Ramification of Yield in Hallmark Wheat Germplasm of the Indo-Gangetic Plains of India

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The two mega-zones located in the Indo-Gangetic plains receive a great attention by the All India Coordinated Wheat and Barley Improvement Project in developing high yielding wheat varieties for timely sown irrigated conditions. Breeders from either zone can compete in releasing wheat varieties for both the zones. Even though varieties have been notified for the NEPZ in the recent past, release of new varieties has remained elusive in wheat bowl of the country. It has been difficult to break the yield plateau in the NWPZ whereas varieties in the adjoining NEPZ could be released and that too by breeders from the NWPZ. It is therefore necessary to understand the critical components that contribute to yield in either/one. By examining the hallmark germplasm of either zone, it was noted that the main yield determinants are different in these zones. Direct and indirect effect of those key characteristics and the inter-relationship with other components have been investigated to understand differences in yield route among the two group of varieties that have been widely accepted in the Indo-Gangetic plains.

Key words: Bread wheat, Yield components, Hallmark germplasm, Path analysis, Yield route

The Indo-Gangetic plains of India have a long history of wheat cultivation where a cool winter favours prospects of high productivity in this winter cereal. Wheat farming in the Gangetic plains, therefore, has proved vital in assuring food security in the country. Wheat occupies about 10 million hectares area under timely sown irrigated condition in this region. The All India Coordinated Wheat and Barley Improvement Project (AICW&BIP), therefore, imparts lot of importance to this region as instead of one, two national trials (NIVT 1A and NIVT IB) are conducted for initial yield evaluation of the new breeding materials. The whole region has been classified into two mega-zones i.e. North Western Plains Zone (NWPZ) and North Eastern Plains Zone (NEPZ) by the AICW&BIP. The NWPZ comprises the states of Punjab, Haryana, western Uttar Pradesh, Delhi, parts of Rajasthan as than (Alwar, Bharatpur and Sriganganagar), Ponta valley and Una district of Himachal Pradesh, while the states of Bihar, Jharkhand and eastern parts of Uttar Pradesh, West Bengal, Orissa and Assam constitute the NEPZ. Active wheat improvement centres located in both the zones enrol new bread wheat entries for wide scale initial evaluation in the Indo-Gangetic plains.

In the NWPZ, some very popular wheat varieties have been released for timely sown conditions. Among new varieties of the region, PBW 343 has created all time record as its acreage has gone over five million hectares. UP 2338 and WH 542 also had great seed demand in late nineties. In the past, HD 2329 was another highly popular variety in the eighties. However, the new varieties notified for timely sown condition have never become so popular in the adjoining NEPZ. Now when breeders from either zone are entitled to compete for variety release in whole of the Indo-Gangetic plain, it is important to realise the key traits that have contributed yield in the present day popular varieties of both the zones. Therefore, important yield attributes in the hallmark germplasm from this region have been investigated by utilising trial data generated by the AICRP on Wheat and Barley. This search to understand differences in the yield route under different environments will prove handy to the wheat breeders in developing suitable new varieties for two major zones of the country.

Material and Method

The All India Coordinated Wheat and Barley Improvement Project conducts Advance Varietal Trials (AVT) separately for the NWPZ and NEPZ. For comparison, the most popular varieties in the zone are included as checks. Varieties like PBW 343, HD 2687, WH 542, UP 2338 and HD 2329 are taken as checks for the normal sown AVT of the NWPZ. Five years zonal mean (AVT: 1996-97 to 2000-01) of these popular varieties of NWPZ was compared with corresponding check varieties of NEPZ i.e. MUW 468, K 9107, NW 1012, PBW 443, HP 1731 and HD 2733 (Progress Reports, AICRP on Wheat and Barley). According to guidelines mentioned by Rasmusson (1996), these superior varieties that have occupied cultivation in such a large area can be termed as hallmark germplasm. The trials are conducted under high fertility (120kg N, 60kg

P_2O_5 and 40kg K_2O per hectare) and irrigated condition in Randomised Complete Block Design where each has a plot size of 16.56 m^2.

