Agric Res (April–June 2012) 1(2):100–116
DOI 10.1007/s40003-012-0020-z

REVIEW

Wheat Improvement in Northern Hills of India

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Received: 16 November 2011 / Accepted: 14 April 2012 / Published online: 1 June 2012

Abstract Wheat (*Triticum* spp.) is one of the important winter cereal crops of India. The Northern Hills Zone (NHZ) of India covers humid western Himalayan regions, which produces approximately two million tons of wheat with rather low productivity level of 1.75 t/ha. This low level of productivity is mainly due to difficulty in availability of improved varieties on one hand and occurrence of diseases that pose severe threat to wheat production on the other. In contrast, the prevalence of cool climate and comparatively longer crop season offer ample scope for raising the level of wheat yield in this region. Furthermore, this zone assumes great importance in management of rust in the country due to the fact that the hills are the foci of infection for wheat rusts. The Green Revolution bypassed these hills largely because of the lack of suitable varieties on one hand and poor seed multiplication of the available varieties on the other. As a result, indigenous land races are still under cultivation in these areas. Semi-dwarf varieties, however, made significant impact on increasing wheat production in the post-green revolution era and release of VL *Gehun* 616 in 1986 fulfilled the long-felt need for a suitable variety for early sown condition in the hills. Subsequently, wheat improvement work gained momentum and at present, research organizations of the Indian Council of Agricultural Research and the State Agricultural Universities based in the region are playing important role in breeding new varieties for the hills. These centers have deployed modern methods of breeding with special emphasis on transferring rust resistance. Additionally, they have developed and released more than 40 varieties including facultative wheat varieties that are suitable for dual purpose (green fodder-cum-grain) under limited irrigated condition. One of the prime contributions of these institutions has been the timely detection of new variants and identification of rust-resistant materials that have prevented major loss to wheat production during the last 35 years. Concerted efforts, being made by these institutions, will help not only in increasing the production and productivity of wheat in the NHZ of India but will also help in containing spread of wheat rusts in the plains of the country.

Keywords Wheat · Northern hills · Winter × spring wheat · Dual purpose · Wheat

Introduction

Wheat (*Triticum* spp.) contributes almost one-third to the total food grain in India. It occupied around 29.5 million hectare (Mha) area that produced 85.9 million tons (Mt) of wheat during the year 2011 [4]. The Northern Hills Zone (NHZ) of India covers the humid Western Himalayan Regions situated beyond 750 m above mean sea level, i.e., Jammu and Kashmir (J&K) (except plains of Jammu and Kathua) (0.28 Mha), Himachal Pradesh (HP) (except Una and Paonta Valley) (0.36 Mha), hills of Uttarakhand (UK) (except tarai region) (0.39 Mha), Sikkim (0.05 Mha), hilly regions of West Bengal (0.31 Mha) and North Eastern States. In total, wheat is grown in 1.39 Mha area in the NHZ of which highest acreage is in UK followed by HP and J&K [2]. The region produces around 1.83 Mt of wheat

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with the productivity level of around 1.75 t/ha, which is rather low as compared to the national average of 2.9 t/ha [5]. Apart from the long vegetative growth and relatively shorter grain filling period in the semi-temperate climatic adaptation, non-availability of improved seeds, irrigation systems, mechanical field tilling equipment suited to terraced small fields, and other inputs on time, poor-extension of the modern technological packages, prevalence of diseases, small and fragmented land holdings, shallow soil depth, severe soil erosion, and difficult terrain are some of the main constraints for the low productivity level in this disadvantaged area [11].

The zone is characterized by cool climate and longer growing season. Soils are medium deep to deep, well-drained loam to clay loam. Sowing is normally done in October/November and the crop is harvested in May/June. In higher hills, where winter is severe, the crop is raised during summer between May and September. Cultivated area consists of terraces of smaller size and irregular shapes. Use of farm yard manure ranges from 3 to 8 t/ha but chemical fertilizers are hardly applied [11]. Frequent variations in the climatic parameters are encountered due to the changing altitudes and aspects of hills. Stripe (Yellow) and Leaf (brown) rust, powdery mildew, stinking smut (hill bunt), and loose smut are important diseases. Damage due to frost is frequent [30]. The common physical constraints include occurrence of low temperature early in the season, high temperature coinciding with the reproductive growth and limitations of soil moisture and soil fertility. Thus, the success of the crop is mainly dependent on residual moisture and rainfall distribution during the season. All these factors result in low productivity resulting in considerable loss in production. However, cool climate and comparatively longer crop season in hills offer enormous scope for raising the level of wheat yields. In NHZ, the major area under wheat is rainfed (83 %) and the irrigated area is confined only to valleys [2]. Though area and production wise, this zone is of minor importance but being foci of infection for rust diseases, it assumes national importance for the management of rust diseases even in major wheat-growing regions of the country [30].

Triticum aestivum is the only wheat species grown by the farmers in NHZ of India. A large number of land races are still cultivated as for example, indigenous land races/farmers' varieties like *Bhati, Chanosi, Chotia safed, Chy-ud, Dapti, Dhang, Dhaulia, Dudgyn, Doldakhani, Dudh, Geruwa, Intor, Jhusia, Kanyari, Kavjhusi, Lalgyun, Lalnoi, Mangraje, Munar, Naulia, Pothi, Rata, Syatgyun* [17], *Tank, Dualatkhani, Munda gehun, Setta, Sathi, Chini, Thull, Safed Jhusia, Lal misri, Safed misri, Naphal* (VPKAS, unpublished exploration records) are popular in the hills of UK. *Bhangru, Bharadoo, Chawera, Cheeuni, Chiti kanak, Daru, Darmori, Daron, Desi Mundal, Gazaria, Jael, Joth, Jhuladi, Kasieun, Kothek, Kothi, Kankoo, Kiawali, Lal kanak, Lalpuri, Latar, Kalee bauri, Mundra, Mandaleu, Marodum, Misri, Mundu, Paluwa, Ralieum, Rigaliya, Rundan, Shruin, Trimudi* in cultivation in the hills of HP [21]. Efforts are on to collect, characterize and protect these landraces which have been selected by the farmers for specific traits like *Safed mundri* and *Lal mundri* are considered as drought-tolerant; *Jhusia, Kishav, Churi,* and *Farmi* are known for high yield potential; *Safed mundri, Lal mundri,* and *Bhuri mundiya* for high biomass. *Mundiya* has been reported to be suitable for drought as well as higher biomass production both [18]. *Naphal* is known for biscuit quality and softness; *Lal Gehun* is known for high quality and tastier chapati; *Rata* for good *dalia* and better fodder quality; *Bhati* for long awns and excellent fodder for livestock; *Tank* for long awns and small grains due to which monkey do not damage the crop. These land races with indigenous knowledge have been collected during the explorations and need to be validated. In this endeavor VPKAS, Almora has registered one land race '*Tank*' for long awns and small grains not preferred by monkeys [9]. Efforts are on to protect other land races/farmers' varieties too. However, these farmers' varieties and land races are often not pure but high-class mixtures of many contrasting characters. They differ with respect to grain color (white and red), size (medium and small), glume color (white and brown), awned character (awned, awnletted and awnless), early growth habit (erect and prostrate), and maturity duration. By and large, the indigenous land races of NHZ can be characterized as tall with weak straw, small ear head, high biological yield, low harvest index, longer vegetative and shorter reproductive period, less responsive to high inputs and susceptible to rusts, and various other diseases. As a result of these constraints, improvement of the local types can be made only through pure line selection [27]. Further, winter types are cultivated in some pockets of the snow-bound regions of the HP comprising districts of Lahaul & Spiti and Kinnaur and tehsils Pangi and Bharmour of district Chamba. Mixture of various landraces of winter wheat are cultivated by the farmers in these areas, which suffer from various problems such as poor yield (0.8–1.0 t/ha), lodging and disease susceptibility, poor regenerability after one green forage is cut. Hence, there is dire need to replace the presently grown landraces with the improved cultivars [15]. Wheat cultivation in J&K has been started relatively late in the 1970s. However, temperate climate of Kashmir valley and higher hills is more conducive for realizing higher yields of wheat crop. The valley of Kashmir and higher hills receive most of the annual precipitation during the months of December to May, which coincides with the critical growth period of the crop in the valley. Availability of adequate moisture at sowing during mid-October to mid-

November ensures good crop growth. Of late, most of the traditional wheat-growing rainfed belt in the foot hills have now been brought under apple orchards. Wheat cultivation on some of the remaining rainfed areas has, however, been revived now. The impact of Front Line demonstration on wheat has been excellent, attracting farmers towards cultivation of this crop [33]. Besides, wheat is cultivated in Ladakh region too where it occupies an area of 3.9 thousand ha with a productivity of (0.88 t/ha) that is much lower than the national average (2.9 t/ha). In this region the crop is sown during early to mid May and harvested in the middle to last week of September [32].

