Morphological Diversity in Naked Barley Landraces from North-Western Himalayas of India

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The Himalayan barleys, particularly, naked forms, are important phylogenetically and require adequate research and marketing interventions because of their high feed value. In the present study, 84 naked barley landraces mainly from north-western Indian Himalayas comprising three main administrative regions, Jammu & Kashmir, Himachal Pradesh and Uttaranchal states were characterized for morphological traits. The range and pattern of variations were studied. Jammu & Kashmir accessions were more diverse than Himachal Pradesh and Uttaranchal accessions. Landraces from mid-elevational zones were relatively more diverse than landraces from lower and extreme high elevational zones in each administrative region. The multilocation evaluation of selected naked barley landraces revealed greater adaptability and potential of Himalayan naked barleys even to non-conventional plain zones for commercial cultivation. The importance of Himalayan naked barleys for agriculture and also their safe conservation *ex situ* and *in situ* (on-farm) was suggested.

Key words: Naked barley, *Hordeum vulgare* L., Genetic diversity, North-western Himalayas

Cultivated barley (*Hordeum vulgare* ssp. *vulgare*) can be classified into covered (hulled), those in which the lemma and palea (the chaff) are tightly fused to the pericarp of the caryopsis (grain) and naked (hull-less), those in which the chaff is easily separated from the grain. This character is not only unique to barley, but is also directly connected to its utilization. At present, most barley varieties are of the hulled form, and they are mainly used for brewing malt and animal feed. By contrast, naked barley is produced on a small scale and used mainly as human food because of the ease in processing and edibility. In recent years, naked barley is attracting attention as feed and as a healthy food because of the high feed value and abundance of dietary fibre, respectively (Liu *et al.*, 1996). According to a survey by Takahashi (1955), naked barley is distributed widely, but its frequency greatly differs among regions; naked barley accounts for more than 95% of the domesticated barley in the highlands of Nepal and Tibet, and almost 50% in China, Korea, and Japan, but the frequency decreases toward the west, becoming low in Europe. In fact, in the regions where naked barley is grown at high frequencies, it is an important staple food.

The Himalayan barleys particularly, naked forms, are of great potential utility, which require research and marketing interventions. The Himalayas, Ethiopia, and Morocco have all been considered as centers of barley domestication (Åberg, 1938; Bekele, 1983; Molina-Cano *et al.*, 1987). Harlan *et al.* (1976) refer to the Near East as the "centre of agricultural innovation" where barley was the first crop to be domesticated followed by wheat. The widespread distribution of naked barley makes the hulled or naked caryopsis character a key trait to follow the origin and domestication process of barley (Harlan, 1995; Salamini *et al.*, 2002). A recent study (Taketa *et al.*, 2004), however, indicates that naked barley has a monophyletic origin, probably in southwestern Iran, and all naked barleys are likely to share a common ancestor.

In many areas of north-western Himalayas, in proximity of Tibet, naked barley was widely cultivated till about 4 or 5 decades ago. Up to 1960s when free trade existed between India and Tibet, naked barley had specific uses. Being highly nutritious and rich in protein, it was eaten as 'sattu' during the long journeys on foot that the traders undertook crossing the mountain passes. This trade came to a standstill after 1962 when the borders between India and Tibet were sealed. The local farmers thereby lost the most important incentive of cultivating naked barleys and the result was that most of these landraces are on the verge of extinction now. Naked barley landraces have gradually been replaced by wheat in these areas as a cereal of direct human consumption. Much of the naked barley populations, however, are still grown in high plateaus

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of China and Tibet for direct human consumption and eaten as 'tsåmba'.

About 400 barley landraces including naked types have been collected recently from north-western Himalayas during 1999-2004 and are being maintained *ex situ* in National Genebank at the National Bureau of Plant Genetic Resources (NBPGR). These landraces are yet to be systematically characterized/evaluated. Limited information is, therefore, available on genetic diversity of existing naked barley landraces grown in north-western Himalayas. The extent of diversity between populations adapted to the high altitude region of north-western Himalayas would suggest need for their continuous collection and devising strategies for both *ex situ* and *in situ* (on-farm) conservation. It would also suggest possibility of using the useful genetic variation in these landraces for improved yield and a better utilization of these products in agriculture and industry.

Materials and Methods

Morphological Diversity of Naked Barley Landraces

The experimental material consisted of 84 naked barley landraces assembled from different parts of north-western Himalayas and represented all agro-ecological conditions of the region. The material also included 12 naked barley landraces from exotic sources including eight accessions from Ethiopia, two from Peru and one accession each from France and Nepal. Three cultivars from Udaipur (Rajasthan state of India) were also included in the study. The passport information on the origin of accessions are given in Table 1. The material was grown in randomized block design with two replications at NBPGR, New Delhi during rabi 2004-05. The accessions were grown in three 2m row plots, with a between-row spacing of 25cm, and a within-row spacing of 10cm. Five hulled (covered) commercial barley varieties (DL-36, DL-85, Jyoti, VLB-1 and VLB-60) were included as controls as no improved local controls for naked barley are available. Recommended agronomic practices were followed through various stages of crop growth. Data were recorded on 10 randomly chosen competitive plants per plot for 27 descriptors (18 quantitative and 9 qualitative, Table 2) following the IBPGR (1982) descriptor list and descriptors proposed by Murphy and Witcombe (1986). The data on quantitative traits were subjected to analysis of variance (ANOVA).

