triticum aestivum*) productivity in hot climate of central India and congenial environment of north-western plains

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Physical grain quality characteristics of wheat (*Triticum aestivum* L.) grown in central India is best in the country (Mohan *et al.* 2013, Mohan and Gupta 2015). Though climate in central zone (CZ) is dry and hot during the entire crop season, wheat productivity is quite high and comparable with the north-western plain zone (NWPZ) which is rated as the most favourable wheat growth environment in India (Mohan *et al.* 2011). Data of All India Coordinated Wheat and Barley Improvement Programme (AICW and BIP) reveals that wheat productivity in CZ is also as good as that of NWPZ. The present study has tried to examine temperature and the heat load which wheat crop experience in these agro climatically diverse wheat zones.

In AICW and BIP, released and pre-released irrigated varieties, i.e. checks and final year entries are evaluated in Advance Varietal Trials (AVT) for each zone. This evaluation is done separately for two production conditions known as timely-sown (TS) and late-sown (LS) trial series. Each year, zonal mean of each entry evaluated in these trial series is mentioned in the annual report and data includes wheat yield and yield governing traits like days to heading, maturity period, plant height and 1 000 grains weight. During the crop seasons (2004-05 to 2013-14), 61 TS and 63 LS entries were tested in total under NWPZ environments. In the same period, 35 TS and 53 LS entries were evaluated in CZ. Ten years average of timely-sown genotypes indicates that wheat crop completes maturity about 25 days earlier in CZ because of hot climatic conditions (Table 1). In late-sown trials also, wheat crop in CZ matures 16 days earlier in comparison to NWPZ. It is interesting to observe that in spite of elevated temperature, mean kernel weight in CZ wheats is higher than NWPZ under both the production conditions, i.e. TS and LS. Improving signs in wheat yields of central India had been highlighted earlier by Mohan *et*

*al.* (2011) and Nagarajan (2013) rated such development in CZ as big boon for Indian agriculture. It is quite evident that higher grain bearing in NWPZ and better grain weight in CZ balance wheat yields in these two agro-climatically different zones. As a matter of fact the reason of high grain number in NWPZ is mainly the longer vegetative phase whereas longer reproductive phase in CZ helps in attaining higher grain weight. It is presumed and also evident from previous studies (Mohan *et al.* 2011) that reduction in vegetative period occurs when climate is hot but the reason of large grain filling period under such hot conditions is not well understood. The present study focuses upon the weather conditions that prompt better grain growth in the wheat grown in CZ.

Weekly meteorological data of six NWPZ (Ludhiana, Hisar, Karnal, Delhi, Pantnagar and Durgapura) and 10 CZ sites (Anand, SK Nagar, Vijapur, Junagarh, Kota, Udaipur, Gwalior, Indore, Powarkheda and Jabalpur) was computed for the crop season 2008-09 to 2013-14 to derive six year mean of minimum and maximum temperatures, sun shine hours and relative humidity (Table 2). Sites selected in NWPZ were less as many of them had similar weather

Table 1 Mean yield and yield attributing traits in NWPZ and CZ

Characteristic	NWPZ-TS	CZ-TS	NWPZ-LS	CZ-LS
Grain yield (q/ha)	49.6	49.6	40.5	42.6
1000 grain weight (g)	38.8	44.8	36.3	40.3
Grain number ('000/m <sup>2</sup> )	12.8	11.2	11.2	10.6
Plant height (cm)	92	89	86	80
Maturity (days)	142	117	122	106
Heading (days)	96.6	67.0	83.3	62.4
Grain filling days (days)	45.4	49.7	38.6	43.8

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Table 2 Weather conditions in CZ and NWPZ