History of Wheat Improvement in Northern Hills

The northern hills assume national significance for management of rust diseases in the major wheat-growing regions of the country as the annual recurrence of the rusts of wheat takes place from their over-summering spores on volunteer plants of wheat and related species at different altitudes in the hills. This realization came in 1934 as a result of pioneering work of late Dr. K. C. Mehta, who after his return from UK, initiated systematic investigations on cereal rusts in India. In the year 1930, Imperial Council of Agricultural Research sanctioned a scheme to strengthen rust research work in India. Out of Agra, Shimla, Almora, and Murree (now in Pakistan), Prof Mehta ultimately preferred the location at Shimla, popularly known as Flowerdale, as he found it to be the most suitable site to maintain the rust cultures around the year. The Imperial Agricultural Research Institute (now IARI, New Delhi) established a rust research laboratory at Flowerdale, Shimla under the leadership of Dr. Mehta. Systematic research on the annual recurrence of wheat and barley rusts, led to the identification of the hills as the primary reservoir of inoculums for causing fresh infections in the Indo-Gangetic Plains. Dr. Mehta further demonstrated that though the alternate hosts for the various *Pucccinia* spp. occur in the hills they are nonfunctional with regard to wheat rusts. The recurrence of the disease, therefore, is only through *urediospores* and the benefit of sexuality in the evolution of the pathogenic forms does not occur. This knowledge laid a strong foundation for a systematic programme to breed varieties possessing resistance to the rust pathogen [19]. Later in April 1935, the first wheat breeding project for disease resistance was commissioned by IARI under a scheme for 'Breeding Rusts–Resistant Wheat' sanctioned to Dr. B. P. Pal [27]. It was in May 1951, that a full-fledged regional station then named Wheat Breeding Station [now Regional Station (Cereals and Horticultural Crops), IARI] at Tutikandi, Shimla with a post of Wheat Breeder was established [2]. The scheme had a close collaboration with Dr. K. C. Mehta. In 1949, Indian Council of Agricultural Research (ICAR) sponsored schemes on wheat rust. Under this programme the IARI established wheat research centers at Pusa (Bihar), Indore (Madhya Pradesh), Wellington (Tamil Nadu), and Bhowali (the then UP Hills now Uttarakhand hills).

Most organized work on breeding for rust resistance was carried out at IARI under the leadership of Dr. B. P. Pal. The research carried out during the period from 1935 to 1948 by Prof. K.C. Mehta and his associates had generated very comprehensive knowledge regarding the annual cycle of rust occurrence in India as also the physiological specialization of races. IARI, Regional Station, Shimla led in developing improved varieties of traditional tall Indian wheats like NP 770, NP 809, NP 818, and NP 829. NP 809 was the first variety evolved after 18 years of work that combined substantial degree of resistance to all the then existing races of three rusts. Some attempts were also made to introduce exotic wheat varieties from Canada, US, England, Egypt, Australia, Mexico, and Russia [20]. An Australian wheat variety "Ridley" was recommended by IARI for cultivation in hill regions of the country. This variety combined thick straw with bold amber grains and resistance to stem and leaf rusts. The breeding work carried out at Bhowali resulted in the development of a high yielding rust-resistant variety NP 846. However, in the absence of proper extension work and supporting seed production programme, there was little impact of these varieties in wheat-growing areas of NHZ.

At IARI, New Delhi, wheat improvement started as early as in 1935 in coordination with Pusa and Tutikandi and it was further strengthened in 1962 when IARI took lead and initiated an inter-disciplinary and inter-institutional co-operative research programme by involving several wheat researchers from many research centers in the country on a voluntary basis. The All India Coordinated Research Project (AICRP) on wheat was launched in the year 1965. Being a national institute, IARI and its regional stations at Tutikandi, Shimla, and Bhowali (till 1985–1986) contributed materials to Northern hills. At GBPUA&T, Pantnagar wheat improvement programme started couple of years before the inception of AICRP on wheat and the hill campus of the University have been contributing materials for Northern hills since then.

Wheat improvement work was taken up at the then Vivekananda Laboratory [now known as *Vivekananda Parvatiya Krishi Anusandhan Sansthan* (VPKAS)] in early 1950s and two tall wheat varieties viz., VL 78 and VL 88 were developed for lower and higher hill areas, respectively. In 1957, work on the development of dwarf varieties started and crosses were attempted between dwarf introductions CI 52147/24 and NP 4. In addition, a number of mutants having long spike were developed by irradiating grains of VL 13 with thermal neutrons. However, all these strains were susceptible to brown rust. In late 1960s, work on selection and hybridization was started after receiving the segregating materials from Dr. Glen Anderson of the Rockefeller foundation. As a result, three gene dwarf cultures VL 501, VL 502, and VL 506 and two gene dwarf culture VL 6 were developed which had yield potential up to 7–8 t/ha. However, the three gene dwarf cultures possessed red grains and needed high fertilizer application for realizing their yield potential and the two gene dwarf cultures were highly susceptible to yellow and brown rusts [27].

Before the establishment of erstwhile Himachal Pradesh Krishi Vishwa Vidyalaya (HPKVV), Palampur, the University of Himachal Pradesh, Bhuntar and Solan took up some wheat improvement work and contributed materials to All India Coordinated trials. HPKVV (now named Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya), Palampur was established in the year 1978. Wheat improvement work began in the early 1970s at Keylong during summer and at Kullu, Bajaura, Solan, Palampur, and Dhaulakuan during *rabi* season. The AICRP was started in 1975 at the University. Since its inception in 1975 till 2002, this project was in operation at Palampur, which was shifted to Malan and the station was renamed as Rice & Wheat Research Center, Malan.

In the Jammu & Kashmir state, a full-fledged coordinating center on wheat was established at Shere Kashmir University of Agricultural Science and Technology (SKUAST) since its establishment in 1983. However, with bifurcation of the University, the center was shifted to Jammu (SKUAST-J) during the X Five Year Plan. However, SKUAST-Kashmir at Srinagar continues to be associated with AICRP on wheat as a voluntary center. Indigenous as well as exotic germplasm evaluated for suitability to the J&K region have been contributed to the All India trials from 1983 to 1984 onwards. The Kargil center is situated under cold arid zone, where research work on wheat was started in 1990 immediately after the establishment of the station. The Leh station also falls under cold arid zone and wheat cultivation in this region is undertaken during summer season [32].

Major Constraints and Strategies to Attain Higher Productivity

Wheat is usually sown during October–November and the crop is harvested in April, May, or June in mid-hills. In higher hills, where winter is severe, the crop is raised in summer between May and September.

Abiotic

Moisture Stress

During the normal sowing time of wheat in mid-hills, residual moisture of the rainy season is the main source for germinating seed as a result, any occurrence of moisture stress results in poor germination.

Management Germination of wheat can be improved, if the *kharif* crops can be harvested by the end of September and wheat can be sown in the beginning of October utilizing the residual soil moisture built up from the preceding monsoon rains, as the monsoon normally recedes by the end of September in hills.

Low Temperature Stress Early in the Season

The spring wheat cultivars if sown before middle of October, flower in December–January and get damaged because of prevalence of extremely low temperature. Typical winter wheats also do not perform well under this condition, due to their requirement of longer vernalization and maturity.

Management Specific emphasis to be given for the development of varieties which can be sown in early October and have intermediate vernalization requirements to overcome the low temperature stress. These are neither true spring nor true winter wheats. They belong to the facultative group of wheat having intermediate vernalization and photoperiod requirements.

Moisture Stress at Flowering to Grain Filling

The growth of wheat crop is adversely affected from December to February followed by rapid growth due to favorable climatic conditions in March and April. The crop may again suffer a moisture stress, from April end, the period coinciding with grain filling stage, as no rains are expected between middle of April to first half of May, the normal time of harvesting of the wheat crop.

Management The varieties should have phenological plasticity, so that at limiting moisture they can increase the rate of grain filling. The flowering should start by the middle of March to give sufficient time for grain filling. Further, the varieties should have higher grain filling rate with some terminal heat tolerance.

Short Duration Varieties for Higher Hills

In high hill areas (>1,700 m above mean sea level) wheat has still not become remunerative for want of short duration varieties.

Management There is a need to develop varieties requiring at least 10–15 days less to mature than that is required for *Sonalika* in higher hills.

Biotic

Production of wheat in the hills suffers by occurrence of more than one disease; therefore, efforts should be made to develop varieties resistant to these diseases.

Yellow Rust

Yellow rust of wheat caused by *Puccinia striiformis* West. f. sp. *tritici* is the most important disease of wheat in the NHZ. Unfortunately, most of the famers' varieties/land races are highly susceptible to yellow rust resulting in heavy yield losses and poor quality of grains. The region suffered heavy loss in wheat due to yellow rust in 1987–1988 season. In recent times, the most prevalent and virulent pathotypes 46S119 and 78S84 (PBW 343 virulence) of the country are the most prevalent pathotypes in the zone too.