Table 1. Passport Information of Barley Landraces Studied

Origin	No. of accessions			Elevational
	Six-rowed	Two-rowed	Total	ranges (masl)
Jammu and Kashmir	38	–	38	1,700-4,200
Uttaranchal	15	1	16	1,500-4,500
Himachal Pradesh	13	2	15	1,500-4,200
Udaipur (Rajasthan)	3	–	3	400-500
Exotic	7	5	12	1,700-3,800

The frequency distribution and comparative summary statistics of barley accessions for quantitative and qualitative traits were computed for different administrative regions (States) in the north-western Himalaya, viz. Jammu & Kashmir, Uttaranchal and Himachal Pradesh, and a separate group of exotic accessions. The phenotypic frequencies of both quantitative and qualitative characters were also analysed by the Shannon-Weaver information index (H') in order to estimate the diversity of each character administrative region-wise and altitude-wise across administrative regions. The index was calculated as presented by Negassa (1985) and Engels (1991):

$$H' = -\sum_{i=1}^{n} p_i \log_e p_i$$

where p_i is the proportion of the accessions in the ith class of an n-class character. In order to keep the values of H' in the range of 0-1 each value of H' was divided by its maximum value, $\log_e n$.

Classification (cluster analysis) and ordination (principal components analysis) analyses were also performed. Skewed data on quantitative traits were transformed before multivariate analysis. Ward's minimum variance clustering method was used to classify accessions in discrete clusters (Sneath and Sokal, 1973), whereas the Weighted Average Linkage technique using ISS similarity index was used for qualitative traits. The scores for various character states of different accessions were converted to a binary code before analysis using qualitative traits. Principal components analysis was performed using quantitative traits. The statistical analysis was carried out using INDOSTAT statistical package developed at the INDOSTAT Services, Hyderabad, India.

Multilocation Evaluation of Selected Naked Barley Landraces

A set of 30 selected naked landrace populations comprising 16 accessions from Uttaranchal, 5 from Jammu & Kashmir, 2 from Himachal Pradesh, 1 from Udaipur (cultivar) and 6 from exotic sources (4 accessions from Ethiopia and

1 each from Nepal and Peru) was also subjected to multilocation evaluation for quantitative traits at two NBPGR locations, Delhi (semi-arid, plain zone: latitude 28°35'N, longitude 78° 18' E, altitude 226 masl) and Bhowali (temperate, hilly area: latitude 29° 20' N, longitude 79° 04'E, altitude 1600 masl) during 2003-04 *rabi* season. The trials were conducted in order to assess the adaptability of Himalayan naked barleys for widespread cultivation. The material was grown in Randomized Block Design with two replications at both the locations. The material was grown in 4-row plots of 2m row length, and 25 x 10 cm row to row and plant to plant spacing, respectively. Data on all 18 quantitative traits (Table 2) at NBPGR, New Delhi and on 10 selected important traits at NBPGR, Regional Station, Bhowali were recorded. ANOVA was carried out separately for both locations. ANOVA for pooled analysis was also carried out. The multivariate analysis was also performed separately for data of both locations.

Table 2. List of Descriptors Used for Germplasm Characterization

S. No.	Descriptors/Characters	Frequency class*
Quantitative Descriptors		
1.	Days to flowering	1= <70; 2 = 70-85; 3 = 85-100; 4=>100
2.	Days to maturity	1= <100; 2 = 100-115; 3 = 115-130; 4=>130
3.	No. of tillers/plant	1= <10; 2= 10-15; 3= 15-20; 4 =>20
4.	No. of leaves	1= <100; 2= 100-125; 3=125-150; 4= >150
5.	Plant height (cm)	1= <80; 2= 80-100; 3= >100
6.	Height of top node (cm)	1= <50; 2= 50-70; 3= >70
7.	Length of top internode (cm)	1= <15, 2= 15-20; 3= >20
8.	Length of flag leaf sheath (cm)	1= <20, 2= 20-25; 3= >25
9.	Length of neck (cm)	1= <5; 2=5-10; 3=10-15; 4=>15
10.	Length of flag leaf (cm)	1=<10; 2=10-15; 3=>15
11	Breadth of flag leaf (cm)	1=<1; 2=1-2; 3=>2
12.	Length of penultimate leaf (cm)	1=<20; 2=20-30; 3=>30
13	Breadth of penultimate leaf (cm)	1= <2; 2=2-2.5; 3=>2.5
14.	No. of spikelet groups/spike	1=<15; 2=15-20; 3 = 20-25, 4=25-30; 5 =>30
15.	Length of main ear (cm)	1= <5; 2=5-7; 3= 7-9; 4=>9
16.	No. of grains/spike	1= <50; 2=50-65; 3=65-80; 4=>80
17.	Seed weight per plant	1=<15; 2= 15-20, 3=20-25; 4=>25
18.	100- seed weight	1=<2.5; 2=2.5-3; 3=3-3.5; 4=3.5-4;5= >4
Qualitative Descriptors		
19.	Row numbers/lateral florets	1= Six rowed; 2= Two rowed: lateral florets large and sterile; 3= Two rowed: lateral florets rudimentary
20.	Spike density	1= Lax (=4 mm); 2= Intermediate; 3= Dense (=2 mm)
21.	Hoodedness	1= Sessile hood; 2= Elevated hood; 3= Awnless or Awnletted (=2 mm) on all rows; 4= Awned (on central rows for 2 rowed and on all six rows for 6-rowed); 5= Awned on central rows only lateral rows awnless or awnletted
22.	Awn roughness	1= Smooth; 2= Rough
23.	Length of rachilla hair	1= Short; 2= Long
24.	Hairiness of leaf sheath	1= Hairless; 2= Hairy
25.	Pigmentation of leaf sheath	1= Green; 2= Purple
26.	Nature of collar	1= Closed; 2= Open; 3= 'V' shaped
27.	Grain colour	1= Pale; 2= Brown; 3= Blue; 4= Purple; 5= Black

*Codes used for diversity analysis

Results

Morphological Diversity of Naked Barley Landraces

Analysis of variance (ANOVA) of 89 barley landraces (including 5 hulled controls) for quantitative traits indicated highly significant differences for all quantitative variables. The range of variation for various quantitative traits is presented in Table 3. The Table 3 revealed maximum variation for length of neck, length and breadth of flag leaf, no. of tillers/plant, no. of leaves/plant, no. of grains/spike, seed weight per plant and no. of grains/spike. Many naked landraces were found to be superior to hulled controls (commercial varieties) used for comparison in the present study for agronomically desired traits like early flowering, high tillering capacity, no. of grains/spike, yield/plant and 100-seed weight.

