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*Research Article*

# Genetic variability, correlation and path analysis studies for grain yield and morpho-physiological traits under moisture-stress conditions in bread wheat (*Triticum aestivum* L.) under north-western Himalayan conditions

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## Abstract

**In order to determine best selection criteria for moisture stress tolerance, thirty-one diverse genotypes including 27 bread wheat lines along with two triticale and one each of durum and barley were evaluated to assess different components of variability, correlation and path analysis using various morpho-physiological, grain yield and yield contributing traits in moisture-stress conditions under both field and controlled conditions. Analysis of variance revealed significant genotypic variation for all the traits studied under field and controlled conditions which indicated the presence of sufficient genetic variability amongst genotypes for these traits. Grain yield per plant, tillers per plant and harvest index exhibited moderate estimates for PCV, GCV, heritability and genetic advance while seedling dry weight exhibited high PCV and GCV coupled with high heritability and genetic advance. Based on correlation and path analysis, grains per spike, biological yield and harvest index emerged to be the important selection criteria under moisture stress conditions. Flag leaf area, peduncle length and dry matter accumulation also appeared to be the important traits based on their direct or indirect contributions towards grain yield.Most of the seedling traits showed positive correlations among themselves, but none showed significant positive correlation with biological yield, harvest index and grain yield per plant at maturity. Elite genotypes *viz.,* HPW 432, HPW 433, *Tarmori*, *Kanku*, Old Synthetic 26 and Old Synthetic 54 having good combination of important yield components and / or morpho-physiological traits could be utilized in the wheat improvement programme for enhancement of productivity under moisture-stress conditions.**

**Keywords:** Drought tolerance, selection, correlation, path, stem reserve mobilization

## 1. Introduction

Wheat (*Triticum aestivum* L.) belongs to family Poaceae and among one of the most important cereal crops around the world. It plays a crucial role in human nutrition. It occupies 220.89 million hectares of acreage with 775.9 million tons production globally (USDA 2021) and often regarded as the 'King of Cereals' due to its major role in food trade. With rising human population, increasing wheat production and procuring stable yields is still a challenge faced by many countries. However, wheat like many other crops encounters both biotic and abiotic stresses. Among abiotic stresses, moisture-stress is the major environmental stress affecting wheat production leading to reduced yields as compared to more than any other environmental stress. Drought or moisture stress is basically inadequacy of water availability required for normal plant growth and development. It can occur at any growth stage depending upon many factors. Two major factors influencing moisture stress is more or less is precipitation levels and temperature variation prevalent in an area (Langridge and Reynold s2021). It leads to depression in expression of full genetic potential of crops to higher yields. In dry or arid regions, wheat production can fall up to 50 to 90% of the crops' actual yield potential. About half of all the wheat grown throughout the world encounters moisture stress and around 20 million hectares of which experiences water shortages routinely (Braun *et al.,,* 2010; Cossani and Reynolds 2012).

Certainly for a very long time, the principal goal in wheat improvement programmes is to enhance drought tolerance. Wheat breeding programmes are aimed at enhancing genotypes capable of providing stable yields under variable agro-climatic conditions and stresses which can help improve wheat production (Inamullah *et al.,* 2006). Genetic improvement of crops like wheat for drought tolerance needs thorough examination of all possible variability present in the primary or different gene pool for agro-physiological constituent traits which could confer drought tolerance. Although, the balance of getting higher genetic gain in terms of yields on one hand and tolerance to drought severity at other has always been a challenge to the plant breeders.

Some genotypes can tolerate stress at early stages but are sensitive during flowering stage while some cannot tolerate stress at early stages but can tolerate moisture stress in their later stages (Sallam *et al.,* 2019). Hence, identification of traits responding to drought tolerance requires an efficient and effective selection criteria based on various morphological, physiological and biochemical traits for appropriate screening of potential germplasm for drought tolerance in wheat. According to the wheat scientists, seedling growth parameters like root length, shoot length , root:shoot ratio are influenced under drought stress, but the influence changes from variety to variety. Thus, selection of lines with the best performance under moisture-stress conditions could increase the production of rainfed areas (Noorka *et al.,* 2013; Ahmad *et al.,* 2014; Ahmed *et al.,* 2017; Trethowan *et al.*, 2018) under contrasting water regimes. Moreover, preliminary selection of morpho-physiological drought adaptive traits is very important for next generations. Therefore, this study was performed with purpose of drought stress evaluation in wheat cultivars for selection of superior cultivars and also determining the amount of drought stress effect on morphological traits, yield and yield components.