Management There is clear shift in the pathotypes from 46S102 (N) and 46S103 (P) to 46S119 (*Yr*9) and 78S84 (PBW 343 virulence) to which the earlier varieties are susceptible. Therefore, continuous efforts to breed resistant varieties to the changing racial flora of this disease are highly essential. Diversification of resistant genes from *Yr9* and *Yr18* to genes like *Yr5, Yr10, Yr15* and *China 84* type would be helpful to combat this disease.

Brown Rust

Brown rust of wheat, caused by *Puccinia triticina* Eriks., is the second most important disease of the zone. Though leaf rust appears late in the season, it can cause severe losses with the increase in temperature during grain filling stages. This may become more important in the changed climatic conditions where there are clear indications of rise in temperatures.

Management The pathotypes like 109R31-1 (77-2), 121R63-1 (77-5), and 21R55 (104-2) are the most prevalent pathotypes in the NHZ. Appearance of the pathotypes like 93R15 (162 A) and 21R63 (104-3) in recent years suggests the need to continue the efforts to breed brown rust-resistant varieties. Diversification of resistant genes as well as incorporation of Adult Plant Resistance (APR) genes would be helpful in combating this disease.

Loose Smut

Loose smut of wheat caused by *Ustilago nuda tritici* though can be managed easily by seed treatment by *Carboxin (Vitavax)*. But, the disease is still an important disease of the zone particularly with the non-availability of the chemical in far flung areas and use of farmers' own saved seed.

Management Incorporating resistance by using the proven stocks in the crossing programme and thereafter rigorous screening of the breeding materials particularly of the advance lines would be helpful in identification and promotion of the resistant lines.

Breeding Suitable Wheat Varieties for NHZ

Dr. Norman E. Borlaug and his associates in Mexico were successful in transferring the Norin dwarfing gene to the high yielding background of the spring tall wheat as a result; dwarf spring wheat varieties became available in 1961 for commercial cultivation in Mexico. Introduction of Mexican dwarf wheat varieties in early 1960s, their initial evaluation followed by multilocational trials resulted in the release of Sonora 64 and Lerma Rojo 64 for cultivation in the year 1965. Safed Lerma, a semi-dwarf variety was found suitable for cultivation in hills. From the advanced generation material received from Mexico in 1963 and evaluated during 1963–1964 at IARI, New Delhi, Pusa, Bhowali, Wellington, Punjab Agricultural University (PAU) Ludhiana and Uttar Pradesh Agriculture University (UPAU), Pantnagar for its adaptability to Indian environment, reactions to the prevailing races and biotypes of all the three wheat rust under natural condition of infection, several original selections such as S 227, S 307, S 308, S 331 were found to perform well [1]. Evaluation of these advanced generation lines from Mexico led to the selection and release of *Kalyansona* and *Sonalika* for cultivation in the country including the northern hills [1, 10]. Semi-dwarf varieties like *Kalyansona, Sonalika,* and *Safed* Lerma were found better than the earlier tall varieties with respect to yield, disease resistance, and adaptation. Thus, the priority shifted from developing tall varieties to semi-dwarf varieties. However, the hill farmers did not prefer the dwarf varieties as they did not produce enough straw under rainfed condition which is an important source of fodder in the region. This called for a reorientation to breed for high biomass based high yielding varieties of wheat.

With this shift in wheat improvement, the breeding work was taken up at Shimla, Bhowali, New Delhi at IARI and Pantnagar, GBPUAT in post-green revolution era. During mid-1970s, wheat improvement work also started at VPKAS, Almora, erstwhile HPKVV, Palampur and in mid-1980s at SKUAST, Srinagar specifically for developing suitable varieties for different conditions of Northern hills zone. Concerted efforts made at these centers under AICRP on wheat have resulted in the development of a series of new semi-dwarf varieties possessing high yield, disease resistance coupled with drought tolerance. At present, adequate number of improved wheat varieties are available for growing under different agro-climatic conditions of northern hills.

Green Revolution and its Impact on Hills

The Green Revolution varieties, *Safed* Lerma, *Kalyan Sona,* and *Sonalika* were released for cultivation in the northern hills too. Although the dwarf wheat varieties yielded exceptionally high under best management and production conditions especially in Indo-Gangetic Plains (IGP), in the hills, the impact of these varieties was not as high though *Kalyan Sona* and *Sonalika* became popular in hills and particularly, *Sonalika* is still being cultivated in some parts of the higher hills due to its adaptation under late sowing and rainfed situations. The dwarf stature and relatively lower biomass of these varieties under rainfed conditions was the major bottleneck in their spread as hill farmers prefer varieties that produced sufficient straw for their cattle. By the 1970s, it was realized that semi-dwarf, high yielding and input responsive lines should be crossed with local wheats to combine attributes from both the groups.

Although the Green Revolution did not create an impact in the hills compared to that in the plains, mainly due to lack of suitable varietal alternatives and poor seed multiplication/production of the available varieties, some of the varieties made significant impact on wheat production like *Sonalika,* VL *Gehun* 421(Fig. 1), Shailja, Girija and HB 208 in northern hills [1]. The landmark varieties like *Sonalika, Kalyansona*, VL *Gehun* 616 dominated wheat areas for simple reasons of wider adaptability, high yield potential, disease resistance, grain quality, appropriate maturity duration, plant height, and other desirable agronomic traits. Further, some the varieties like CPAN 1796 and CPAN 1922 were specifically developed to provide genetic diversity for rust resistance at the foci of rust perpetuation and spread (the northern hills). This strategy was successful in reducing the spread of rust on the wheat crop in plains [1].

Varieties for the New Trends in Wheat Cultivation

The development of high yielding, disease resistant, and semi-dwarf varieties with wide adaptability set in motion new trends in wheat cultivation. Resultantly, wheat cultivation was extended to non-traditional wheat-growing regions like Srinagar valley of J&K. Further, situation in many areas of Northern hills necessitated very early/early sowing of wheat under unirrigated conditions. Up to 1983, no suitable variety was available for this situation. To meet the requirements of hill farmers, special series of coordinated varietal trials under low fertility rainfed, early sown conditions were initiated in the zone from 1979 to 1980 crop season. The developmental and testing efforts resulted in the identification and release of wheat variety VL *Gehun* 616 (Fig. 2) in 1984 and 1986, respectively, thereby fulfilling the long-felt need of farmers in the hills [1]. The successful release of varieties specifically suited for rainfed areas did not make any significant impact on the production and productivity in spite of good number of wheat varieties. The varieties NP 846 (1965) and VL *Gehun* 421 (1977) continued to be popular in Northern hill areas. Non-availability of seed of newer varieties seems to be the main constraint for the above situation [1].

Before mid-1970s, eight set of trials were constituted viz., Uniform Regional Trials (URT) lower hills irrigated,

Fig. 1 VL *Gehun* 421: a variety suitable for rainfed areas which had made significant impact

Fig. 2 VL *Gehun* 616: the landmark variety recommended in 1986 for early sown rainfed conditions and still is one of the most popular variety among farmers of hills

higher hills irrigated, late sown irrigated lower hills, rainfed lower hills, rainfed higher hills, summer sown, Initial Evaluation Trials (IET) irrigated lower hills, and rainfed lower hills. Late sown testing under low fertility rainfed condition has been started in place of good fertility irrigated condition in the Northern hills Zone from 1980 to 1981.

Early sown testing under low fertility rainfed situation started in the northern hills zone in 1980–1981 to identify suitable varieties, which exists in certain parts of the zone. Summer sown varietal testing in high altitudes of northern hills with *aestivum* wheats of spring habit was organized in 1976–1977 under medium fertility irrigated condition. However, it was discontinued from the summer 1979. Testing of *aestivum* wheats of winter habit at higher elevations of Northern Hills was undertaken in 1971–1972 under medium fertility, irrigated condition and thereafter it was discontinued in 1973–1974. This trial as well as the summer sown trial had to be discontinued because of their unsatisfactory conduct, poor yield, and late receipt of data. In the year 1983–1984 the trial series was reduced to six, namely URT, irrigated, rainfed, early sown rainfed, late sown rainfed, IET irrigated, and rainfed. Testing of *aestivum* wheats of spring habit in high altitude areas of northern hills which was discontinued from 1974 to 1975 was revived from 1985 to 1986 with modification that these would be now tested during regular *rabi* season instead of summer season [1]. The trial series was renamed as advanced varietal trial (AVT) irrigated timely sown, rainfed timely sown, early sown rainfed, late sown rainfed, timely sown rainfed high altitude, initial varietal trial (IVT) timely sown irrigated, and timely sown rainfed in 1990–1991. In 1992–1993, AVT irrigated summer sown trial was started for very high altitude areas. The IVTs were replaced by National Initial Varietal Trials all over the country but the hills were kept out of this as they have specific conditions different from the other zones. The AVT timely sown rainfed high altitude trial was discontinued from 2006–2007.