The comparative descriptive statistics of barley landraces from different regions, Uttaranchal, Jammu & Kashmir, Himachal Pradesh and exotic sources is presented in Table 4. It was revealed that the landraces from Jammu & Kashmir are relatively early in flowering/ maturity. The exotic accessions had the highest tillering capacity whereas the Uttaranchal accessions had the lowest no. of tillers/plant. The exotic accessions recorded the highest number of leaves/plant. Uttaranchal accessions were relatively taller than accessions from other areas. Uttaranchal accessions recorded highest no. of spikelet groups/plant but the Jammu & Kashmir accessions had relatively high seed weight/plant and 100-seed weight. Marked regional variations were also recorded for other characters viz. height of top node, length of top internode, length of neck, length and breadth of flag leaf, length of penultimate leaf, etc. (Table 4).

The frequency distribution for various quantitative characters revealed skewness, both positive and negative. Not much variation was, however, recorded for qualitative traits except spike density, nature of collar and grain colour.

The administrative region-wise diversity indices for both quantitative and qualitative characters are presented in Table 5. The diversity indices showed wide variations between characters administrative region-wise. The pooled diversity indices by characters (quantitative traits) indicate relatively high diversity for 100-seed weight, length of main ear and length of flag leaf whereas low diversity for no. of spikelet groups/spike and no. of grains/spike was recorded. For other quantitative traits, diversity was

Table 3. Range of Variation for Quantitative Traits in Barley Landraces

Descriptors	Lowest	Highest	Kurtosis	Skewness	Mean	CV
Days to flowering	56	112	-0.33	-0.51	86.57	14.61
Days to maturity	88	137	4.49***	-1.11	121.91	5.6
No. of tillers/plant	7	34	-0.39	0.28	18.66	28.21
No. of leaves	48	226	-0.48	0.29	132.62	28.93
Plant height(cm)	75	129	1.06**	0.29	101.98	8.66
Height of top node (cm)	19	92	2.46***	-0.43	66.12	14.58
Length of top internode (cm)	10.5	23.5	-0.45	0.3	16.81	16.46
Length of flag leaf sheath (cm)	15	27.5	0.08	0.13	21.22	10.66
Length of neck (cm)	2	20.7	1.16**	1.15***	7.36	55.52
Length of flag leaf (cm)	4.9	26.5	-0.22	0.38*	13.23	34.13
Breadth of flag leaf(cm)	0.4	5	12.36***	2.14***	1.41	36.37
Length of penultimate leaf (cm)	15.5	38	0.35	0.64***	23.98	18.74
Breadth of penultimate leaf (cm)	1.4	3	0.14	0.16	2.03	14.45
No.of spikelet groups/spike	16	38	-0.12	0.53**	23.99	18.06
Length of main ear(cm)	5.5	12	-0.4	0.13	8.17	15.37
No.of grains/spike	22	96	2.02***	-0.95	61.49	22.31
Seed weight/plant	5.34	37.7	-0.22	0.3	21.24	28.78
100-seed weight	1.98	5.54	-0.24	-0.28	3.67	19.48

Table 4. Comparative Summary Statistics of Barley Landraces from Different Regions of North-Western Himalayas for Quantitative Traits

S.No.	Characters	Uttaranchal	Jammu & Kashmir	Himachal Pradesh	Exotic
1	Days to flowering	92±7	79±11	94±11	94±10
2.	Days to maturity	120±4	120±6	126±5	124±12
3.	No. of tillers/plant	14±4	20±4	18±4	26±3
4.	No. of leaves	111±27	135±31	134±29	186±27
5.	Plant height	107±10	99±8	101±7	103±8
6.	Height of top node	72±10	63±9	68±9	66±5
7.	Length of top internode	17±2	18±3	15±2	16±2
8.	Length of flag leaf sheath	20±2	21±2	22±2	21±2
9.	Length of neck	7±3	7±3	4±2	9±6
10.	Length of flag leaf	9±3	14 ±4	13±4	14±4
11.	Breadth of flag leaf	1.2±0.7	1.4±0.4	1.7±0.6	1.5±0.3
12.	Length of penultimate leaf	20±2	25±4	23±3	26±5
13.	Breadth of penultimate leaf	2±0.2	2±0.3	2±0.2	2±0.3
14.	No. of spikelet groups/ spike	27±4	23±4	22±4	26±3
15.	Length of main ear	8±1	8±1	8±1	8±1
16.	No. of grains/spike	63±10	64±8	58±12	42±17
17.	Seed weight/plant	18±4	23±7	17±5	22±3
18.	100-seed weight	3±0.5	4±0.5	4±0.6	4±0.6

Table 5. Estimates of Diversity Indices (*H'*) for Quantitative Traits

S. No.	Characters	J&K	UA	HP	Exotic	Average
		Administrative regions				
Quantitative Traits						
1.	Days to flowering	0.72	0.76	0.45	0.52	0.61±0.2
2.	Days to maturity	0.59	0.81	0.36	0.52	0.57±0.2
3.	No. of tillers/plant	0.73	0.64	0.58	0.75	0.68±0.1
4.	No. of leaves	0.83	0.81	0.89	0.27	0.70±0.3
5.	Plant height	0.89	0.55	0.63	0.62	0.67±0.2
6.	Height of top node	0.72	0.76	0.63	0.59	0.68±0.1
7.	Length of top internode	0.91	0.64	0.63	0.82	0.75±0.1
8.	Length of flag leaf sheath	0.78	0.35	0.91	0.75	0.70±0.2
9.	Length of neck	0.77	0.51	0.59	0.92	0.70±0.2
10.	Length of flag leaf	0.78	0.64	0.91	0.84	0.79±0.1
11.	Breadth of flag leaf	0.71	0.44	0.88	0.27	0.58±0.3
12.	Length of penultimate leaf	0.73	0.61	0.22	0.75	0.58±0.3
13.	Breadth of penultimate leaf	0.81	0.63	0.67	0.84	0.74±0.1
14.	No. of spikelet groups/ spike	0.38	0.35	0.67	0.41	0.45±0.2
15.	Length of main ear	0.84	0.55	0.91	0.93	0.81±0.2
16.	No. of grains/spike	0.44	0.21	0.50	0.63	0.45±0.2
17.	Seed weight/plant	0.80	0.64	0.82	0.41	0.67±0.2
18.	100-seed weight	0.81	0.76	0.82	0.91	0.83±0.1
	Average	0.74	0.59	0.67	0.65	0.66+0.2
Qualitative Traits						
1.	Spike density	0.36	0.35	0.47	0.26	0.36±0.1
2.	Hoodedness	0	0.35	0.36	0	0.18±0.2
3.	Awn roughness	0	0	0.25	0.27	0.13±0.2
4.	Length of rachilla hairs	0	0.34	0.25	0.27	0.21±0.2
5.	Nature of collar	0.44	0.58	0.46	0.46	0.48±0.1
6.	Grain colour	0.44	0.43	0.41	0.14	0.35±0.1
	Average	0.25	0.41	0.44	0.28	0.34±0.1