## 2. Material and methods

### *2.1 Experimental material and site*

The experimental material comprised of thirty one diverse genotypes including 27 bread wheat lines along with two triticale and one each of durum and barley procured from different sources. The material included some land races, released cultivars of Northern Hill Zone, some from national breeding programme and some pre-release advance lines from the on-going breeding programs. These thirty one genotypes varying in their adaptability and yield potential were laid out in randomized block design in field conditions during *rabi* 2017-18 where each genotype was grown in 1.0 m × 0.40 mplot with row to row spacing of 20 cm and standard agronomic practices were followed to raise the crop under moisture- stress conditions.

Table 1: Details of the experimental material along with source used in the study

| S.No. | Genotype | Pedigree | Source |
|---|---|---|---|
| 1. | HI 8381 | JO 'S'/AA 'S'//FGO 'S' | IARI, RS. Indore |
| 2. | HD 2009 | LR64A/NAI 60 | IIWBR, Karnal |
| 3. | HW 1085 | UNNATHKALYAN SONA*2//CPAN3057 | IARI, RS, Wellington |
| 4. | JW 3020 | C 306/C.B.SPRING(BW)84 | GAU, Junagarh |
| 5. | JWS 17 | SELECTION FROM HUW 334 | GAU, Junagarh |
| 6. | KO 307 | K8321/UP2003 | CSAUAT, Kanpur |

| | | | |
|---|---|---|---|
| 7. | RAJ 4120 | PBW 373/ V-1 | RAU, Durgapur |
| 8. | UP 2526 | HD 2009/Sonalika //HD 2329 | GBPUA& T, Pantnagar |
| 9. | VL 907 | DYBR1982-83842ABVD50/VW9365//PBW343 | VPKAS, Almora |
| 10. | WH 1080 | 21stSAWSN 151 | HAU, Hisar |
| 11. | HPW 432 | HS295X flw2-1 | RWRC, Malan |
| 12. | HPW 433 | VL-832X.PBW 498 | RWRC, Malan |
| 13. | HPW 422 | HPW 155×HD 29 | RWRC, Malan |
| 14. | HPW 368 | NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR | RWRC, Malan |
| 15. | HS 562 | OASIS/SKAUZ//4*BCN/3/2*PASTOR | IARI,RS, Shimla |
| 16. | HS 490 | HS 364/HPW 114//HS 240//HS 346 | IARI,RS, Shimla |
| 17. | Old Synthetic 26 | ACO89/AE. SQUARROSA | IIWBR , Karnal |
| 18. | Old Synthetic 54 | YAV2/TEZ//AE. SQUARROSA | IIWBR, Karnal |
| 19. | IC 594378 | RIL component line of WL 711/C306 | IIWBR, Karnal |
| 20. | IC 594379 | RIL component line of WL 711/C306 | IIWBR, Karnal |
| 21. | MLW 1356 | HPW 185 × HPW 211 | RWRC, Malan |
| 22. | *Kanku* | Local landrace | RWRC, Malan |
| 23. | *Desi Mundla* | Local landrace | RWRC, Malan |
| 24. | TL 2942 (TCL) | TL 2732/DT 54 | PAU, Ludhiana |
| 25. | TL 2969 (TCL) | JNIT 141/TL 1210//JNIT141 | PAU, Ludhiana |
| 26. | PDW 291 | BOOMER 21/ MOJO 2 | IIWBR, Karnal |
| 27. | BHS 352 (Barley) | HBL 240/BHS 504//VLB129 | IARI, RS, Shimla |
| 28. | Vorobey | Vorobey | CIMMYT Rainfed WheatImprovement Programme(Check) |
| 29. | *Tarmori* | Local Landrace | Local Landrace |
| 30 | HPW 89 | INTERMEDIO RODI / HD 2248 | RWRC, Malan |
| 31 | C 306 (C) | REGENT1974/3*//*2C591/3/P19/C 281 | CCS, HAU, Hisar |

### *2.2 Field experiment and phenotypic measurements*

Data were recorded on five competitive plants selected randomly from each plot in three replications on the following traits: days to 50% flowering (D50%F), plant height (PH), tillers per plant (NOT), flag leaf area (FLA), peduncle length (PL), days to 75 per cent maturity (D75%M), grains per spike (GPS), grain yield per plant (GY), 1000-grain weight (1000-GW), biological yield per plant (BY), harvest index (HI), stem reserve mobilization (SRM), dry matter accumulation (DMA) under field conditions. Observations were also recorded for Root length (RL), coleoptile length (CL), shoot length (SL), seedling dry weight (SDW), root-shoot ratio (RSR), seedling vigour index (SVI) and index of drought resistance (IDR) under controlled conditions at seedling stage.

