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RESEARCH ARTICLE

Wheat (*Triticum aestivum* L.) Landrace Diversity in Traditional Production Landscapes of Uttarakhand Himalaya in North-Western India

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Wheat landraces are traditionally grown in rainfed farming landscapes of Uttarakhand hills. Except a few interspersed river valleys, where improved wheat cultivars are grown under assured irrigation, about 95% of the net sown area under rainfed farming mainly grows traditional wheat landraces. The present communication documents a total of 36 unique bread wheat (*Triticum aestivum* L.) landrace populations from diverse representative agro-ecologies of Uttarakhand hills. Information on their distinctive properties, informal community-based seed systems, private and public incentives of wheat landrace populations to farmer households and society, diversity loss from production landscapes over time and space, etc. were also documented from all niche habitats. Potential of making use of landrace diversity have been suggested as sources of resistance/tolerance to biotic and abiotic stresses, and more importantly the climate change resilience, as the extreme heat and drought has affected grain yields worldwide and threatened food security.

Key Words: Climate resilience, Traditional rainfed farming, Uttarakhand hill farming landscapes, Wheat landrace diversity

Introduction

Wheat (*Triticum aestivum* L.) is one of the first cereals known to have been domesticated and is the third most-produced cereal globally after maize and rice. The Fertile Crescent (the area known as the cradle of civilization surrounded by arid and semi-arid land in western Asia) was home to wild wheats and traditional varieties and other valuable crops of the modern world (Diamond, 2002). However, the migration process from the Fertile Crescent, as well as both natural and human selection, resulted in the development of local landraces. It is generally accepted that during the process of domestication and the spread of domesticated wheat, new adaptive traits suitable for new environments were selected (Charmet 2011; Peng *et al.,* 2011).

Wheat domestication was responsible for the increase in human population by enabling humans to produce food in large quantities, thereby contributing to the emergence of the human civilization (Zohary and Hopf, 2000). The domestication of wild emmer (*Triticum dicoccoides*), the progenitor of all cultivated wheats (Feldman and Kislev, 2007), was one of the key events during the emergence of agriculture in Southwest Asia, and was the prerequisites for the evolution of tetraploid durum and hexaploid bread wheat. However, the domestication of wild emmer in the Fertile Crescent and the subsequent breeding of domesticated durum and bread wheat drastically narrowed their genetic diversity (Dvorak *et al*., 1998). Upon domestication, it was estimated that initial diversity was reduced by 84% in durum wheat and by 69% in bread wheat. Historically, traditional farmers planted diverse assemblages of wheat genotypes (i.e. landraces) to lower the risk of failure and increase food security because they had limited capacity to control the spatially heterogeneous and temporally unpredictable environment (Jaradat 2006, 2013). This practice led to the development of landrace meta-populations of wheat and the emergence of farmers' seed systems through which they accessed and exchanged diverse genetic material. A meta-population structure, defined as a group of subpopulations interconnected by gene-flow and seed exchange among farmers, villages and eco-geographical regions, favours a dynamic evolution of diversity (Jaradat, 2013).

The material conserved either *ex situ* or *in situ* is a safeguard against genetic erosion and a source of resistance to biotic and abiotic stresses, improved quality and yield traits for future crop improvement. Although landraces of wheat are no longer grown in Europe and North America, they still continue to be important elsewhere (FAO, 2015).

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Throughout their history, farmers subjected wheat landraces to strong selection pressures; therefore, wheat landraces developed multi-locus structures as a result of selection, genetic drift, or fragmentation of their populations (Brown, 2000). These structures predominantly are retained through selection, isolation, lack of migration, and restrictions on outcrossing and genetic recombination. Little has been done to understand the genetic structure of wheat landraces and the inter-specific diversity available in the subsistence agro-ecosystems they still dominate in parts of the Old World (Altieri and Merrick, 1987).

The Green Revolution, which occurred throughout the 1940s to the 1960s, led to the development of high-yielding, disease-resistant wheat varieties with dwarfing genes; these were lodging resistant and highly responsive to inputs. The success of these varieties is probably the most important event in the history of modern agricultural research and enabled such wheat-importing countries as India and Pakistan to become exporters. Currently, modern high-yielding varieties grown in major wheat environments have an assembly of genes or gene combinations pyramided by breeders. However, increasing reliance on relatively few varieties in most breeding programmes has led to the loss of well adapted, genetic diversity. It is well documented that selection targeted at individual loci will reduce genetic diversity within and around the selected loci (Tanksley and McCouch, 1997). Selection in modern breeding programmes acts simultaneously upon many loci, controlling a variety of traits under selection, and such selection would greatly reduce diversity throughout the genome as has been predicted (Tanksley and McCouch, 1997). Decreases in genetic diversity are often recognized as genetic bottlenecks imposed on crop plants during domestication and in modern plant-breeding practices.

In traditional small-holder rainfed farming of Uttarakhand hills, wheat populations still consist of informal farmer-maintained populations often with high levels of morphological diversity. The reasons for their continued cultivation are, i) about 90% farming landscapes in hills are rainfed and only native landraces can only be grown under marginal management, and ii) farmers have several cultural and consumption preferences for these landraces. There has, however, been loss of landrace diversity mainly because of non-availability of seed of local landraces under poorly developed informal local-level seed exchange network. An investigation was, therefore, specifically designed with the objectives of documenting the wheat landrace diversity in production landscapes of Uttarakhand hills.

