Australian Journal of Crop Science AJCS
AJCS 8(9):1266-1271 (2014) ISSN:1835-2707

Genetic diversity of agro-morphological characters in Indian wheat varieties using GT biplot

Rekha Malik*, Hemani Sharma, Indu Sharma, Sushila Kundu, Ajay Verma, Sonia Sheoran, Rajendra Kumar and Ravish Chatrath

Directorate of Wheat Research, Karnal-132001, India

***Corresponding author: rekhasmalik1@gmail.com**

Abstract

This study examined the extent of agro-morphological variations in Indian wheat varieties and graphically displayed the interrelationships among them at phenotypic level. 258 wheat varieties developed in last fifty years (1961-2010) for six different agro-climatic wheat sowing regions of India were characterized for Distinctness, Uniformity and Stability (DUS) using 20 agro-morphological characters. DUS descriptors such as waxiness on plant parts, plant height and growth habit were identified as prominent morphological determinants for genetic diversity in Indian wheat. Genetic variability among these varieties was assessed using GT biplot and ordination analysis. First two PC axes explained 36.9 % of the total multivariate variation during PCA. GT biplot grouped Indian varieties in four distinct groups for selected DUS traits majorly on the basis of waxiness on plant parts, plant height and growth habit. Patterns of descriptor states were found almost similar for six different agro-climatic regions. This suggested that selection criteria for high yielding genotypes led to selection of similar descriptors pattern for Indian wheat and is independent of external factors like climate and demography. This information on variability and correlations of DUS descriptors will be useful to evaluate germplasm at agro-morphological and to develop core collections of Indian wheat using highly variable DUS descriptors identified in this study.

Keywords: *Triticum aestivum*; DUS Descriptors; Genetic variability; GT Biplot; PCA.
Abbreviations: AICW&B IP_All India Coordinated Wheat and Barley Improvement Program; DAC_Department of Agriculture and Cooperation; DAS_Days after sowing; DUS_Distinctness, Uniformity and Stability; GT Biplot_Genotype x Trait Biplot; PCA_Principal component analysis; PC_Principal component; PPVFRA_Protection of Plant Variety and Farmers' Right Authority; PGH_Plant Growth; Au_col_Auricle colour; F_col_Foliage Colour; Leaf_attd_Flag Leaf attitude; HT_Height; Ear_L_Ear Length; Awn_L_Awn length; Leaf_L_Flag Leaf Length; Leaf_B_Leaf width_Leafsheath waxiness; Wax_BL_Leafblade waxiness; Wax-Ped_Peduncle waxiness; Glu_Pub_Outer Glume Pubescence; Sh_wid_Shoulder width; Shl_sh_ Shoulder Shape; BeakL_Beak Length; Phenol_Grain Phenol Test; Brush_L_Brush hair length; Gr.size_Grain Size; IPGRI_ International Plant Genetic Resources Institute; UPOV_The International Union for the Protection of New Varieties of Plants.

Introduction

Wheat is one of the most important cereal crops and its cultivation has been related to the development of the major civilizations all over the world. Wheat (*Triticum* spp.) breeding for high yielding varieties generally leads to reduce genetic diversity that can change gene frequencies of local and traditional wheat lines (Malik et al, 2013). It is, therefore, important to study genetic variability in wheat germplasm to meet the diversified goals such as increasing yield, wider adaptation, desirable quality, pests and disease resistance (Fufa et al., 2005). Growing numbers of candidate varieties and decrease in variability for morphological traits has led to the establishment of evaluation procedures, especially for their distinctness, Uniformity, and Stability (DUS) components. These morphological descriptors are displayed as presence/absence of character state to discriminate accessions during germplasm evaluation (Aghaee et al., 2010). UPOV and IPGRI (now, known as Bioversity International) recommend morphological characterization (DUS) as criteria to characterize and identify accessions for the estimation of genetic diversity in wheat (Schut et al., 1997). Multivariate analysis is the most commonly used approach for genetic variability estimation to illuminate the patterns of variation in germplasm collections. Among multivariate techniques, PCA and cluster analysis are preferred tools for morphological characterization of genotypes and their grouping on similarity basis (Mohammadi and Prasanna, 2003; Peeters and Martinelli 1989). Combination of these two approaches gives comprehensive information of characters which are critically contributing for genetic variability in crops (Rachovska et al., 2002). GT Biplot is another extensively used method to display graphical grouping of accessions for studying interrelationships among agro-morphological traits in various crops (Aghaee et al., 2010). In India, more than 300 bread wheat varieties have been developed and released through AICW&B IP programme for cultivation (Kundu et al., 2006). These varieties have been characterized at agro-morphological level for DUS descriptors on recommendation of PPVFRA, a nodal agency for crop varietal registration in India. The objective of this study was to examine efficacy of