Present Scenario of Varietal Development

Broadly, development of high yielding disease-resistant varieties possessing desirable quality characters for cultivation in the following production conditions of northern hills zone (NHZ) has been the major objective of the centers working for wheat improvement in the Northern hill zone.

- Early Sown Low Fertility Rainfed
- Timely Sown Low Fertility Rainfed and Medium Fertility Irrigated
- Late Sown Low Fertility Restricted Irrigation
- Timely Sown Low Fertility Rainfed (Summer Sown)

In the beginning, the active breeding centers which developed the materials and contributed to the AICWIP of NHZ were IARI RS, Tutikandi, Shimla, IARI, New Delhi, GBPUAT, Pantnagar, Wheat Project Directorate, New Delhi, Bhuntar, Solan and Palampur center of H.P. University, VPKAS, Almora, Shalimar, and IARI RS Bhowali. Subsequently, erstwhile HPKVV, Palampur contributed the entries as an active center since 1975. In the year 1982 SKUAST came in existence and became a part if AICRP on wheat and barley. As a result of active breeding research it started contributing entries to coordinated programme. At present the active breeding centers are IARI RS, Shimla, VPKAS, Almora, GBPUAT, Pantnagar, CSKHPKV, Palampur (with active breeding contributions from Bajaura, Dhaulakuan, and Malan), SKUAST, Srinagar. However, the testing centers are Dhaulakuan, Shimla, Malan, Rajouri, Hawalbagh, Bajaura, Majhera, Kalimpong, Mantripukhri, Sundarnagar, Shalimar, Ranichauri, Kumuseri, Leh, Kargil, Dalang Maidan, Chamba, Gangtok, and Berthin.

Breeding Methodology

Evaluation of Wheat Germplasm for Direct Introduction and Enrichment of Genetic Variability

Large number of exotic and Indian wheat materials are initially screened for various important traits and thereafter made available to all the breeders through various national nurseries. Besides, DWR, Karnal and NBPGR, New Delhi organize field days to provide all the breeders of the country to lay hands on the new germplasm available through international nurseries. Like other breeders, hill zone breeders also select materials from these nurseries.

VPKAS, Almora has been given the responsibility of national register for winter and facultative wheats and also gets a set of the winter and facultative wheat nurseries for proper evaluation and utilization along with NBPGR, New Delhi. Evaluation of foreign material at the centers of wheat breeding research in the hill zone not only resulted in identification of genetic stocks for various important characteristics but also in release of 14 varieties in NHZ through coordinated testing and 5 varieties in respective states. Further, evaluation of germplasm has resulted identification and registration of 39 genetic stocks with NBPGR, New Delhi. These can be used as donors in the breeding programme countrywide (Table 1).

Breeding Methodology and Varietal Development

Though the breeding methodologies vary depending upon the breeder and center, methods such as the pedigree method involving single, double, triple, multiple crosses

Table 1 Genetic stocks of wheat from Northern hill zone registered with NBPGR, New Delhi

S no.	Species	Name	Source	Traits
1	*T. aestivum*	RL 22	HPKVV, Palampur	Carrying a new recessive resistance gene for powdery mildew pathotype no 2
2	*T. aestivum*	RL 4	HPKVV, Palampur	Cytogenetic stock
3	*T. aestivum*	RL 83	HPKVV, Palampur	Cytogenetic stock
4	*T. aestivum*	VL 798	VPKAS, Almora	Immunity to hill bunt disease
5	*T. aestivum*	VL 639	VPKAS, Almora	Resistance to loose smut
6	*T. aestivum*	FLW 1	DWR RS, Shimla	Resistance to black and brown rusts in different background.
7	*T. aestivum*	FLW 2	DWR RS, Shimla	Resistance to yellow, black and brown rusts in different background (*Lr*24, *Sr*24, *Lr*26, *Sr*31, *Yr*9M).
8	*T. aestivum*	FLW 3	DWR RS, Shimla	Resistance to black and yellow rusts in different 03016 background (*Lr*26, *Sr*31, *Yr*9M).
9	*T. aestivum*	FLW 4	DWR RS, Shimla	Resistance to black and brown rusts in different background (*Lr*24, *Sr*24, *Lr*26, *Sr*31, *Yr*9M).
10	*T. aestivum*	FLW 5	DWR RS, Shimla	Resistance to black and brown rusts in different background (*Lr*24, *Sr*24, *Lr*26, *Sr*31, *Yr*9, Sr2).
11	*T. aestivum*	FLW 6	DWR RS, Shimla	Resistance to leaf and stem rusts (*Lr*9 + 24, *Sr*2 + 24).
12	*T. aestivum*	FLW 8	DWR RS, Shimla	Resistance to leaf and stem rusts
13	*T. aestivum*	FLW 11	DWR RS, Shimla	For multiple rust resistance
14	*T. aestivum*	FLW 12	DWR RS, Shimla	For multiple rust resistance
15	*T. aestivum*	FLW 13	DWR RS, Shimla	For multiple rust resistance
16	*T. aestivum*	FLW 15	DWR RS, Shimla	For multiple rust resistance
17	*T. aestivum*	RNB1001	DWR RS, Shimla	For multiple rust resistance
18	*T. aestivum*	FKW 1	DWR RS, Shimla	Completely resistance to stripe rust and stem rust with genes from Chinese winter wheat
19	*T. aestivum*	FKW 3	DWR RS, Shimla	Completely resistance to leaf rust with genes from durum variety HD 4672
20	*T. aestivum*	TANK	VPKAS, Almora	Local land race from Kapkot, Bageshwar, Long awns
21	*T. aestivum*	FKW 20	DWR RS, Shimla	Amber grain genetic stock with pyramided rust resistance genes, *Sr*24 and *Sr*25
22	*T. aestivum*	VL 858	VPKAS, Almora	Excellent chapatti quality
23	*T. aestivum*	VL 824	VPKAS, Almora	Powdery mildew resistance
24	*T. aestivum*	FLW 24	DWR RS, Shimla	Resistance to leaf and stem rusts and predominant pathotypes of stripe rust
25	*T. aestivum*	FLW 25	DWR RS, Shimla	Providing genetic diversity for resistance to leaf rust
26	*T. aestivum*	FLW 26	DWR RS, Shimla	Another source for resistance to leaf rust
27	*T. aestivum*	FLW 27	DWR RS, Shimla	Another source for resistance to leaf rust
28	*T. aestivum*	WBM 1587	IARI RS, Shimla	Stripe rust resistance
29	*T. aestivum*	WBM 1591	IARI RS, Shimla	Stripe rust resistance
30	*T. aestivum*	FLW 28	DWR RS, Shimla	Resistance to leaf and stripe rust
31	*T. aestivum*	FLW 29	DWR RS, Shimla	Resistance to leaf, stem and stripe rust
32	*T. aestivum*	FLW 30	DWR RS, Shimla	Resistance with diverse gene for stripe rust

Table 1 continued

S no.	Species	Name	Source	Traits
33	*T. aestivum*	HS 424	IARI RS, Shimla	Resistance to all the pathotypes of leaf and stem rusts
34	*T. aestivum*	HS 431	IARI RS, Shimla	Resistance to all the pathotypes of leaf and stem rusts from different parents
35	*T. aestivum*	HS 492	IARI RS, Shimla	Resistance against all the pathotypes of leaf rust
36	*T. aestivum*	VL 876	VPKAS, Almora	High bread loaf volume (>575 ml), very good quality bread (>7)
37	*T. aestivum*	VL 852	VPKAS, Almora	Excellent chapatti quality (>8 score)
38	*T. aestivum*	HS 491	IARI RS, Shimla	Very high spread factor and very low value of grain hardness
39	*T. aestivum*	UP 2698	GBPUAT, Pantnagar	High grain protein content (>13 %)

and back crosses and modified bulk method were mostly followed [1]. The breeding material, fixed lines, genetic stocks and strains under test in varietal trials, are evaluated under artificial disease epidemics as well as at a number of hot spots in the country where natural incidence of disease is very high. Summer nursery facilities available at the Dalang Maidan in Lahual Spiti valley (HP), DWR and at the Wellington center, IARI in the Nilgiri hills (TN) are used for screening the experimental material against three wheat rusts and powdery mildew, advancement of generations of breeding material and multiplication of newly fixed lines of promise for inclusion in *rabi* seasons varietal trials. Services of rust research laboratory of IARI (now DWR, RS) located at Flowerdale, Shimla (HP) is utilized for getting the genetic stocks and new strains tested against different races and biotypes of 3 wheat rusts and for getting initial inoculums of rusts for spreading after its multipli cations.

At CSKHPKV Palampur, selected bulk method is being followed from 1990s. Prior to this pedigree method was followed. IARI RS Tutikandi, Shimla follows modified bulk-pedigree method whereas, GBPUAT, Pantnagar follows typical pedigree method. At SKUAST, Shalimar introduction/selection from exotic or national germplasm is followed. At VPKAS, Almora typical pedigree method of breeding was followed earlier, however, recently it was changed to selected bulk-pedigree method of breeding.