### *2.3 Statistical Analysis*

The index of drought resistance was calculated based on 20-22 days old seedlings (on completion of two leaf stage) for the length of the seminal root (a), total length of first and second leaf (b) and the width of the first leaf (c). IDR was calculated over the standard variety C 306 by the method suggested by Latyuk (1989).

$$\text{IDR} = \frac{a / b\times c \text{ for the variety being studied}}{a / b\times c \text{ for standard variety}} \times 100$$

Further, observations recorded for the various traits were subjected to analysis of variance as per Panse and Sukhatme (1985). The genotypic, phenotypic and environmental coefficients of variation, heritability in broad sense ($h^2_{bs}$) and expected genetic advance (GA) resulting from the selection of 5 per cent superior individuals were estimated following Burton and De Vane (1953) and Johnson *et al.,* (1955). To determine the degree of association of traits with yield and among other traits, genotypic, phenotypic and environmental coefficients of correlation were computed as per Al-Jibouri (1958). The partitioning of the correlation coefficient into direct and indirect effects on grain yield of different traits was done following Dewey and Lu (1959).

## 3. Results and Discussion

Analysis of variance revealed significant variation among genotypes for all the traits under study evaluated under field conditions (Table 1), indicating wide range of variability present in the experimental material under moisture-stress conditions. Earlier, Ashfaq *et al.,*(2014) revealed significant genotypic differences for D50%F, FLA, PH, NOL, SL, PL, 1000-GW and GY. Rana *et al.,* (2014) also reported significant differences in GY and D50%F under moisture-stress conditions. Ghuttai *et al.,* (2015) showed significant genotypic differences for PH, FLA, SL, 1000-GW, BY and HI. Singh (2015) also showed significant genotypic differences for NOL, GPS, PH, 1000-GW, BY and HI under stress and non-stress environments. While analysis of variance for traits observed under controlled conditions indicated significant genotypic variation for RL, CL, SL, SDW, RSR, SVR and IDR, indicating significant genotypic differences for the all the seedling traits. Baloch *et al.,* (2016) also reported significant differences among treatments for CL, RSR and SVI.

Table 1: Analysis of variance for different characters in wheat genotypes

| **Sr. No.** | **Character** | **Replication** | **Treatment** | **Error** |
|---|---|---|---|---|
|  | **df** | 2 | 30 | 60 |
|  |  | **Field conditions** |  |  |
| 1. | D50%F | 12.462* | 69.397* | 2.240 |
| 2. | PH (cm) | 20.379* | 392.942* | 3.203 |
| 3. | NOT | 0.035 | 1.653* | 0.213 |
| 4. | FLA (cm$^2$) | 5.071* | 51.756* | 1.558 |
| 5. | PL (cm) | 0.462 | 63.392* | 1.424 |
| 6. | D75%M | 17.089* | 392.942* | 2.592 |
| 7. | GPS | 19.26* | 130.392* | 5.147 |
| 8. | GY (g) | 0.002 | 3.066* | 0.236 |
| 9. | 1000-GW (g) | 3.043 | 94.753* | 2.276 |
| 10. | BY (g) | 0.334 | 14.543* | 0.945 |
| 11. | HI (%) | 0.568 | 168.978* | 11.611 |
| 12. | SRM (%) | 3.597 | 208.458* | 8.111 |
| 13. | DMA (g) | 0.130 | 4.828* | 0.309 |
|  |  | **Controlled conditions** |  |  |
|  | **df** |  | 30 | 62 |
| 1 | RL (cm) |  | 133.08* | 1.60 |
| 2 | CL (cm) |  | 6.01* | 0.51 |
| 3 | SL (cm) |  | 0.64* | 0.03 |
| 4 | SDW (g) |  | 0.10* | 0.02 |
| 5 | RSR |  | 0.01* | 0.00 |
| 6 | SVI |  | 1599379.20* | 18889.94 |
| 7 | IDR (%) |  | 1657.30* | 90.65 |

*Significant at $P \leq 0.05$

### *3.1 Estimates of variability parameters*

Under field conditions, phenotypic coefficients of variation had generally greater, but closer values to their corresponding genotypic coefficients of variation values presented in Table 2, which indicated presence of lower environmental influence on the expression of these traits.Almost all the traits studied exhibited moderate level (10-30%) of PCV and GCV except D50%F (<10%). Heritability(broad-sense) estimates were found high (>60%) for all the traits while expected genetic advance expressed as percent of mean was recorded high (>30%) for FLA, PL and DMA. Moderate (10-30%) genetic advance estimates were recorded for rest of the characters except D50%F (<10%). High heritability coupled with high genetic advance was found for FLA, PL and DMAindicating that selection would be effective for these traits.

