



Significance of yield sustainability to develop climate smart wheat (*Triticum aestivum*) in India

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ABSTRACT

To ensure food security in India, not only the wheat (*Triticum aestivum* L.) productivity but yield sustainability is also crucial especially when the production environments are quite diverse. An experiment was conducted to examine multi-environment wheat yield trial data of popular wheat cultivars in two agro-climatically diverse regions i.e. north-western plains zone (NWPZ) and central zone (CZ) under timely-sown (TS) and late-sown (LS) conditions with an aim to differentiate yield and yield sustainability at the level of 4 production environment, 11 prominent locations and 7 crop years. Wheat productivity matched in both zones; yet the level of yield-sustainability was much less in warmer climate of CZ. Yield sustainability was poorest in late-sown wheat of CZ and the drop in sustainability index (SI) was realized in locations, years and genotypes. For grain yield; locations and location-year interaction mattered most in each production environments but the years were crucial only in NWPZ-TS. Results showed that yield sustainability of test sites can not be adjudged by its productivity alone. Location status was associated with the yield sustainability only in NWPZ. Substantial drop in sustainability could be noticed in some crop seasons of CZ but deviations in NWPZ were smaller. In test sites, the causative factors associated with yield-sustainability varied under different production environments. Genotype-year interaction was effective in each situation except CZ-LS where only the crop year variations were supreme. Variations in locations and genotypes mattered most in NWPZ-TS whereas the crop year deviations were impactful in NWPZ-LS and CZ-TS environments. Based on the results; prospect of improvisation and breeding strategy have been suggested to select suitable production sites and the genotypes.

Keywords: Climate resilience, Production environments, Sustainability index, Wheat, Yield variations

In India, the north-western plains zone (NWPZ) and the central zones (CZ) are the two very important wheat (*Triticum aestivum* L.) agro-climatic-zones for high wheat productivity with acreage of 18 to 19 million hectares (Bhati *et al.* 2022). The mean temperature during crop growth (45th to 12th Julian weeks) is generally 3.6 to 4.0°C higher in CZ whereas relative humidity is 6.8 to 9.8% lesser in comparison to NWPZ (Mohan *et al.* 2017). In spite of the hot and dry climate, wheat yield in CZ is also comparable to NWPZ under both production conditions (Mohan *et al.* 2022). In the era of global environmental changes (GEC); it's essential not only to produce more but harnessing full yielding potential of the developed cultivars across all locations and in all crop seasons is also equally important (Mishra *et al.* 2015). Intensive, innovative and location-specific adaptations to improve wheat productivity in the future climate have been emphasized by Kumar *et*

al. (2014). Wheat breeding strategies can be improved by routinely assessing the breeding results for yield gain and sustainability over time in a particular environment (Xiao *et al.* 2012). Therefore, it becomes necessary to assess impact of different variation sources like locations, crop years and the sowing time not only for wheat yield but for yield sustainability as well. This investigation is a comprehensive study to examine influence of different variation sources on yield and yield sustainability. In this endeavour; sustainability index (SI) suggested by Singh *et al.* in (1990) has been used as a tool to assess yield sustainability in wheat. In wheat, this approach had been used to examine yield sustainability divergence in some wheat-growing nations (Meena *et al.* 2017), study adaptability and stability variations (Szarecki *et al.* 2017) and demarcate sustainability differences between the genotypes and test sites under Indian conditions (Mohan *et al.* 2020). This study aims to highlight analogy between yield and yield sustainability, identify the factors crucial to sustain good wheat harvest under contrasting growth environments, examine location specificity, assess the

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prospects and challenges and suggests way forward for further improvisation in yield sustainability of wheat.

