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RESEARCH ARTICLE

Genetic diversity of landraces of wheat (*Triticum aestivum* L.) from hilly areas of Uttaranchal, India

P. Routray · O. Basha · M. Garg · N. K. Singh · H. S. Dhaliwal

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Abstract Seed samples of 27 landraces of wheat were collected from farmers' fields of hilly areas of Himalaya in Uttaranchal state of India during April 2004. Genetic diversity among 41 genotypes (cultivars and landraces of wheat) was studied using morphological traits, microsatellite markers and SDS-PAGE of HMW-GS. The dendrogram and PCA (Principal Component Analysis) based on morphological data clearly separated landraces of wheat from cultivars. In the dendrogram based on microsatellite markers data all the wheat cultivars released after the introduction of high yielding dwarf wheat varieties from CIMMYT, used in this study, were grouped separately with the exception of NP4. The pre-green revolution indigenous varieties grouped with landraces suggesting that the same had been probably developed through selection among landraces in India. The landraces had higher diversity for HMW-glutenin subunits coded by *Glu-B1*, with distinct subunit combinations 6 + 8, 7 + 9, 13 + 16, than within the wheat cultivars analyzed. Most of the landraces except IITR10 and IITR14 are clearly distinct from the indigenous and modern wheat cultivars released in India in the 20th century. More than half of the landraces were heterogeneous mixture of plants with different glume color, awnness, grain color and HMW-GS profile and hence need purification through single plant selection. Some of the landraces with resistance to yellow rust and powdery mildew and distinct HMW-GS subunits can be used in appropriate breeding programs. It will be desirable to conserve and protect the landraces as geographical indications of Uttaranchal.

Keywords Diversity · Landraces · Microsatellite · Morphology · *Triticum* · Wheat

P. Routray · O. Basha · N. K. Singh · H. S. Dhaliwal (✉)
Department of Biotechnology, Indian Institute of Technology Roorkee, Roorkee 247 667, Uttranchal, India
e-mail: hsdhafbs@iitr.ernet.in; hsdhaliwal76@hotmail.com

M. Garg
Laboratory of Plant Genetics and Breeding Science, Faculty of Agriculture, Tottori University, Tottori 680-8553, Japan

Introduction

The primitive cultivars, landraces and wild relatives of crop plants constitute a pool of useful genetic variability required for the effective breeding programs. Most of the rich plant biodiversity which supported agriculture for the past 9000 years has been eroded or being rapidly eroded due to the introduction of new high yielding varieties (HYVs). Such erosion could have serious consequences, both on the genetic vulnerability of

crops to changes in the spectrum of pests and diseases and on their plasticity to respond to future changes in climate or in agricultural practices (Clunies-Ross 1995; Tripp 1996; Smale and McBride 1996). The danger of erosion of genetic resources was recognized as early as 1974 when the Consultative Group on International Agricultural Research established International Board of Plant Genetic Resources with a view to develop a global network of genetic resources centers.

The National Bureau of Plant Genetic Resources, New Delhi has been organizing a number of expeditions to various places within India to collect landraces of wheat and other plants, only some of which are being actively maintained and utilized. To the best of our knowledge, no such expedition has been sent for collection of wheat landraces in the remote Garhwal Himalayan Hills of Uttaranchal state keeping in view the limited area under wheat. At the suggestion of a visiting team of Japanese scientists of Tottori and Okayama Universities, some remote Himalayan hills of Uttaranchal state were explored for the collection of wheat and barley landraces. Seeds of landraces were either collected directly from the standing wheat crop at the farmer's field ready for harvest or seed samples for the unripe crop were taken from the grains stored for home consumption after wheat sowing. The present article deals with the genetic diversity analysis of landraces of wheat (*Triticum aestivum*) collected recently from the remote areas of Himalaya in Uttaranchal state of India based on morphological traits, high molecular weight-glutenin subunits (HMW-GS) and microsatellite markers.

Material and methods

Seed material and field experiments

Seed samples of 27 landraces of wheat were collected from farmers' fields of hilly areas of Himalaya in Uttaranchal state of India during April 2004 and were given Indian Institute of Technology Roorkee (IITR) accession numbers. The detail information about site of collection is given in Fig. 1. The landraces were collected purely on the basis of gross morphology including plant height, awnness, seed color etc. and information from farmers cultivating them. Only those wheat plots with taller plants, fewer tillers per plant, smaller spikes and seeds raised under rainfed and limited irrigation and fertilizer conditions for specific purpose from the village or regional seed source were considered as the landraces and sampled.

These landraces were grown along with 14 wheat cultivars developed and released in northern India during the 20th century, at the Department of Biotechnology Research farm, Indian Institute of Technology, Roorkee, India during winter season of 2004–2005 with a plant-to-plant distance of 10 cm and row-to-row distance of 23 cm.