Table 1. Indian wheat varieties used for detection of genetic diversity.

Wheat sowing region in India	Varieties developed and released during 1961-2010
North Western Plain Zone	Choti lerma, C 306, CPAN 1676, CPAN 3004, DBW 17, DL 153-2, Durgapura 65, GW 120, HD 1949, HD 1981, HD 2009, HD 2177, HD 2204, HD 2270, HD 2281, HD 2285, HD 2329, HD 2385, HD 2428, HD 2687, HD 2851, HD 1941, IWP 72, KALYANSONA, KRL 14, KRL 19, KHARCHIYA 65, KSML 3, LAL BAHADUR, MLKS 11, Motiya, PBW 12, PBW 120, PBW 138, PBW 154, PBW 175, PBW 222, PBW 226, PBW 299, PBW 343, PBW 373, PBW 396, PBW 509, PBW 54, PV 18, PBW 502, PBW 65, Raj 1972, Raj 1482, Raj 2184, Raj 3077, SAFED LERMA, SONAK, Sharbati Sonora, SKAML 1, SONORA 64, UP 2382, UP 301, UP 2338, UP 2425, UP 368, WG 357, WG 377, WH 157, WH 283, WH 291, WH 416, WH 533, WL 1562, WL 2265, WL 410, WH 542, WH 711, WR 544, WH 147, WL 711
Central Zone	AKW 1071, DL 788-2, D 134, DL 803-3, GW322, GW 10, GW 18, GW 40, GW 89, GW 366, GW 173, GW 190, GW 273, GW 496, GW 503, HD2278, HD 2236, HD 2327, HD 2864, HD 4530, HD 4672, HI 1500, HI 1531, HI 385, HI 617, HI 784, HI 1077, HW 2004, HI 1418, HI1454, HYB 65, HYB 633, J 1-7, JWS 17, J 24, J 405, Lerma Rajo, Lok 1, MP 4010, MACS 6145, NP 839, Narbada 4, NARMADA 112, NARMADA 195, Raj 821, RAJ 1114, TAWA 267
Peninsular Zone	Ajanta, AKAW 3722, AKW 381, DWR 16(Keerthi), DWR 39, DWR 162, DWR 195, HD 1925, HD 2189, HD 2501, HD 2781, HD 2833, HD 4502, HI 977, HUW 510,HW 657, K 9644, MACS 2496, NI 747-19, NI 917, NI 5439, NIAW 917, NI 5643, NIAW 34, NIAW 301, PBN 142, PBN 51, Raj 4037, Raj 4083, UP 215, VINATA
Southern Hill Zone	HD 2135, HW 741, HUW 318, HW 517, HW 1085
North Eastern Plain Zone	BW 11, DBW 14, DBW 16, DL 784-3, HD 1982, HD 2307, HD 2402, HD 2643, HD 2733, HD 2824, HD 2888, HDR 77, HP 1493, HP 1102, HP 1209, HP 1633, HP 1731, HP 1744, HP 1761, HUW 533, HUW 12, HUW 37, HUW 55, HUW 206, HUW 213, HUW 234, HUW 468, HW 2045, K 68, K 7903, K 8434, K 9006, K 9162, K 9351, K 9533, K 0307, K 78, K 9423, K 816, K 852, K 88, K 7410, K 8020, K 8027, K 8962, K 9107, K 9465, NP 852, NP 884, NW 1012, NW 1014, NW 2036, NW 1067, NW 1076, PBW 443, RW 346, RW 3016, RAJ 3765, SAGARIKA, Sonalika, UP 115, UP 262, UP 2003, UP 2113,UP 2121, UP 2565, UTKALIKA
North Hill zone	CPAN 1796, HB 208, HD 2380, HPW 89, HPW 147, HPW 184 , HPW 42, HS 86, HS 207, HS 240, HS 277, HS 295, HS 365, HS 375, HS 420, HS 1097 -17, HS 1138-6-4, NP 846, NP 818, RAJ 3777, SKW 196, UP 1109, VL 421, VL 616, VL 738, VL 804, VL 829, VL 832, VL 802, VL 401, VL 404, VL 719