MATERIALS AND METHODS

Data generated for grain yield in the Advanced Varietal Trials conducted under the All India Coordinated Research Project on Wheat and Barley in NWPZ and CZ was examined for two production conditions i.e. timely-sown (TS) and late sown (LS). Seven years of performance pertaining to 3 promising wheat varieties of 2 categories i.e. timely-sown wheat (TSW) and late-sown wheat (LSW) were analyzed in 4 production environments (PE) i.e. NWPZ-TS, NWPZ-LS, CZ-TS and CZ-LS at fixed 11 test sites of each zone. In NWPZ; the study material included WH 1105, HD 2967 and HD 3086 as TSW and WH 1124, HD 3059 and DBW 173 as LSW. Durum cultivation is quite prevalent in CZ-TS; therefore one durum variety (HI 8498) was included along with two bread wheat cultivars i.e. GW 322 and HI 1544 in TSW. The 3 varieties of LSW in CZ were MP 3336, HD 2932 and MP 4010. In NWPZ, 7 crop seasons data were available in continuity during the period 2015 to 2021. Since the yield trials in CZ were not conducted during the period 2016–18, the 7 years period covered the 2019–21 and 2012–15 crop seasons. The fertilizer dose used in the NWPZ was 150N:60P:40K kg/ha in TSW and 120 N: 60 P: 40 K kg/ha in LSW. The fertilizer dose was 120 N: 60 P: 40 K kg/ha in CZ-TS and 90 N: 60 P: 40 K kg/ha in CZ-LSW.

Per cent contribution of each variation source was derived from the Type III Sum of Squares provided in the ANOVA obtained by applying the univariate analysis of variance (general linear model) with the SPSS version 16.0 software. F-test was applied to test significant differences in variance whereas t-test was used for significant difference between mean of two variables. Regression analysis was done to i) elaborate on the role of the component traits in yield-sustainability and ii) determine relationship between the two variables. Pearson and Spearman's rank correlations were computed to examine response of test sites under different sowing schedules. The sustainability index was computed to determine variations in yield sustainability as:

$$[(\text{Mean} - \text{Standard deviation})/\text{Maximum value}] \times 100$$

It was derived for every PE and the three main factors of each PE. Any difference in SI was accounted substantial if margin was either $\geq 10\%$ or when significant difference could be noted in the variance. Based upon the sustainability, the test sites were classified into 3 groups, i.e. Category A, Category B, Category C

- Category A = $\text{SI} > (\text{Mean} + 0.5 \text{ SD})$
- Category B = $(\text{Mean} - 0.5 \text{ SD}) < \text{SI} < (\text{Mean} + 0.5 \text{ SD})$
- Category C = $\text{SI} < (\text{Mean} - 0.5 \text{ SD})$

RESULTS AND DISCUSSION

Factors causing yield variations and yield uncertainty:

In every PE, yield variations are accrued through three main

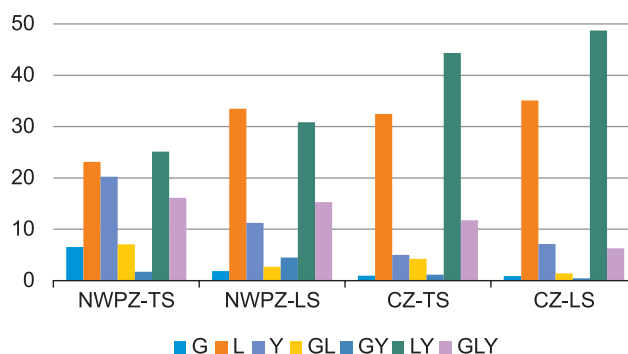


Fig 1 Contribution of variation sources in yield.

affects i.e. genotypes (G), years (Y), locations (L) and their interactions like GL, GY, LY and GLY. The contribution of these variation sources varied in different PE of this study (Fig 1). It was revealed that when there was less stress in wheat growth, as observed in NWPZ-TS, practically every variation source exerted influence on grain yield. In all other PE; location and LY emerged as the two leading contributors in yield variation. It underlined that the impact of years on yield variations may not be as high as L or LY but its impact on yield is high when temperature in the region is favourable for the crop growth. The variation sources which are most impactful in uncertainty of wheat yield are LY and GLY (Mohan *et al.* 2020) and their collective contribution dominated all other sources of yield variation. In genotypes, the yield variations are accrued from the locations, years and LY. It implies that LY is crucial for the genotypic differences in yield sustainability. Relevance of GYL can be related with the yield potential and its contribution was highest in NWPZ-TS and lowest in CZ-LS.