Recording of morphological and disease data

Data from five morphologically similar and competitive plants of each of the genotypes was recorded for plant height (cm), days to flowering (in days), no. of tiller/plant, no. of spikelets/spike, spike length (cm), leaf color, growth habit, seed color, 1000 grain weight (g) and awnness. The data on leaf rust and yellow rust on each line was recorded under field conditions at the adult plant stage as the per cent leaf area covered with rust uredia using modified Cobb's scale as developed by Peterson et al. (1948). The rust reaction of each line was recorded as follows—0: resistant, no infection; R: resistant, necrotic areas with or without minute uredia; S: susceptible, large uredia without necrosis or chlorosis and t: trace severity.

Microsatellite markers analysis

DNA was extracted from leaves of five uniform plants of each genotype in bulk using a modified CTAB method (Saghai-Maroof et al. 1984). Nine microsatellite primer pairs were used, which were randomly chosen from a set of primers available with Dr. P.K. Gupta (CCS University, Meerut, India).

Polymerase chain reaction

The DNA amplification of wheat genotypes for each primer pair was carried out in a volume of

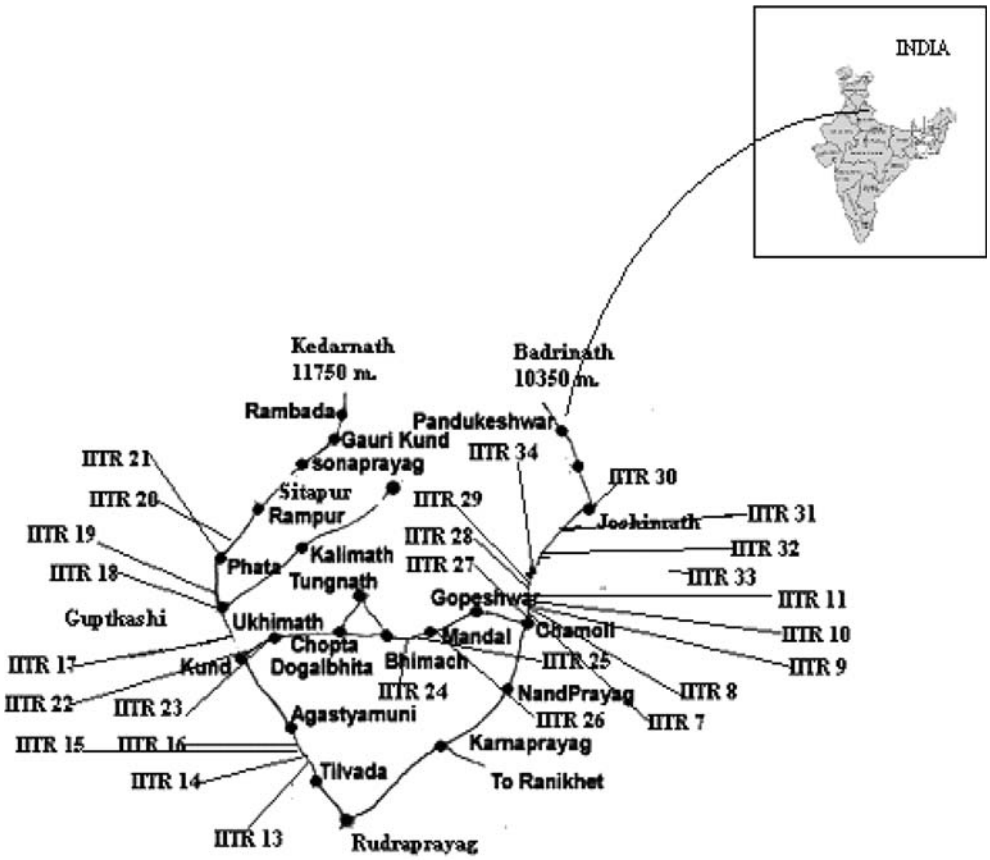

Fig. 1 Map showing site of collection of the wheat landraces of Uttaranchal, India

25 μl reaction mixture. Each reaction mixture contained 200 μM each of the dNTPs, 100 ng template DNA, 2 μM microsatellite primer pairs, 2.5 mM $MgCl_2$, 1×PCR buffer and 2 U Stoffel fragments (Perkin Elmer). DNA amplification was done following the PCR profile: (1) initial denaturation at 95°C for 5 min, (2) 40 cycles each at 95°C for 1 min, 51°C/61°C for 1 min, 72°C for 1 min with a ramp at the rate of 0.5°C, (3) final extension at 72°C for 5 min in a Perkin Elmer DNA Thermal Cycler (Prasad et al., 2000). The fragment size in genotype Chinese Spring was taken as the standard for the analysis of band patterns of the microsatellite markers. The size differences of the fragment in other genotypes were considered as the result of alteration in the repeat number of the simple sequences at the corresponding microsatellite.

High molecular wheat-glutenin subunits

High molecular weight-glutenin subunit (HMW-GS) composition of the seed storage proteins of 31 genotypes were analyzed from the seed samples collected from farmers using sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) using 10% acrylamide according the method of Smith and Payne (1984) with a few modifications. The pH of separating gel was changed from 8.8 to 8.6 and volume of 20% bisacrylamide was changed from 1.625 to 2.08 ml. The gels were stained with Comassie Blue R250 and destained in methanol–acetic acid–water (5:1:5). The identification and allocation of different HMW-GS to different group 1 chromosomes of the wheat landraces and cultivars were made after comparing their electrophoretic mobilities with the HMW-GS of those of the

wheat standards (Payne and Lawrence 1983) used for the purpose.