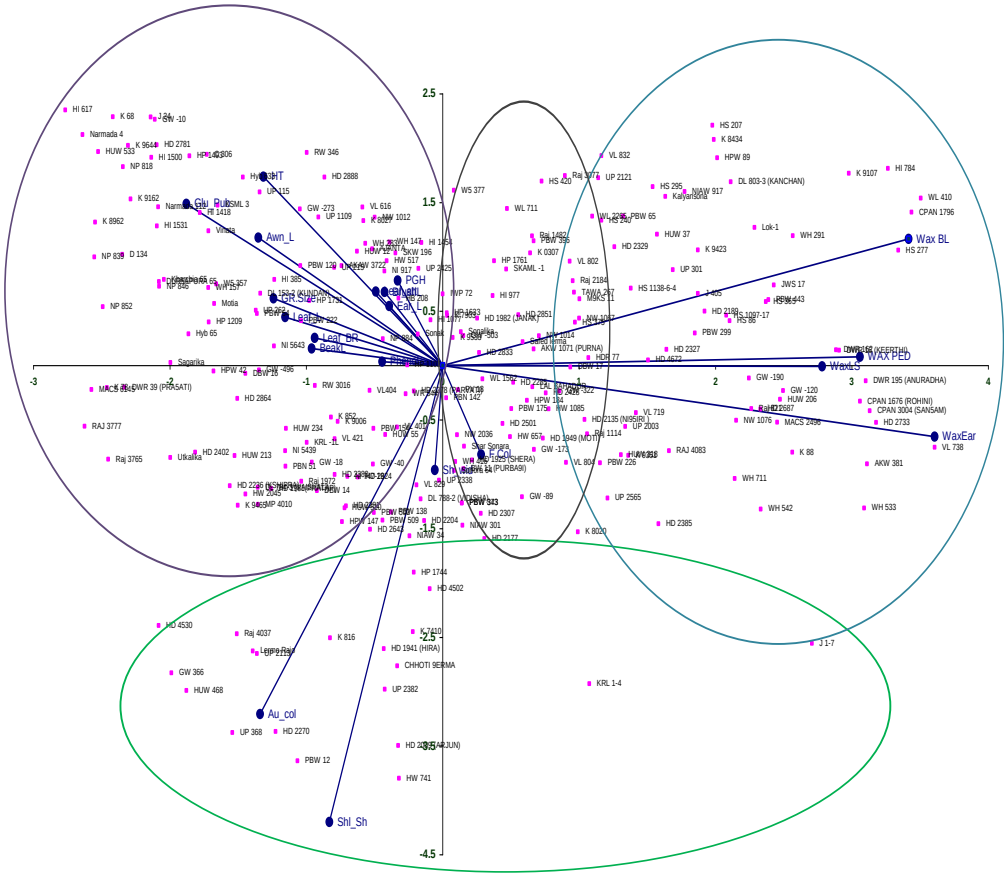

Fig 1. Genotype by trait biplot of 258 Indian wheat varieties on the basis of 20 agro morphological characters.

these DUS descriptors for agro-morphological variability in Indian wheat.