Parameter	Mean		Range		CV (%)	
	NWPZ	CZ	NWPZ	CZ	NWPZ	CZ
Minimum temperature (°C)	9.0	11.5	5.7-15.3	8.1-16.8	29.4	21.3
Maximum temperature (°C)	23.2	28.4	16.8-31.6	24.1-36.0	17.4	11.5
Min and max temp. mean (°C)	16.1	20.0	11.4-23.4	16.1-26.4	20.5	14.2
Min and max temp. difference (°C)	14.3	17.0	10.9-16.7	15.7-19.2	12.3	6.35
Growing degree days	10.6	14.5	5.9-17.9	10.6-20.9	31.1	19.6
Relative humidity (%)	68.0	58.7	56-80	46-64	9.07	8.54

conditions in this region. It was observed that during the Julian week-47 (middle of November) to week-12 (end of March), overall minimum temperature in CZ across the locations was 2.5°C higher than NWPZ whereas difference in maximum temperature was 5.2°C. Sun shine hours per day were also more in central India but the relative humidity was 9% less in comparison to NWPZ. Investigation further revealed that even though the minimum and maximum temperatures were higher in CZ, there was better consistency as fluctuations noted through coefficient of variation (CV), were less in comparison to NWPZ. Elevated temperature regime also led to lower difference between minimum and maximum temperature in CZ. Range of this difference was lower in CZ (15.7 to 19.2°C) in comparison to NWPZ (10.9 to 16.7°C). It states that in spite of high temperature, heat shocks (high fluctuations) are less in CZ when compared with cooler climate of NWPZ. This stability in temperature upholds good wheat growth environment in CZ. Better consistency in temperature and less heat shocks therefore compensate the loss incurred in CZ by elevated temperature conditions.

Phenological development is the single most important attribute of crop adaptation to shifting climates (Huda *et al.* 2011). The wheat plant phenology is commonly described as the changes that occur from emergence to harvest maturity. Both crop season duration and the length of the phenological stages are important determinants of grain yield. The beginning and the ending of these stages are good indicators of potential crop growth (Anderson *et al.* 1978, Schwartz 1999, Calviño *et al.* 2003). The effect of temperature on phenology and growth of crops has been studied under field condition through the determination of accumulated heat units. These units are also called as growing degree days (GDD). Each plant has a specific GDD requirement before the certain phenological stages are attained (Sikder 2009). It is the daily mean temperature, above a base temperature which is suitable for plant growth (Shaykewich 1995).

Influence of latitude and longitude, and the locations on crop duration of wheat has been examined by some researchers (Peterson *et al.* 1992, Zhang *et al.* 2004, Sial *et al.* 2000). Growing degree days (GDD) is another parameter to quantify the heat load. The study underlined that mean GDD was higher in CZ and this temperature loaded abiotic stress reduced the total crop duration of wheat. Overall mean

of GDD during the growth period (47<sup>th</sup> to 12<sup>th</sup> week) was 10.6 in NWPZ and 14.5 in CZ (Table 2). It confirms that heat load during crop growth is quite high in CZ. Even though GDD was higher in CZ, the consistency level was better in comparison to NWPZ. As depicted in Table 3, fluctuations in GDD realized through CV were strikingly less in CZ (19.6%) as compared to NWPZ (CV: 31.1%). It amply demonstrates that better consistency helps the CZ wheats to combat the hindrance imposed by high temperature and brings productivity levels to the level of NWPZ.

Besides zonal mean, the individual locations also registered similar observations (Fig 1). It was noticed that overall mean of GDD varied vividly among the test sites of hot climate of CZ (11.4 to 17.9), whereas in favourable climate of NWPZ, site difference was very small (9.6 to

Table 3 Comparison of temperature, GDD and RH in two zones

Julian weeks	Mean of min & max temp. (°C)		GDD (week mean)		Average humidity (%)	
	NWPZ	CZ	NWPZ	CZ	NWPZ	CZ
47	18.3	21.0	12.8	15.5	63.8	63.3
48	17.4	21.1	11.9	15.6	62.5	63.4
49	17.2	20.9	11.7	15.4	64.2	63.9
50	15.9	19.6	10.4	14.1	66.8	64.0
51	14.4	18.5	8.9	13.0	71.2	64.9
52	12.7	17.5	7.2	12.0	72.1	65.4
1	11.4	16.1	5.9	10.6	79.5	66.1
2	11.9	16.2	6.4	10.7	74.5	64.7
3	12.6	17.0	7.1	11.5	77.4	65.2
4	13.3	17.4	7.8	11.9	71.8	63.2
5	14.6	18.4	9.1	12.9	70.3	62.2
6	15.4	19.3	9.9	13.8	69.3	61.0
7	15.2	19.4	9.7	13.9	69.9	60.9
8	16.9	20.6	11.4	15.1	68.6	59.0
9	18.3	22.1	12.8	16.6	64.7	57.8
10	19.6	23.1	14.1	17.6	61.1	53.5
11	21.3	24.6	15.8	19.1	59.8	50.5
12	23.4	26.4	17.9	20.9	56.0	49.1
Mean	16.1	20.0	10.6	14.5	68.0	61.0
CV (%)	20.5	14.2	31.1	19.6	8.81	8.42