VPKAS's wheat breeding methodology is focused on developing disease-resistant genotypes with high and stable yield across a wide range of climatic conditions—favorable as well as marginal, available in the Northern hill zone. VPKAS through collaboration with AICRP on Wheat in the form national and international nurseries screens and evaluates a large number of entries for yield potential and other traits of interest. Utmost attention is given to the genetic diversity within VPKAS germplasm to minimize the risk of genetic vulnerability because of their countrywide use in research programmes. The crossing block of any year consists of around 50–60 winter and facultative wheat, and 100 spring wheat donor lines. These include commercial cultivars and non-conventional resources like *butire* and synthetic wheat lines. About 250 crosses are made each year. At VPKAS, parental sources are used to incorporate desired traits through recombination.

Though majority of the area under wheat in NHZ is rainfed, it gets about 250 mm average rainfall during the season. Therefore, it was thought imperative to breed genotypes with inbuilt drought tolerance with simultaneous ability to capitalize the available rainfall. For this the methodology presented in Table 2 is currently being followed.

The comprehensive efforts in wheat improvement have resulted in development and release of wide choice of varieties suited for different growing conditions and duration (Table 3) (Fig. 3).

Breeding for Durable Resistance

As a part of national strategy, horizontal resistance to rust diseases should be promoted in NHZ rather than vertical resistance which have higher frequency of breaking down. Therefore, incorporation of durable, non-specific disease resistance genes into wheat varieties have been a high priority so as to obtain high yielding, widely adapted genotypes with adequate degree of disease resistance. To achieve this, diverse sources of resistance for rusts and other diseases are intentionally used in the crossing programme. Since, the yellow and brown rusts are most important diseases in northern hill zone, rigorous efforts have been made to develop genotypes with built in resistance against the two rusts. Loose smut is also an important disease of hill region. Therefore, in breeding programme high priority is given to the development of resistant

Table 2 Methodology for breeding drought-tolerant wheat also responsive to favorable environmental conditions

	Activity
F_1	Crosses involving widely adapted germplasm, representing yield potential, yield stability and input responsiveness, with lines carrying proven drought tolerance and input (water) use efficiency
	Winter and facultative wheats are emphasized
F_2	Individual plants are raised under irrigated and optimally fertilized conditions, and inoculated with a wide spectrum of rust virulence. Single spike from robust and horizontally resistant plants are selected, which may represent adaptation and responsiveness to favorable environmental conditions. Selected spikes from a single cross harvested as bulk
F_3	Selected F_2 bulked evaluated under rainfed conditions or very low water availability. The selection is based on such criteria as spike density, biomass/vigor, and grains/m^2, among others [31]. This index helps identify input efficient lines. Two to three spikes per plant selected and the spikes from the same cross harvested as bulk
F_4	Selected bulk lines from F_3 further evaluated under optimum conditions, as for the F_2
F_5	Evaluated under rainfed conditions or very low water availability. Single plants are harvested and threshed separately
F_6	Single plant progenies evaluated and desirable progenies harvested as bulk
F_7, F_8	Simultaneous evaluations under low and intermediate (representing the higher rainfall years in marginal drought environments) water regimes. Selection of lines showing outstanding performance under both conditions

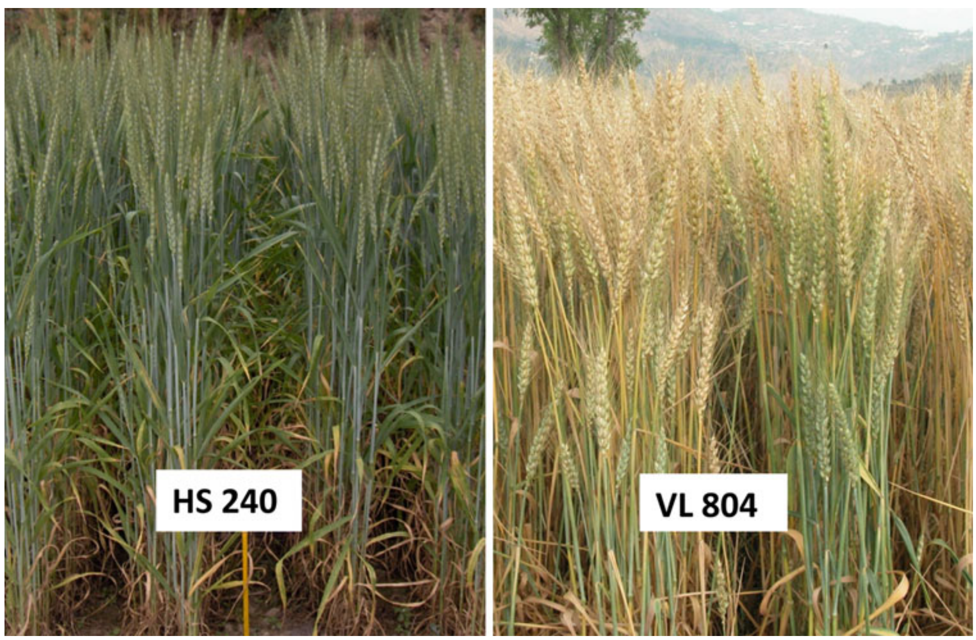

Fig. 3 HS 240 and VL 804 varieties with wider adaptability and suitable for rainfed as well as irrigated conditions

cultivars. The screening techniques are highly effective which helps to identify resistance in the ongoing breeding programme.

Introgressing Spring and Winter Wheat Gene Pools for Breeding High Yielding Varieties

Agronomically, most wheat can be divided into two distinct groups: winter and spring types. Both groups may manifest sensitivity or insensitivity to photoperiod. However, growth and developmental phases (tillering, stem elongation, ear emergence, anthesis, and ripening) of wheat are controlled by vernalization (*Vrn*) and photoperiod response, and earliness per se genes [16]. Winter wheats have a considerable vernalization requirement for reproductive phase initiation whereas the spring wheats are generally insensitive or only partially sensitive to vernalization. However, between these groups, intermediate wheats (semi-winter, alternative, facultative) also exist. These are usually characterized by strong photosensitivity and partial sensitivity to vernalization. Qualitative differences in growth habit due to vernalization requirement are controlled by a system of *Vrn* genes [22, 23]. Fully recessive genotypes respond to vernalization, whereas dominant alleles fully or partially inhibit this requirement. Typical alternative wheats often carry dominant *Vrn* 2 in a photosensitive background [29].

Winter wheats possess various desirable attributes such as profused tillering, plant height, leaf size, maturity duration, spike length, grain size, and grain number.

Table 3 High yielding varieties of wheat for different sowing conditions of Northern hill zone

S. no.	Variety	Parentage	Year	Production condition
Released by CVRC				
1	CPAN 1796[a]	NAPO/TOB'S'//8156/3/KAL/BB	1983	TS IR/LIR
2	HB 208[a]	SPO/MTA//MQ/2[a]RNW//3/PJ'S'/P14/KT54B	1981	TS RF/LIR
3	HD 2380	HD 2255/HD 2257	1989	TS/LS/IR/RF
4	HPW 42[a] (Aradhana)	VEE'S'/4/PVN'S/CBB//CNO'S'/3/JAR/ORZ'S'	1992	TS RF
5	HPW 251	WW24/LEHMI/P2-II149	2007	ESRF
6	HS 86	E6160/S/S 227/4/S 308	1981	TSRF/LIR
7	HS 207[a]	KAVKAZ/BUHO//KAL//BB	1989	LSRF
8	HS 240[a]	AU/KAL-BB//WOP'S/PAVON'S'	1989	TS RF/LIR
9	HS 277[a]	KVZ/CGN	1992	ESRF
10	HS 295[a]	(OT-AZ/IA 555-ALD'S'/ALD'S'-NATN)PJN'S'-PEL 'S'	1992	LS LIR
11	HS 365	HS 207/SONALIKA	1997	TSRF
12	HS 375 (HIMGIRI)[a]	BB/G 11/CJ 71/3/TA EST//KAL/BB	2002	SUMMER SOWING
13	HS 490	HS 364/HPW 114/HS 240/HS 346	2007	LS RI
14	HS 1097-17 (Girija)[a]	CJ60/3/SPO/MTA//MQ/2[a]RNW	1973	TS LIR
15	HS 1138-6-4 (SHAILJA)	E4870/SONALIKA	1975	TS LIR
16	NP 846	NP 760/RIONEGRO	1965	TS RF/LIR
17	NP 818[a]	DO/E518//SPP/NP114/3/WIS245 'S'	1965	TS RF/LIR
18	SKW 196 (Shalimar Wheat-1)[a]	BSP93-21 (SELECTION FROM EIGN 98)	2004	TSRF
19	UP1109	UP262/UP 368	1985	TSRF/IR
20	VL *Gehun* 421[a]	SN64/Y 50E/GTO	1979	TSRF
21	VL *Gehun* 616	SONALIKA/CPAN 1507	1986	ESRF
22	VL *Gehun* 738[a]	NS 12.07/LIRA 'S'//VBEE 'S'	1996	TSRF/IR
23	VL 804	CPAN 3018/CPAN 3004//PBW 65	2002	TS IR/RF
24	VL *Gehun* 829	IBWSN 149/CPAN 2099	2002	ES RF
25	VL *Gehun* 832	PBW 65/CPAN 3031	2003	TSRF HA
26	VL *Gehun* 892	WH 542/PBW 226	2007	LS RI
27	VL *Gehun* 907	DYBR 1982-83/842 ABVD 50/VW 9365//PBW 343	2010	TS RF/IR
28	HS 507	KAUZ/MYNA/VUL/BUC/FLK/4/MILAN	2011	TS RF/IR
Released by SVRC				
29	HPW 89 (SURABHI)	INTERMEDIO RODI/HD 2248	1997	TS RF
30	HPW 147 (PALAM)	CPAN 1869/HIM 10BA (WS)	1999	TSRF
31	HPW 155[a]	BT 2549/FATH	2005	TSRF
32	HPW 184 (CHANDRIKA)[a]	ND/VG 9144/KAL/BB/YACO/4/VEE#5	2003	TSIR
33	MANSAROVAR	HS 342	1999	TSRF HA
34	SAPTDHARA	SELECTION FRON 'Atou'	1994	TSRF
35	UP 2572	HD 2009/SKA//HD 2329	2005	TS IR
36	UP 2584	UP 2282/WH 593	2006	TS IR
37	VL *Gehun* 401[a]	FKN/N 10B	1978	TS RF
38	VL *Gehun* 404[a]	KT/BAGE//FN/GU/3/ST 464 (DR)/P 174106 (DR)	1978	TS RF
39	VL *Gehun* 719[a]	VEE #5 'S'	1994	TS RF/IR