Relevance of locations, years and LY has been well recognized in wheat (Kaya and Akcura 2014, Mohan and Tiwari 2016, Mohan *et al.* 2022). It has also been pointed that uncertainty is major fallout of climate change (Asseng *et al.* 2013, Falloon *et al.* 2014, Pingali *et al.* 2019) and LY acts as big contributor in this unreliability (Mohan *et al.* 2020). The magnitude of uncertainty varies spatially and increases with time (Kumar *et al.* 2014). The unpredictability observed in this investigation may further be an indication of GEC. Under its influence, yield variation between two locations might keep changing in different crop years, and alternately difference between crop years may magnify or shrink at some test sites. Few studies have indicated earlier that hidden impact of global warming can still be present even when average productivity shows no major deviation (Mohan *et al.* 2020).

Yield and yield sustainability distinctions in different zones: There was no significant difference between NWPZ and CZ (observation: 232) in average wheat productivity of timely-sown and late-sown wheat (Table 1). The researchers have reported earlier also that the wheat productivity can be equally good in the congenial and harsh environments provided well adapted high-yielding varieties (Mohan and Tiwari 2016, Mohan *et al.* 2022). In spite of matching yield, there were certain distinctions between the zones.

Table 1 Production environment distinctions in yield, yield variations and sustainability index

Parameter	Timely-sown wheat		Late-sown wheat	
	NWPZ	CZ	NWPZ	CZ
Mean yield (q/ha)	56.2	56.1	47.3	48.5
Yield potential (q/ha)	75.9	93.9	62.7	83.4
Coefficient of variation (%)	16.0	16.9	13.0	25.8
Variance	81.3	89.9	38.0	133
Sustainability index (%)	62.2	49.6	65.6	50.4

The yield potential (maximum yield) was higher in CZ in comparison to NWPZ in both categories of wheat. In LSW, yield variations under CZ were much higher as compared to NWPZ and there was significant difference in the variance, too. Consequently, the SI in NWPZ was higher than CZ under both production conditions. It underlined that even if productivity match, it is harder to sustain grain yield when climate is hot and dry. An indication of reduced yield sustainability in harsh environments, given earlier by Mohan *et al.* (2020), was further validated in this investigation. Difference in yield variations (standard deviation) and maximum yield must have contributed for divergence in yield sustainability of two zones.

Big variations in grain yield over locations and the crop years were expected but the differences in SI were even larger (Table 2). Just like the zonal mean; yield range matched in TSW and LSW of each zone but the scenario was different in case of SI. Location range in SI was almost same in NWPZ-TS, NWZ-LS and CZ-TS. Location mean of SI therefore also matched as it was 58.8% in NWPZ-TS, 57.5% in CZ-TS and 63.9% in NWPZ-LS. In CZ-LS, range shrank and the mean was also reduced (49.5%). Situation was almost same in case of crop season as the mean across the crop years was 68.3% in NWPZ-TS, 70.5% in NWPZ-LS and 65.0% in CZ-TS. The corresponding SI mean in CZ-LS was merely 52.3%. Difference occurred in the genotypes also but the SI mean matched in NWPZ as it was 63.4% in TSW and 66.9% in LSW. In comparison, varieties of CZ were poorer as SI mean was 54.1% in TSW and merely 45.1% in LSW. It was evident that SI decline in CZ-LZ was realized at all the three levels i.e. location, crop season and genotypes.