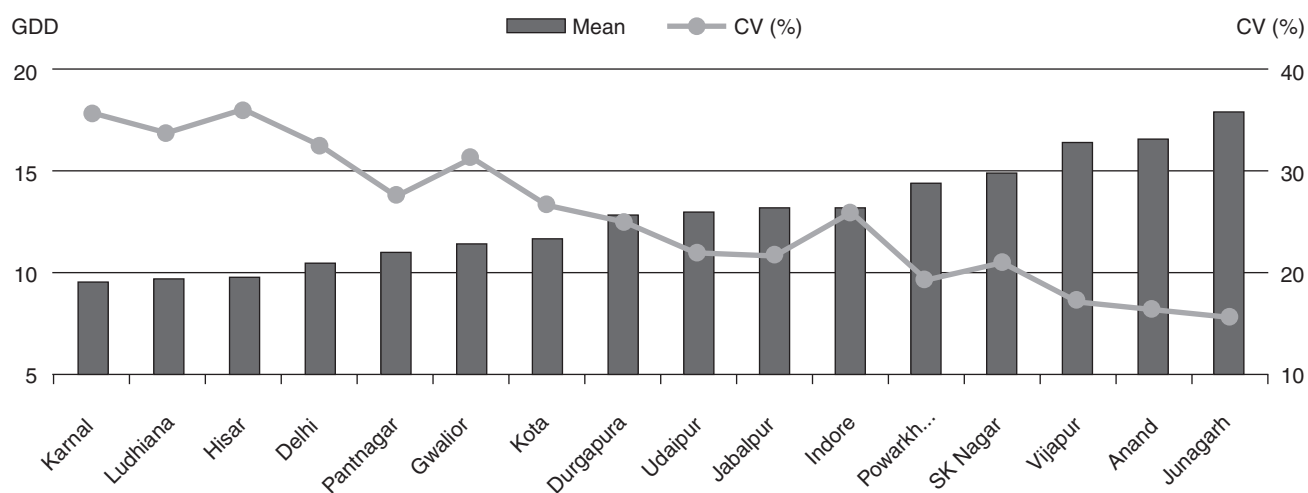


Fig 1 Location differences in mean GDD and weekly variations during crop growth

12.8 GDD). It underlines that differences in heat intensity were high among CZ locations. It was observed that mean weekly GDD which was 11.4 at Gwalior could go as high as 17.9 at Junagarh. In comparison, mean weekly GDD in NWPZ was low (9.6 to 9.8) at Karnal, Ludhiana and Hisar and at the hottest test site of the region also, i.e. Durgapura, it could touch only 12.8 mark. There were cooler sites in CZ and some hot ones in NWPZ as Gwalior and Kota located in CZ had overall GDD less than Durgapura location of NWPZ. Though heat load was more at different locations of CZ, consistency levels between the test sites was higher as depicted by lower CV (15.6 to 31.3%) in comparison to NWPZ test sites where CV between the test sites was 26.8 to 38.6%. It was very clear that the fall in GDD in NWPZ climate gathered more fluctuations. In this region, the difference in GDD between the sites was also not high. Durgapura which expressed lowest variations in NWPZ had highest mean GDD in the region. Pattern of GDD during the growth weeks hinted that lowest weekly GDD was noted in the first week of January at all sites of NWPZ. In CZ, it occurred in the second week of January at some sites like Indore, Udaipur, Jabalpur and Powarkheda. When mean GDD and the variations during the growth stage were plotted against each test site (Fig 1), inverse relationship between mean GDD and the fluctuation was very clear. Consistency increased when GDD or heat load was lower at the test sites.