[a] Introduction/pure line selection from exotic materials

Besides, they are also responsive to low input conditions, have a superior level of tolerance to abiotic stresses (drought, heat, etc.) and improved nutrient efficiency (N and P efficiency). Besides this, many winter wheats have shown stay green tendency, even at receding moisture level and high temperature. By introgressing genetic variability from winter wheats, breeders have considerably augmented the yield potential of spring wheats. The Veery wheats, developed from crosses of CIMMYT spring wheats and Russian winter wheat, represented a quantum leap in spring wheat yield and resulted in its wide adaptation during the 1970s and 1980s [6]. Introgression of the winter wheat gene pool into spring wheat is being considered as one of the strategies to break the yield plateau, especially for the hills [12, 14, 28].

VPKAS, Almora is the main center for winter × spring wheat hybridization programme in the country. Realizing the potential of winter × spring wheat hybridization for breaking the yield barrier in wheat DWR, organized a meeting in 1998 at VPKAS, Almora to review the status of winter × spring wheat programme in the country and strengthened it during the IXth Plan. As an outcome of this meeting a new inter-institutional collaborative project entitled, "New Avenues for yield advancement—winter × spring hybridization" was started. In this project extensive crossing work has to be taken at VPKAS, Almora. Screening of the crossing block has to be done at DWR, RS, Flowerdale, Shimla. The crosses have to be attempted based on this information and VPKAS, Almora to provide segregating materials to DWR, Karnal for further distribution to the cooperating centers. The target areas of this programme are, to develop superior wheat genotypes for favorable environments of the North Western Plains Zone and North Eastern Plains Zone, the drought prone/low moisture regimes of MP, Rajasthan and very high altitudes of Himalayan region. Since then 995 winter × spring wheat crosses have been attempted and 480 F_2 bulks have been supplied to DWR, Karnal. These materials have been distributed to Delhi, Pantnagar, Kanpur, Varanasi, Palampur, Vijapur, Faizabad, Sabour and Powerkheda. Utilization report over the years varies from 28 to 100 % among the centers. Out of these advance lines like HPW 289, HPW 290, HPW 291, HPW 293, and WH 1083 were included in All India Coordinated Trials.

Recently, VPKAS, Almora has developed one high yielding disease-resistant variety VL *Gehun* 907 (Fig. 4) through winter × spring wheat hybridization. IARI, RS, Shimla has also developed HS 507 (Fig. 4) from winter × spring wheat hybridization which was released during 2011. Both of these varieties are resistant to 46S119 and 78S84 the two most devastating races of yellow rust in the northern hills. In addition they have shown high yielding ability under changes climate conditions in the zone.

Facultative Wheat Varieties for Rainfed Conditions of NHZ

Wheat varieties possessing a moderate vernalization requirement and photosensitivity are generally called facultative. These are neither true spring nor true winter wheats but fall in between the two categories. By and large, these materials need around 6–8°C temperature for about 30–35 days to meet their vernalization requirement and 11–11½ h photoperiod for flowering [13]. Facultative wheats are also called as thermo-sensitive or intermediate types.

The early sowing in the beginning of October may ensure good germination of rainfed wheat with built up of available soil moisture from the monsoon rains. Realizing this fact early sown testing under low fertility rainfed was started in the NHZ from 1980 to 1981 to identify suitable

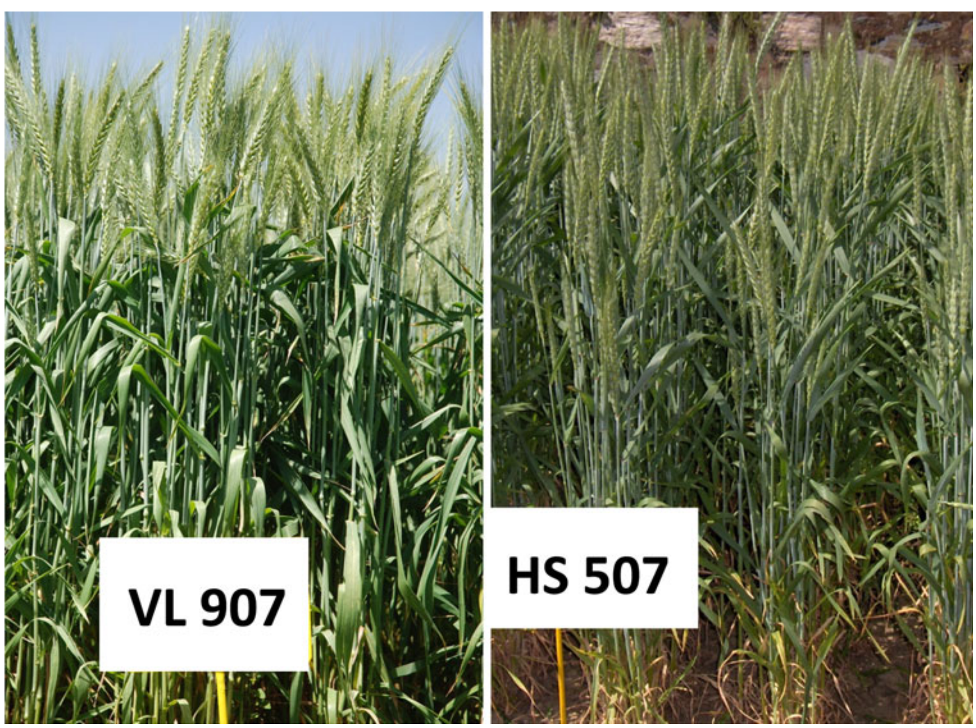

Fig. 4 VL *Gehun* 907 and HS 507 recently released varieties with resistance to 46S109 and 78S84, the two most prevalent races in northern hills

varieties for this situation which exists in certain parts of the zone [1]. This condition requires specific set of varieties. The spring wheat varieties if sown early get damaged by extremely low temperatures prevailing during the months of December and January which coincide with their flowering period. Typical winter wheats have also not been found suitable for these conditions as they require longer vernalization and mature very late. Only those wheat varieties which have low vernalization could be successful under such condition [25]. With the changed climatic conditions in which the winter rains particularly in the month of November and December have become scarce the early sown wheat has become more relevant. Hence, there is a need to evolve facultative wheat varieties suitable for early sown rainfed condition of northern hills.

VL *Gehun* 616, a facultative wheat variety derived from a cross of *Sonlaika* and CPAN 1507 was found promising and released in 1986 as the first facultative wheat variety for cultivation under early sown rainfed condition in NHZ. It has high resistance and wider adaptability and still the most popular variety among the farmers. Subsequently, HS 277 derived from selection from an introduced material KVZ/CGN was released in 1992. This variety was slightly late as compared to VL *Gehun* 616 and it was main bottleneck in its spread. VL *Gehun* 829 (Fig. 5) is another promising variety developed through a cross between IBWSN 149—a winter wheat and CPAN 2099—a spring wheat, and has been recommended for cultivation under rainfed early sown conditions of Northern hill zone. VL *Gehun* 829 on an average yields 8–10 % higher grain yield than the checks VL *Gehun* 616 and HS 277 (Table 4).