Statistical analysis

The standard F test and t-test were applied for testing the significance of differences between pre-green revolution and post-green revolution wheat cultivars and landraces of Uttaranchal for the six morphological traits.

For the purpose of assessing genetic diversity and preparation of a dendrogram, polymorphic microsatellite markers were scored in binary format giving unity score to presence of band and zero to the absence of band (Cao et al. 1999, 2000; Prasad et al. 2000). The binary data were used to compute pair wise similarity coefficient (Jaccard 1908). Similarity matrix was used to study the cluster analysis using the Unweighted Pair Group Method With Arithmetic Average (UPGMA) algorithm and Principal Component Analysis (PCA) from NTSYS-PC V.1.70 (Rohlf 1992). Morphological data, on qualitative traits was converted to binary form (1/0) while keeping quantitative data as such for calculating Squared Euclidean Distances by using NTSYS-PC software.

Results

The data on salient qualitative traits and year of release of various pre-green revolution wheat cultivars, post-green revolution cultivars and landraces of Uttaranchal used for diversity analysis is given in Tables 1 and 4. Most of the pre-green revolution wheat cultivars were tall, erect, resistant to prevalent pathotypes of yellow rust and susceptible to leaf rust and powdery mildew diseases. The limited number of post-green revolution wheat cultivars released from 1973 to 2004 in Northern Western Plains Zone of India included in the study, were semi-dwarf, erect, early to flower, having bold and amber grains and were highly susceptible to rusts and powdery mildew. Most of the collected landraces with the exception of landraces IITR 10 and IITR 14 were tall, semi-spreading, susceptible to leaf rust, resistant to yellow rust and powdery mildew and had high tillering capacity, red to amber grains, awned to awn less spikes and smaller seeds.

The mean and analysis variance for six morphological traits among three different groups viz., seven pre-green revolution indigenous wheat cultivars, seven post-green revolution wheat cultivars and 27 wheat landraces of Uttaranchal is given in Table 2. As evident from F value (Table 2), the mean values of the three groups are significantly different from each other for five traits whereas there are no significant differences for spike length. Application of t-test for testing the significance of difference of means of different groups indicates that landraces were significantly different from the post-green revolution cultivars for all the traits and differed from the pre-green revolution indigenous wheat cultivars for 1000-grain weight. The landraces had lower grain weight. The pre-green revolution cultivars were significantly different from the post-green revolution cultivars for days to flowering and plant height. The latter being early to flowering and dwarf in height (Table 4).

The HMW-glutenin subunit composition of the landraces and some wheat cultivars is given in Table 3. The landraces had higher diversity for HMW-glutenin subunits coded by *Glu-B1* than within the wheat cultivars analyzed, with distinct subunit combinations 6 + 8, 7 + 9, 13 + 16. More than half of the landraces were heterogeneous for HMW-GS coded by *Glu-A1, Glu-B1* or *Glu-D1*.

Genetic diversity based on morphological traits

The Squared Euclidean Distances for all the possible 820 pairs ranged from 0.43 (between cultivars PBW-343 and PBW-502) to 9.10 (between IITR-20 and 'Chinese Spring'). The Squared Euclidean Distance matrix was subjected to agglomerative hierarchical clustering utilizing the UPGMA methods by NTSYS PC program to construct a dendrogram (Fig. 2). The dendrogram had two broad clusters, cluster I with 14 cultivars and cluster II with 24 landraces. 'Chinese Spring' and IITR17 formed a third cluster. Principal Component Analysis (PCA) based on morphological data (Fig. 3) also clustered genotypes broadly into two groups, wheat cultivars and

Table 1 Brief descriptions of 41 wheat cultivars and landraces used for diversity analysis