Among seedling traits under controlled conditions (Table 2), high (>30%)PCV and GCV estimates was recorded fortrait i.e.SDW only while rest of the characters exhibited moderate (10-30%) level of PCV and GCV except lower (<10%) estimates of GCV were recorded for CL and SL. All the seedling traits exhibited high (>60%) heritability (broad-sense). High (>30%) expected genetic advance expressed as percent of mean was recorded for RL, SDW, RSR and IDR while moderate estimates (10-30%) was found for CL, SL and SVI. High heritability coupled with high genetic advance was found for RL, SDW, RSR and IDR.

Table 2: Range, mean and variability parameters for different traits in wheat

| Sr No. | Characters | Mean ± SE | Range | PCV | GCV | $h^2_{bs}$ | GA (% of mean) |
|---|---|---|---|---|---|---|---|
| | | | **Field conditions** | | | | |
| 1. | D50%F | 115.83 ± **1.22** | 105.00-125.67 | 4.28 | 4.09 | 90.90 | 8.02 |
| 2. | PH (cm) | 92.66 ± **1.46** | 78.20-115.53 | 12.45 | 12.30 | 97.59 | 25.03 |
| 3. | NOT | 4.41 ± **0.38** | 3.53-6.20 | 18.89 | 15.72 | 69.30 | 26.96 |
| 4. | FLA ($cm^2$) | 25.66 ± **1.02** | 12.98-33.49 | 16.67 | 15.94 | 91.48 | 31.41 |
| 5. | PL (cm) | 16.24 ± 0.97 | 9.11-25.60 | 28.93 | 27.98 | 93.55 | 55.75 |
| 6. | D75%M | 92.66 ± **1.32** | 78.20-115.53 | 12.43 | 12.31 | 98.05 | 25.11 |
| 7. | GPS | 44.99 ± 1.85 | 32.87-55.73 | 15.22 | 14.36 | 89.02 | 27.91 |
| 8. | GY (g) | 6.43 ± **0.40** | 4.40-8.73 | 16.88 | 15.10 | 79.99 | 27.82 |
| 9. | 1000-GW (g) | 49.51 ± **1.23** | 40.00-64.00 | 11.62 | 11.22 | 93.12 | 22.30 |
| 10. | BY (g) | 16.44 ± 0.79 | 12.73-20.07 | 12.87 | 11.44 | 79.02 | 20.96 |
| 11. | HI (%) | 40.11 ± **3.35** | 3.57-57.10 | 18.76 | 15.73 | 70.32 | 27.17 |
| 12. | SRM (%) | 56.42 ± **2.33** | 42.26-77.35 | 15.33 | 14.84 | 89.17 | 28.18 |
| 13. | DMA (g) | 5.35 ± **0.45** | 3.00-8.22 | 25.18 | 22.94 | 82.99 | 43.04 |
| | | | **Controlled conditions** | | | | |
| 1 | RL (cm) | 36.40 ± 1.03 | 22.97-50.73 | 18.51 | 18.19 | 96.53 | 36.81 |
| 2 | CL (cm) | 2.06 ± 0.11 | 1.74-2.39 | 10.30 | 8.20 | 63.35 | 13.44 |
| 3 | SL (cm) | 13.92 ± 0.57 | 11.07-16.83 | 10.97 | 9.74 | 78.82 | 17.81 |
| 4 | SDW (g) | 0.15 ± 0.01 | 0.07-0.24 | 33.34 | 32.61 | 95.64 | 65.69 |
| 5 | RSR | 2.63 ± 0.15 | 1.63-3.57 | 18.48 | 17.19 | 86.50 | 32.93 |
| 6 | SVI | 5032 ± 107.6 | 3704.6-6495.3 | 14.67 | 14.43 | 96.81 | 29.25 |
| 7 | IDR (%) | 117.70 ± 6.77 | 53.54-169.53 | 20.78 | 19.55 | 88.51 | 37.89 |