Location specificity yield sustenance: Although the SI range was quite big (Table 2, Fig 2), it was not possible to determine significant difference. Therefore test sites were grouped into three classes depending upon the mean and the yield variations recorded in a particular PE. For uniformity, same technique was adopted in yield as well. By this standard, there were two locations in NWPZ-TS (Faridkot and Bathinda) which occupied the top ranking in yield as well SI. On the other extreme, Nagina and Durgapura remained poor by both demarcations. In NWPZ-LS also, top ranking locations in both the aspects were Faridkot and Bathinda whereas Durgapura held its tag of poor ranking. In NWPZ-LS, there was no site with SI below 60% whereas there were two such sites (Durgapura and Karnal) in NWPZ-TS. In CZ-TS also there were three locations (Powarkheda, Kota and Vijapur) which could be characterized in class "A" for yield and SI. In this PE, Junagadh remained poor in both the aspects. Just like NWPZ-TSW, some sites in CZ-TS like SK Nagar and Gwalior lacked in yield and SI. In CZ-LS, there was no site which could be rated well in both the aspects. In this PE also, Junagadh retained the tag of poorest test site. In CZ, Gwalior was such a location where yield sustainability was poor in TSW and well as LSW even though it yielded ≥ 60 q/ha under both sowings. On the contrary, there was Bilaspur where SI was highest even when productivity level was very low in CZ-LS. It all proved that yield sustainability of a test site cannot be judged by the productivity level alone.

It is evident that SI location status is generally maintained in a region where climate is congenial for wheat production. Majority of the sites retain their sustainability class in both production conditions of NWPZ. Spearman's rank correlation coefficient recorded between common test sites of two production conditions was also highly significant ($r: 0.813^{**}$) in NWPZ. This association was non-significant in warmer areas i.e. CZ ($r: 0.403$). Except Indore, no location in CZ could retain the SI status when sowing conditions were changed. Location difference in yield and yield sustainability are in reports (Mohan *et al.* 2020). This study further added that divergence in SI status of the locations can occur when sowing condition changes in these regions.

Yield sustainability differences in varieties and crop years: Although genotypes were limited, some difference was still visible. In NWPZ-TS, variety HD 2967 (SI:

Table 2 Range of yield and yield sustainability index in locations, crop years and genotypes

Factor	Zone	Grain yield (q/ha)		Sustainability index (%)	
		TSW	LSW	TSW	LSW
Location	NWPZ	46.9 – 63.1	43.9 – 51.5	56.1 – 85.8	61.4 – 84.4
	CZ	45.5 – 63.8	37.2 – 62.1	52.4 – 80.7	46.1 – 77.5
Year	NWPZ	51.4 – 63.0	40.0 – 49.3	63.8 – 73.7	66.3 – 77.9
	CZ	53.3 – 63.2	43.8 – 53.2	54.2 – 70.8	41.5 – 61.6
Genotype	NWPZ	52.9 – 58.4	46.4 – 48.7	59.3 – 67.5	64.7 – 68.7
	CZ	54.5 – 56.9	47.7 – 50.2	47.6 – 57.7	43.1 – 48.8