Genotype	Category	Year of release	Description
8A	Pre-green revolution indigenous cultivar	1919	Awned, amber seed, resistant to yellow rust, erect growth habit
9D	-do-	1930	Awned, erect growth habit, amber seed color, resistant to yellow rust
C-273	-do-	1957	Amber color, awned, erect, resistant to yellow rust
NP-4	-do-	1911	Awn less, resistant to yellow rust and powdery mildew
C518	-do-	1933	Erect growth habit, awned
C591	-do-	1934	Erect growth habit, resistant to yellow rust, amber seed color
C306	-do-	1965	Erect, resistant to yellow rust, awned, amber seed color
Chinese Spring	Landrace from China	1936	Resistant to leaf rust, yellow rust, powdery mildew, awn less
WG357	Post-green revolution, modern cultivar	1973	Erect, resistant to yellow rust, awned, amber seed color
UP 262	-do-	1977	Erect, resistant to leaf rust, amber seed color, awned
WL 711	-do-	1979	Erect, amber seed color, awned
PBW 343	-do-	1994	Erect, resistant to yellow rust, amber seed color, awned
PBW 502	-do-	2004	Erect, resistant to yellow rust, amber seed color, awned
WL 711(NN)	-do-	1990	Erect, resistant to leaf rust, awned, amber seed color
IITR 7	Landrace	Not known	Semi-erect, resistant to yellow rust and powdery mildew red seed color, awned, late flowering
IITR 8	Landrace	-do-	Erect, late flowering, amber seed color, awned
IITR 9	Landrace	-do-	Semi-erect, resistant to yellow rust and powdery mildew, amber seed color, awn less
IITR 10	Landrace	-do-	Erect, resistant to yellow rust, amber seed color, awned
IITR 11	Landrace	-do-	Semi-erect, resistant to yellow rust and powdery mildew, red seed color, awn less
IITR 13	Landrace	-do-	Semi-erect, resistant to yellow rust red seed color, awn less
IITR 14	Landrace	-do-	Erect, early flowering, resistant to leaf rust, yellow rust and powdery mildew, amber seed color, awned
IITR 15	Landrace	-do-	Semi-erect, resistant to yellow rust and powdery mildew
IITR 16	Landrace	-do-	Red seed color, awn less
IITR 17	Landrace	-do-	Resistant to yellow rust, amber seed color, awned
IITR 18	Landrace	Not known	Semi-erect, resistant to yellow rust and powdery mildew, awn less, amber seed color
IITR 19	Landrace	-do-	Erect, resistant to yellow rust and powdery mildew, red seed color
IITR 20	Landrace	-do-	Erect, resistant to yellow rust and powdery mildew, red seed color
IITR 21	Landrace	-do-	Semi-erect, awned, amber seed color
IITR 22	Landrace	-do-	Semi-erect, resistant to yellow rust, red seed color, awn less
IITR 23	Landrace	-do-	Resistant to powdery mildew and yellow rust, amber seed color, awned
IITR 24	Landrace	-do-	Semi-erect, resistant to yellow rust and powdery mildew, red seed color
IITR 25	Landrace	-do-	Semi-erect, resistant to powdery mildew and yellow rust, red seed color
IITR 26	Landrace	-do-	Semi-erect resistant to yellow rust and powdery mildew
IITR 27	Landrace	-do-	Semi-erect, resistant to powdery mildew and yellow rust, red seed color
IITR 28	Landrace	-do-	Semi-erect, late flowering, resistant to powdery mildew
IITR 29	Landrace	-do-	Semi-erect, resistant to yellow rust, awn less
IITR 30	Landrace	-do-	Semi-spreading, resistant to powdery mildew, red seed color
IITR 31	Landrace	-do-	Semi-erect, amber, awned

Table 1 continued

Genotype	Category	Year of release	Description
IITR 32	Landrace	-do-	Semi-spreading, late flowering, resistant to powdery mildew, red seed color
IITR 33	Landrace	-do-	Semi-spreading, late flowering, resistant to powdery mildew, red seed color
IITR 34	Landrace	-do-	Semi-spreading, late flowering, resistant to powdery mildew and yellow rust, awn less

wheat landraces. The first three component of PCA accounted for 56.9% of the total variation. This clustering pattern of genotypes obtained on the basis of PCA largely resembled the clustering in dendrogram obtained from UPGMA analysis.

Genetic diversity based on microsatellite markers analysis

All the 41 wheat genotypes including cultivars and landraces were analyzed using nine microsatellite primer pairs. The genetic similarity coefficient (GS) for 820 possible pairs ranged from 0.0625 (between UP-262 and C-273) to 1.00 (between 9D and C518, IITR07 and IITR13, IITR18 and IITR32, IITR16 and IITR22). The genetic similarity matrix prepared on the basis of GS value was used for cluster analysis through UPGMA resulting in a dendrogram (Fig. 4). The dendrogram had two broad clusters. All the wheat cultivars released after the introduction of semi-dwarf HYVs from CIMMYT used in this study were grouped in cluster I along with NP 4 a pre-green revolution cultivar. Most of the landraces grouped in cluster II along with pre-green revolution cultivars.

The PCA clustering was prepared from the microsatellite marker data to further study the diversity among the genotypes (Fig. 5). The first three components of PCA accounted for 37.7% of the total variation. The PCA clustering pattern largely supported the UPGMA based dendrogram clustering.

Discussion

All the landraces, as a group, were significantly different from the post-green revolution wheat cultivars developed and released after the introduction of dwarf wheat cultivars and germplasm from CIMMYT, Mexico in 1960s. The landraces also differed significantly from the pre-green revolution indigenous wheat cultivars for 1000-grain weight.