Results

Distribution of DUS descriptors in Indian varieties

The quantitative attributes for 20 DUS descriptors and their respective states were scored as numeric values for 258 wheat varieties as given in Table 3. The growth habit in Indian wheat ranged from erect to semi-erect and most of the varieties were grouped in semi-erect state. Height of Indian wheat varieties mostly ranged between medium to long (90-120 cm) and only 5% lines were categorized in tall category (>120 cm). 90% Indian varieties showed medium Leaf_L (20-30 cm) and Leaf_BR (1.0-1.5 cm) with varying Leaf_att from erect to semi-drooping. The genotypes showed marked variability for presence of Wax_Ear, Wax_LS and Wax_BL with levels ranging from absence of wax to very strong state. Morphological characters like Beak L, Brush L, Gr size and waxiness on plant parts were found evenly distributed. The prominent states of descriptors for Indian wheat varieties were absence of auricle colour; medium grain size, awn length and leaf width; narrow flag leaf; semi-erect spreading and green colour of foliage. Almost similar distribution was observed for DUS descriptors across six wheat sowing regions of India with minor exception like waxiness on peduncle in varieties developed for southern hilly regions of India.

Principal Component Analysis for DUS descriptors variability

During PC, variance for two principal components, PC1 and PC2, were scored 24.55% and 11.4%, respectively. Cumulative variance of first two PCA was found 36.9% (Table 4). The first PC was found more related to Wax_Ear, Wax_LS, Wax_BL and Wax_Ped as reflected for PC1values and gave high contributing factor loadings for Wax_Ear, Wax_LSWax_BL and Wax_Ped. Similarly, second principal component (PC1) accounted high contributing factor loadings for PGH, HT, Awn_L and Glu_Pub. DUS characters with high positive or negative load contributed more for the diversity and were the most differentiated descriptors in the clusters.

Correlations among DUS descriptors

A GT biplot was constructed by plotting PC1 scores against PC2 scores for each genotype (258) and each trait (20) as shown in Fig 1. Genotype by trait biplot explained total 36.9% variation. DUS characters like Wax_BL, Wax_Ped, Wax_LS, Wax_Ear, Shl_Sh etc. were placed at long vectors in GT biplot and found most discriminating for Indian wheat. Short vectors were scored for characters like Beak_L, PGH, Shl_Sh, Glu_Pub etc. and revealed less variation. Characters like Wax_BL, Wax_Ped, Wax_LS, Wax_Ear at an acute (<90°) angles with Shl_Sh, Sh_wid, F_col indicated almost similar variations. Correlation between plant height and waxiness was found negative with an obtuse angle. Positive correlations were observed among presence of wax on plant parts. Descriptors like Wax_BL, Wax_Ped, Wax_LS, Wax_Ear, and Au_col, Shl_Sh, Sh_wid, F_col were found at an obtuse (>90°) angles with each other and indicated incompatible variation within these characters.

Characters like HT and F_col with a near-right angle with Au_col, Wax_BL, indicated variation more or less independent of each other. The GT biplot grouped Indian wheat genotypes into 4 major groups.

Group1(mostly tall genotypes with strong waxiness, erect habitat and green foliage colour)

Group2(genotypes with medium Flag leaf (length and Breadth), weak/Absent waxiness and sloping shoulder shape)

Group3(genotypes with either strong or absent Glume Pubescence, dark green/green foliage colour and long flag leaf)

Group 4(genotypes having strong waxiness on peduncle either absent or weak waxiness on Leaf Blade and Ear)