### *3.2 Correlation studies*

Direct selection of traits based on yield alone is not effective in plant breeding programmes but requires further understanding of nature and magnitude of associations existing among these traits in a complex trait like yield in order to bring about genetic improvement. The magnitude of associations between traits under study in field conditions are depicted in the form of heat map (Fig. 1). GY showed significant positive correlation with GPS,BY and HI while significant negative correlation with PH and D75%M. This indicated that these traits can be used as indirect selection criteria to select high yielding genotypes under moisture-stress conditions. Positive and significant correlation of GY with GPS, BY and HI were also reported by earlier workers (Rana and Sharma 2001; Khan *et al.*,2010; Tripathi *et al.,* 2011; Ebrahimnejad and Rameeh 2016) under non-stress and moisture-stress environments.Recently, Rajput (2018) also found that GY had positive and significant association with 1000-GW and HI, whereas D75%M exhibited significant negative association with GY.Drought tolerant varieties are capable of sustaining high HI when subjected to drought stress conditions. Hence, HI may be considered important for varietal improvement for enhanced drought resistance and tolerance. Tillers per plant had significant positive correlation with 1000-GW and HI whereas significant negative correlation with FLA and D50%F highlighting the importance of high tillering genotypes to contribute towards higher grain weight under moisture stress. Jat and Dhakar (2003) observed positive and significant correlation of GY with NOT.GPS had significant positive correlation with BY whereas, significant negative correlation with 1000-GW, FLA, PH, PL and D75%M. Khan *et al.,* (2015) reported significant positive association of GY with GPS and 1000-GW and negative association with PH. 1000-GW showed significant positive correlation with FLA, PH, PL, D75%M, SRM and DMA, while non-significant correlation with GY. These results corroborate the findings of Chowdhry *et al.,* (2000) who found that there was poor relation between 1000-GW and GY, which was due to limited capacity of reservoir and lack of ability of their absorption of photosynthesis material. FLA showed significant positive correlation with PH, PL, D50%F, D75%M, SRM and DMA, but showed no correlation with GY. PH showed significant positive correlation with PL, D75%M and DMA. Bogale*et al.,* (2011) have reported significant and positive correlation between PH and PL. Parihar *et al.,* (2018) also showed positive significant correlation of PH with SL.PL showed significant positive correlation with D75%M and DMA, while it showed significant negative correlation with BY, while a non-significant correlation with GY. D50%F showed significant positive correlation with SRM and DMA, however no correlation was observed with GY. Contrary to the present findings, Boligon *et al.,* (2011) suggested that PH, D50%, D75%M maturity at heading stage might be effective selection criteria for drought tolerance in semi-arid regions. D75%M showed significant positive correlation with DMA, but significant negative correlation with GY indicating that early maturity is desirable trait under moisture stress conditions and late maturing genotypes are generally stress susceptible. SRM showed significant positive correlation with 1000-GW, FLA, D50%F and DMA. Gupta *et al.,* (2011) showed that drought tolerant genotypes of wheat had the higher capacity to mobilize its nutrients under drought stress. Noorka *et al.,* (2013) suggested SRM to be an important index of drought resistance. A genotype having higher capacity to mobilize its reserves may be considered to show good performance under drought stress. Srivastava at al. (2017) suggested that the genotypes with better SRM based on 1000-GW in the absence of photosynthesis may also provide good estimate of relative tolerance to drought. They also reported significant positive correlation between SRM and PL under drought conditions. DMA showed significant positive correlation with 1000-GW, FLA, PH, PL, D50%F, D75%M and SRM but no significant correlation with GY.

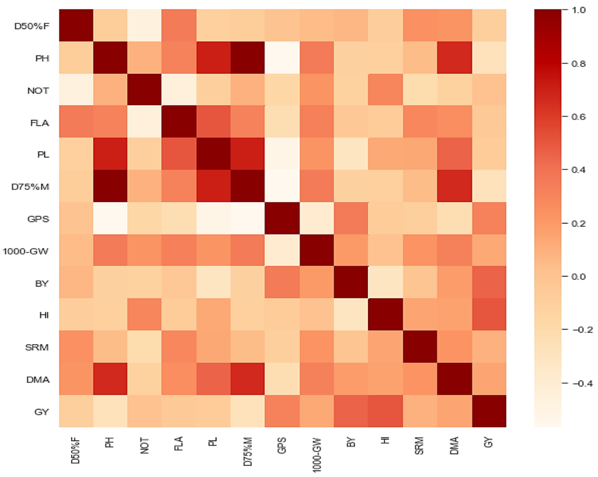

Fig.1: Coefficients of correlation among different characters in wheatunder field conditions