The genetic diversity analyses, UPGMA and PCA, based on morphological data clearly grouped out all the commercial pre- and post-green revolution wheat cultivars away from the landraces except NP4. The two collections IITR10 and IITR 14 clustered with the com-

Table 2 Mean and analysis of variance of six morphological traits of pre-green revolution, post-green revolution wheat cultivars and landraces of Uttaranchal

Morphological trait	Pre-green revolution indigenous cultivars (7)	Post-green revolution modern cultivars (7)	Landraces of Uttaranchal (27)	F value
Days to flowering	108.43[a]	91.85[b]	111.0[a]	7.74**
No. of tillers/plant	10.60[ab]	7.52[b]	11.98[a]	4.05*
Plant height (cm)	121.48[a]	88.97[b]	133.64[a]	19.42**
No. of spiklets/spike	20.24[ab]	18.20[b]	21.49[a]	7.75**
Spike length (cm)	10.27[a]	10.02[a]	11.46[a]	2.83
1000 seeds weight (g)	38.00[a]	39.09[a]	27.09[b]	18.87**

*, ** F values at 5 and 1% levels of significance, respectively

Common superscript letters on mean values of different traits denote non-significant differences among groups as based on the t-test

Table 3 SDS-PAGE analysis of high molecular weight-glutenin subunits (HMW-GS) composition of some wheat cultivars and landraces of Uttaranchal

Genotype	HMW-GS subunits coded by chromosome		
	1A	1B	1D
WL 711	2*	17 + 18	2 + 12
CS	–	7 + 8	2 + 12
PBW-343	1	7	5 + 10
NP-4	2*	17 + 18	5 + 10
C-591	–	20	2 + 12
K-68	2*	17 + 18	5 + 10
UP-262	2*	7 + 8	2 + 12
Kalyan Sona	2*	17 + 18	2 + 12
IITR-11	–	17 + 18, 7 + 8	2 + 12
IITR-13	2*	7	2 + 12
IITR-14	–, 2*	7 + 8	2 + 12
IITR-15	–, 2*	17 + 18, 7 + 8	2 + 12
IITR-16	–	20	2 + 12
IITR-17	2*	7 + 8,7	2 + 12
IITR-18	–	7 + 8, 17 + 18	2 + 12
IITR-19	–	7 + 8	5 + 10
IITR-20	–	7 + 9	5 + 10
IITR-21	–, 2*	7 + 8	5 + 10, 2 + 12
IITR-22	–	7 + 8, 17 + 18	2 + 12
IITR-23	2*	7 + 8	5 + 10, 2 + 12
IITR-24	2*	7 + 8	2 + 12
IITR-25	2*	7 + 8, 13	5 + 10
IITR-26	–	17 + 18	5 + 10
IITR-27	–	13 + 16, 7 + 8	2 + 12
IITR-28	2*	7 + 9	5 + 10
IITR-29	–	7 + 8	2 + 12
IITR-30	2*	7 + 8, 20	2 + 12, 5 + 10
IITR-31	2*	17 + 18, 17 + 8	2 + 12
IITR-32	–	6 + 8	2 + 12
IITR-33	2*	6 + 8	2 + 12
IITR-34	–	17 + 18	2 + 12

– null

mercial varieties and not with the landraces further confirming that these were not the landraces.

Although the landrace IITR 17 has grouped with 'Chinese Spring', it still differs from 'Chinese Spring' in leaf rust and powdery mildew incidence, plant height and seed color etc. with 5.36 Squared Euclidean Distances between them. It can be safely concluded that IITR 17 is a distinct landrace. 'Chinese Spring' was also a landrace from China. Among the landraces IITR 19 and IITR 20 with similar morphology and collected from adjoining areas had least Squared Euclidean Distance (1.10), the second shortest distance next to that between PBW 343 and PBW 502. They, therefore, could constitute a single landrace.

Among wheat cultivars, PBW 343 and PBW 502, released from PAU, Ludhiana in 1994 and 2004, respectively, from the CIMMYT introduction 'Attila' and a three way cross involving PBW 343 (Karam Chand, personal comm.) were highly similar.

The cluster with landraces appeared to have higher diversity as compared to that of wheat cultivars.

In the dendrogram based on microsatellite markers, the pre-green revolution cultivars 8A, 9D, C518, C591, C273 and C306 of India were grouped with landraces in cluster II suggesting that the former had been probably developed through selection and hybridization among prevalent landraces in India.

Clustering through two sets of data viz. morphological traits and molecular markers gave more or less similar results with a few exceptions as reported previously (Powell et al. 1996; Russell et al. 1997; Davila et al. 1999; Roy et al., 2004). The use of additional microsatellite/molecular markers is expected to reveal more intra-group (cultivars vs. landraces) differences and unique DNA fingerprints.

Some of the landraces also were heterogeneous for HMW-GS, red versus amber grain color, red versus white glume color and awned versus awnless. The heterogeneity for protein profile and other traits over a long period of their cultivation is expected. It will be desirable to purify them through single plant selection.

The genetic diversity and clustering analysis based on the morphological traits and molecular markers have unequivocally demonstrated that wheat genotypes collected from remote Himalayan hills of Uttaranchal on the basis of morphological attributes are indeed distinct landraces. The landraces are, however, more closely related to the pre-green revolution cultivars. Some of the landraces with resistance to yellow rust and powdery mildew and with distinct HMW-GS can be used in appropriate wheat breeding programs. It will be desirable to protect and conserve the landraces as geographical indications of Uttaranchal.

