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Analysis of long-term wheat varieties for climate resilience and productivity oscillation in different environments of India

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Abstract

Six long-term wheat cultivars of India were examined for the period 1993-2012 to observe climate induced variations in productivity and growth pattern. Each cultivar represented a particular environment manifested by a specific agro-climatic region and production condition, productivity of which was derived from 6-10 fixed locations. Significant yield fluctuations in majority of the environments indicated that climatic conditions were changing in different parts of the country. Trend in yield change appeared cyclic and site differences also turned larger in certain situations. Pattern of climate induced yield variations depended upon region and production condition as the extent was high in late-sown wheats in comparison to timely-sown and less in the Indo-Gangetic plains in comparison to central-peninsular India. Disparity occurred within Indo-Gangetic plains also, as yield fluctuated more in the eastern region. Direction of change varied in different environments as yield decelerated in late-sown wheats of Indo-Gangetic plains and enhanced in harsh climate of central-peninsular India. Crop growth during vegetative phase turned favourable in central-peninsular India whereas reduction in grain ripening period was evident in north-eastern plains. Linear trends and magnitude of variations in yield cum component traits were applied to demarcate differences in varietal response. Level of climate resilience differed in the study material and two cultivars namely HUW 234 and LOK 1 appeared climate resilient.

Key words: Climate resilience, global environmental change, Indian wheat, yield sustainability

Introduction

Climatic change is a global challenge to sustainability of staple food crops. Indian agriculture is particularly sensitive to the changed climate rhythm which has occurred with rise in minimum night temperature [1]. Changes in the geographical limits to agriculture, variations in crop yields and impacts on agricultural system have been envisaged as major areas of concern in Indian agriculture [2]. Wheat is particularly affected by such changes as the warming is getting sharpest in winter. It becomes imperative therefore to realize influence of changing weather conditions on wheat, which is not only a major staple food crop but also a commodity too dear for national exchequer and food security. Reduction in crop duration and productivity of wheat was predicted very early in India [3, 4]. Vulnerability of Indo-Gangetic plains (IGP) to global environmental changes (GEC) had been reported from CIMMYT and India [5-7]. It has been predicted that rise of 1^{o} C temperature alone could lead to decrease of 6 million tons of wheat production in India [8]. However, India has witnessed tremendous improvement in wheat production and productivity in recent times. Wheat production climbed from 69.7 to 94.9 million tons during 2001-12 and ascent in productivity was also tremendous i.e. from 27.2 to 31.8 q/ha. It is important therefore to examine the direction and magnitude of variations which GEC has caused in Indian wheat.

Wheat research in India has been a success story. Developing varieties in demand with the local and regional requirements and strategic planning to deploy matching production technology have contributed immensely in this endeavour. To strengthen the role of wheat in food security under changing climatic conditions, it is pertinent to develop wheat varieties with in-built climate resilience. For this, an in-depth study of climate change on wheat growth in

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different parts of the country is essential. Impact of climate change can be gauged by examining variations in performance of long-term varieties as manifestation of such variations is reflected in yield and other agronomic attributes. Certain wheat varieties like PBW 343, PBW 373, HUW 234, LOK 1, DL 788-2 and NIAW 34 had been under testing for 16-20 years in All India Coordinated Wheat and Barley Improvement Project (AICW&BIP). These cultivars had been in the charter of most popular varieties under seed production and cover four zones accounting 27 million hectare area. Since each one of them has been recommended for a particular environment; the present study examined direction of change, magnitude of impact and pattern of yield change in these varieties to realise GEC influence in different parts of India. This study also investigates level of climate resilience in popular Indian wheat cultivars and yield balancing between the regions; the two instruments which articulated insurance to food security in India.