Discussion

This study was aimed to evaluate genetic variability of Indian wheat varieties on the basis of DUS characters. Quantitative characteristics studied show significant variation among genotypes and efficiently grouped them at agro-morphological level. Most of the Indian varieties showed medium to long plant height, erect to intermediate growth habits, medium length and breadth of flag leaf, erect to semi erect leaf attitude, green foliage colour and medium size grain. Almost similar patterns of DUS descriptors were observed for varieties developed for different agro-climatic regions of India. This indicated that irrespective of demography or climate, selection criteria for high yielding genotypes led to selection of similar DUS descriptors. Only exception observed was presence of wax on peduncle that was found only in varieties cultivated in southern hill region of India. Descriptors like waxiness on plant parts, plant height, foliage colour, plant growth habit, flag leaf and seed size were found important in contributing genetic variability in Indian wheat. In previous report also, phenotypic characters important for diversity studies were identified in rice genotypes (Moukoumbi et al., 2011) during variability studies. During PC analysis first two PCs were found important when most significant variables in the components represented by high loadings were taken into consideration in evaluating each PC. The overall PC analysis found waxiness on plant parts Wax_Ear, Wax_LS,Wax_BL and Wax_Ped as important for genetic diversity studies in wheat because they revealed maximum variability among selected descriptors in each PC. These traits should be important and taken into account during phenotypic scoring in future Indian wheat variability studies. Characters like Leaf_att, Ear_L, Sh_wid, BrushL, F_col and PGH revealed low PC and lesser phenotypic variation. Therefore, these characters should be taken into consideration while selecting parental lines for wheat improvement program to incorporate genetic variability. PCA estimates observed in present study were found similar with previously reported cluster analysis of Indian wheat genotypes for DUS descriptors (Malik et al., 2013). They reported clustering as useful method to look for morphological variation in wheat to identify new source of variation for breeding purposes. In another study for genetic variability in wheat, gluten, semolina and softening of grains were reported as most significant traits for quality traits in durum wheat (Mangova and Petrova, 2007). Previous studies accounted significance of genotype by trait biplot based evaluations of agro-morphological traits in wheat, sweet potato and potato (Afuape et al., 2011).We observed total 36.9% variation during genotype x trait biplot for 258 Indian wheat varieties

Table 2. Agro-morphological characters, their states and numerical codes characterized in Indian wheat varieties.

S.No.	Characters	Descriptor	Abbreviation
1	Plant growth habit	1 Erect 3 Semi-erect 5 Intermediate 7 Semi- spreading 9 Spreading	PGH
2	Height (cm)	1 Very short (<75.0) 3 Short (75.1-90.0) 5 Medium (90.1 – 105.0) 7 Long (105.1 -120.0) 9 Very Long (>120.1)	HT
3	Foliage colour	1 Pale green 5 Green 9 Dark green	F Col
4	Auricle colour	1 Absent 5 Medium 9 Very Strong	Au_col
5	Ear length (cm)	1 Very short (<6.0) 3 Short (6.1-8.0) 5 Medium (8.1 – 10.0) 7 Long (10.1 -12.0) 9 Very Long (>12)	Ear_L
6	Awn length (cm)	1 Very short (<6.0) 3 Short (6.1-7.5) 5 Medium (7.6 – 9.0) 7 Long (9.1 -10.5) 9 Very Long (>10.5)	Awn_L
7	Flag leaf attitude	1 Erect 3 Semi-erect 5 Semi-drooping 7 drooping	Leaf_att
8	Flag leaf length (cm)	1 Short (<20) 5 Medium (20-30) 9 Long (>30)	Leaf_L
9	Leaf breadth (cm)	1 Narrow (<1.5) 5 Medium (1.01-1.5) 9 Broad (>2.0)	Leaf_BR
10	Ear waxiness	1 Absent 3 Weak 5 Medium 7 Strong 9 Very strong	Wax_Ear
11	Leaf sheath waxiness	1 Absent 3 Weak 5 Medium 7 Strong 9 Very strong	Wax_LS
12	Leaf blade waxiness	1 Absent 3 Weak 5 Medium 7 Strong 9 Very strong	Wax_BL
13	Peduncle waxiness	1 Absent 3 Weak 5 Medium 7 Strong 9 Very strong	WAX_Ped
14	Outer Glume Pubescence	3 Absent 5 Medium 7 Very Strong	Glu_Pub
15	Shoulder width	1 Absent 3 Narrow 5 Medium 7 Broad 9 Very broad	Sh_wid
16	Shoulder Shape	1 Sloping 3 Round 5 Straight 7 Elevated 9 Indented	Shl_Sh
17	Beak Length (mm)	1 Very short (<1) 3 Short (1-3) 5 Medium (3-5) 7 Long (5-7) 9 Very long (>7)	BeakL
18	Brush hair length	3 Absent 5 Medium 7 Long	BrushL
19	Grain size (mm)	3 Small (<35.0) 5 Medium (35.1-40) 7 Large (40.1-45) 9 Very large (>45)	GR.Size
20	Grain phenol test	1 Nil 3 Light 5 Medium 7 Dark 9 Very dark	Phenol