For the purpose of present investigation, pooled data of each year was sorted out for each variety and 25 data files were created for a period of five years. Concerned data for both the zones were computed for statistical analysis i.e. multiple regression analysis by LSQ technique and path coefficient analysis with the purpose to identify the most significant yield contributing traits and analyse their direct and indirect effect on grain yield. Data pertaining to some important characteristics like per hectare grain yield, phenology, plant height, grain weight and grains per square meter were taken for detailed analysis. Since the high yielding varieties arc equally competitive in per hectare yield, differences in their physiological efficiency were therefore examined by partitioning the yield into two major components i.e. kernel number and kernel grain weight. As these traits arc highly dependent on growth period, per clay growth as suggested by Sayre *et al.*, (1998) and Przulj and Mladenov (1999), was also computed by deriving following parameters that can explain different attributes concerning physiological efficiency:

Height Gain Rate	(HGR)	Plant height/day during vegetative period (c)
Grain Formation	(GSR)	Grains formed/m/day during vegetative period (#)
Grain Growth Rate	(GDR)	Grain weight/day during grain filling period (mg)
Yield Filling Rate	(YFR)	Per hectare yield/day during grain filling period (kg)

Results

Varietal superiority and variability: Summary of five years overall performance of the Hallmark germplasm suggests that the NWPZ varieties have higher yield potential than the NEPZ varieties. Yield superiority in the NWPZ arises mainly due to longer vegetative period (a consequence of cooler winter) that results into higher bio-mass and more number of grains/in^2 (Table 1). Higher per day yield filling under NWPZ conditions suggests that these varieties are capable of fast translocation rate during grain ripening period. On the contrary, though the varieties cultivated under NEPZ suffer in yield due to less number of grains/m by virtue of short vegetative period as heading goes early due to relatively high temperature, they are fast in attaining height and filling of the grain. Even though the NEPZ varieties mature 20-25 days earlier when compared to NWPZ varieties, the grain ripening period remained almost similar i.e. around 45 days. It again emphasised that in relation to the total growth period, the NEPZ varieties could get proportionately more time for grain filling (36.2% of the total crop duration) in comparison to NWPZ where varieties got only 31.7% total maturity period for this purpose. The reverse stood true for the grain formation during vegetative period upto heading. Further examination of the results indicated that even though per hectare yield is less in NEPZ, the Hallmark germplasm enjoys more diversity as it throws more variability when compared to NWPZ varieties. The eastern material is distinctly diverse in height, yielding ability and per day growth rate i.e. physiological efficiency. This edge in varietal diversity under NEPZ environment not only gives more options in selecting right genotype for cultivation but also helps in minimising pressure from certain abiotic stresses.

Yield Associated Traits: Association of yield contributing traits with grain yield was examined for eleven traits in each zone (Table 1). In NWPZ, the crop phenology (days

Table 1. Performance, variability and association of component traits with yield

Variables	Overall performance		Coefficient of variability		Correlation with yield		Direct effect on yield	
	NWPZ	NEPZ	NWPZ	NEPZ	NWPZ	NEPZ	NWPZ	NEPZ
Yield (q/ha)	48.2	40.7	5.18	9.35	1.00	1.00	–	–
Days to heading	97.8	77.2	4.94	4.12	0.58**	0.14	–1.57	–0.77
Ripening period (days)	45.4	43.8	5.46	6.71	–0.56**	–0.43*	0.95	–0.91
Total duration (days)	143	121	2.85	1.90	0.35	–0.36	0.79	0.70
Vegetative phase (%)	68.3	63.8	2.96	3.67	0.65**	0.33	0.50	–0.37
Plant height (c)	93.4	89.7	5.07	10.6	0.41*	–0.17	0.00	0.08
Grain weight (mg)	37.5	38.3	8.17	9.7	0.28	0.32	–0.14	0.66
Grains/m^2 ('000)	12.9	10.7	8.60	10.6	0.27	0.56**	0.84	0.03
Height Gain Rate (c)	0.96	1.16	4.17	8.6	–0.25	–0.30	0.01	–0.11
Grain Formation Rale (#)	132	139	7.53	13.0	–0.07	0.42*	–0.55	0.32
Grain Growth Rate (mg)	0.83	0.88	8.43	13.6	0.60**	0.42*	0.42	–0.58
Yield Filling Rate (kg/ha)	106	93.7	8.55	13.7	0.86**	0.88**	1.55	1.08