J&K= Jammu & Kashmir; UA= Uttaranchal; HP=Himachal Pradesh

moderate. Based on administrative region-wise pooled diversity over all the characters, Jammu & Kashmir state was the most diverse followed by accessions from Himachal Pradesh, Exotic group and Uttaranchal State. Among qualitative traits, nature of collar, spike density and grain colour recorded relatively high diversity. Himachal Pradesh accessions were relatively more diverse for these qualitative traits followed by accessions from Uttaranchal, exotic group and Jammu & Kashmir. The pattern of diversity indices over characters within ecogeographic regions (altitude-wise) across region were relatively uniform. More diversity was recorded in relatively mid-elevational zones across all administrative regions (Table 6).

Cluster analysis using Ward's minimum variance technique classified the 84 barley accessions (controls excluded) into three major groups. Cluster III comprised 40 accessions followed by 22 accessions each in cluster I and II (Fig. 1).

A fair degree of association between geographical origin and genetic diversity was revealed. Cluster I mainly comprised landraces assembled from Uttaranchal state. Cluster II comprised accessions mainly from Jammu & Kashmir. Most of the exotic landraces were grouped in cluster III together with some accessions from parts of Jammu & Kashmir and Himachal Pradesh.

Table 6. Estimates of altitude-wise diversity indices (*H'*) for quantitative traits of barley landraces

S.No.	Characters	Low (<2000 masl)	Medium (2000-3000 masl)	High (>3000 masl)	Average
		Altitude			
1.	Days to flowering	0.43	0.91	0.68	0.67
2.	Days to maturity	0.43	0.72	0.60	0.58
3.	No. of tillers/plant	0.63	0.64	0.91	0.73
4.	No. of leaves	0.83	0.91	0.91	0.88
5.	Plant height	0.83	0.91	0.91	0.88
6.	Height of top node	0.63	0.58	0.83	0.68
7.	Length of top internode	0.63	0.92	0.91	0.82
8.	Length of flag leaf sheath	0.85	0.88	0.51	0.75
9.	Length of neck	0.63	0.78	0.68	0.70
10.	Length of flag leaf	0.70	0.91	0.91	0.84
11.	Breadth of flag leaf	0.91	0.54	0.94	0.80
12.	Length of penultimate leaf	0.79	0.80	0.76	0.78
13.	Breadth of penultimate leaf	0.85	0.66	0.60	0.70
14.	No. of spikelet groups/spike	0.86	0.91	0.91	0.89
15.	Length of main ear	0.91	0.94	0.83	0.89
16.	No. of grains/spike	0.70	0.70	0.28	0.56
17.	Seed weight/plant	0.84	0.87	0.91	0.87
18.	100-seed weight	0.91	0.91	0.91	0.91
	Average diversity	0.74	0.80	0.77	0.77