Material and methods

Varieties, environments and sites

Study included multi-year and multi-location yield performance of six irrigated bread wheat (*Triticum aestivum* L.) varieties used as checks during 1993-2012 in Advance Varietal Trials of AICW&BIP (Table 1). Each variety was specific to a particular production condition i.e., timely-sown/ late-sown; and agro climatic ecologies namely north-western plains zone (NWPZ), north-eastern plains zone (NEPZ), central zone (CZ) and peninsular zone (PZ). Irrigated wheat in India is grown under two situations i.e. timely-sown and late-sown. Timely-sown wheat is planted in the middle of November where as late-sown is seeded in mid December. Varieties differ for these two situations as wheat raised under late planting face more heat and accordingly the duration gets curtailed. Environment for wheat growth is different in each zone. NWPZ and NEPZ, labelled as ME-1 region by CIMMYT, represent the fertile and well irrigated IGP. NWPZ, the most productive wheat land of India, has the most congenial wheat growth environment whereas adjoined NEPZ has shorter winter in comparison and the climate remains generally humid. Among two zones of central-peninsular India (CPI), CZ climate is hot and dry and crop often faces soil moisture stress as there is hardly any rain in winter. Climate in PZ is also hot but humidity is higher than CZ.

Statistical analysis

Using location mean of each year, coefficient of variation (CV) and standard error (SE) was calculated to assess magnitude of seasonal yield fluctuations. Two-factor analysis without replication was applied to mark significant differences in years/ sites. Spearman rank correlation was derived to compare GEC pattern between two environments. To study direction and pattern of change, linear and polynomial trends were derived. Since changes in crop behaviour occur very slowly under GEC, impact was recognised important only when R^2 value was $\geq$ 0.10.

Results and discussion

Productivity fluctuations

Yield fluctuations over the years have been recognised as strong indicator of GEC [6-8]. Plotting of mean yield (across all test sites) against the years suggested that yield fluctuation occurred in each cultivar or environment (Fig. 1). Range of yield variations (q/ha) was quite large i.e. 44.9 to 56.4 in PBW 343, 35.0 to 46.9 in PBW 373, 30.6 to 44.5 in HW 234, 40.1 to 49.7

Table 1. Varieties, years and test sites

Variety	Environment	Years	Test sites	Name of test sites
PBW 343	Timely-sown, NWPZ	20	10	Delhi, Hisar, Uchani, Bathinda, Ludhiana, Gurdaspur, Sriganganagar, Durgapura, Modipuram and Pantnagar
PBW 373	Late-sown, NWPZ	20	10	Delhi, Hisar, Uchani, Bathinda, Ludhiana, Gurdaspur, Sriganganagar, Durgapura, Modipuram and Pantnagar
HUW 234	Late-sown, NEPZ	19	6	Varanasi, Faizabad, Kanpur, Pusa, Barabanki and Arul
LOK 1	Timely-sown, CZ	16	10	Anand, SK Nagar, Sanosara, Vijapur, Junagarh, Kota, Indore, Gwalior, Powarkheda and Udaipur
DL 788-2	Late-sown, CZ	16	10	Anand, SK Nagar, Vijapur, Junagarh, Badroli, Gwalior, Jablapur, Bilaspur, Powarkheda and Udaipur
NIAW 34	Late-sown, PZ	20	6	Niphad, Pravarnagar, Karad, Pune, Dharwad and Ugar