It is reported in literature that shift from vegetative to reproductive phase occurs in wheat crop after certain GDD (Klepper *et al.* 1988). Comparison between the two zones (Table 1) showed that pre-anthesis period in CZ was a month shorter in comparison to NWPZ. Large vegetative phase here helps in formation of more grains through better tillering. About 97 days period up to anthesis in NWPZ indicated that when sowing is done in week-47 (mid November); flowering occurs after 14 week, i.e. in week-7. It indicates that shift to reproductive period occurred when 831 GDD were accumulated under NWPZ conditions (Table 3). Similar heat load in terms of GDD was experienced by

the crop after week-3 (829 GDD) in CZ. Similar pattern could be observed when comparison is made taking into account the mean of minimum and maximum temperature. It appeared that flowering was initiated in NWPZ when mean of minimum and maximum temperature crossed 17°C after week-7 in NWPZ. Similar temperature conditions occurred in CZ in week-2. After week-8, relative humidity (RH) also started declining at a faster rate in NWPZ and it fell below 70%. At the flowering time, RH in CZ was around 60% but the decline after week-8 was gradual. In comparison to minimum GDD which is achieved in the first week of January in both the zones, rate of increase till the end of March was 1.09 GDD per week in NWPZ and 0.94 GDD in CZ. When rise in temperature load is slow, the loss in grain weight will be less. The late-sown crop even though face more heat stress in comparison to timely-sown one, its manifestation on grain weight is therefore less in hot CZ climate.

Study further revealed that the post-anthesis period remained steady in CZ. A comparison till March end, i.e. week-12 revealed that after heading in the week-7, GDD reached 23.4 from 15.2 in five weeks under NWPZ conditions with GDD increase at the rate 1.64/week (Table 2). After heading in the third week; GDD in CZ rose from 17.0 to 26.4 in 9 weeks with 1.04 rate of increase per week. Temperature rise at slower rate extended ripening duration of the grains in CZ. Steady grain ripening and less bearing therefore was helpful in harnessing higher grain weight in wheats cultivated in central India.

Flowering time in wheat is influenced by several genetic factors like Vrn, Rht genes (Yadav *et al.* 2014) and non-genetic parameters (air temperature, humidity etc.) and attaining anthesis is the first priority of the plant. The grain filling period is controlled more by the environmental factors like temperature, surface winds, humidity etc. (Saiyed *et al.* 2009). In NWPZ, yield filling thereafter takes place at a faster rate as more number of grains is to be filling in a shorter period. In the favorable NWPZ climate therefore, even small jerks realized through abiotic pressures can

impose big yield penalty when yield fill rate is high. In contrast though temperature is high in central India, slower grain filling rate helps the wheat crop to withstand the weather shocks better and the yield penalty is less. Longer grain filling period provides more buffering to the grain development process; consequently grains are bold even in the hot and dry environment of central India. Among the environmental factors studied in NWPZ and CZ, the consistency in GDD during grain filling period contributed significantly in steady grain filling and yield increase in CZ. To the best of our knowledge, this is the first study on dissecting environmental factors that cause yield equivalent in NWPZ and CZ.

#### SUMMARY

Six years weather data in two diverse wheat zones of India was examined to understand the factors that contribute to high grain yield under hot and dry climate of central zone (CZ) of India. Though number of grains was less in CZ when compared with favourable environment of north-western plains zone (NWPZ) due to shorter pre-anthesis period, total yield matched due to higher grain weight achieved from larger post-anthesis period. Even though higher growing degree days (GDD) and less humidity caused early flowering in CZ, better consistency in temperature and less heat shocks compensated the loss incurred by elevated temperature conditions. Comparison of six NWPZ and ten CZ locations involved in the study revealed that hotter sites expressed fewer variations in GDD during the entire growth weeks. The study also demonstrated that the post-anthesis period was steady in CZ as temperature rise during the course of grain filling was slower in comparison to cooler climate of NWPZ.

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