Number of observations = 25, * Significant at 5% level, ** Significant at 1% level to heading, grain filling period and % crop duration spent for days to heading i.e. % vegetative phase) and the rate of grain development and yield filling during ripening period showed highly significant correlation with yield. Plant height also had significant effect on the grain yield in this zone. Similar relationship in the NEPZ varieties could be noted only for three traits i.e. grain filling period, grain development rate and yield filling rate. In both the zones, grain filling period was negatively associated with grain yield. Unlike NWPZ, number of grains per unit area and the rate at which they were set during vegetative period were also very important in determining yield in the NEPZ. The rate at which height is attained, total crop duration and the grain size or weight was not correlated with grain yield in any of the zones. Surprisingly, even number of grains/m^2 remained unrelated to yield in NWPZ varieties. Since high grain number per unit area is always a common trait in varieties of this region, there may not be enough variability to register any significant effect on yield in the NWPZ varieties. Grain number per unit area, however, has great significance in the varieties of this region but the predominance of negative indirect effect on yield via certain other traits might have diluted a positive correlation with yield. As evident from the historical evidence, it is the grain number that has been consistently associated with increase in wheat yields. (Slafer *et al.*, 1994 and 1996; Villariel *et al.*, 1994 and 1995). The elite gene pool derived in this region comes largely from winter x spring gene pool recombination. Besides the 1B/1R translocation, a higher number of grains through either higher number of heads/m^2 or through bigger heads contribute to high yield in winter x spring wheat derived gene pool (Rajaram and Van Ginkel, 1996).

Determining the yield route through eleven traits is quite a complex exercise and it is not easy for the breeders to exercise selection with so many yield components. Also, judging importance of any yield component trait with yield through correlation studies may not necessarily reflect real importance of a given trait as its overall impact on yield can also be influenced by certain other associated traits. Investigation was further carried to identify the key components in each set of varieties and multiple regression analysis by LSQ technique was applied (Table 2). This technique provides combined effect of key yield components by studying real importance of concerned traits after separating the indirect influence that any involved trait could have had on the yield.

Yield Governing Traits

NWPZ varieties: It was interesting to note that out of the six traits that had registered significant or highly significant correlation with yield in the NWPZ varieties, only two of them i.e. ripening period and yield fill rate played the most crucial role in determining grain yield. With a very high multiple regression coefficient (R^2=0.958), these two components could be seen as the deciding factor in high yield potential of the NWPZ varieties. Ripening period even though showed negative contribution and association with yield (r=-0.57) but at its own it regressed positively with yield direct its direct effect on yield was positive and quite high (0.95). These two attributes not only aid to high physiological efficiency of NWPZ varieties but also to attain quick ripening-thereby enhancing the genotype ability in negotiating abiotic stress especially terminal heat. Contribution of yield filling rate was found the most predominant yield parameter in the NWPZ varieties. It proved that physiological efficiency during grain ripening plays a most crucial role in realising genetic yjeld potential of the wheat varieties cultivated in the NWPZ.

NEPZ varieties: Multiple regression analysis presented a different yield route in the NEPZ varieties where four traits i.e. yield fill rate, grain weight, grain development rate and proportionate vegetative phase were noted as crucial yield governing factors (R^2 = 0.997). Among

Table 2. Multiple regression analysis by LSQ technique

Character (Predictor)	% contribution of the predictor to the R^2 value	Correlation of the predictor with regression function	Regression coefficient value	SE (b)	t value (b)
NWPZ (R^2 = 0.958)					
Ripening period	–62.64	–0.57	1.08	0.10	10.88
Yield Filling Rate	162.64	0.86	0.50	0.03	1.84
NEPZ (R^2 = 0.997)					
% vegetative phase	–5.25	0.33	–0.26	0.08	3.96
Grain weight	24.20	0.32	0.78	0.05	15.25
Grain Growth Rate	–45.38	0.42	–33.17	2.45	13.57
Yield Filling Rate	126.43	0.88	0.42	0.01	72.34

these, two characters registered a negatively contribution to the overall yield i.e. proportionate vegetative phase and the rate of grain filling i.e. grain development rate. Unlike NWPZ, grain filling period failed to emerge as a crucial yield component even when it was significantly (-ve) correlated with grain yield. Among phenological traits, the vegetative phase registered a negative impact on grain yield. It means that longer vegetative period for a given maturity duration adds negative impact in NEPZ. Percent duration for grain filling was higher in these varieties (63.8%) when compared to corresponding varieties of NWPZ. This trait, however, failed to establish a significant correlation with yield perhaps due to the over riding positive effect that this trait might have had on the associated characters. The grain weight made a positive contribution to yield in these varieties even when significant positive correlation with yield was not registered. Third important yield attribute of the NEPZ varieties was grain development rate. Its contribution to yield was negative and it also regressed negatively with yield. It showed that rapid filling in the individual grain proves detrimental to yield of the varieties under cultivation in NEPZ. It needs slow filling in each grain whereas the existing eastern varieties have grain filling (0.88mg/day) faster than the NWPZ (0.83mg/day). The only common factor between the two sets of varieties was the yield fill rate and at its own, this single factor had maximum contribution to grain yield in both the zones. It reflects that movement of sink to source during grain filling period is high in both kinds of varieties. High yield filling rate even when fast grain development hinders grain yield, makes the NEPZ varieties complex and so special.