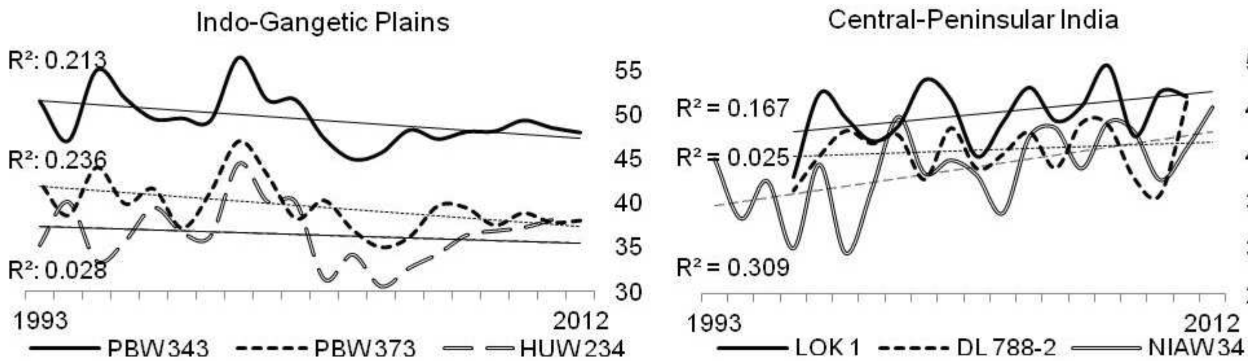

Fig. 1. Yearly fluctuations and linear trend in average yield

in LOK 1, 36.5 to 46.0 in DL 788-2 and 29.5 to 46.0 in NIAW 34. It suggests that GEC induced variations occurred not only in IGP but in other environments, too. Fluctuating productivity in different crop seasons was a clear manifestation of the changing climatic conditions occurring in different parts of India.

To test significance level of yield variations; year and location data of each cultivar was computed for two-factor statistical analyses. For uniformity among environments, 16 year data (1996-2011) was considered for this investigation (Table 2). It was observed that yearly variations in wheat yield were significant in most of the cases. The only environment where yield remained stagnated was late-sown wheat of PZ. It asserts that GEC induced yield changes can't be ignored as they have significant bearing on wheat yields.

Difference in significance levels (P values) confirmed that GEC impact can be of different magnitude in diverse agro-climatic situations (Table 2). Year-wise yield variations were non-significant in DL 788-2 and highly significant NIAW 34, PBW 373 and HUW 234. Although yield variations occurred in PBW 343 and LOK 1 too, the significance level was very small. It shows that cultivar response to GEC vary depending upon the environment in which they were raised. Perusal of CV reflects that GEC induced variations were minimal in the most congenial growth environment i.e. timely-sown wheat of NWPZ (5.84%). Late-sown wheat of this region expressed more variations (7.28%) as crop faced relatively elevated temperature conditions. Variations in late sown wheat of NEPZ went further high (9.38%) as growth conditions were warmer in comparison to late-sown wheat of NWPZ. Under hot and dry climate of central India, yield variations were mediocre (6.29 and 7.00%). Pattern was entirely different in late-sown wheat of PZ as yield deviations were very large (CV: 11.4). It shows that intensity of GEC caused yield deviations vary according to the climatic conditions of that environment.

Cyclic nature of GEC induced yield variations

Polynomial trend of order 3 revealed that GEC induced productivity changes emerged in phases (Fig. 2). Higher R^2 value in comparison to linear trend asserts that this trend fits better to gauge the impact of climatic

Table 2. Significance of sites and locations (ANOVA of two-factor analysis without replication)

Variety	Degree of freedom			Mean sum of square			Significance (P value)	
	Year	Sites	Error	Year	Sites	Error	Year	Sites
PBW 343	15	9	135	76.0	181	41.8	0.038	<0.001
PBW 373	15	9	135	85.5	171	35.5	0.004	<0.001
HUW 234	15	6	90	75.6	57.1	34.4	0.011	0.140
LOK 1	15	9	135	99.2	613	55.1	0.040	<0.001
DL 788-2	15	9	135	66.0	493	44.4	0.119	<0.001
NIAW 34	15	5	75	118	264	37.2	0.001	<0.001

Table 3. Magnitude of yield (q/ha) fluctuations

Variety	Mean	SE	CV (%)
PBW 343	49.43	0.41	5.84
PBW 373	39.63	0.46	7.28
HUW 234	36.52	0.57	9.38
LOK 1	44.98	0.47	7.00
DL 788-2	40.77	0.40	6.29
NIAW 34	38.55	0.71	11.4

change. A long wave was visible in all cases underscoring the cyclic change in wheat productivity i.e., fall for some years followed by a cycle of improvement and *vice versa*. It supports occurrence of "boom and bust" cycle in productivity changes which appears similar to that of wheat pathogens cycle. Similar conceptual model was visualized in Western Australian Agricultural Region which has experienced sequential periods of growth and accumulation followed by reorganization and renewal, and currently is in the back loop (reorganization to exploitation phases) of the adaptive cycle [9].