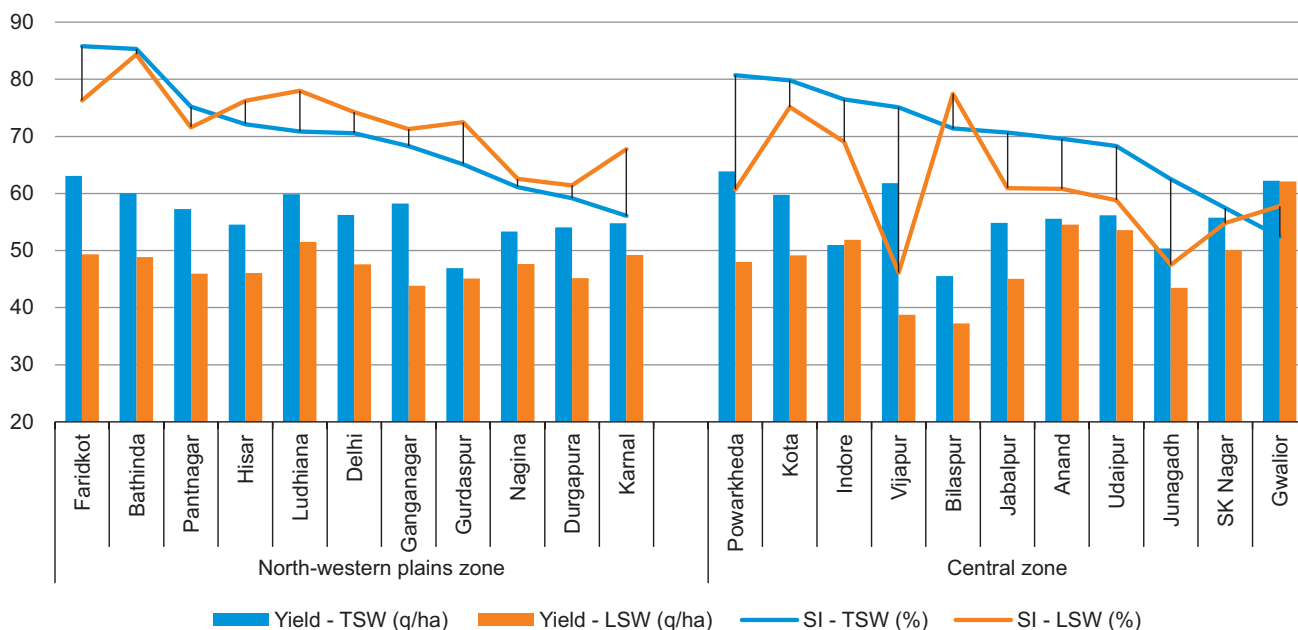


Fig 2 Yield and yield sustainability at different test sites.

59.3%; yield variance: 99.1) was distinctly inferior in comparison to HD 3086 (SI: 67.5%; yield variance: 57.4). Similarly in CZ-TS, yield sustainability in HI 1544 (SI: 57.7%) was distinctly higher in comparison to HI 8498 (SI: 47.6%). In LSW, varietal distinction was not visible in any zone. Comparison of SI amongst the crop years pointed that variations did exist and the differences were more pronounced in LSW (Fig 3). In NWPZ, 2018 and 2016 were quite distinct in TSW whereas 2017 season was distinctly superior in comparison to 2020 and 2021 in LSW. In CZ, SI got a big plunge during 2019 in both categories of wheat. In CZ-TS, yield sustainability during 2019 was highly inferior in comparison to 2015. In LSW, the crop seasons of 2019, 2013 and 2014 were poor as compared to 2014. It shows that CZ-LS can have some crop seasons when it becomes extremely difficult to sustain yield. Difference in climate resilience and yield retaining capacity of genotypes had been reported from India (Mohan *et al.* 2020) but this study further added that varieties are likely to express such differences better when crop is grown under normal sowing conditions. Difference in genotypes and test sites is generally examined by the breeders (Yang *et al.* 2019) but crop seasons cannot be selected in advance. Hence, it's better to pick the varieties or locations best in the region and compare them for SI. When varieties have minimal environmental interaction, it becomes easier to harness their true potential (Mohan and Tiwari 2016).

Divergence in timely and late-sown wheat: This investigation made it very clear that delayed sowing hampers yield sustainability under

harsh environment. Besides locations and years, it is another variable that articulates variations in yield sustainability. In NWPZ, crop seasons showed little SI variations in NWPZ-TS and NWPZ-LS but in CZ, the difference was substantial in most of the crop seasons (Fig 3). With the exception of 2014, SI in LSW of CZ remained distinctly lower in comparison to TSW. It underlines that reduction in yield sustainability is inevitable in warmer areas. Response of the locations could also vary under late planting. In CZ, there were several sites like Vijapur, Powarkheda and Junagadh; where delayed planting reduced SI was $\geq 15\%$ (Fig 2). This indicates that SI is quite specific to the sowing window of such sites. In contrast, there was a unique location in NWPZ i.e. Karnal, where SI was enhanced by late planting.