Effect of key components on yield route in different environments: The traits identified as crucial factors in governing grain yield were further studied in detail for their indirect effect on yield via other traits (Table 3). It was interesting to note that except plant height (total as well as per day gain), all other traits had a high direct effect on yield even when correlation with yield could not be established. It showed that indirect effect on an individual trait via associated characters was also paramount. Though a number of traits had shown significant correlation with yield, their importance can still differ as a few of them actually played a crucial role in determining yield. Since selection for some of the traits like grain development rate, yield filling rate and percent vegetative phase can not be exercised in the field, the correlation matrix and their direct and indirect effect on yield via other traits were closely examined. Very low residual effect under both the environments (NWPZ=0.0383 and NEPZ=0.0018) assured that the characteristics under investigation, covered majority of the traits that are useful for grain yield. Besides better understanding of the yield route in this elite germplasm, such an exercise also simplifies the selection criteria to be adopted in the breeding material.

Grain filling period: A major key component that emerged as a limiting factor in governing yield of the NWPZ varieties is the grain ripening period. However it appeared to be a ticklish characteristic as regression coefficient with yield stood positive even when correlation with yield was negative. Further investigation through path coefficient analysis revealed that the grain ripening period did have a high direct positive impact on yield that is why at its own it regressed positively with yield (Table 3). However, high indirect negative effect through certain other traits like grain size and yield filling rate negated its favourable impact. No indirect high effect on yield was observed via either grain weight or grain development rate. The correlation matrix made it further clear as the ripening period had a significantly negative correlation with days to heading, number of grains/m^2, grain setting rate and yield filling rate (Table 4). It means that by curtailing grain filling period through fast grain ripening, grain number per unit area is enhanced in the NWPZ varieties. The duration of grain ripening failed to appear as the key yield contributor in the hallmark germplasm of NEPZ where its direct effect on yield was quite in contrast to the effect that the NWPZ varieties had in the adjoining zone. Ripening period was the only trait that carried indirect high and positive effect on yield via days to heading in each zone. It shows that any attempt to curtail heading carry adverse impact on yield via ripening period as well.

Yield filling rate: This characteristic had a very high positive direct effect on yield and correlation with yield was also highly significant in both types of varieties. However, divergence for this particular parameter was quite conspicuous between the two sets of varieties when its indirect effect on yield was examined. In the NWPZ varieties, it had a high positive indirect effect on yield via grains/m' and vegetative phase whereas it was the grain filling period that registered a positive indirect effect on yield in the NEPZ varieties. Similarly, characters adding indirect negative effect on yield were also different in both the production conditions. Heading had a very high indirect negative effect on yield in the NWPZ varieties (-1.01) whereas in the other group, this type of negative effect was milder (-0.35). Besides, grain filling period also had a high negative indirect effect on yield in the NWPZ varieties whereas in the other group, the focus was shifted to grain development rate. So the indirect effect of grain filling period was high and positive in the NWPZ varieties whereas it turned opposite (high, -ve) in the NBPZ varieties. Diversity among the zones was visible for the common trait yield fill rate when its correlation was examined for certain other important traits. In the NWPZ, yield filling rate registered negative correlation with height gain rate. It implies that the varieties with slow vertical growth were benefited in yield filling rate under NWPZ conditions. Slow vertical growth aids lateral/horizontal growth that is manifested in more tillering and biomass production and better physiological efficiency in the zone. In NEPZ, the yield-filling rate was also correlated positively with grain weight and negatively with crop duration. Varieties with longer maturity period and small grain size, therefore, fail to draw any yield advantage in NEPZ.

Grain weight: Size of the grain was important for good yield in wheat varieties of the NEPZ. This key yield determinant in the NEPZ varieties regressed positively with yield as it had high direct positive effect. However, it failed to exhibit any correlation with yield. An examination of indirect effects revealed that a high negative indirect effect via some important traits like heading and rate of grain development nullified the direct positive effect and converged to an insignificant correlation with grain yield. A close look on the correlation matrix shows that bolder grains in the NEPZ hallmark germplasm were recorded in the varieties that had long grain filling period/ higher proportion of vegetative phase/ total duration/ plant height where as such correlation failed to exist in the NWPZ varieties.