Materials and Methods

For documenting wheat landrace populations, all the thirteen districts of the Uttarakhand state were systematically surveyed during 2010-13. A participatory approach was adopted to document information on distinctive properties and diverse uses of native landrace populations. Unique wheat landraces from representative traditional farming landscapes were then collected (Fig. 1). The passport information of landrace

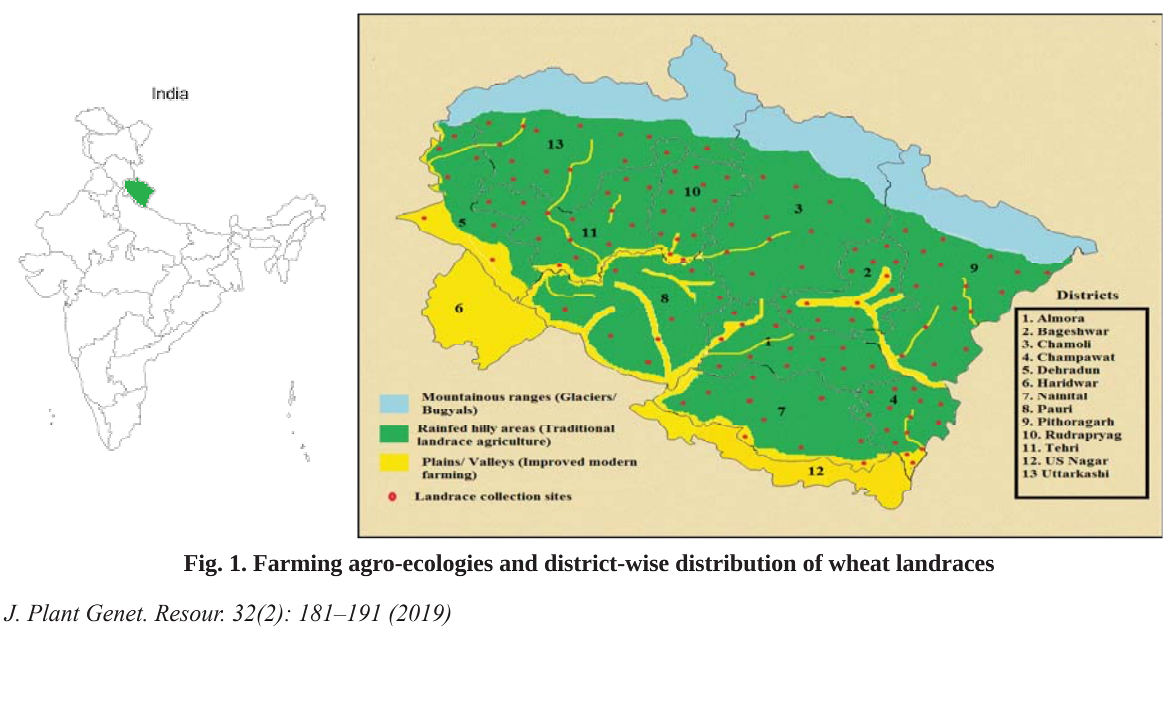

Fig. 1. Farming agro-ecologies and district-wise distribution of wheat landraces

Table 1. Passport information on wheat landrace diversity of Uttarakhand hills

S. No.	Accession Number	Landrace name	District	Altitude (masl)
1.	IC-266791	Gerua	Champawat	1710
2.	IC-266852	Dudh gehun	Pithoragarh	1430
3.	IC-266921	Mota gehun	Pithoragarh	1430
4.	IC-382664	Sona gehun	Rudraprayag	1340
5.	IC-383593	Lakha gehun	Chamoli	1800
6.	IC-398294	Jhunsi ninsa	Bageshwar	1350
7.	IC-398303	Chini	Bageshwar	2113
8.	IC-398305	Munnar	Bageshwar	2087
9.	IC-398307	Thull gehun	Bageshwar	2156
10.	IC-406724	Syat gehun	Champawat	1650
11.	IC-444226	Rajg gehun	Pithoragarh	2403
12.	IC-444232	Bhotia gehun	Pithoragarh	2685
13.	IC-564090	Mundari	Pauri	1511
14.	IC-564096	Bareek lal	Pauri	1362
15.	IC-564113	Lamba lal	Pauri	1316
16.	IC-564114	Safed mundia	Pauri	1316
17.	IC-564147	Lal chanosi	Pauri	598
18.	IC-573138	Syat mundia	Nainital	1456
19.	IC-573139	Rayat gehun	Nainital	1456
20.	IC-573152	Lamba Syat gehun	Nainital	1144
21.	IC-573165	Mundia	Nainital	1856
22.	IC-573167	Daulat khani	Nainital	1684
23.	IC-585633	Pahari	Bageshwar	1338
24.	IC-585635	Lal gehun	Bageshwar	1309
25.	IC-585641	Safed Jhunsi	Bageshwar	1294
26.	IC-585643	Dug gyun	Bageshwar	1350
27.	IC-585655	Dapaati	Bageshwar	1885
28.	IC-585659	Thang gehun	Bageshwar	2122
29.	IC-589276	Hasia	Uttarkashi	1320
30.	IC-589278	Gharia	Uttarkashi	1511
31.	IC-589288	Safed gehun	Uttarkashi	2037
32.	IC-589289	Lal mishri	Uttarkashi	1563
33.	IC-589296	Chhota lal gehun	Uttarkashi	1610
34.	IC-589300	Mishri	Uttarkashi	1045
35.	IC-595376	Jhusia	Bageshwar	1326
36.	IC-595395	Thanga	Almora	1870

diversity representing Uttarakhand hills is presented in Table 1.