Pattern of yield change in different environments

Spearman rank correlation was derived to study similarity in the productivity pattern between two environments. Among two production conditions of a given zone, rank correlation was significant only in NWPZ (r: 0.670**). It shows that if productivity jumps in timely-sown wheat of this region, simultaneous benefit in late-sown wheat is also accrued in that particular year. In fact enhanced productivity in NWPZ is very closely related to coldness and duration of winter which benefits tillering under both production conditions. In CZ, rank correlation remained non-significant which shows that if productivity trend is altered in timely-sown wheat of CZ, similar impact may not be expressed in late-sown wheat of the region. Insignificance of rank correlation was noted between PBW 343 and timely sown variety of CZ i.e., LOK 1. Result was similar when PBW 373 was correlated with late-sown varieties of other zones. It reflects that when GEC turn favourable for a given production condition in wheat bowl of the country i.e. NWPZ, it does not guaranty productivity enhancement in other wheat zones. Between the regions, similarity in GEC impact could only be noticed in late-sown wheats of CZ and PZ (r: 539*) which shows that when a crop season turns favourable for late-sown wheat of CZ, similar impact can be realised in PZ as well. Unlike IGP, pattern of GEC induced yield variations can be similar among two wheat zones of CPI.

Effect on yield potential of sites

GEC affected yield changes have been reported in wheat and maize under Indian conditions [10-11]. This investigation further tried to examine whether variations also go wider in yielding ability of the test sites. For this purpose, variance observed between sites was computed against each year of study (Fig. 3). Location differences were larger in CPI in comparison to IGP which was an indication that sites variations remain wider under harsh climatic conditions. It was observed that GEC alters not only the yielding ability of a genotype but also the yielding potential of sites located in the affected region. Just like average productivity; direction and extent of site variations also varied in different environments. When situations with $R^2 \geq 0.10$ were focussed, it was noted that site variance had registered an increasing trend in late-sown wheat of NEPZ. There was no major site deviation in both production conditions of NWPZ but the impact was minimal in timely-sown wheat of the region. Results were entirely different in CPI as site variations were