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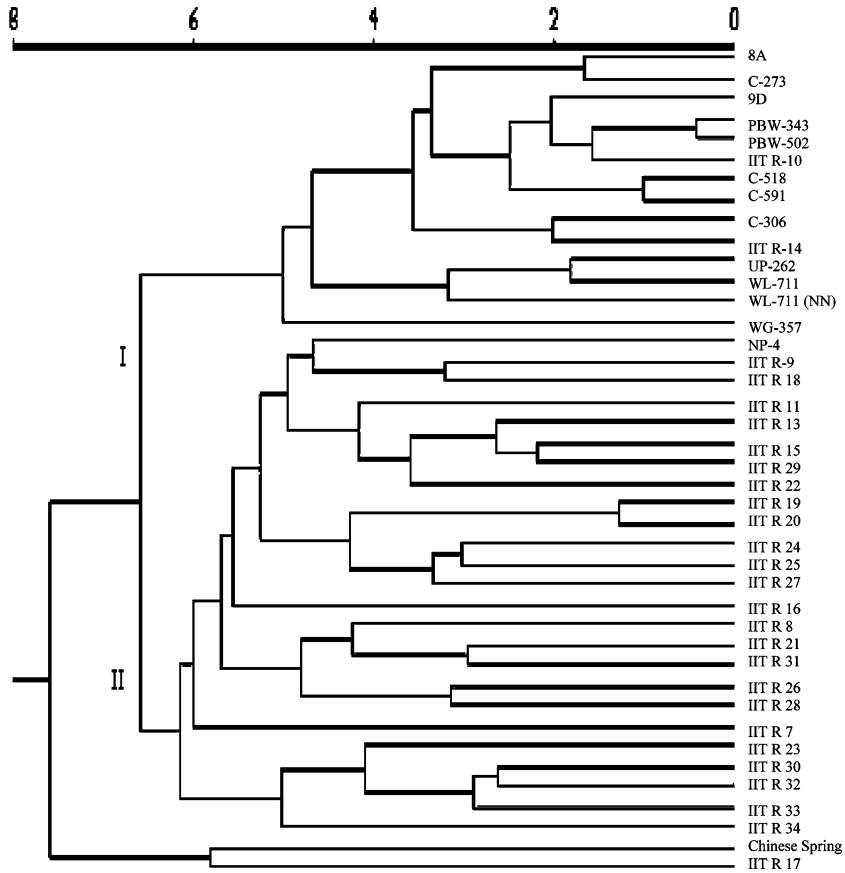

Fig 2 Dendrogram of 41 wheat genotypes based on UPGMA method, using Euclidean distribution variance of morphological traits

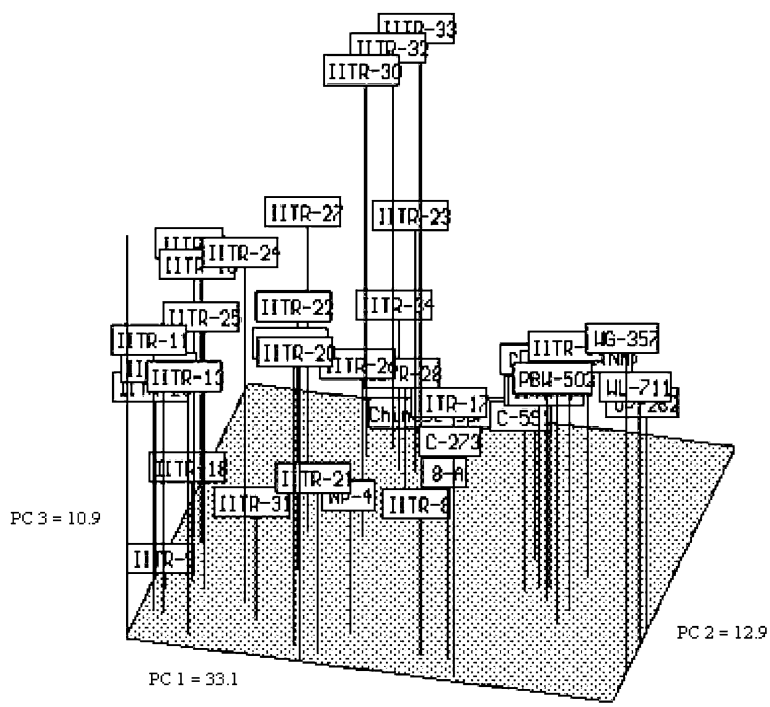

Fig. 3 Clustering among 41 wheat genotypes as revealed by Principal Component Analysis on the basis of morphological data