and 20 DUS descriptors. Lesser values of variability for morphological traits are expected as genotypes selected in this study are the elite Indian varieties. These varieties have been bred for high yield during breeding program that mainly depends on selection of better yielding parental lines with almost similar agro-morphological traits. GT Biplot grouped Indian wheat varieties in four clusters and graphically displayed the interrelationships among traits as reported in earlier studies for wheat (Aghaee et al., 2010: Zarkti et al., 2010 & Malik et al., 2013). Waxiness on plant parts was observed as the most variable phenotypic trait with long vectors in Indian wheat varieties and corroborated the observation of PCA. Descriptors like Beak_L, PGH, Shl_Sh, Glu_Pub etc were found less variable with relatively short vectors. Group one mainly included old or obsolete tall varieties once cultivated prior to green revolution in India and rest three groups clustered varieties developed during post green revolution time in India. This era of wheat program in India witnessed mainly semi-dwarf varieties like WL 711, WH 147, Lok 1, HD 2329, PBW 343, and PBW 373 with high yield (Jain, 2009). Genotype x trait biplot was reported as effective multivariate approach to assess phylogenetic diversity and relationship among 40 rice accessions of Nigeria (Ogunbayo et al., 2005). In another study, Ahmad et al. (2008) characterized barley accessions for qualitative and quantitative traits and explored significant variation in morphological traits for selection and breeding using GT biplot.

Materials and Methods

Plant materials

258 elite varieties developed and released in last fifty years under AICW&BIP, India were used for to estimate of genetic variability (Table 1). The plant material was sown in experimental plots at Directorate of Wheat Research, Karnal (29˚42'N, 77˚02'E). The experimental design was randomized block design with three replications for 6 lines of 6 m for each entry. Recommended cultural practices used for the characterization included fertilizer NPK (15-15-15) as basal application at a rate of 200 kg ha- 1 during land preparation and urea was applied at the rate of 50 kg ha-1 as top dressing at 14 DAS (first weeding) and at panicle initiation. Selected wheat varieties were scored for agro-morphological characters for three consecutive crop seasons (2003-06) under DAC funded project (Kundu et al., 2006).

Statistical Analysis

Total 20 DUS descriptors were used for variability analysis and data were recorded. Scoring values for each state of selected descriptor were given discrete number value to generate numerical dataset as shown in table 2. Correlation matrix was used to define the patterns of variation among genotypes using statistical software SAS, version 9.3 in the PCA analysis (SAS institute, 2006; Ward, 1963 ; Rachovska et al. 2003). The first two PC (PC1 and PC2) were used to generate a GT Biplot to display the genetic variability among wheat genotypes at phenotypic level (Gabriel, 1971). PC1 and PC2 were scaled so that values are symmetrically distributed between the genotype scores and trait scores. Both the accession and attribute in plotting point can be interoperated as vector on the biplot where the origin of biplot represents average value of all attributes (Delacy et al., 2000). The length of each vector is proportional to how well the each vector is model and the angels of the vector. The cosine of the angle between the vectors of two traits measured the similarity or the correlation between them relative to their variation among genotypes. An angle of zero indicated a correlation of +1, an angle <90° suggests a positive correlation, an angle of 90° indicates no (0) correlation, implying independence, an angle >90°

Table 3. Distribution of agro-morphological characters in Indian wheat varieties (indicated in numbers).