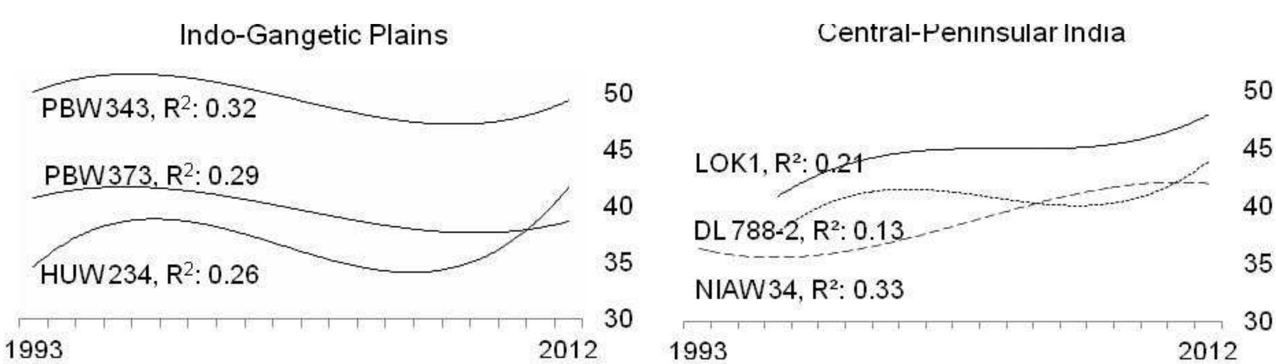

Fig. 2. Polynomial trend of order 3 in productivity (q/ha) of different regions

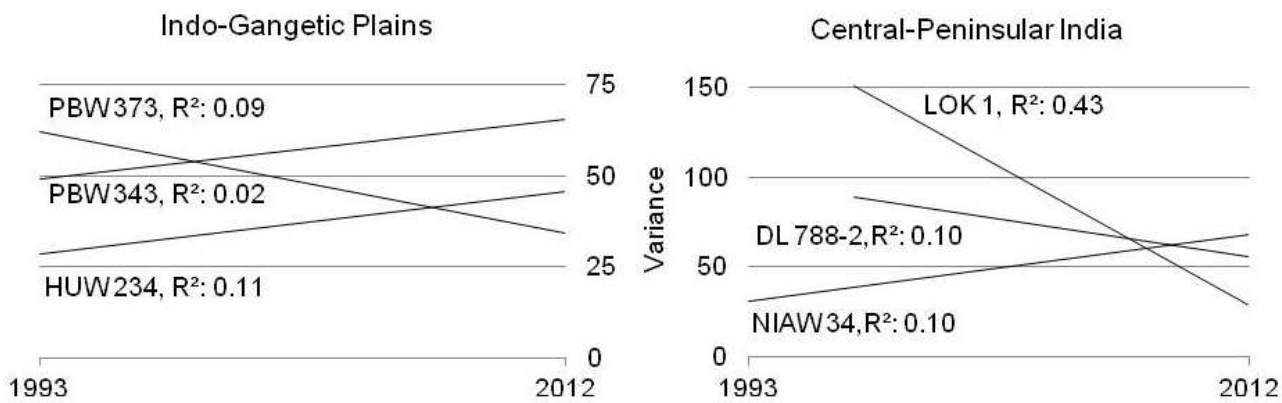

Fig. 3. Linear trend in site variations

getting minimised in CZ and this trend was very sharp in timely-sown wheat. Trend changed in late-sown environment of PZ as site differences started increasing. The study opines that besides productivity, site differences can also be distorted by changing weather conditions.

Impact and direction of productivity change

Efforts to realize productivity changes have gone widespread in the era of global warming. Besides uncertainty [12-13], decline or stagnation in yield has also been reported from Mexico and China, respectively [14-15]. Yield deceleration was recorded in cultivars of NWPZ i.e. PBW 343 and PBW 373 (Fig. 1) whereas stagnation was observed in HUW 234 cultivar of NEPZ. In CPI, the trend was altogether different as there was no yield decline in any cultivar; rather signs of improvement were visible in LOK 1 and NIAW 34. Stagnation in yield was noticed in DL 788-2 variety of CZ. Enhancement in production and productivity is becoming strong point of wheat cultivation in CZ. Productivity friendly trend of climate change in central India had also been reported earlier [7, 16] which reflects scaling down of climate severity in that hot region. It clearly demonstrates that manifestation of GEC is realized differently in IGP and CPI. Slight yield loss in one region and improvement in the other has been helpful in vitalizing dynamism in Indian wheat production system. This kind of yield balancing among the regions commensurate well with the defining role that wheat has played to ensure food security under diverse and changing environment of India.

Trend of yield decline in timely-sown wheat of NWPZ was also deceptive as loss of yield in last five years of the study came from reduced grain weight caused by high incidence of yellow rust in PBW 343. If 1000 grain weight (TGW) is adjusted in accordance with the period of grain filling for those five years (period when high incidences of yellow rust started appearing), TGW would have increased from 38.6 to 42.0g. Corresponding yield for the period 2008-12 would also have advanced from 48.4 to 52.7q/ha. Incidence of yellow rust increased in PBW 373 also but with similar correction, this late-sown variety showed marginal improvement in grain yield i.e. from 38.3 to 40.1 q/ha. It indicates that in wheat favouring growth environment of NWPZ, late-sown wheat is more sensitive to adversaries of GEC.

Impact on growth parameters

Yield fluctuations over the years are manifestation of climate change on wheat growth. In India, frequency of occurrence of hot days and hot nights has registered widespread increasing trend while that of cold days and cold nights was decreasing [1]. Frequency of such changes was variable in different regions. According to this report, frequency of the occurrence of hot days is found to have significantly increased over east-coast, west-coast and interior peninsula, while that of cold days showed significant decreasing trend over western Himalayas and west coast. The three regions of east-coast, west-coast and northwest showed significant increasing trend in the frequency of hot nights. Such changes are bound to affect vegetative and reproductive growth in wheat. Although vulnerability of Indian wheats had been reported for IGP in some earlier studies [5, 7, 10], its implications on yield components was not elaborated. This investigation focused at GEC effect on different growth stages to identify yield components that contribute in productivity changes. Impact on growth parameters (plant height, heading days, grain number/m^2, grain filling period, maturity days and TGW) were examined through linear trend (Table 4).