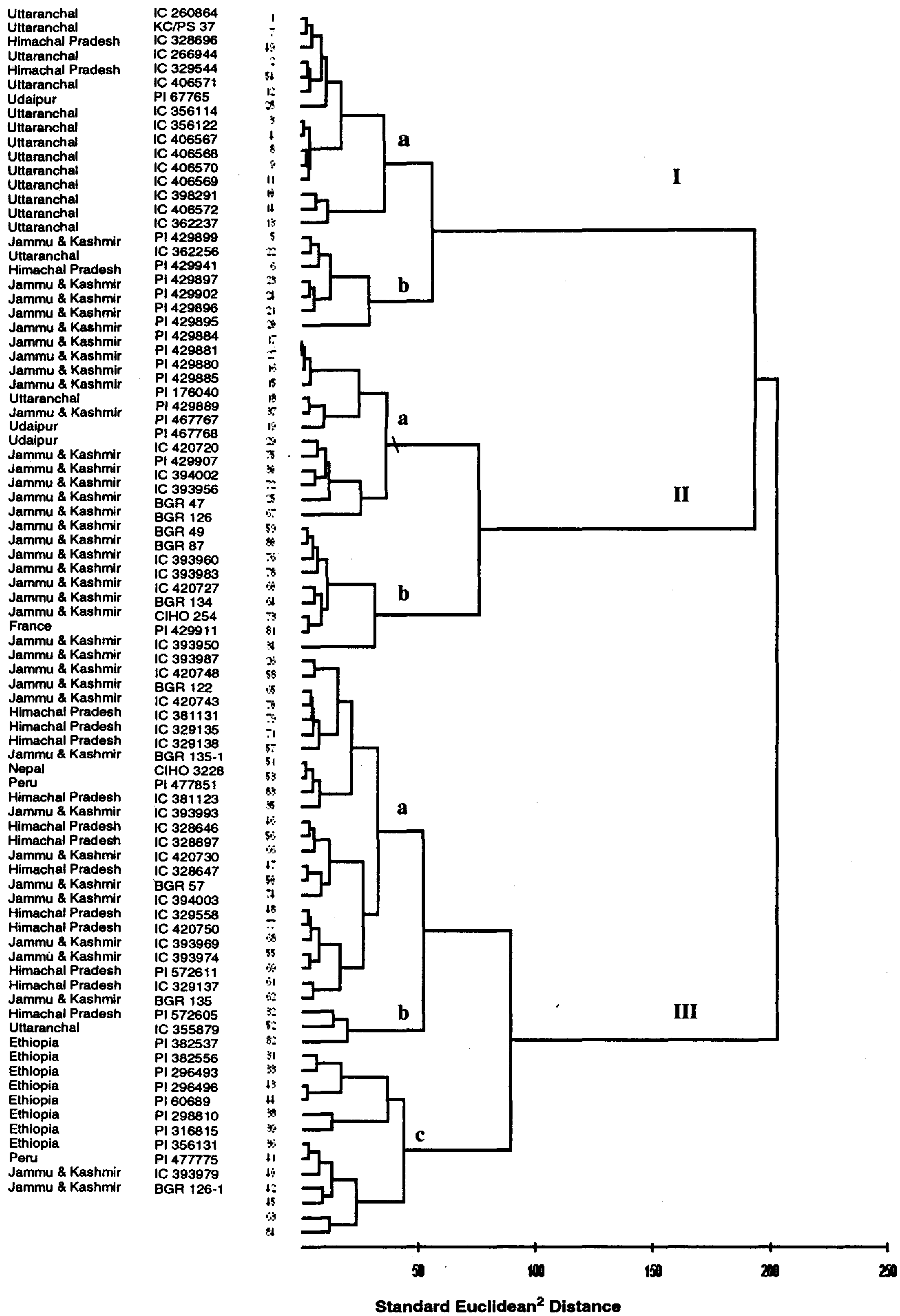

Fig. 1: Ward's minimum variance dendrogram of 84 barley landraces based on quantitative traits

Cluster I was characterized with accessions late in flowering, low tillering capacity, high number of grains/spike, low seed weight/plant and low 100-seed weight. Cluster II was characterised with accessions early in flowering/maturity, moderate numbers of tillers/ plant, high number of grains/spike, high seed weight/ plant and 100-seed weight. Cluster III comprised late flowering/maturing accessions with high tillering capacity, moderate seed weight/ plant and 100-seed weight. Cluster III was most diverse followed by cluster II and I.

Weighted average linkage clustering using qualitative traits classified the accessions into two major clusters (Fig. 2). Cluster I comprised only six accessions, two accessions each from Uttaranchal, Himachal Pradesh and Ethiopia with high degree of similarity at sub-cluster level. Cluster II comprised the remaining 78 accessions. At sub-cluster level association of geographical origin and genetic diversity was clearly evident.

Principal components analysis performed on quantitative traits revealed that the first three most informative components accounted for 51.15% variance. It also presented the characters with greater weightings in each of the three principal component axes. Important characters with greater weightings in principal component axis I included length of flag leaf, length of penultimate leaf, 100-seed weight and number of tillers/plant. Important characters with greater weightings in principal component axis II included days to flowering, length of top internode, days to maturity and length of neck. Important characters with greater weightings in principal component axis III included plant height, height of top node, number of leaves and number of grains/spike. The principal components analysis in general confirmed the groupings obtained through cluster analysis (the PCA scatterplot ordination not shown here).

Multilocation Evaluation of Selected Barley Landraces

The analysis of variance (ANOVA) performed on 30 selected barley landraces (in addition 5 check varieties for Delhi location and two check varieties for Bhowali location also included) and means of various quantitative traits indicate highly significant differences for important quantitative traits, such as, days to maturity, plant height (cm), length of flag leaf (cm), length of main ear, number of tillers/plant, number of grains/ spike, seed weight/ plant and 100-seed weight at both Delhi and Bhowali locations (Table 7).

Mean performance of selected barley landraces revealed that all the accessions flowered and matured early at Delhi location (Table 8) with high tillering capacity, greater plant height, high number of spikelet groups/spike and high seed weight/plant as compared to those at Bhowali location. There was high genotype x environment interaction and the populations behaved differently for quantitative traits at both the locations.

Based on F-test for homogeneity of error mean squares between locations, significant differences were observed between error mean squares of all the common characters recorded at both locations. Therefore, no pooled analysis was possible for these characters.

Cluster analysis using Ward's minimum variance technique classified the accession into four major groups at Delhi location and two major groups at Bhowali location. A fair degree of association of geographical diversity and genetic diversity was revealed. Principal components analysis performed on quantitative traits recorded at both the locations revealed that the first three most informative components accounted for 57.12% and 73.9% variation, respectively, for Delhi and Bhowali location. Important characters with greater weightings in principal component axis I from Delhi location

Table 7. ANOVA Summary for Important Quantitative Traits of Selected Barley Landraces

	DF	Days to maturity	Plant height (cm)	No. of spikelet groups/ spike	No. of grains/ spike	Seed weight/ plant	100-seed weight (g)
Delhi location							
Replicates	1	28.92*	17.20	3.21	0.01	10.63*	0.01
Treatment	34	60.72***	219.18***	29.54***	532.46***	39.38****	1.10***
Error	34	6.34	19.44	1.10	2.632	1.994	0.054
Total	69	33.46	117.84	15.15	263.671	20.546	0.571
Bhowali location							
Replicates	1	0.141	49.879	6.502	1.183	0.244	0.191
Treatment	31	45.74***	206.93***	1.84*	390.36***	12.38***	2.29***
Error	31	4.65	1.96	0.83	0.91	0.30	0.04
Total	63	24.80	103.58	1.42	192.55	6.24	1.15