Agro-Morphological Character		Descriptor state and number of varieties in parenthesis				
		1	3	5	7	9
Early Growth Habit (PGH)		Erect (86)	Semi-erect (139)	Intermediate (32)	Semi-spreading (1)	Spreading (0)
Plant Height in cm (HT)		Very short: <75 (1)	Short: 75.1-90.0 (3)	Medium: 90.1- 105 (92)	Long : 105.1-120 (146)	Very long:>120 (16)
Foliage colour (F Col)		Pale green (16)	-	Green (210)	-	Dark green (32)
Auricle Colour		Absent (223)	-	Medium (13)	-	Very strong (22)
Ear Length Ear_L (cm)		Very short: <6.0 (0)	Short: 6.1-8.0 (5)	Medium: 8.1-10 (48)	Long : 10.1-12 (168)	Very long :>12 (37)
Awn Length Awn_L (cm)		Very short <6 (3)	Short: 6.1-7.5 (58)	Medium: 7.6-9 (169)	Long: 9.1-10.5 (21)	Very long>10.5 (7)
Flag Leaf	Leaf_att	Erect (27)	Semi-erect (121)	Semi-drooping (110)	Drooping (0)	-
	Leaf_L (cm)	Short: <20 (1)	-	Medium: 20-30 (230)	-	Long: >30 (27)
	Leaf_BR (cm)	Narrow (0)	-	Medium:1-1.5 (230)	-	Broad >2.0 (28)
Wax	Wax_Ear	Absent (43)	Weak (47)	Medium (111)	Strong (27)	Very strong (30)
	Wax_LS	Absent (0)	Weak (26)	Medium (87)	Strong (82)	Very strong (63)
	Wax_BL	Absent (152)	Weak (36)	Medium (41)	Strong (14)	Very strong (15)
	WAX_PED	Absent (3)	Weak (37)	Medium (79)	Strong (83)	Very strong (56)
Outer Glume	Glu_Pub		Absent (228)	Medium (13)	Very strong (17)	
	Sh_wid	Absent/Very narrow (5)	Narrow (119)	Medium (99)	Broad (1)	Very broad (34)
	Shl_Sh	Sloping (81)	Round (63)	Straight (61)	Elevated (53)	Indented (0)
	Beak L (mm)	Very short: <1 (3)	Short: 1-3 (32)	Medium: 3-5 (140)	Long: 5-7 (77)	Very long >7 (6)
Grain	Brush Hair Length	-	Absent (62)	Medium (160)	Long (36)	-
	GR. Size (mm)	-	Small <35 (46)	Medium: 35-40 (158)	Large: 40-45 (54)	Very large (0)
Quality	Phenol	Nil (0)	Light (0)	Medium (115)	Dark (113)	Very dark (30)

Table 4. Principal components (PC1 and PC2) for 20 DUS descriptors in Indian wheat varieties.

DUS Descriptor	PC1	PC2
PGH	-0.044	0.123
Au_col	-0.177	-0.504
F Col	0.037	-0.128
Leaf_att	-0.065	0.107
HT	-0.174	0.273
Ear_L	-0.052	0.086
Awn_L	-0.179	0.185
Leaf_L	-0.153	0.070
Leaf_BR	-0.124	0.039
Wax_Ear	0.477	-0.102
Wax_LS	0.368	-0.001
Wax_BL	0.452	0.183
Wax_Ped	0.405	0.012
Glu_Pub	-0.248	0.234
Sh_wid	-0.007	-0.151
Shl_Sh	-0.110	-0.660
BeakL	-0.127	0.024
Phenol	-0.058	0.005
BrushL	-0.056	0.106
Gr size	-0.164	0.097
Eigen Values	> 1	> 1
% Variance	24.65	12.35
Cumulative % Variance	24.65	36.90

indicates negative correlation, and an angle of 180° represents a correlation of -1.

Conclusion

DUS characters identified for Indian wheat are found sufficiently discriminating and diverse to describe agro-morphological variability in this study. Morphological characters like waxiness on plant parts, plant height and growth habit are found as important phenotypic markers for genetic variability and germplasm evaluation. These descriptors should necessarily be considered for breeding program, varietal discrimination and formulation of core sets of Indian wheat. Multivariate techniques, PCA and GT biplot, used in this study effectively described the variability for DUS descriptors in Indian wheat varieties. Varieties grouped on the basis of descriptors like plant height and waxiness using GT biplot demarcated pre and post green revolution era of Indian wheat program. Almost similar descriptors patterns are observed in selected varieties although these have been developed for six different agro-climatic Indian conditions still. It is, therefore, suggested that selection criteria for high yielding genotypes eventually lead to selection of plant type with similar descriptors pattern and is independent of external factors like demography and climate. Sufficient genetic variability observed at morphological level in wheat varieties developed in last fifty years concluded major contribution of coordinated wheat improvement program in India.