Under controlled conditions (Fig. 2), RL had significant positive correlation with SL, SDW, RSR, SVI and IDR. However, RL showed significant negative correlation with GY under field conditions, indicating that longer roots at seedling stage cannot be taken as an indicator of plant performance at maturity. Ahmad *et al.,* (2013) reported RL showed positive association with SL and CL.CL exhibited significant positive correlation with SL and SRM under moisture-stress conditions in field, while it showed negative correlation with RSR and IDR. SL exhibited significant positive correlation with SDW and SVI, whereas it showed negative significant correlation with RSR and IDR.SDW had significant positive correlation with RL, CL and SVI, while it showed negative correlation with SRM. In earlier studies, SDW showed positive correlation with GY. So, this character can effectively used as selection criterion for GY (Kumar *et al.,* 2018; Singh and Chaudhary 2006). Alom *et al.,* (2017) also reported that SDW maintained a significant positive correlation with SVI, SL and RL. RSR exhibited significant positive correlation with SVI and IDR. However, it showed significant negative correlation with GY. Ahmad *et al.,* (2013) reported positive association of RL with SL and CL. While SL had positive correlation with CL and SVI. Seminal root number and total RL were both positively associated with GPS, above-ground biomass and GY. More seminal roots and longer total RL were also associated with delayed maturity and extended grain filling, likely to be a consequence of more grains being defined before anthesis. SVI appeared to be an important character as it had significant positive correlation with IDR. While it showed significant negative correlation with GY under moisture-stress conditions. Kumar *et al.,* (2014) also suggested that seedling vigour of genotypes could be indicator of greater sensitivity to stress. Earlier, contrary to the present findings,SVI is suggested to be good parameter for selection of drought tolerant genotypes (Santha *et al.,* 2000).IDR had significant negative correlation with BY and GY.

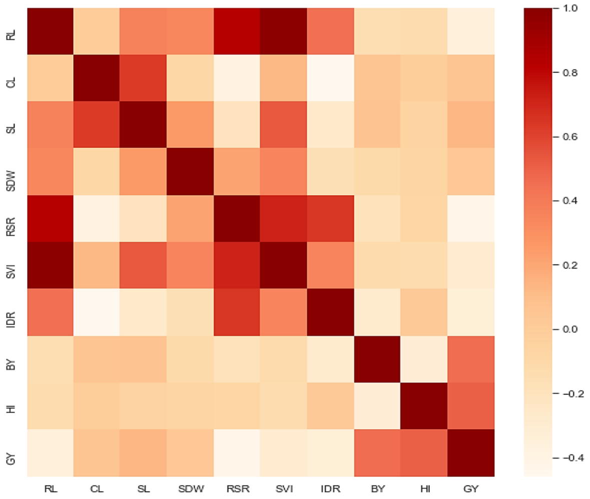

Fig.2: Coefficients of correlation among different characters in wheat for seedling traits

### *3.3 Path Analysis*

To get the idea about actual effects of a character on the GY, the estimates of direct and indirect effects through path analysis at phenotypic and genotypic level were worked out (Table 3). Association of various plant characters with the traits of major interest and economic importance like GY is the consequence of their direct and indirect effects. Hence, it becomes essential to partition such association into direct and indirect effects of component characters through path coefficient analysis. In the present study, residual effects for path coefficients were lower having values 0.19914 and 0.25583 at genotypic and phenotypic level, respectively indicating that the characters studied accounted for most of the variation in grain yield.

GPS had positive direct effects of substantial magnitude on GY and also had indirect positive effects of high magnitude *via* PH and BY and negative indirect effects *via*PL and D75%M while rest of indirect effects were of lower magnitude. Mohsin *et al.,* (2009) found that SL and GPS had positive direct effects on GY. All these studies including the present one indicate the importance of this character in selection of high yielding genotypes under both moisture-stress and non-stress conditions. The significant negative correlation of PH with GY was mainly due to high magnitude of negative direct effects which were partially counterbalanced by positive indirect effects *via* D75% M and PL. Mohammad *et al.,* (2005) reported that D75%M were negatively correlated at both genotypic and phenotypic levels with BY, HI and GY and the level of negative genotypic correlation was significant with HI and GY. PH showed negative genotypic and phenotypic correlation with HI and GY.

The high positive direct effects of BY and HI on GY at both phenotypic and genotypic level were the sole contributors in building their respective positive correlation with GY. These results corroborate the findings of earlier workers like Dorin*et al.,* (2007) revealed the highest positive direct effect of BY on GY followed by HI, 1000-GW and D50%F.