Grain growth rate: The fourth important factor that governed yield in the NEPZ varieties was the rate at which filling in the individual grain take place. Grain weight in wheat is the product of rate and duration of grain filling (Nass and Reiser, 1975). Przulj and Mladenov (1997) found no strong connection between grain fill duration and grain fill rate, which enables the combining of these two traits in the process of cultivar development. They have suggested that in regions with shorter growing season, the yield can be more easily raised by increasing grain fill rate while in the temperate regions different values of these parameters can be combined. By this study, grain fill rate appeared to be a complex trait as its contribution to grain yield was negative. It regressed with yield in negative direction and its direct effect was also high and negative. However, it did register a significant positive correlation with yield. A positive correlation with yield was observed in NWPZ varieties also (r=0.60) but the direct effect on yield was also positive in that environment (0.42). Its high indirect positive effect on yield in the NEPZ varieties via gram filling period, grain size/weight and yield filling rate were the basis of shaping positive correlation. The correlation matrix in NEPZ showed that grain development rate in the prevalent varieties is highly influenced by phenological traits as it improves with delayed heading (r=0.79) and falls when grain filling period gets longer (-0.76). Such a correlation between phenological traits and grain development rate was not established in NWPZ.

Vegetative phase: The NEPZ hallmark germplasm was special in many other respects. Even though there was no correlation between yield and the percent crop duration utilised for vegetative growth, this phenological attribute registered a high and negative direct effect on yield (-0.37). And this crucial yield determinant regressed negatively with grain yield in the NEPZ varieties. It also drew negative indirect effect on yield via heading and rate of grain development, however, an indirect positive effect via grain filling period, grain weight and yield filling rate nullified the positives effect in the final analysis. This was in total contrast to the NWPZ varieties where a high direct positive effect (0.50) and positive correlation with yield (0.65) were established for this trait, indirect effect on yield via other traits was also different for most of the traits in the NWPZ varieties. The conspicuous differences between two groups of varieties were also observed in the correlation matrix. It appeared that vegetative phase has an important role to play in different environments. In the NWPZ varieties, it was positively correlated with total duration, plant height and grain number per unit area (Table 4). It means that an increase in the percent time spent in vegetative phase, adds to the grains per unit area and bio-mass of the NWPZ varieties. No such effect was visible in the NEPZ varieties. Negative selection for this trait in NEPZ can be exercised by enhancing the grain ripening period.

Table 3. Direct and indirect effect of yield contributing traits in the timely sown varieties of NWPZ and NEPZ

Characteristic	Zone	Effects via											Correlation with yield
		1	2	3	4	5	6	7	8	9	10	11	
1. Days to heading	NWPZ	**–1.57**	–0.51	0.67	0.42	0.00	0.02	0.39	0.00	0.06	0.09	1.00	0.58**
	NEPZ	**–0.77**	0.66	0.32	–0.33	0.03	0.41	–0.01	–0.00	–0.21	–0.46	0.50	0.14
2. Ripening period	NWPZ	0.84	**0.95**	–0.02	–0.44	–0.00	–0.03	–0.44	–0.00	0.14	–0.16	–1.39	–0.56**
	NEPZ	0.55	**–0.91**	0.20	0.35	–0.02	–0.22	–0.00	–0.00	0.05	0.44	–0.86	–0.43*
3. Total duration	NWPZ	–1.35	–0.03	**0.79**	0.24	0.00	–0.00	0.19	0.00	0.16	0.01	0.33	0.35
	NEPZ	–0.35	–0.26	**0.70**	0.00	0.02	0.28	–0.02	–0.01	–0.23	–0.07	–0.42	–0.36
4. Vegetative phase (%)	NWPZ	–1.36	–0.85	0.38	**0.50**	0.00	0.03	0.48	0.00	–0.05	0.14	1.37	0.65**
	NEPZ	–0.68	0.88	0.00	**–0.37**	0.03	0.31	–0.00	–0.00	–0.12	–0.48	0.77	0.33
5. Plant height	NWPZ	–1.11	–0.18	0.57	0.25	**0.00**	–0.04	–0.05	–0.00	0.29	0.17	0.52	0.41*
	NEPZ	–0.32	0.23	0.17	–0.12	**0.08**	0.42	–0.02	–0.10	–0.21	–0.34	0.03	–0.17
6. Grain weight	NWPZ	0.18	0.22	0.00	–0.10	0.00	**–0.14**	–0.70	–0.00	0.47	0.34	–0.00	0.28
	NEPZ	–0.48	0.31	0.30	–0.17	0.05	**0.66**	–0.02	–0.04	–0.22	–0.50	0.43	0.32
7. Grains per unit area	NWPZ	–0.73	–0.50	0.18	0.28	–0.00	0.11	**0.84**	0.00	–0.45	–0.20	0.74	0.27
	NEPZ	0.32	0.07	–0.47	0.05	–0.05	–0.40	**0.03**	0.06	0.30	0.23	0.43	0.56**
8. Height sain rate	NWPZ	0.61	0.44	–0.14	–0.24	0.00	–0.07	–0.57	**0.01**	0.28	0.09	–0.64	–0.25
	NEPZ	–0.03	–0.01	0.05	–0.00	0.07	0.24	–0.01	**–0.11**	–0.13	–0.16	–0.20	–0.30
9. Grain setting rate	NWPZ	0.18	–0.24	–0.23	0.05	–0.00	0.12	0.69	0.00	**–0.55**	–0.28	0.20	–0.07
	NEPZ	0.52	–0.15	–0.51	0.14	–0.05	–0.45	0.02	0.05	**0.32**	0.33	0.20	0.42*
10. Grain develop. rate	NWPZ	–0.34	–0.37	0.01	0.17	0.00	–0.11	–0.40	–0.00	0.37	**0.42**	0.84	0.60**
	NEPZ	–0.61	0.69	0.09	–0.30	0.05	0.57	–0.01	–0.03	–0.18	**–0.58**	0.73	0.42*
11. Yield filling rate	NWPZ	–1.01	–0.85	0.17	0.44	0.00	0.00	0.40	0.00	–0.07	0.23	**1.55**	0.86**
	NEPZ	–0.35	0.73	–0.27	–0.26	0.00	0.26	0.01	0.02	0.06	–0.40	**1.08**	0.88**