Information on distinctive properties of wheat landraces; informal seed systems and landrace exchange at community level; incentives to farmers from traditional wheat landraces; diversity loss from production landscapes and factors responsible for their loss, etc. were also documented from all representative niche habitats. About 30 Focus Group Discussion (FGD) meetings were organized in hill farming agro-ecologies involving average 15-20 farmer participants, mostly elderly women farmers to document information on all above aspects.

The wheat landraces assembled were then characterized in on-station trials at the experimental farms of ICAR-NBPGR, Regional Station, Bhowali (Nainital), Uttarakhand for a set of 21 agro-morphological characters, 9 qualitative and 12 quantitative (Table 2). The range and pattern of variations (cluster and principal components analysis) were statistically analyzed using DARwin statistical software (Perrier and Jacquemoud-Collet, 2006).

Results

Distribution of Wheat Landraces

A total of 36 unique landrace populations were assembled. Distribution of landraces along different altitudinal gradients in Uttarakhand hills are presented in Table 3. Maximum 24 landraces were being cultivated between elevations 1500-2000 m followed by 20 landraces between 1000-1500 m; 4 landraces beyond 2000 m elevations, and lowest 2 landrace populations in lower elevation areas (<1000 m), with some overlaps. Unique landraces specifically grown in different elevations are also presented in Table 3. All the wheat landraces were invariably named with some landraces sounding alike but have different spellings (homophones).

Table 2. Descriptors for wheat landrace characterization and evaluation

Qualitative characters		
1.	Growth class	1-Winter; 2-Facultative; 3-Spring
2.	Early plant vigour	3-Poor; 5- Good; 7-Very good
3.	Plant growth habit	1-Erect; 2-Semi-spreading; 3-Spreading
4.	Lodging tendency	0- Nil; 3-Low; 5-Medium; 7-High
5.	Glume colour	1-White; 2-Red to brown; 3-Purple to black
6.	Glume pubescence	0-Nil; 3-Low; 5-Medium; 7-High
7.	Awn type	1-Awnless; 2-Awnleted; 3-Awned
8.	Awn colour	1-White; 2-Brown; 3-Black
9.	Grain colour	1-White; 2-Amber; 3-Brown; 4-Red; 5-Purple
Quantitative characters		
10.	Days to 80% spike emergence	
11.	Flag leaf length	
12.	Flag leaf width	
13.	Spike length	
14.	Number of spikelets/ spike	
15.	Number of effective tillers/plant	
16.	Number of grains/ spikelet	
17.	Plant height	
18.	Days to 80% maturity	
19.	Number of grains/spike	
20.	Grain yield/plant	
21.	100-seed weight	

Table 3. Distribution of wheat landraces along altitudinal gradients in Uttarakhand hills

Altitude	No. of landraces grown	Unique landraces
<1000 m	01	Chanosi (Lal chanosi)
1000-1500 m	17	Lal gehun, Bareek lal, Mishri, Syat gehun, Mota gehun, Safed mundia, Sona, Safed, Dudh, Hasia Jhunsi ninsa, Ryat gehun, Pahari, Dug gyun, Jhunsi, Lamba syat, Lamba lal
1500-2000 m	10	Chota lal gehun, Gerua, Mundari, Lakha, Thanga, Mundia, Daulatkhani, Safed gehun, Dapaati, Gharia
>2000 m	08	Lal mishri, Safed gehun, Bhotia, Munnar, Thull gehun, Thang gyun, Chini, Rajg gehun

Table 4. Frequency distribution of qualitative characters in different descriptor states

Descriptor	Descriptor state	Frequency (%)
Growth class:	1- Winter	8.3
	2- Facultative	63.8
	3- Spring	27.9
Plant growth habit	1- Erect	52.8
	2- Semi-spreading	44.4
	3- Spreading	2.8
Glume colour	1- White	91.6
	2- Red to brown	5.6
	3- Purple to black	2.8
Awn type	1- Awnless	30.6
	2- Awnleted	19.4
	3- Awned	50.0
Awn colour	1- White	50.0
	2- Brown	50.0
	3- Black	0
Grain colour	1- White	19.4
	2- Amber	61.2
	3- Brown	0
	4- Red	19.4
	5- Purple	0

Morphological Diversity of Wheat Landraces

Diversity for important qualitative characters is presented in Table 4. Substantial diversity was recorded for some of the qualitative characters viz. awn type, awn colour and grain colour. For growth class, most of the landraces were either facultative or spring types; either erect or semi-spreading in growth habit, and predominantly with white glume colour.