Table 3: Estimates of direct and indirect effects of different traits on grain yield at phenotypic (P) and genotypic (G) level

| | | NOT | GPS | 1000-GW | FLA | PH | PL | D50%F | D75%M | BY | HI | SRM | DMA | Correlation with yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NOT** | **P** | **-0.1337** | -0.0140 | 0.0261 | 0.0183 | -0.0439 | -0.0240 | 0.0430 | 0.0211 | -0.0749 | 0.1676 | 0.0036 | 0.0003 | -0.011 |
| | **G** | **-0.3372** | -0.0365 | 0.0664 | 0.1006 | -0.0568 | -0.0307 | 0.0596 | 0.0418 | -0.0755 | 0.2619 | 0.0134 | 0.0183 | 0.025 |
| **GPS** | **P** | 0.0161 | **0.1162** | -0.0449 | 0.0103 | 0.2507 | -0.1161 | -0.0006 | -0.1208 | 0.2120 | -0.0163 | 0.0021 | 0.0005 | 0.309* |
| | **G** | 0.0632 | **0.1946** | -0.1089 | 0.0487 | 0.3342 | -0.1762 | -0.0007 | -0.2453 | 0.2434 | -0.0647 | 0.0058 | 0.0368 | 0.331* |
| **1000-GW** | **P** | -0.0279 | -0.0417 | **0.1252** | -0.0152 | -0.1623 | 0.0502 | -0.0050 | 0.0783 | 0.1110 | 0.0142 | -0.0043 | -0.0008 | 0.122 |
| | **G** | -0.0831 | -0.0786 | **0.2695** | -0.0703 | -0.2117 | 0.0778 | -0.0054 | 0.1553 | 0.1402 | 0.0130 | -0.0147 | -0.0511 | 0.141 |
| **FLA** | **P** | 0.0506 | -0.0248 | 0.0394 | **-0.0483** | -0.1414 | 0.1154 | -0.0374 | 0.0677 | -0.0138 | -0.0465 | -0.0057 | -0.0006 | -0.045 |
| | **G** | 0.1668 | -0.0466 | 0.0932 | **-0.2034** | -0.1850 | 0.1683 | -0.0423 | 0.1362 | -0.0261 | -0.0429 | -0.0173 | -0.0409 | -0.040 |
| **PH** | **P** | -0.0126 | -0.0626 | 0.0437 | -0.0147 | **-0.4651** | 0.1597 | 0.0083 | 0.2233 | -0.0690 | -0.0692 | -0.0011 | -0.0015 | -0.261* |
| | **G** | -0.0335 | -0.1137 | 0.0997 | -0.0657 | **-0.572 4** | 0.2334 | 0.0087 | 0.4209 | -0.0759 | -0.0870 | -0.0020 | -0.1048 | -0.292* |
| **PL** | **P** | 0.0136 | -0.0572 | 0.0266 | -0.0236 | -0.3148 | **0.2359** | 0.0108 | 0.1511 | -0.1791 | 0.0832 | -0.0026 | -0.0010 | -0.057 |
| | **G** | 0.0316 | -0.1049 | 0.0641 | -0.1047 | -0.4085 | **0.3270** | 0.0130 | 0.3004 | -0.2184 | 0.1110 | -0.0083 | -0.0736 | -0.071 |
| **D50%F** | **P** | 0.0541 | 0.0006 | 0.0059 | -0.0170 | 0.0363 | -0.0239 | **-0.1062** | -0.0177 | 0.0399 | -0.0469 | -0.0045 | -0.0006 | -0.080 |
| | **G** | 0.1714 | 0.0012 | 0.0123 | -0.0733 | 0.0425 | -0.0361 | **-0.1174** | -0.0310 | 0.0454 | -0.0772 | -0.0148 | -0.0353 | -0.112 |
| **D75%M** | **P** | -0.0126 | -0.0628 | 0.0438 | -0.0147 | -0.4648 | 0.1596 | 0.0084 | **0.2234** | -0.0695 | -0.0685 | -0.0010 | -0.0015 | -0.260* |
| | **G** | -0.0335 | -0.1135 | 0.0995 | -0.0658 | -0.5726 | 0.2335 | 0.0087 | **0.4208** | -0.0756 | -0.0874 | -0.0020 | -0.1046 | -0.293* |
| **BY** | **P** | 0.0157 | 0.0386 | 0.0218 | 0.0010 | 0.0502 | -0.0662 | -0.0066 | -0.0243 | **0.6387** | -0.2262 | 0.0000 | -0.0004 | 0.442* |
| | **G** | 0.0391 | 0.0728 | 0.0580 | 0.0082 | 0.0668 | -0.1097 | -0.0082 | -0.0489 | **0.6510** | -0.2267 | 0.0007 | -0.0314 | 0.472* |
| **HI** | **P** | -0.0325 | -0.0027 | 0.0026 | 0.0033 | 0.0466 | 0.0284 | 0.0072 | -0.0222 | -0.2093 | **0.6901** | -0.0026 | -0.0004 | 0.508* |
| | **G** | -0.1146 | -0.0163 | 0.0045 | 0.0113 | 0.0646 | 0.0471 | 0.0118 | -0.0477 | -0.1915 | **0.7708** | -0.0098 | -0.0267 | 0.504* |
| **SRM** | **P** | 0.0231 | -0.0117 | 0.0263 | -0.0133 | -0.0236 | 0.0303 | -0.0231 | 0.0110 | 0.0006 | 0.0866 | **-0.0206** | -0.0005 | 0.085 |
| | **G** | 0.0775 | -0.0193 | 0.0680 | -0.0606 | -0.0196 | 0.0468 | -0.0299 | 0.0148 | -0.0082 | 0.1293 | **-0.0582** | -0.0374 | 0.103 |
| **DMA** | **P** | 0.0149 | -0.0231 | 0.0388 | -0.0123 | -0.2903 | 0.0965 | -0.0242 | 0.1402 | 0.1034 | 0.1042 | -0.0045 | **-0.0025** | 0.141 |
| | **G** | 0.0408 | -0.0474 | 0.0911 | -0.0550 | -0.3970 | 0.1592 | -0.0274 | 0.2911 | 0.1353 | 0.1362 | -0.0144 | **-0.1511** | 0.161 |