Residual effect: NWPZ = 0.0383, NEPZ = 0.0018, Bold figures signify direct effect, * Significant at 5% level of probability, ** Significant at 1% level of probability

Table 4. Correlation matrix of different traits in the timely sown varieties of the NWPZ and NEPZ

Characteristic	Zone	1	2	3	4	5	6	7	8	9	10	11	12
1. Grain yield	NWPZ	1.00	**0.58**	**–0.56**	0.35	**0.65**	**0.41**	0.28	0.27	–0.25	–0.07	**0.60**	**0.86**
	NEPZ	1.00	0.14	**–0.43**	–0.36	0.33	–0.17	0.32	**0.56**	–0.30	**0.42**	**0.42**	**0.88**
2. Days to heading	NWPZ	**0.58**	1.00	**–0.54**	**0.86**	**0.86**	**0.71**	–0.12	**0.47**	**–0.39**	–0.12	0.21	**0.64**
	NEPZ	0.14	1.00	–0.72	**0.46**	**0.89**	**0.41**	**0.62**	–0.42	0.05	**–0.68**	**0.79**	0.46
3. Ripening period	NWPZ	–0.56	–0.54	1.00	–0.03	**–0.89**	–0.19	0.23	–0.53	**0.46**	–0.25	**–0.39**	–0.90
	NEPZ	–0.43	–0.72	1.00	0.29	–0.96	–0.25	–0.34	–0.08	0.01	0.16	–0.76	–0.80
4. Total duration	NWPZ	0.35	**0.86**	–0.03	1.00	**0.48**	**0.73**	0.01	0.23	–0.18	–0.29	0.02	0.22
	NEPZ	–0.36	**0.46**	0.29	1.00	0.00	0.24	**0.42**	–0.68	0.07	–0.72	0.13	–0.39
5. Vegetative phase (%)	NWPZ	**0.65**	0.86	–0.89	**0.48**	1.00	**0.50**	–0.21	0.57	–0.48	0.09	0.34	**0.88**
	NEPZ	0.33	**0.89**	–0.96	0.00	1.00	0.34	**0.48**	–0.13	0.01	–0.39	**0.82**	0.71
6. Plant height	NWPZ	**0.41**	0.71	–0.19	0.73	**0.50**	1.00	0.31	–0.07	0.38	–0.52	**0.40**	0.34
	NEPZ	–0.17	**0.41**	0.25	0.24	0.34	1.00	**0.65**	–0.67	**0.89**	–0.67	**0.59**	0.03
7. Grain weight	NWPZ	0.28	–0.12	0.23	0.01	–0.21	0.31	1.00	–0.83	**0.53**	–0.86	**0.80**	–0.00
	NEPZ	0.32	**0.62**	–0.34	**0.42**	**0.48**	**0.65**	1.00	–0.60	0.37	–0.68	**0.87**	**0.40**
8. Grains per unit area	NWPZ	0.27	0.47	–0.53	0.23	**0.57**	–0.07	–0.83	1.00	–0.68	**0.82**	–0.47	**0.48**
	NEPZ	**0.56**	–0.42	–0.08	–0.68	–0.13	–0.67	–0.60	1.00	–0.53	**0.95**	–0.40	**0.40**
9. Height gain rate	NWPZ	–0.25	–0.39	**0.46**	–0.18	–0.48	0.38	**0.53**	–0.68	1.00	–0.52	0.22	–0.41
	NEPZ	–0.30	0.05	0.01	0.07	0.01	**0.89**	–0.37	–0.53	1.00	–0.42	0.27	–0.19
!0. Grain setting rate	NWPZ	–0.07	–0.12	–0.25	–0.29	0.09	**–0.52**	–0.86	**0.82**	**–0.52**	1.00	–0.66	0.13
	NEPZ	**0.42**	–0.68	0.16	–0.72	–0.39	–0.67	–0.68	**0.95**	**–0.42**	1.00	–0.57	0.19
11. Grain develop. rate	NWPZ	**0.60**	0.21	–0.39	0.02	0.34	**0.40**	**0.80**	–0.47	0.22	–0.66	1.00	**0.54**
	NEPZ	**0.42**	**0.79**	–0.76	0.13	**0.82**	**0.59**	**0.87**	**–0.40**	0.27	–0.57	1.00	**0.68**
12. Yield filling rate	NWPZ	**0.86**	**0.64**	**–0.90**	0.22	**0.88**	0.34	–0.00	**0.48**	**–0.41**	0.13	**0.54**	1.00
	NEPZ	**0.88**	**0.46**	**–0.80**	**–0.39**	**0.71**	0.03	**0.40**	**0.40**	–0.19	**0.19**	**0.68**	1.00