The range of variations for quantitative characters is presented in Table 5. Moderate variations were recorded for most of the quantitative characters studied, maximum variations recorded for traits grain yield /plant and no. of effective tillers/plant, whereas least variations were recorded for days to flowering and maturity.

The pattern of variations as revealed by cluster analysis classified the accessions in two major groups. Wheat landraces from high mountainous regions were, however, distinct and formed a separate cluster (Fig. 2). Large scale overlapping of landraces originating from different agro-ecologies in two clusters may be due to widespread informal seed exchange at community level. In principal components analysis (Fig. 3, Table 6), the first three PC axes explained a total of 96.97% variations. Individually, PC axes I explained 83.92%, PC axes II 9.02 % and PC axes III 4.30 % variations, respectively.

Important Wheat Landraces with their Distinctive Characteristics

Important wheat landraces and their distinctive properties are presented in Table 7. Better adaptation to various biotic/abiotic stresses, chapatti making quality and consumption characteristics have been the important features of traditional landraces rather than yield alone.

Private and Public Incentives of Wheat Landrace Diversity to Farmer Households and Society

Cultural and consumption preferences play a major role in decision making of farmer households. Market prices are a small fraction of the private incentive that farmer attach to maintaining wheat diversity. The surplus crop produce, if any, is sold locally in the community, sometime in barter system. With enhanced awareness about the nutritional importance of native landraces, in well-functioning markets, the native landraces can, however, be competitive, fetching a premium price.

Loss of Landrace Diversity and Factor Responsible for their Loss

Loss of landrace diversity from production landscapes and the factors responsible for diversity loss are presented in Table 8. Farmers recall cultivating a total of 52 landraces till 1990s. Over the years, 16 landraces were lost from production landscapes and presently only 36 landraces were recorded being grown in different farming ecologies of Uttarakhand hills. Widespread informal seed exchange at local level was recorded but none of the landraces were introduced in farming from outside the state boundaries.

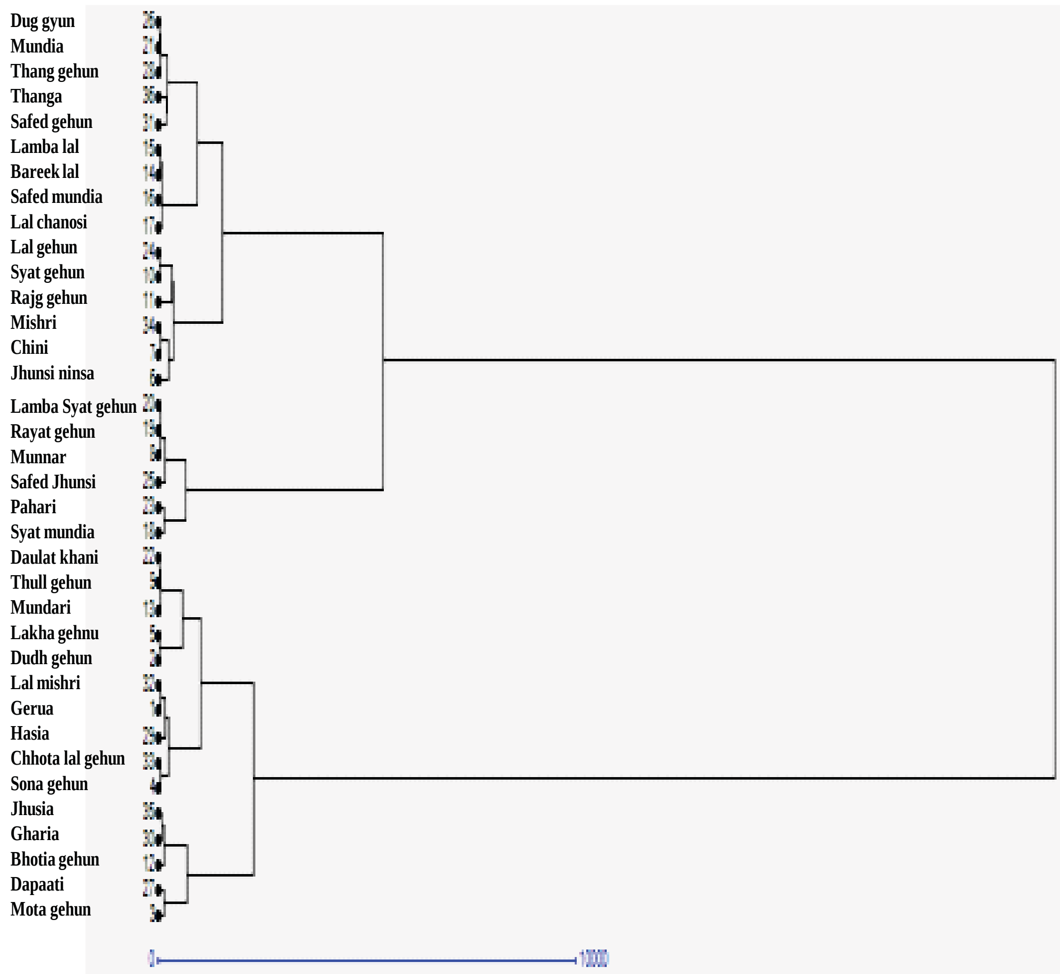

Fig. 2. Ward's minimum variance dendrogram of 36 wheat landrace accessions using quantitative characters