Residual effects (G) = 0.19914, Residual effects (P) = 0.25583, *Significant at P≤0.05

Gelancha and Hanchinal (2013) showed that BY, HI, D50%F and PH imparted significant direct influence on GY. The remaining traits affected GY rather indirectly, mainly through impact on total biomass production. Kumar *et al.,* (2016) also revealed the positive direct effect of NOT, BY and HI on GY.

Since none of the traits studied at seedling level showed desired positive correlation with GY under field conditions, path coefficient analysis was thought to be inconclusive, hence not conducted.

## Conclusion

The effectiveness of any breeding or selection programme requirescareful selection criteria depending on nature of variability and associations between different traits for grain yield. In this study, significant genotypic variationwere recorded for all the traits studied under field and controlled condition which indicated the presence of sufficient genetic variability amongst genotypes for these traits. Almost all traits exhibited moderate levels of PCV and GCV estimates while FLA, PL, DMA, RL, SDW, RSR and IDR had high heritability coupled with high genetic advance indicating importance of these traits for selection.FLA, PL and DMA also appeared to be the important traits based on their direct or indirect contributions towards GY.Most of the seedling traits like RL, SL and CL did not show correlation with GY under seedling stagebut exhibited significant correlations with other important traits influencing GY. Therefore, these traits can be further used as indirect selection criteria, to select high yielding genotypes at seedling stage. Therefore, based on correlation and path analysis (direct and indirect contributions) GPS, BY and HI emerged to be the important selection criteria under moisture stress conditions.

Out of the thirty one genotypes, elite wheat genotype HPW 432 exhibited a good combination of traits *viz.*GY, HI, early flowering and long PL under moisture stress conditions. HPW 433 was found to be superior for GY, FLA and early flowering. Local land race *Tarmori* was found to have a combination of NOT, 1000-GW, PH, PL, FLA and early flowering. Similarly, another local landrace *Kanku* also exhibited superiority for PH, HI, SRM and DMA. It has long roots, high RSR and SVI studied under controlled conditions. Elite drought tolerant genotype, Old Synthetic 26 was found to be superior for 1000-GW, FLA, PH, PL, SRM and DMA. As well as displayed a good combination of long RL, SL and SVI. Another genotype, Old Synthetic 54 was found to be superior for FLA, PL, PH and SRM. This genotype was also found to be superior for RL, RSR, SVI and IDR at seedling stage. HPW 89 was found to be superior for 1000-GW, PH, D75%M and SRM.

## Author contributions

Conceptualization of experimentation (DK & VR); Designing of the experiments (DK & AR); Experimental materials (DK, VR & AR); Execution of field experiments and data collection (DK & PG); Analysis of data and interpretation (DK & VR); Preparation of the manuscript (all authors).

## Conflict of interest

The authors declare no conflict of interest.

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