Table 4 Yield (q/ha) performance of VL *Gehun* 829—as compared to checks in Northern hill zone

Year	VL *Gehun* 829	HS 277	VL *Gehun* 616
1999–2000	34.7	31.5	31.4
2000–2001	25.0	23.4	21.5
2001–2002	27.4	25.6	26.2
Average	29.0	26.8	26.4

Dual Purpose (Green Fodder-cum-Grain) of Facultative Wheat Varieties

Availability of green fodder becomes scarce in hills during winter season because all the grasses dry up due to severe cold and frost. Cultivation of oat, berseem, and other fodder crops is possible with irrigation which is not available and most subsistence farmers cannot spare their small holdings for fodder production at the cost of food crops. One approach to meet the challenge of the shortage of fodder and food grains is by developing wheat varieties that can be cut for fodder in winter and thereafter allowed to produce grain. Every wheat variety does not have the ability to produce green fodder in the early vegetative phase and grain and straw at harvest. Only the facultative varieties possess a comparatively longer vegetative phase and can serve as dual purpose wheat. The experimentation with facultative wheat has shown the possibility of utilizing them for dual purposes by growing under early sown high fertility limited irrigated condition in northern hills [26].

VL *Gehun* 616 is one such variety, if grown in early sown irrigated (limited) condition, provides 7–8 t/ha green fodder by clipping 4–5 cm above the ground level 75 days after sowing. Application of one irrigation and 25 kg N/ha can compensate the harvest of fodder and provide almost normal grain production. Results show that there is no significant reduction in the grain yield as compared to uncut. Due to the dual purpose nature (green fodder-cum-grain) of VL *Gehun* 616, it is one of the most popular varieties in northern hills and more than seven tons breeder seed of this variety has been produced so far. The other recent variety VL *Gehun* 829 (Fig. 6) produces much more green fodder as compared to VL *Gehun* 616 and HS 277.

Fig. 5 VL *Gehun* 829: a popular dual purpose (green fodder-cum-grain) wheat variety that has become popular in plains too

The recently released variety HPW 251 could not perform well in terms of green fodder (5.8/ha) as well as grain yield (3.8 t/ha). The performance of facultative entries has been summarized in Table 5.

Although VL *Gehun* 829 was released for hills it has performed very well in plains too. Several demonstrations conducted by Rice–Wheat consortium in UP and Haryana have helped in its spread among the farmers. The variety has also performed well in limited irrigation areas of in Central India especially in Madhya Pradesh.

Quality of Wheat in NHZ

Traditionally, wheat plays an important role in ensuring household food security in hills. To grade it in terms of product quality wheat samples from farmers' field as well as from mandis were collected and analyzed at the quality laboratory at DWR, Karnal for 3 years. The mean value reflected that the samples had low protein content (10.0 %) and low sedimentation value (34 cc). The moisture content (11.7 %) was within the acceptable limit of <12.0 %. The hardness, alkaline water retention capacity (AWRC), and extraction rate were 5.1, 71, and 68.2 %, respectively. The value of alveographic parameters *P*, *L*, *P*/*L*, and *W* were 95.18 mm, 55.28 mm, 1.48, and 150.3 erg/g, respectively. Majority of the samples were having protein content, hectoliter weight, and moisture in the range of 9.0–10.0 %, >78.0 kg/hl, and 11.0–12 %, respectively. Wheat quality analysis indicate that the wheat grown in northern hills are in general soft having low protein content that makes it highly suitable for biscuit making [8]. Therefore, this can be of great industrial use.

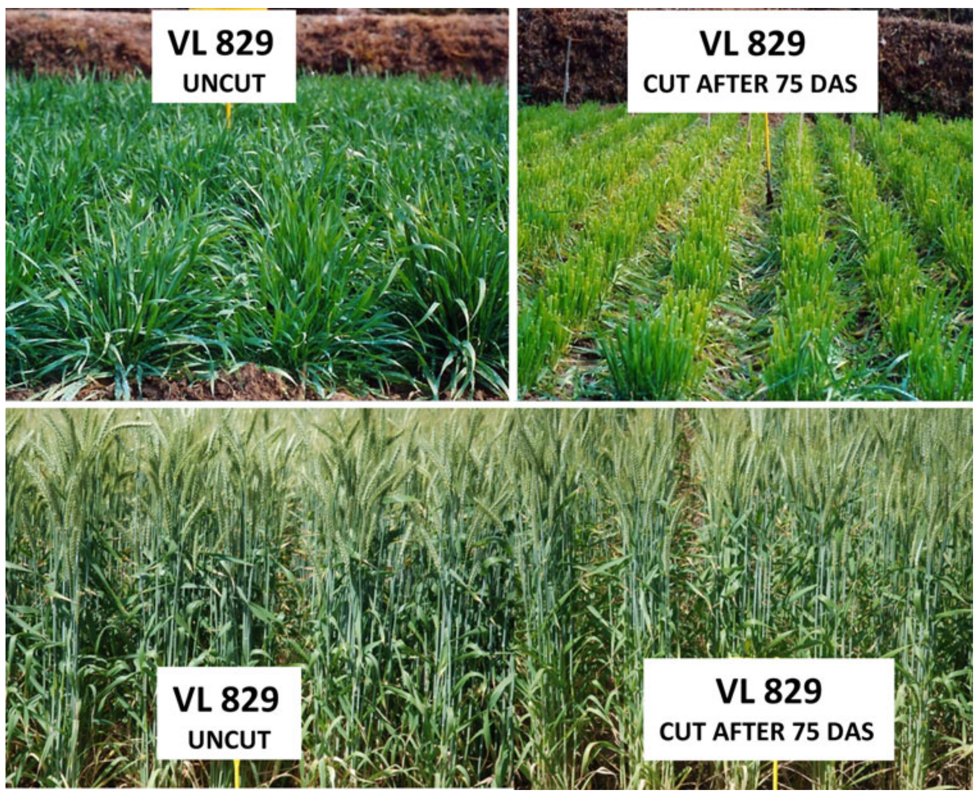

Fig. 6 VL 829 uncut (*top left panel*) and 75 days after sowing (*top right panel*) and the same plots at heading stage with no loss in grain yield (*lower panel*)

Table 5 Grain and green fodder yield of dual purpose facultative wheats

Name of the strain/variety	Uncut		Cut (70 days after sowing)	
	Grain yield (q/ha)	Green fodder yield (q/ha)	Grain yield (q/ha)	Green fodder yield (q/ha)
2001–2002				
VL *Gehun* 829	62.1	–	58.3	94.4
HS 277	60.1	–	43.5	62.4
VL *Gehun* 616	47.0	–	36.8	74.6

Application of New Technological Approaches for Wheat Improvement

The yield increase achieved through IB/IR translocation from rye is well documented. In order to look for such other translocations CSKHPKV Palampur has developed breeding materials through wheat × triticale crosses. The materials generated through this approach entered in the All India Coordinated Trials with 'RL' series from 1988–1989 to 2002–2003. However, these materials often showed instability for homogeneity and could not outyield the prevailing checks.

CSKHPKV, Palampur also worked on double haploids through wheat × maize crosses but recently an innovative and highly efficient technique of wheat × *Imperata cylindrica* system of chromosome elimination-mediated Double Haploid (DH) breeding approach has been developed at the CSKHPKV, Palampur. *I. cylindrica* growing widely in the winter season coincides well with wheat and triticale for flowering under natural conditions, whereas maize needs to be raised in polyhouse during winter season for the coincidence of flowering with that of wheat and triticale. The success rate of DH production through *Imperata* system is significantly better than the maize system in winter × winter wheat, spring × spring wheat, and winter × spring wheat hybrids, whereas it exhibits par excellence in triticale × wheat and wheat × rye derivatives. Therefore, only *Imperata* system is suggested to be adopted in triticale × wheat and wheat × rye derivatives so as to achieve significant results for especially winter × spring wheat, triticale × wheat, and wheat × rye for accelerated, precise, and efficient genetic upgradation of bread wheat. Besides, the *I. cylindrica*-mediated system can generate instantly a large number of mapping populations of bread wheat required for quick and precise mapping of the targeted genes [4].

During last few years, IARI RS Shimla has started working on MAS for rust resistance genes where the station is targeting transfer of *Yr15* through marker-assisted selection. Similarly, VPKAS, Almora has also started transferring *Yr5* and *Yr10* yellow rust resistance genes to a popular variety VL *Gehun* 738.