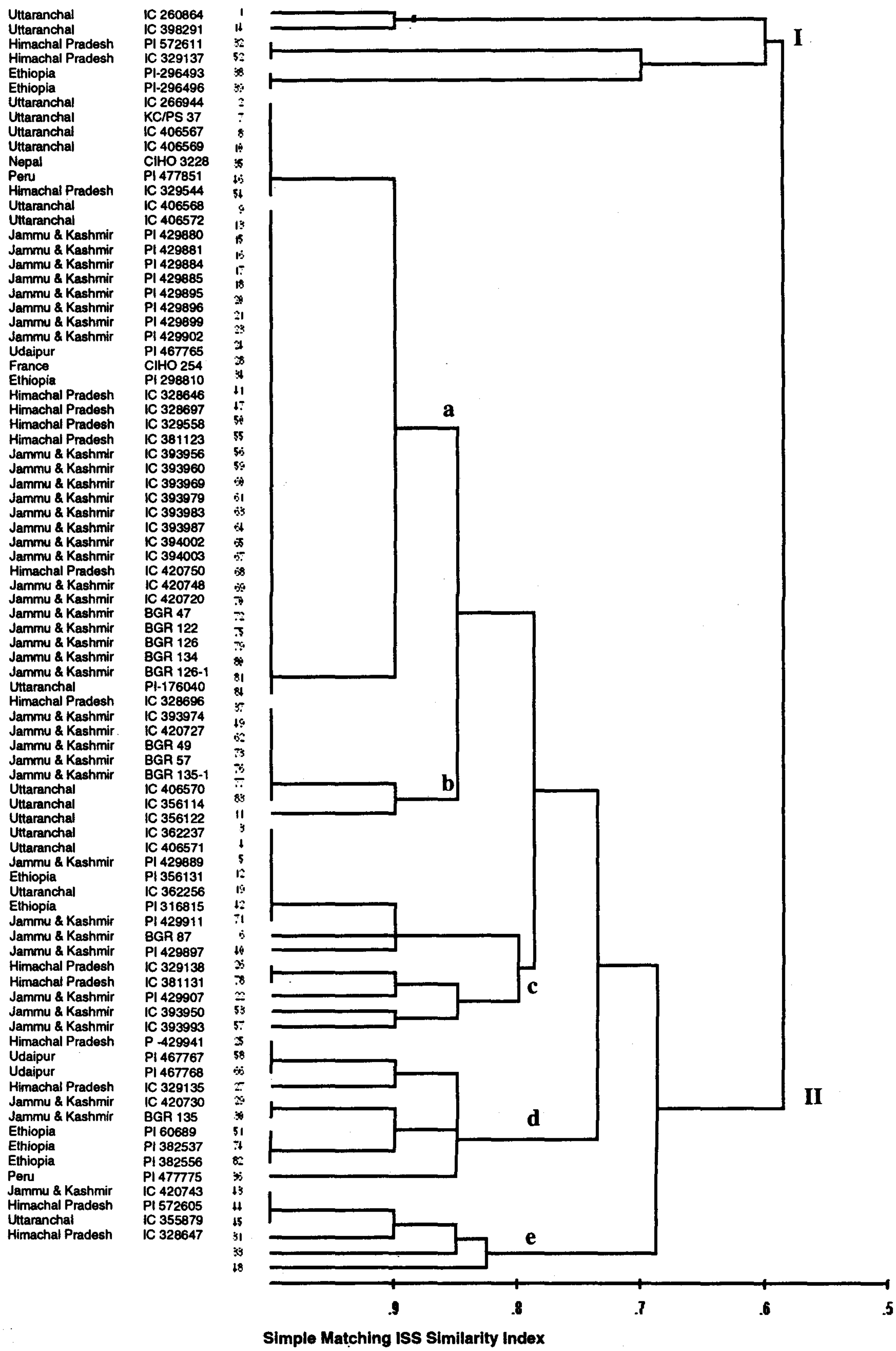

Fig. 2: Weighted average linkage dendrogram of 84 barley landraces based on qualitative traits

Table 8. Mean performance of selected barley landraces at Delhi and Bhowali locations for important quantitative traits