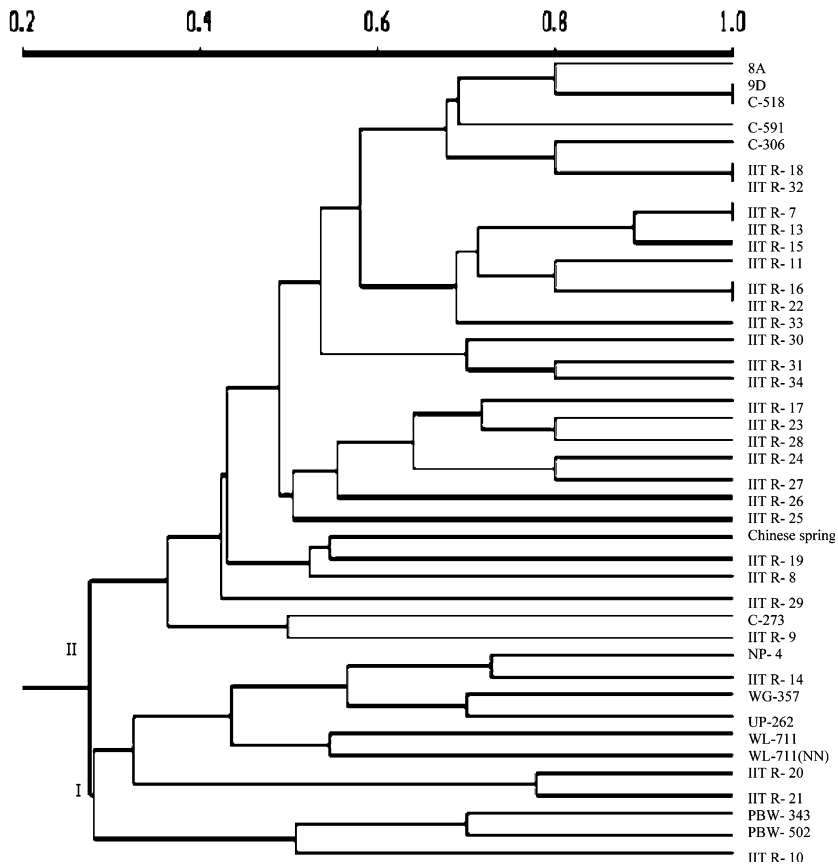

Fig. 4 Dendrogram of 41 genotypes based on UPGMA method, using the matrix of Jaccard's coefficient from microsatellite markers data. The scale shown above is the measure of genetic similarity calculated according to Jaccard's similarity coefficient

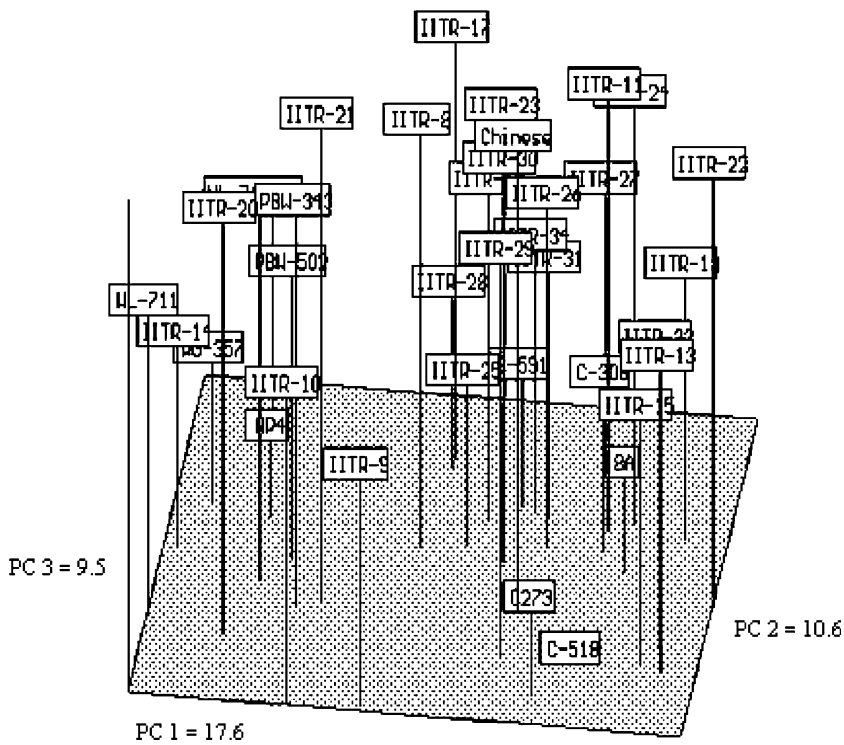

Fig. 5 Patterns of relationships among 41 wheat genotypes including commercial varieties and landraces of Uttaranchal as revealed by Principal Component Analysis based on microsatellite markers data

Appendix

Table 4 Year of release of cultivars, morphological data and rust incidence of landraces and cultivars of wheat