Acknowledgements

The authors thankfully acknowledge the financial support provided for this study under Protection of Plant Variety and Farmers' Right Authority (GOI) and Agri-Bioinformatics Promotion Program by Bioinformatics Initiative Division, Department of Electronics and Information Technology (GOI), New Delhi.

References

Afuape SO, Okocha PI, Njoku D (2011) Multivariate assessment of the agro-morphological variability and yield components among sweet potato (*Ipomoea batatas* L. Lam) landraces. Afr J Plant Sci. 5(2):123-132.

Aghaee M, Mohammadi R, Nabovati S (2010) Agro-morphological characterization of durum wheat accessions using pattern analysis. Aust J Crop Sci. 4: 505-514.

Ahmad Z, Ajmal SU, Munir M, Zubair M, Shahid M (2008) Genetic diversity for morpho-genetic traits in barley germplasm. Pak J Bot. 40(3): 1217-1224.

Delacy IH, Skovmand B, Huerta J (2000) Characterization of mexican wheat landraces using agronomically useful attributes. Genet Resour Crop Evol. 47: 591-602.

Fufa H, Baenziger PS, Beecher BS, Dweikat I, Graybosch RA, Eskridge KM (2005) Comparison of phenotypic and molecular marker-based classifications of hard red winter wheat varieties. Euphytica. 145: 133- 146.

Gabriel KR (1971) The biplot graphic display of matrices with application to principal component analysis. Biometrika. 58: 453-467.

Jain N, Yadav R (2009) Genetic diversity analysis among pre-green revolution. Crop Pasture Sci. 60: 373-381

Kundu S, Shoran J, Mishra B, Gupta RK (2006) Indian wheat varieties at a glance. Directorate of wheat Research, Karnal – 132001, Indian Research Bulletin No. 21: 447.

Mangova M, Petrova I (2007) Detection of quality diversity of durum wheat (*Triticum durum* Desf.) using cluster and principal component analyses. Bulg J Agric Sci. 13: 301-308.

Malik R, Sharma H, Verma A, Kundu S, Sharma I, Chatrath R (2013) Hierarchical clustering of Indian wheat varieties using morphological diversity assessment. Indian J Agric Res. 47(2): 116-123.

Mohammadi SA, Prasanna BM (2003) Analysis of genetic diversity in crop plants-salient statistical tools and considerations. Crop Sci. 43: 1235-1248.

Moukoumbi YD, Sie M, Vodouhe R, Dri BN, Toulou B, Ogunbayo SA, Ahanchede A (2011) Assessing phenotypic diversity of interspecific rice varieties using agro-morphological characterization. J Plant Breeding Crop Sci. 3(5): 74-86.

Ogunbayo SA, Ojo DK, Guie RG, Oeylakin OO, Sanni KA (2005) Phylogenetic diversity and relationships among 40 rice accessions using morphological and RAPD techniques. Afr J Biotechnol. 4: 1234-1244.

Peeters JP, Martinelli JA (1989) Hierarchical cluster analysis as a tool to manage variation in germplasm collections. Theor Appl Genet. 78: 42-48.

Rachovska G, Dimova D, Bojinov B (2003) Application of cluster analysis and principal component analysis for evaluation of common winter wheat genotypes. Proceedings of the scientific session of jubilee 2002-Sadovo, volume III: 68-72 (Bg).

SAS institute. (2006) SAS/STAT user's guide: Statistics. Version 9.1.3. SAS Inst., Cary, NC.

Schut JW, Oi X, Stam P (1997) Association between relationship measures based on AFLP markers, pedigree data and morphological traits in barley. Theor Appl Genet. 95: 1161-1168.

Ward J (1963) Hierarchical grouping to optimize an objective function. J Am Stat Assoc. 38: 236–244.

Zarkti H, Ouabbou H, Hilali A, Udupa SM (2010) Detection of genetic diversity in Moroccan durum wheat accessions using agro-morphological traits and microsatellite markers. Afr J of Agril Res. 5(14): 1837-44.