S. No.	Accession*	Days to maturity		Plant height (cm)		No. of spikelet groups/		No. of grains/ spike		Seed weight/ plant spike		100-seed weight (g)	
		D	B	D	B	D	B	D	B	D	B	D	B
1.	IC 260864	123.0	163.5	119.5	96.1	29.0	24.4	75.5	62.0	23.7	3.6	2.3	2.3
2.	IC 266944	126.5	161.5	115.5	93.5	30.0	23.4	69.0	38.0	18.1	4.9	2.2	4.7
3.	IC 355879	126.0	158.0	195.5	78.9	37.5	22.5	27.5	43.6	18.6	4.9	3.9	3.7
4.	IC 356114	118.5	158.0	101.5	78.7	27.0	23.2	66.0	43.1	15.3	4.9	2.5	4.0
5.	IC 356122	119.0	164.0	79.0	96.5	23.5	24.2	65.0	61.5	14.7	3.8	2.8	2.1
6.	IC 362237	117.5	162.0	104.0	95.0	22.5	24.6	60.5	61.0	22.2	4.1	3.0	2.1
7.	IC 362256	125.0	162.5	96.5	96.1	23.0	24.5	60.5	60.5	19.9	5.9	3.3	2.1
8.	IC 398291	120.0	162.5	95.5	96.1	29.5	25.1	65.5	60.5	26.5	3.6	3.5	2.3
9.	IC 406567	115.5	161.5	95.5	96.5	25.5	24.0	60.0	60.0	13.2	3.4	2.1	2.2
10.	IC 406568	113.0	161.5	97.0	95.5	25.5	23.5	65.5	61.5	14.0	3.6	2.0	2.3
11.	IC 406569	115.5	162.5	123.0	96.1	25.5	24.0	65.5	60.0	15.3	3.6	2.5	2.0
12.	IC 406570	118.0	162.5	91.5	94.5	20.5	24.5	66.5	61.5	16.9	3.6	2.4	2.0
13.	IC 406571	123.5	161.5	127.5	96.0	29.5	24.0	71.0	61.5	15.8	3.6	2.9	2.0
14.	IC 406572	116.5	160.0	116.0	72.6	23.5	23.1	60.5	27.7	18.2	6.7	2.9	4.1
15.	PI 467765	132.0	147.5	84.0	82.1	25.5	24.4	70.5	43.1	13.7	6.5	2.7	1.9
16.	PI 429907	119.5	154.5	91.5	80.8	21.5	23.2	72.0	45.1	20.9	8.9	3.9	3.6
17.	PI 429885	116.5	157.0	97.0	93.5	31.0	23.2	70.5	46.7	18.7	6.4	3.2	3.8
18.	PI 429895	136.5	148.0	159.5	78.7	26.5	23.2	74.0	35.1	5.7	3.9	2.9	2.9
19.	PI 429889	116.0	149.0	143.5	79.1	31.0	22.4	89.5	43.7	23.0	8.5	3.7	3.0
20.	PI 429896	117.0	157.5	124.5	80.4	30.0	23.0	67.5	23.3	23.6	6.4	3.3	2.9
21.	PI 429941	113.5	156.0	83.0	60.6	25.5	22.2	65.5	22.1	24.0	5.0	3.7	2.8
22.	CIHO 3228	127.0	163.0	152.5	94.0	26.0	23.4	65.5	37.5	15.9	4.9	3.3	4.9
23.	PI 176040	121.5	160.0	114.5	76.8	30.0	26.4	69.0	61.6	19.9	12.0	3.2	4.6
24.	PI 316815	125.0	158.5	177.0	87.4	27.0	24.1	54.0	43.8	21.5	5.4	3.0	2.7
25.	P 356131	124.5	160.0	181.0	76.4	29.0	24.4	43.5	43.6	23.6	4.9	3.2	4.0
26.	PI 382537	131.0	159.5	173.5	72.6	25.0	24.7	24.5	28.7	19.4	7.2	4.1	4.0
27.	PI 382556	131.0	159.5	130.0	66.0	25.0	25.5	24.0	26.7	19.2	6.2	4.9	5.1
28.	PI 477851	125.0	160.0	206.5	85.4	22.5	22.8	66.5	44.3	20.2	14.1	4.0	4.9
29.	KC/PS 37	123.5	162.0	95.5	94.5	29.5	24.6	65.5	61.5	17.6	3.6	2.8	2.3
30.	PI 572605	121.5	151.5	152.0	89.1	33.0	24.9	28.5	19.6	17.4	4.6	5.0	5.0
31.	DL-36 (Control)	120.0	–	102.0	–	24.0	–	85.0	–	24.2	–	3.7	–
32.	DL-85 (Control)	124.5	–	48.5	–	20.0	–	70.5	–	22.5	–	4.1	–
33.	Jyoti (Control)	119.5	–	95.5	–	23.0	–	95.5	–	23.2	–	3.8	–
34.	VLB 1 (Control)	126.0	163.0	65.5	78.8	30.5	22.8	68.0	48.2	15.3	8.5	3.5	4.1
35.	VLB 60 (Control)	122.0	168.5	70.5	77.5	23.0	24.6	72.5	63.1	27.7	7.2	4.2	3.2
Overall Mean		122.0	159.3	117.3	85.5	26.6	23.9	63.4	46.8	19.1	5.8	3.3	3.3
C.V. (%)		2.1	1.36	4.7	1.64	3.9	3.82	2.6	2.04	7.4	9.48	7.1	6.18
C.D. (5%)		5.1	4.40	11.3	2.86	2.1	1.86	3.3	1.95	2.9	1.12	0.5	0.41

D= Delhi; B=Bhowali; C.V.= Coefficient of Variation; C.D.= Critical Difference; * No local controls were available in naked barleys hence comparison was made wirh improved local covered controls

included number of tillers/ plant, number of leaves, days to maturity and 100-seed weight and from Bhowali location included flag leaf width, number of grains/ spike, plant height and 100- grain weight. Important characters with greater weightings in principal component axis II from Delhi location included days to flowering, length of flag leaf, length of main ear and length of flag leaf sheath and from Bhowali location included spike length, days to ear emergence, flag leaf length and days to maturity. Important characters with greater weightings in principal component axis III from Delhi location included plant height, height of top node, breadth of flag leaf and number of leaves, and from Bhowali location included number of tillers/ plant, leaf length, 100-grain weight and number of spikelet groups/ spike.

Discussion

Except two populations (intermediate types), all the landraces included in the present study were strictly spring type. The study revealed a wide range of variations among naked barley landraces for all the 18 quantitative traits studied (Table 3). Significant differences for most of the traits were recorded. In general, as per earlier observations (Manjunatha 2004), the naked barleys were poor yielder in comparison to hulled types but in the present investigation many of the naked barley landraces were found to be superior to hulled controls (commercial varieties). Twelve accessions were very early in flowering (<75 days) than the earliest flowering hulled control Jyoti (75.5 days). The extra early flowering accessions include PI 429881 (58 days) and PI 429884 (58.5 days) assembled from Jammu & Kashmir and PI 429941 (56.5 days) from Himachal Pradesh. Accessions with high spikelet groups/spike include PI 572611 (37.5) from Himachal Pradesh, PI 429902 (33) from Jammu & Kashmir, PI 572605 (33) from Himachal Pradesh, PI 296493 (31.0) from Ethiopia, PI 429885 (31.0) from Jammu & Kashmir and PI 429889 (31.0) from Jammu & Kashmir as compared to the best hulled control VLB 60 (30.5). Similarly, for no. of grains/spike, several accessions viz. PI 429889 (89.5), IC 420720 (84.0) and BGR 47 (84.0) from Jammu & Kashmir, and IC 329544 (82.0) from Himachal Pradesh were comparable to the best hulled check VLB 1 (85.5). Likewise for 100-seed weight, several landraces viz. BGR 135 (5.38g) and IC 420730 (5.1g) from Jammu & Kashmir, and PI 572605 (5.0g) from Himachal Pradesh out performed the best hulled control DL 36 (4.2g). The above findings highlight the potential of naked barleys as important raw material for crop improvement for several of the desired traits.