Causative factors for deviations in sustainability index:

It was challenging to determine the variables influencing varietal difference in yield-sustainability because of few genotypes but the possibilities did exist for the test sites. At any location, yield is influenced by three factors i.e. genotype, years and GY. Therefore, the relationship of SI was

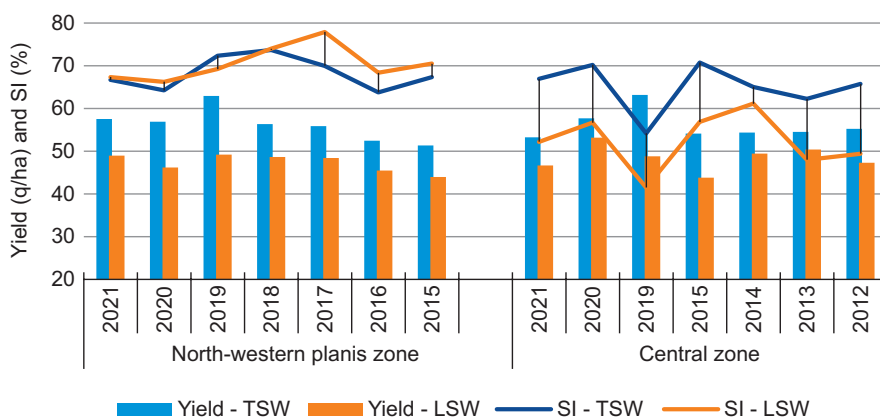


Fig 3 Yield sustainability distinctions in crop years.

Table 3 Relationship between SI and the key components

Production environment	R ² value	Regression coefficient of key factors				Per cent contribution			
		Location	Genotype	Year	GE	Location	Genotype	Year	GE
NWPZ-TS	0.994	1.11***	-0.15***	–	-0.96***	70.3	11.1	–	24.1
NWPZ-LS	0.976	1.21***	–	-0.32***	-1.29***	18.1	–	26.5	55.5
CZ-TS	0.970	0.86***	–	-0.27*	-1.12***	1.18	–	25.9	73.0
CZ-LS	0.932	–	–	-0.97***	–	–	–	100	–

*** and * indicates the significance level at P 0.001 and 0.05.

examined with these three components through regression analysis. In this exercise, the yield differentiation index was computed for genotypes and the years as the ratio between the maximum and minimum yield whereas the maximum yield recorded at each location was taken as reflection of GY. For required degree of freedom, number of sites was raised to 14. The additional locations were Jammu, Modipuram and Kashipur in NWPZ and they were common in both categories of wheat. For CZ; Bhopal, Sagar and Amreli were added in TSW whereas Jagdalpur, Ambikapur and Bardoli were the additional sites in LSW.

This analysis revealed that the factors which define yield sustainability in locations of a mega-zone vary in different situations (Table 3). Individually, the locations registered a positive impact on SI but this contribution was high only in NWPZ-TS. The maximum yield which symbolizes the GY or GE effect had significant and high contribution in NWPZ-LS and CZ-TS but it was not so in CZ-LS. Genotypes proved significance in this relationship only in NWPZ-TS but the crop year deviations had no meaningful contribution in this PE. Overall, the three main contributors were the locations, genotypes and GY in NWPZ-TS; locations, years and GY in NWPZ-LS and CZ-TS; and merely the crop year deviations in CZ-LS. It suggests that the prospects of SI improvisation are at best when the climate is most conducive for wheat growth (NWPZ-TS) as varietal superiority and location specificity can be employed to improvise yield sustainability under such conditions. It is particularly challenging to make improvement in SI when the growth environment is very harsh as in CZ-LS because it entirely depends upon the crop season fluctuations which can't be controlled by the breeders.

Distinctions in yield and yield-sustainability are vital in wheat research. Study makes it amply clear that sustaining wheat yield under late-planting is extremely difficult in warmer areas and late-sown wheat should not be encouraged in CZ. This investigation underlines that the hackles of climatic fluctuations, LY and GE have to be properly managed to enhance yield sustainability. Proper site and varietal selection is paramount in this endeavour. To determine actual breeding value of the fixed materials, evaluation should be preferred at locations where environmental influence is minimal. Centres where yield variations remain high due to frequently occurring seasonal variations, can be preferred for early generation selection. It is crucial to plan the breeding strategy in accordance with

the causal factors that regulate yield-sustainability in the region. This strategy will surely be more rewarding in a region where environment is congenial for wheat growth. The varieties evaluated and selected by this methodology can withstand the climatic fluctuations better and shall be more useful in sustaining high yields under varying environmental conditions.

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