Bold figures denote significant correlation at 5% level of probability

Discussion

The north-western plain zone known as wheat bowl of the country, has a kind of environment that help in exploiting genetic yield potential of a genotype to the maximum. Information generated by the AICW&BIP, and computer simulations on the attainable yield indicates that NWPZ has potential of 7.0t/ha grain yield (Nagarajan, 1998). PBW 343 has recorded productivity of such a magnitude at many places in the yield trials of the zone. This variety has been notified for the whole Indo-Gangetic region and it has covered over five million hectare cultivation in the in the NWPZ alone. However, this zone could not get any other alternate variety of such a wider adaptation ever since the release of PBW 343 in 1995. For such an important zone, only one more variety i.e. HD 2687 was notified four years later but it could not catch on to PBW 343. The NWPZ needs varietal diversity under timely sown conditions, as only a few varieties occupy very large area. Avoiding threats of mono-culture in NWPZ has captured attention of the breeders but the suitable alternative are not coming. The percentage of new materials promoted to Una I stage testing and found to yield better than the best check is too low in NWPZ whereas the NEPZ is comfortably placed for wheat varieties of timely sown condition (Jag Shoran *et al.* 1998, Mohan *et al.* 2001). Some of the impediments that come in the way of finding new varieties for this region have been thrown to light by this investigation.

The present study has revealed that quick ripening and high yield fill rate are the two important yield determinants for wheat varieties of the NWPZ. In another study, the authors have indicated that wider adaptation and ability to exploit favourable conditions to yield advantage through high number of grains/m is an in-built advantage tagged to the elite wheat material developed in the north-western region (Mohan and Jag Shoran, 2002). To harness the benefit of large number of grains per unit area, high physiological efficiency is needed during grain ripening. This kind of physiological efficiency is ensured through high yield fill rate (Sayre *et al.*,1998). Quick ripening, so essential to escape terminal heat at the time of grain maturity, also guarantee development of good grain size through tolerance against abiotic stress. A manifestation of both these attributes is the wheat variety PBW 343 (Mohan *et al.*, 2004). The study revealed that the grain filling period is an important but highly complex attribute and its contribution to yield varies in accordance with the environment. Since the direct effect for this trait is very high and positive in the NWPZ, direct selection for this trait can be exercised even when correlation is negative. Yield fill rate has not only high and positive correlation with yield but the direct effect is also very high and positive. However, a direct selection for this parameter will be difficult in the field. Indirect selection to cash on the positive effects on yield under NWPZ conditions can be exercised for yield fill rate through grains per unit area and well-partitioned phenology with more packing for vegetative growth. However, the indirect high to very high negative effect that yield fill rate gets through phonological attributes like heading (-1.01) and ripening period (-0.85) can not be overlooked though it can be minimised to certain extent through more grains per unit area and vegetative phase.