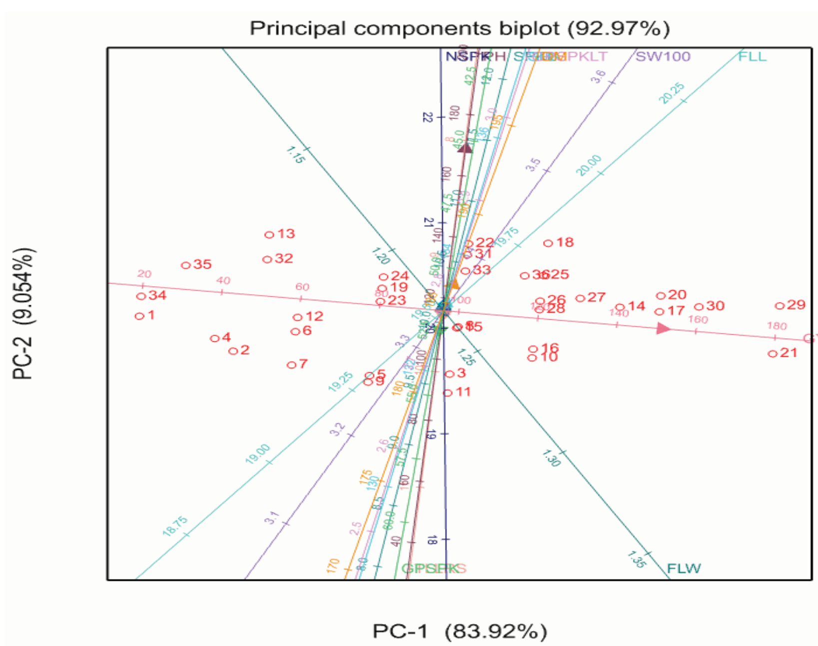

Fig. 3. Principal components biplot of 36 wheat landrace accessions using quantitative characters

Table 5. Range of variations for different quantitative characters

Characters	Min.	Max.	Mean	SD	CV (%)
Days to 80% spike emergence	119.0	149.0	133.0	6.6	5.0
Flag leaf length (cm)	17.0	26.2	19.5	2.9	14.9
Flag leaf width (cm)	1.0	1.6	1.2	0.2	13.5
Spike length (cm)	6.3	12.9	10.1	1.4	13.7
No. of spikletes/spike	17.2	24.8	20.2	1.9	9.5
No. of effective tillers/ plant	5.6	29.4	9.8	3.8	38.9
No. of grains/spikelet	2.4	3.4	2.8	0.2	8.3
Plant height (cm)	88.3	141.3	115.9	14.3	12.3
Days to 80% maturity	174.0	189.0	184.6	4.2	2.3
No. of grains per spike	31.6	71.8	51.7	8.9	17.1
Grain yield/plant (g)	20.0	180.0	96.1	42.1	43.8
100-seed weight (g)	2.7	3.9	3.3	0.4	10.7

Table 6. Principal components analysis of wheat landraces

PC axes	Variations explained	Cumulative variations	Characters with greater weightings
1	83.47	83.47	Grain yield per plant
2	9.02	92.49	Plant height, days to maturity
3	4.30	96.79	GPSPK, SPK

Replacement of local landraces by improved varieties was mainly recorded in river valleys (average 70-80%) than upland rainfed farming (2-3%).

The important factors responsible for landrace diversity loss include, i) non-availability of seed of native landraces, ii) changing climate particularly greater frequency and severity of droughts, iii) lack of manpower (family labour), iv) poor market infrastructure for local crops, and v) loss of ITK/LEK, in descending order of priority from farmers' perspective.

Discussion

On-farm Conservation of Wheat Landraces

It was found that traditional wheat landraces are still being cultivated and maintained on-farm in hill farming landscapes of Uttarakhand state. It provides the farming community enough opportunity to plant, select and continue cultivating the landrace populations for better climate resilience, and tolerance/resistance to other biotic and abiotic stresses. Most of the landrace populations are well adapted to specific agro-ecologies in traditional hill farming.