The comparative statistics for different quantitative traits indicated that there were distinct regional variations for some important traits in barley landraces (Table 11). Landraces from Jammu & Kashmir Himalayas were relatively early flowering. These landraces, in general, also performed better for various yield related traits such as length of main ear, no. of grains/spike, seed weight/ plant and 100-seed weight. The exotic accessions, particularly from Ethiopia, had very high tillering capacity. No. of leaves/plant were also high in Ethiopian landraces.

For the qualitative characters, landraces differed considerably for spike density. Uttaranchal accessions, in general, had lax rachis, a primitive character of Himalayan naked barleys. Populations from Jammu & Kashmir and Himachal Pradesh had dense rachis whereas exotic accessions were intermediate types. Indian barleys were mostly 6-rowed, only three accessions, one from Uttaranchal and two from Himachal Pradesh were 2-rowed. Of the 12 exotic accessions, five were two-rowed, four from Ethiopia (PI 296493, PI 296496, PI 382537 and PI 382556) and one from Peru (PI 477775). Landraces varied little for seed colour. Majority of the landraces from Indian Himalayas had brown seed colour as against pale seed colour of exotic accessions. Two Ethiopian landraces (PI 60689 and PI 316815) had black seed colour (with high protein content). The blue seed colour, typical of Himalayan naked barleys described earlier (Takahashi *et al.*, 1968) was recorded in only 3 accessions, one from Uttaranchal (assembled from >4,000m elevation at Gunji in Pithoragarh), and two from Jammu & Kashmir (from Ladakh region). The pale and black seed coloured barleys with high protein content from exotic sources has great potential for exploitation in crop improvement. PI 382556, PI 382537, PI 356131 from Ethiopia and PI 572611 from Uttaranchal had more than 16% protein content (data on protein content not presented here).

The diversity indices were high for landraces assembled from Jammu & Kashmir followed by Himachal Pradesh, exotic group and Uttaranchal state. The higher diversity in landraces from Jammu & Kashmir may be because of relatively more number of samples in the study from this region. Further, there is high environmental heterogeneity in the state of Jammu & Kashmir and Himachal Pradesh. The higher Himalayan ranges in Jammu & Kashmir (Leh and Ladakh plateau) and Himachal Pradesh (Lahaul Spiti) where naked barley are still grown largely for direct human consumption are cold deserts. In these higher Himalayan ranges there might be greater natural selection in barley due to generally low rainfall. Greater natural selection for extreme cold and low rainfall also resulted in relatively low diversity in barley landraces from these higher Himalayan ranges (>3000 masl) as compared to middle Himalayan ranges (2000-3000 masl). The relatively low diversity in Uttaranchal state was attributed to low cultivation of naked barleys in this region. A few populations of naked barleys are, however, still grown mainly in higher elevations (>3000 masl). Covered barleys, however, are still popular in this region for brewing and animal feed. The naked barley grown in Uttaranchal state, however, seemed more primitive and unique as compared to landraces from Jammu & Kashmir and Himachal Pradesh. Study of population genetic parameters using STMS markers substantiated the presence of more locally common alleles in Uttaranchal populations (unpublished data). The exotic accessions, particularly the Ethiopian landraces were also diverse and unique indicating Ethiopian region as an important centre of diversity for cultivated barley (Harlan, 1969; Engels, 1990, 1991).

Using quantitative traits, the cluster and principal components analysis (Fig 1,2,3) discriminated accessions in distinct groups based on their geographical origin. Though, at major cluster level the association between area of collection and genetic diversity was not that evident but close perusal of the within-cluster diversity pattern revealed a clear association between the cluster pattern and the topography/altitude of the place of collection. This highlights the regional/microclimatic adaptations of barley landraces from Indian Himalayas. The multivariate analysis therefore provides opportunity to select distinct and suitable types with desired traits for use in crop improvement.

The naked barleys are considered to be wholly oriental and that 80% of the covered forms are of the occidental types (Takahashi *et al.,* 1968). The naked barleys, in general, are far more variable than covered barley for morphological traits. These findings were also corroborated by Murphy and Witcombe (1986), Witcombe and Murphy (1986) demonstrating that covered and naked barleys from the Himalayas differed significantly from each other in a multivariate way. The variation within barley landraces in the Himalayas seems to be regionally distributed. Such regional variability could be due to geographic isolation, founder effects and microclimatic differences between regions.

The multilocation evaluation of selected landraces substantiated the potential of naked barley landraces in crop improvement. Relatively better performance of the landraces at Delhi location (Table 8) highlights the wider adaptability of Himalayan barleys for large scale cultivation even in non-conventional areas. The differences for various quantitative traits across locations, moreover, revealed high genotype x environment interaction. The multivariate analysis (cluster and PCA) performed separately for Delhi and Bhowali location trial data provides the opportunity to select suitable type of wider adaptability for use in crop improvement. The clustering pattern at Bhowali location (dendrogram not shown here) indicated high similarity among Uttaranchal accessions and their distinctiveness from accessions of other regions. This provides the opportunity of introducing desired landraces from other regions in the cropping systems of Uttaranchal state. Detailed population genetic study using molecular markers offers a very effective means of applying the knowledge gained to practical plant breeding (Venkatesan *et al.,* 2005).

The present study, therefore, highlights the importance of Himalayan naked barleys for research, marketing and conservation interventions. The use of quantitative characters which were scaled in an arbitrary way seems to be justifiable and useful as the barley accessions show considerable variation within and between administrative regions for these characters and they are in general of more interest to the plant breeder than the discrete qualitative characters (Engels, 1991). The fact that the naked barleys from the Indian Himalayas performed exceedingly at par with the commercial hulled cultivars (used as controls) at Delhi location, they are of potential utility as source of several desired traits including resistance/tolerance to various stresses and quality. Furthermore, the genetic differences between covered and naked barleys are potentially relevant to breeding programmes in that the variability created through hybridization of the contrasting forms could be exploited.

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