It looks relatively easy to breed varieties for the NEPZ where the yield is ultimately controlled by four traits i.e. grain size, grain development rate, vegetative phase and the yield fill rate. Besides direct selection, yield gain through grain size can also be maximised by indirect selection via heading and grain ripening period. By selecting genotypes of early flowering and extended ripening period, even the correlation of grain size with yield in the NEPZ can be established. Selection for such traits will also minimise the negative contribution that the % vegetative phase has on grain yield. With no compromise on grain size, varieties with similar phenology (early flowering, longer grain filling duration and less packing of vegetative phase) shall be suitable for slow rate of grain filling. Similar phenology in combination with good grain size but low rate of grain filling will indirectly strengthen the already very high effects of yield fill rate. Phenological development therefore, carries importance for varieties of the NEPZ. Role of phenological development and its manipulation for increasing wheat yield potential has been emphasised by many wheat workers (Renolds *et al.*, 1996; Slafer *et al.*, 1996; Richard 1996). The study supports the view point that it is relatively more convenient to capitalise on the characteristics that build yield under NEPZ conditions even if the breeding efforts are made under prevailing conditions of NWPZ. Wheat in the NEPZ region comes to heading 20 days earlier when compared to wheat grown in the NWPZ. When flowering goes early, there remains sufficient time to translocate the food reserves to the grains formed during short vegetative period. So the grain filling duration does not remain a limiting factor as in the adjoining zone. The authors have also noted earlier that the material bred in the NWPZ has an edge over NEPZ bread materials in terms of grains/m^2 and the elite gene pooled developed in these two regions express these attributes in general (Mohan and Jag Shoran, 2002). So when the material rich in grains/m^2 (as in case of NWPZ bred material) is tested in the NEPZ, the prospects of finding a better manifestation of genetic yield potential become brighter. The breeders from the NWPZ could release three varieties (I ID 2733, PBW 443 and PBW 343) in the adjoining zone since 1999 whereas it has been difficult for them to overtake the yield potential of PBW 343, a variety that reins NWPZ.

Conclusion

The hallmark germplasm suitable for timely sowing under irrigated condition have shown high yield potential in their respective zones falling within the Indo-Gangetic plains. Making use of the cool winter, the NWPZ varieties exert good yield potential through longer vegetative period that aids good tillering, biomass and eventually more number of grains per unit area. However, there is not much diversity for the yield component traits in varieties of this region and the varieties of adjoining NEPZ offer more choice to the farmers as they are not only more diverse in yield, plant height and grains per unit area but also register better growth rate that is crucial in varietal adjustment against abiotic pressures.

The yield route examined through direct or indirect effects on the yield and the inter-trait relationship in the hallmark germplasm of each zone is quite diverse. Among different yield components, grain filling period (fast ripening) and yield filling rate are the most crucial characters that govern yield in the NWIV, varieties. Even though combining these two attributes is not distinctly impossible as PBW 343 has stood all tests in this aspect, but high physiological efficiency through high yield fill rate can certainly be seen as a good reason for not finding a matching gene combination. Besides, yield filling rate that contributes maximum to grain yield in the whole Indo-Gangetic plains, yield in varieties of the adjoining zone i.e. NEPZ is also determined by grain weight, grain development rate and percent vegetative phase. Unlike NWPZ, varieties in this zone have longer grain filling period and slow filling in the individual grain will be desirable. Even for yield filling rate, a common trait in both the zones, the contributing traits are not common in two zones. While longer vegetative phase, slow vertical growth and higher grain number per unit area are the important traits related to yield fill rate in the NWPZ varieties, the route is quite different in the other zone. In NEPZ varieties, even though emphasis is on the longer grain filling period but this duration is to be enhanced without increasing the total duration. There is a ceiling on the total maturity period in the NEPZ also it correlates negatively with yield filling rate. Besides, breeder should never loose sight of grain weight in developing varieties for the eastern region.

The present analysis has made it clear that even though common trials are being conducted by the AICW&BIP for the Indo-Gangetic plains of India; the route to yield seems to be quite different in the constituent zones. This study to understand direct and indirect effect of the key characters and the inter-trait relationship in the existing popular varieties will help the wheat breeders in shaping their research programme for different needs of the mega-zones covered in the Indo-Gangetic plains.

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