Table 7. Important wheat landraces with their distinctive characteristics

Landrace name	Unique characteristics
Bhotia	Better adapted to mountainous high elevation areas, bird tolerance, late maturity
Chanosi	Better adapted to valleys up to 1500 masl, early maturity, better chapatti making quality and taste
Dapati	Better adapted to mid-hills, drought tolerance, better taste
Daulatkhani	Wider adaptation from 1000-2000 masl, medium tall, awned, better nutrition and excellent chapatti making quality, and delicious taste and aroma, bird tolerance
Dudh gehun	White seed colour, awned, suitable for valleys and mid hills up to 1500 masl, better yield
Lakha	Thick stemmed, medium tall, tolerance to hailstorms and snowfall
Lal mundia	Tall, red glume, awnletted, amber grain, adapted to mid- to higher elevation areas, better yield
Mundia	Tall, thick stem, awnletted, better quality
Thanga	Dwarf, thick stem, suitable for high altitude areas, red and bold grains, tolerance to hailstorm and snowfall, bird tolerance

It is worth emphasizing that much of the wheat landrace germplasm available world over has been collected during the 1970-1990 and is being conserved across the world mostly in long-term national and international genebanks (Frison *et al*., 2011). However, a small portion of this diversity is being conserved and used on-farm where it continues to evolve (Brush and Meng, 1998). Both of these conservation methods have its merits and limitations. On-farm conservation strategy provides a natural laboratory for evolution to continue

Table 8. Loss of landrace diversity and factor responsible to their loss

Pattern of occurrence of landraces				Important factors responsible for diversity loss (*descending order of priority from farmers' perspective*)
Till 1990s	Loss of landraces	Landraces introduced into farming systems*	Presently grown	
52	16 (Lal Dandi, Rati, Thangi, Jausa, Jwapat, Lalnoi, Hara Pahari, Dogla, Kontha, Dhol Chudia, Muneri, Raje, Bhotta, Dabdi, Palthi, Naphal)	-Nil- Only improved cultivars got introduced in to farming Irrigated valleys VL738, Sonalika, VL 616, UP 1109, PBW 343 Rainfed areas VL 738, VL 832, VL 829, VL 616	36	Non-availability of seed of native landraces Changing climate: greater frequency and severity of droughts Lack of manpower (family labour) Poor market infrastructure Loss of ITK/LEK

* 70-80% replacement of traditional landraces by improved varieties in river valleys and 2-3% replacement in upland rainfed farming

and helps a gradual build-up of traits imparting adaptation to specific eco-geographical regions and those matching the requirements of traditional farming landscapes. The need for on-farm conservation of landraces is one of the most important aspects in plant genetic resources management worldwide (Le Boulch *et al*., 1994; Kebebew *et al*., 2001; Jaradat, 2013). Farmers continue to grow and maintain a wheat landrace if it meets their production and consumption needs. The total cost and benefit of landraces to farmer households are central to their on-farm conservation and continued utilization.

Farmers have private incentives to grow these traditional landraces. Farmers maintain crop landraces if these are valued either for cultural, social, economic, or even ecological reasons. Therefore, direct use values, particularly the quality traits that farmers regard as valuable for consumption are considered to be proxy indicators of private value of a landrace (Brush and Meng, 1998). However, the likelihood of wheat landraces to be conserved on-farm increases when the markets for their derived products are expanded through improved consumer access to information on recipes, nutritive and cultural values (Jaradat, 2013). Therefore, local knowledge of landrace diversity, when documented through interaction with farmers and linked to food traditions, local practices and social norms, is vital for on-farm conservation and would increase their competitive advantage if farmers have other alternative options (Bellon *et al*., 1997; Brush, 2004). For example, socio-cultural values and culinary attributes motivated farmers in central Ethiopia to conserve a durum wheat landrace on their farms; they appreciate its peculiar organoleptic qualities and multiple uses, including 14 dishes and two drinks, despite the availability of several improved durum wheat varieties in their locality (Kebebew *et al*., 2001). Moreover, hundreds of farmers who accessed the landrace through re-introduction program expressed their appreciation and future commitment to growing and conserving it on-farm. This example strongly indicated that farmers in a community collectively can sustain more crop and landrace diversity than individual farmers, thus meeting overall conservation needs and objectives (i.e., private and public values of a landrace). A renewed interest in and increased demand by farmers to grow this durum wheat landrace and the promotion of landrace-derived products generated income, created green jobs for local communities, and supported on-farm conservation of the landrace (Jaradat, 2013).

Along with economic benefits, on-farm conservation and utilization of such wheat landraces is also linked to peoples' cultural, social and ritual values. However, for individual farmers, private values of a landrace are the main motivating factors for growing landraces as a source of income and a means of survival. Therefore, *ex situ* conservation in a genebank may be the only practical option to conserve landraces having low private but high public value (Le Boulch *et al*., 1994).

Seed Systems and Exchange

The majority of the wheat landrace diversity maintained on-farm is managed by smallholder subsistence farmers of the Uttarakhand hills. Mainly the local community-level informal seed system (ISS) dominates and the formal seed system (FSS) plays a negligible role except in river valleys and the plain areas where improved farming is practiced under assured irrigation (Bisht *et al*., 2018). The seed systems in hill farming depend on free exchange of seeds among farmer households either through small gifts or barter exchange or to a limited extent trade. The system, therefore, needs protection from negative impacts of regulations designed to promote the FSS. Such negative impact may stem from IPR protection of FV, seed laws, biodiversity laws regulating access, etc. Further, the modern seed laws do not take into account important aspects of farmers' ISS. The FV in ISS are genetically heterogeneous as against the modern improved varieties under FSS that may be uniform and clearly distinct. The genetic heterogeneity of farmer landrace populations helps farmers' select and advance alleles of local adaptation.