S. No.	Genotype	Year of release	Growth habit	Leaf color	Days to flowering	Leaf rust	Yellow rust	Powdery mildew	No. of tillers/ plant	Plant height	No. of spiklets/ spike	Spike length	Seed color	Awn/ awnless	1000-seed weight
1	8A	1919	Erect	LG	103	40 S	F	9	10.6	112.2	20.6	10.5	A	An	37.2
2	9D	1930	Erect	DG	110	80 S	F	9	6.8	121.6	18.5	10.3	A	An	43.4
3	C-273	1957	Erect	LG	101	60 S	F	9	7.0	116.0	18.2	9.4	A	An	34.4
4	NP-4	1911	Erect	LG	108	60 S	F	F	10.2	123.8	19.3	11.0	A	AL	36.6
5	C518	1933	Erect	DG	109	40 S	F	9	9.8	120.0	20.2	10.8	A	An	38.2
6	C591	1934	Erect	DG	102	40 S	F	9	11.8	128.6	21.0	11.7	A	An	39.0
7	Chinese Spring	1936	Spreading	DG	126	tS	F	F	18.0	128.2	23.9	8.1	A	AL	37.2
8	C 306	1965	Erect	DG	109	10 S	F	9	11.5	120.8	18.8	10.6	A	An	36.4
9	WG 357	1973	Erect	DG	75	80 S	F	9	7.0	71.4	13.0	7.8	A	An	43.0
10	UP 262	1977	Erect	DG	92	tR	40 S	9	5.8	79.6	19.2	10.0	A	An	46.4
11	WL 711	1979	Erect	DG	86	20 S	60 S	9	6.8	79.6	17.8	9.8	A	An	40.0
12	PBW 343	1994	Erect	DG	99	80 S	F	9	6.6	89.8	19.9	10.8	A	An	40.8
13	PBW 502	2004	Erect	DG	96	80 S	F	9	6.0	85.8	19.9	10.6	A	An	38.6
14	IITR 7		Semi-erect	LG	128	100 S	F	F	15.6	128.7	27.8	7.5	R	An	25.0
15	IITR 8		Erect	LG	111	60 S	40 S	9	10.0	106.6	22.4	14.3	A	An	30.0
16	IITR 9		Semi-erect	LG	111	80 S	F	F	17.0	162.8	23.5	15.4	A	AL	25.6
17	WL 711(NN)	1990	Erect	DG	86	20 S	60 S	7	9.0	95.8	18.8	10.5	A	An	28.4
18	IITR 10		Erect	DG	109	60 S	F	9	4.0	80.2	19.2	9.6	A	An	34.6
19	IITR 11		Semi-erect	LG	123	80 S	F	F	–	113.2	22.0	12.2	R	AL	24.0
20	IITR 13		Semi-erect	LG	102	80 S	F	9	10.6	140.0	20.0	9.7	R	AL	24.2
21	IITR 14		Erect	DG	92	F	F	F	8.0	110.0	21.5	10.5	A	An	39.6
22	IITR 15		Semi-erect	LG	103	80 S	F	F	9.2	140.2	21.7	10.8	R	AL	26.4
23	IITR 16		Semi-spreading	LG	104	80 S	20 S	8	18.0	145.6	21.9	10.4	R	AL	17.2
24	IITR 17		Spreading	DG	123	100 S	F	8	16.2	142.4	21.5	12.9	A	An	34.4
25	IITR 18		Semi-erect	LG	113	80 S	F	F	18.0	141.6	20.9	10.7	A	AL	17.0
26	IITR 19		Erect	LG	93	80 S	F	F	11.5	143.0	20.0	12.7	R	An	28.0
27	IITR 20		Erect	LG	83	80 S	tS	F	8.8	141.6	21.6	12.1	R	An	29.6
28	IITR 21		Semi-erect	LG	95	80 S	10 S	8	7.8	140.6	22.5	11.4	A	An	30.4
29	IITR 22		Semi-erect	DG	107	80 S	F	8	6.8	137.4	20.5	10.5	R	AL	32.0
30	IITR 23		Semi-spreading	DG	121	100 S	F	F	8.0	150.0	20.9	12.1	A	An	26.6
31	IITR 24		Semi-erect	LG	108	100 S	F	F	15.0	131.4	17.5	9.1	R	An	28.0
32	IITR 25		Semi-erect	LG	114	80 S	F	F	15.2	129.2	21.3	13.2	R	An	22.6

Table 4 continued

S. No.	Genotype	Year of release	Growth habit	Leaf color	Days to flowering	Leaf rust	Yellow rust	Powdery mildew	No. of tillers/ plant	Plant height	No. of spiklets/ spike	Spike length	Seed color	Awn/ awnless	1000-seed weight
33	IITR 26		Semi-erect	DG	115	80 S	F	F	9.2	136.0	22.7	13.2	A	An	23.8
34	IITR 27		Semi-erect	DG	104	80 S	F	F	16.2	143.2	19.1	10.9	R	An	22.2
35	IITR 28		Semi-erect	DG	127	80 S	20 S	F	12.6	154.2	21.2	13.4	A	An	43.8
36	IITR 29		Semi-erect	LG	118	40 S	F	2	13.0	151.6	22.6	11.6	R	AL	24.0
37	IITR 30		Semi-spreading	DG	116	80 S	10 S	F	12.6	146.6	21.0	9.7	R	An	24.0
38	IITR 31		Semi-erect	LG	111	80 S	20 S	9	12.2	154.6	23.9	14.5	A	An	18.6
39	IITR 32		Semi-spreading	DG	135	80 S	20 S	F	6.0	116.6	22.5	10.0	R	An	23.8
40	IITR 33		Semi-spreading	DG	136	60 S	10 S	F	16.0	108.8	19.1	8.6	R	An	28.8
41	IITR 34		Semi-spreading	DG	114	40 S	F	F	14.0	112.2	21.3	12.3	A	AL	27.2

Abbreviations: LG—light green, DG—dark green, S—susceptible, F—free, R—red, A—amber, An—awn, AL—Awnless., tS—traces susceptible

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