Timely-sown wheat grown in the most congenial environment i.e. NWPZ illustrated reducing plant height which is generally associated with better tillering. There had been small positive change in the maturity period; consequently grain filling period was enlarged. It shows that the chances of better grain filling are increasing in this region. Under late sowing, the vegetative phase was shortened and such situations occur due to warm weather conditions. It caused yield loss due to reduced number of grains. There was not any major threat to late-sown wheat during post-antheisis period. Unlike NWPZ, late-sown wheat of NEPZ faced global warming like situation. Crop duration had been reducing and the grain filling period was curtailed indicating warmer weather conditions happening during grain ripening.

Although climate in central India is harsh in comparison to IGP; wheat productivity registered signs of improvement under timely-sown condition. Grain number and grain weight was improving under timely sown conditions which asserts that climatic conditions were improving in the pre and post vegetative phases. Late-sown wheat in CZ was not influenced at any stage. Productivity trend in PZ was similar to that of CZ and growth was affected mainly during the pre-anthesis period. Delayed heading in this environment indicates that winter period was extended which benefited the grain number/m^2.

Climate resilience

Climate resilience is generally defined as the capacity for a socio-ecological system to i) absorb stresses and maintain function in the face of external stresses imposed upon it by climate change and ii) adapt, reorganize, and evolve into more desirable configurations that improve the sustainability of the system. The Intergovernmental Panel on Climate Change defines Resilience as the capacity over time of a system, organization, community, or individual to create, alter, and implement multiple adaptive actions [17].

Unpredictable yield is a major sign of GEC [5, 6] and to checkmate such adversaries, varieties of inbuilt climate resilience are the best solution. Varieties that can sustain productivity under varying climatic conditions are vital to achieve the targets set in staple food crops. India has joined hands with international organizations to develop new climate-resilient varieties of rice and wheat [18]. At this juncture, it is pertinent to discover whether divergence in climate resilience exists in Indian wheats. Different approaches can be applied to search climate resilience in the cultivars. Impact of climate change had been investigated by mean and variance of crop yield in some studies [19]. In coordinated programme of maize, coefficient of determination (R^2) and magnitude of variance were used for varietal differentiation [11]. The present study applied R^2 values, direction of linear trend (Figs. 1 and 2), significance level (P value), standard error and CV of seasonal yield variations for varietal divergence (Tables 2 and 3). Besides yield, impact on growth parameters was considered in examining cultivars for climate resilience (Table 4).

Since varieties were tested in different environments, difference in their response to changing climate was obvious. PBW 343 variety of NWPZ is well known for its adaptation as farmers of adjoining NEPZ had also started its cultivation in large area. Even with inflated grain filling duration, it failed to add more weight to the grains. Grain filling period which was 40.8 days in first half of the study rose to 42.5 in the second half but PBW 343 failed to convert it into seed weight due to higher incidence of yellow rust. TGW which was 41.5g in first five years of the study

Table 4. Trend of change in pre-anthesis and post-anthesis growth parameters

Environment	Heading days		Plant height		Grains/m^2		Grain filling days		1000 grain wt.		Maturity days	
	Change	R^2	Change	R^2	Change	R^2	Change	R^2	Change	R^2	Change	R^2
NWPZ-TS	(=)	0.006	(-)	0.127	(=)	0.005	(+)	0.155	(-)	0.324	(+)	0.094
NWPZ-LS	(-)	0.151	(=)	0.043	(-)	0.085	(+)	0.048	(-)	0.078	(=)	0.031
NEPZ-LS	(-)	0.017	(=)	0.047	(-)	0.007	(-)	0.378	(-)	0.048	(-)	0.273
CZ-TS	(=)	0.015	(-)	0.176	(+)	0.120	(=)	0.004	(+)	0.174	(=)	0.010
CZ-LS	(=)	0.032	(=)	0.016	(=)	0.010	(=)	0.008	(=)	0.010	(=)	0.019
PZ-LS	(+)	0.103	(=)	0.001	(+)	0.282	(-)	0.061	(=)	0.001	(=)	0.001