Poorly developed seed systems have been a major constraint in deploying more landrace diversity in production systems (Bisht *et al.*, 2018). Improving farmers' capacities to select, produce, and manage quality seed of traditional landrace varieties will help strengthen the ISS of the community. The capacity building program should rely on farmers' IK and should involve the following, i) farmer participatory seed selection for desired adaptive variations in native/naturalized crops, ii) quality seed production, maintenance, and storage of seeds of elite crop landraces, iii) on-farm demonstrations on improved cultivation practices, and iv) community-based *in situ* maintenance of local improved seed varieties.

There is a strong need to establish a traditional seed system network in which the farmers' knowledge of their traditional food system is acknowledged and reflected in the participatory nature of farming activities. Also there is a strong need that the capacity strengthening activities are built on the existing IK of the farming community.

Small-scale family farms worldwide traditionally save seed of heirloom or local varieties in order to sustain harvests and conserve well-adapted traditional crop varieties. Seed saving can contribute to lower supply costs, more diversified goods, improved human nutrition, and farm self sufficiency. On-farm seed saving by small farmers is essential in conserving global agricultural biodiversity (Witcombe *et al*., 1996), in general, and crop diversity, in particular. Recently, however, this effort has been undermined by corporate consolidation of seed markets and the contentious concerns about seed types, sources, and availability (Jaradat, 2013). Commercial and large-scale seed industries are constantly developing seeds that represent genetically uniform, high-yielding, and increasingly genetically modified crop varieties. These seed types are of little or no value to organic and low input farmers; they are usually designed for use in large-scale mechanized farming, and sometimes are packaged with chemical inputs. As modern industrialized farming extends over the global agricultural landscape, the seed industry has become both more technically specialized and increasingly controlled by large corporate firms. The new seed technologies may pose serious and complex economic risks to small farmers (Rijal, 2010); they can become dependent on expensive improved seed varieties and brands that are marketed along with complementary agrochemical packages. In addition, some commercial cultivars may not meet local dietary needs or market demand. Recreating and structuring local seed systems to simulate a source-sink meta-population model is a first step towards restoring the fragmented meta-population structures of wheat landraces. Through this model, stakeholders can (Almekinders *et al*., 1994; Zeven, 1999; Jaradat, 2013), i) identify the unit of analysis (e.g., the farmer as a decision maker and agent of conservation, the field or parcel representing a particular habitat, the landrace, or a seed lot), ii) incorporate variation among farmers in their practices, knowledge and gender, iii) quantify patterns of seed exchange among farmers and their impact on the biology parameters of landrace population, iv) identify the limiting factors that determine distribution and range of a landrace; and, v) define the minimum area needed to create a dynamic equilibrium between "colonization" and "extinction" of a landrace meta-population (Jaradat, 2013).

The goal of this type of participatory endeavour is empowering the farmers by supporting the formation of groups capable of assessing their own needs and addressing them either directly or through demands on publicly-funded research organizations. However, low income traditional farming households often have limited technical capability and facilities to produce and properly store seed lots, and thus can face risks in conserving and sustaining reliable and high-quality seed supplies for their planting needs.

Large scale local level seed exchange can be commonly seen in Uttarakhand hill farming. Traditional farmers periodically resort to replacing seed of their old varieties and landraces with seed from other farmers to combat what they consider as "seed degradation." This "inexplicable" seed replacement may have its origins in farmers' belief that homegrown seed degenerates after several generations of re-sowing under the same environmental and edaphic conditions and management practices (Zeven, 1999). Seed replacement and avoidance of traditional maintenance breeding by farmers could, however, be attributed to the existing, but mostly unsuspected, negative association between yield potential of the landrace and the competitive ability of individual plants within its genetically heterogeneous populations (Jaradat, 2013). As seed of many old varieties and landraces disappear across the world and sales of modern improved seed varieties increase exponentially, more low-income farmers may face difficult choices about the type and source of the seeds they utilize (Baniya *et al*., 2000).

Landraces and the Future of Wheat Diversity

It has been observed that 16 wheat landraces have been disappeared from production landscapes of Uttarakhand hills during past two to three decades, whereas not a single landrace was introduced in traditional farming. Under rainfed hill farming only, 2-3% net sown area is replaced by modern varieties, whereas in river valleys an average 70-80% cropped area have been replaced by improved varieties bred by formal sector institutions. In rainfed hill farming, farmers' are often forced to plant improved varieties when there is crop failure and farmers' are constrained for seed of local varieties available for planting in next season.

World over, durum and bread wheat landraces have been largely replaced, in their centres of diversity by monocultures of pure genotypes. This genetic erosion resulted in significant loss of valuable genetic diversity for quality traits and resistance or tolerance to biotic and abiotic stresses; whereas, the pure wheat genotypes do not have the wide adaptation and the diverse genetic background already present in landraces. Diversity of wheat landrace populations, when structured to build spatial and temporal heterogeneity into cropping systems will enhance resilience to abiotic and biotic stresses. Other resilience sources will include more robust genetic resistances and biochemical response mechanisms derived from landrace genotypes (Bonman *et al*., 2007).

Climate change is expected to differentially affect components of complex biological interactions in modern and traditional wheat production systems. Wheat yield and quality will be affected by climate change directly, and indirectly, through diseases (e.g., stem and leaf rusts) that themselves will change but remain important. These effects will be difficult to dissect and model as their mechanistic bases are generally not well-understood. The manner with which wheat landraces and their populations in and outside their centres of diversity might respond to climate change will determine their continued productivity, utility, and survival. Phenotypic plasticity, evolution, and gene flow, although each presents its own uncertainty, are possible avenues for surviving shifts in biotic and abiotic conditions caused by climate change. Whether there will be constraints on evolution in response to the abiotic and biotic stresses caused by climate change, modern wheat, but not landrace adaptation may not keep up enough to maintain fitness (i.e., seed production). Wheat plants will probably respond through shifts in morphology (e.g., tillering capacity, leaf area index, green leaf area duration), phenology (e.g., days to anthesis, days to maturity, duration of seed filling period), or development (e.g., rate of leaf emergence based on available growing degree days), which may help maintain fitness. However, phenotypic plasticity and gene flow (mainly through seed exchange) of landraces may not produce fully adapted phenotypes or the necessary genetic variation to combat climate change. Declining yields of landrace populations due to expected climate change would cause great concern to farming families and threatens their livelihoods. In their attempt to maintain yields, farmers would consider changing seed sources and discarding their adapted landrace populations (Zeven, 1999). This could result in the loss of certain landrace populations, entire landraces, or, in extreme cases, whole minor wheat species.

The development of new varieties from wheat landrace populations is a practical strategy to improve yield and yield stability, especially under stress and future climate change conditions. Further enhanced productivity and stability can be achieved through practicing continuous selection within landraces across the marginal production environments, to exploit the constantly released useful adaptive variation (Ehdaie and Waines, 1989). Non-breeding approaches to create demand for landrace products to promote on-farm dynamic conservation and sustainable utilization of wheat landraces include, i) raising public awareness regarding current and future value of landraces, ii) diversity fairs to allow for the exchange of landrace materials and associated indigenous knowledge, iii) visits among farmers in different localities to share seeds and experiences, iv) diversity contests to reward farmers who keep special varieties and or conserve the highest diversity, and v) recipe development and niche market creation for landrace products. Together, these activities are expected to complement each other and contribute positively towards sustaining on-farm conservation and landrace diversity for the foreseeable future.

Landraces, as an important genetic resource, have been included in international treaties and national decrees that protect and enhance their use in their local environments. However, legislation is needed to make it possible to market landraces as diversified genetic materials. National and international legislation was designed primarily to protect trade and return royalty income to expensively-funded plant breeding programs; as landraces become more attractive to use in local food production and sustainability, legislation changes are needed to facilitate this trend and to promote exportation and exchange of landrace diversity and encourage their use (Jaradat 1992, 2013; Joshi and Witcomb, 2003).

An unprecedented level of international wheat germplasm exchange has taken place during the past three to four decades resulting in a greater degree of genetic relatedness among successful cultivars globally. Despite considerable progress over the years, huge scope still exists for strengthening and making use of landrace diversity as sources of resistance/tolerance to biotic and abiotic stresses, and more importantly the climate change resilience as extreme heat that have affected grain yields worldwide and threatened food security. Sources of specific adaptation related to drought and heat, as well as associated breeding of genetic traits, will contribute to maintaining grain yields in dry and warm years. Evaluation of wheat landraces stored in gene banks with highly beneficial untapped diversity and sources of stress adaptation, once characterized, should also be used for wheat improvement. Unified development of databases and promotion of data sharing among physiologists, pathologists, wheat quality scientists, national programmes, and breeders will greatly benefit wheat improvement for adaptation to climate change worldwide (Lopes *et al*., 2015).

Wheat Landraces as Functional Food

Beside being a major staple energy source and source of easily digestible quality protein, among health promoting phytochemicals in whole wheat grains, phenolic compounds have gained attention as they have strong antioxidant properties and can protect against many degenerative diseases (Leoncini *et al*., 2012). Profiling of grain phenolic extracts of modern and old common wheat varieties and evaluation of their potential antiproliferative or cytoprotective effect in different cell culture systems have indicated that increased intake of wheat grain derived products, particularly of old farmers' varieties, could represent an effective strategy to achieve both chemoprevention and protection against oxidative stress related diseases (Leoncini *et al*., 2012).

Further, nutrition profiling of farmer landrace diversity is essential as developing food composition database is considered vital for effective advocacy tools and critical for cross-sectoral policy and program development for food-based approach to community nutrition and health. Nap Hal, an Indian landrace of wheat, exhibiting unique characteristics suitable for biscuit making quality can be cited as an example here (Ram *et al*., 2007).

Conclusions

Despite loss of some wheat landraces, substantial diversity is still maintained in traditional production landscapes of Uttarakhand hills. Facilitating systematic documentation and registration of unique landraces are considered necessary to address Farmers' Rights. An integrated seed system, combining both community-level ISS and FSS, also needs to be developed to address the issue of quality seed production and trading of FV. The nutritional value of FV needs to be studied so that they can also be competitive in local markets and provide commercial opportunities of fetching a premium price. Adaptive response of FV to changing climate also needs to be duly documented in order to provide an evolutionary service to the society.

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