was reduced to 38.6g during last five years. It therefore put the ability of its resilience under question. Plant height of PBW 343 registered decreasing trend which should have been culminated into better tillering and more number of grains but it was not apparent in PBW 343. In-spite of wider adaptation therefore, PBW 343 can't be rated climate resilient. PBW 373, the late-sown variety of the region recorded highly significant yield changes and the impact was also negative. PBW 373 succumbed to elevated temperature conditions occurring in the vegetative growth period and expressed no signs of resilience.

In contrast to PBW 373, HUW 234 was able to sustain yield (R^2: 0.03) under late-sown condition NEPZ even when grain filling and maturity durations was being restricted. This cultivar registered high grain filling efficiency and recovered TGW under adverse environmental conditions during grain filling. For this fine yield recovery under climate adversaries, HUW 234 can be rated resilient. This is the only genotype which showed stable yield across the test sites (Table 2). Another peculiarity noted in HUW 234 was non-significant correlation between heading days and maturity duration. Normally, heading is positively correlated with maturity duration [20] and this type of phenology was noticeable in every cultivar of the study except HUW 234.

In central India, resilience capacity of both the cultivars was different. Impact of GEC on yield was lowest in DL 788-2 (R^2: 0.04) and its sustainability therefore was apparent. But non-significant year effect and very low R^2 value in all growth related parameters, suggests that this genotype had not faced aggravated climatic conditions and can't therefore be classified as climate resilient. On the other hand, timely-sown cultivar of this region i.e. LOK 1 had made good use of the favouring climatic conditions during vegetative and reproductive phases. Under changing climate of this hot and dry region, LOK 1 managed to exhibit improvement in grain weight. It had been reported that the rate of increase in grain dry weight increase with temperature and temperature sensitivity and growth rates vary between cultivars during grain-filling [21]. Dynamism registered by LOK 1 in converting improved weather condition for enhanced yield through grain number and grain weight make this genotype truly climate resilient.

In late-sown production condition of PZ, impact of GEC was positive as winter got cooler. Yield differences over the years were very high in NIAW 34 (P value <0.001). High values SE and CV also suggest that yield deviations were higher and deeper in comparison to any other cultivar. Therefore, this genotype of highly fluctuating productivity can't be clubbed with resilient cultivars.

Opportunities

Climate change can open new vistas in development of high yielding wheat varieties. Study clearly depicts that to harness more yield in the era of GEC, approach to combine two major yield governing traits i.e. grain number and grain weight might change. In wheat bowl of the country i.e. NWPZ; yield in majority of the varieties is routed through grain number, especially the spike number. Grain filling period in this region is shorter in comparison to all other zones and just enough to fill the large number of grains produced during vegetative phase. An enhancement in grain filling duration coming largely from prolonged crop duration will be conducive for bolder grains and boost productivity in NWPZ. In wheat breeding, yield enhancement so far has been largely focusing grain number and a call is already there to exploit grain weight in such ventures [22]. A suitable climate to harness better grain weight raises prospects of enhancing productivity in this most productive wheat land of the country. Central India, another productive region of the country, is viewed important to have further increase in wheat production and grain filling duration is improving here too, especially in the timely sown wheat. Potential of raising productivity through bolder grain looks still higher in this region. Situation in NEPZ is tricky and balancing yield would be a challenge. Since post-anthesis period is shortening in late-sown wheat of the region, quick ripening would demand faster accumulation of assimilates in wheat grains. Therefore, physiologically efficient genotypes during grain filling stage would be needed for further yield increase in wheat yield under late sowing of NEPZ.

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