Strategic Inputs from Rust Research Center, Flowerdale

The station is engaged in research on rusts of wheat from early 1930s. At present black (stem) rust of wheat (*Puccinia graminis* Pers. f. sp. *tritici* Eriks. & Henn.), brown (leaf) rust of wheat (*P. triticina* Eriks.), and yellow (stripe) rust of wheat (*P. striiformis* West. f. sp. *tritici*) are the focus of research. This center has been monitoring variability in wheat rusts since 1930. More than 100 pathotypes have been identified in initial stages in different rust pathogens. Resistance sources have been identified against these pathotypes. Every year more than 1,500 samples of wheat and barley rusts are analyzed. Pathotype 121R63-1, 21R55, and 21R63 of *P. triticina* (brown rust); 62G29 and 58G13 of *P. graminis tritici* (black rust); and 46S102 (Nilgiri hills), 46S1119, and 78S84 (northern India) of yellow rust of wheat are prevalent in India. The station has registered more than 22 rust-resistant genetic stocks which carry diverse resistance genes against wheat rusts in agronomically acceptable background. More than 700 advance lines/breeder's materials are evaluated for rust resistance every year using more than 80 pathotypes of wheat and barley rusts. Rust resistance genes were characterized in more than 550 lines. While 10 *Lr* genes viz., *Lr*1, *Lr*3, *Lr9*, *Lr*10, *Lr*13, *Lr*14a, *Lr*23, *Lr*24, *Lr*26, and *Lr*34 were characterized in 350 lines whereas 11 *Sr* gene viz., *Sr2*, *Sr5*, *Sr*7b, *Sr*8a, *Sr*8b, *Sr*9b, *Sr*9e, *Sr*11, *Sr*12, *Sr*24, and *Sr*31 were postulated in 378 lines. Five *Yr* patterns viz., *Yr*2, *Yr*2 (KS), *Yr*3, *Yr*9, and *Yr*18 were postulated in about 180 lines. For facilitating genetic as well as epidemiological work the nucleus inocula were supplied to different wheat scientists/centers every year in the country for creating epiphytotics and conducting genetic studies. Race-specific adult plant resistance to both brown and yellow rusts was observed in HD2937, HPW251, HS461, HUW598, PBW574, PBW575, PBW579, PBW561, PDW300, TL2949, VL882, VL892, and WH1021. The stocks GW322 and NIAW34 showed APR to most virulent and predominant pathotypes of brown rust. Remaining lines possessed APR to one or other pathotype of P. *triticina* or *P. striiformis*. The emergence of Ug99, a pathotype of *Puccinia graminis tritici* in Uganda has threatened cultivation of wheat germplasm covering 40 % of world acreage. However, several Indian varieties such as UP 2338, Lok1, Kundan, DBW17, HD 2967, HD 2985, HD 2987 and a series of durum varieties possess resistance to Ug99. These along with the rust-resistant genetic stocks developed at Flowerdale, DWR, i.e., FLW2, FLW6, FLW8, FLW14 and others could confer resistance to this pathotype and are available for breeders' use. The timely detection of new variants and the identification of resistant material, thereafter, have prevented any major loss to wheat. The efforts of managing wheat rusts involve only the use of available resistance and its intelligent deployment based on pathotype distribution. Due to this highly structured strategy the country did not witness any major rust outbreak in the last 35 years [7].

Future Outlook

Though a number of high yielding and disease-resistant varieties have been released for NHZ, the life span of a variety is usually considered to be 3–5 years. Any new variety or cultivar becomes obsolete not because it loses its yield potential but primarily due to being knocked down by new virulent forms of diseases which evolve in due course of time. With the changed climatic conditions and the recent outbreak of yellow rust requires continuous development of new resistant varieties to counter the threat of new virulent races of pathogens. To surmount the typical problems in the northern hills specially the vagaries of the extreme cold weather (unlike in the plains); the new cultivars are required to possess grass-like characters with shorter heading to maturity period having high translocation efficiency and profuse tillering for overcoming frost damage in addition to resistance to diseases. The future priorities for wheat breeding in hills are as follows:

- Systematic work on the development of wheat cultivars resistant to loose smut, hill bunt, powdery mildew and foliar disease which are gaining importance in the region, in addition to the yellow and brown rust.
- Diversification of yellow and brown rust resistance genes to breed durable rust-resistant varieties.
- Basic studies on yield, its contributory characters, and quality traits relevant to hills in spring and winter wheats to enable the formulation of selection criteria for suitable plant types in wheat.
- Hybridization programme between winter and spring wheats to incorporate desired characters in spring wheats and to breed facultative type of wheat (green fodder-cum-grain purpose) varieties suitable for the area. Interspecific hybridization for incorporation of prolonged vegetative phase with greater resilience to various stresses and evaluation of the lines of interspecific origin may be the alternative approach to breed for facultative type of wheat (green fodder-cum-grain purpose) varieties.
- Breeding drought-tolerant wheat varieties adapted to different agro-climatic conditions of northern hills.
- Strengthening the seed production programme and promoting extension activities.

Acknowledgments The inputs received from Dr. Shafiq Wani, Director Research, SKUAST-K, Srinagar, J&K, Dr. D. P. Walia, Sr, Scientist, IARI RS, Tutikandi, Shimla, HP and Dr. Vijay Rana, CSKHPKV, Rice & Wheat Research Station, Malan, Kangra, HP are gratefully acknowledged.

References

1. Agrawal RK (1986) Development of improved varieties. In: Tandon JP, Sethi AP (eds) Twenty-five years of co-ordinated Wheat Research 1961–86: Wheat Project Directorate. IARI, New Delhi, pp 34–93
2. Anonymous (1995) Research highlights (1970–1995) wheat and barley. Indian Agricultural Research Institute, Regional Station, Tutikandi, Shimla
3. Anonymous (2009) *Pragati Prativedan 2008-09 tatha Karyapurti digdarshika*, Department of Agriculture, Uttarakhand, p 8
4. Anonymous (2011) 100 years of wheat research in India. In: Singh SS, Sharma RK, Singh G, Tyagi BS, Saharan MS (eds) Directorate of Wheat Research, Karnal, Haryana
5. Chanda TK, Sati K, Robertson C, Arora C (2010) Fertilizer statistics, 55th edn. The Fertilizer Association of India, New Delhi
6. CIMMYT (1986) Veery 'S': bread wheats for many environments. CIMMYT, Mexico, Mexico, DF, p 23
7. DWR (2011) "DWR Flowerdale Shimla, H.P." (http://www.dwr.in). DWR, Karnal
8. Gupta RK, Sewa Ram, Chauhan DS (2002) Quality of Indian wheat. Directorate of Wheat Research, Karnal, Research Bulletin No. 14
9. Gupta A, Kant L, Mahajan V, Saha S, Gupta HS (2009) '*Tank*'; local land race of wheat for protection of wheat field against monkey raids—an indigenous technological knowledge. Curr Sci 96:467–468
10. Jain HK (2010) A breakthrough in wheat yields. In: The Green Revolution History—impact and future. Studium Press LLC, Houston, Texas, pp 77–166
11. Kant L (2006) Approaches to improvement in wheat and Barley productivity. In: Gupta HS, Srivastva AK, Bhatt JC (eds) Sustainable production from agricultural watersheds in NWH. VPKAS, Almora, pp 139–151
12. Kant L, Gupta HS (2002) Potential yield advancement by combining winter and spring wheat gene pools. SABRAO J Breed Genet 34(2):95–106
13. Kant L, Mani VP, Singh R (2000) Utilization of long cool days through facultative and winter wheat germplasm: a case study. In: Extended summaries Vol. 2: Voluntary papers, natural resources international conference on managing natural resources for sustainable agriculture production in the 21st century held at New Delhi, India, 14–18 February, 2000, p 769
14. Kant L, Mani VP, Gupta HS (2001) Winter X Spring hybridization—a promising avenue for yield enhancement. Plant Breed 120:255–258
15. Katoch PC (1999) Present status and action plan for improvement of rice, maize and winter wheat for higher hills. Paper presented in "Brain storming session on improving productivity of wheat, maize and rice in higher hills", 22–23 October, VPKAS, Almora
16. Kosner J, Pankova K (1998) The detection of allelic variants at the recessive *vrn* loci of winter wheat. Euphytica 101:9–16
17. Mehta PS, Sharma AK, Negi KS, Muneem KC (2009) Traditional crop diversity in Kumaon Himalaya of Uttarakhand state—a case study. J Plant Genet Resour 21:159–166
18. Mehta PS, Muneem KC, Negi KS (2009) Traditional wheat (*Triticum aestivum* L.) genetic resources for subsistence in District Pauri of Utttarakhand. J Plant Genet Resour 22:70–73
19. Nayar SK, Tandon JP, Kumar J, Prashar M, Bhardwaj SC, Goel LB, Nagrajan S (1994) Basis of rust resistance in Indian Wheats. DWR, Regional Station, Flowerdale, Shimla, Research Bull No. 1
20. Pal BP (1966) Wheat. Indian Council of Agricultural Research, New Delhi, India
21. Pal D, Kumar S, Rana JC (2007) Collection and characterization of wheat germplasm from North-west Himalaya. J Plant Genet Resour 20:170–173
22. Pugsley AT (1968) Genetic studies of phases development and their application to wheat breeding. In: Finlay KW, Shepherd KW (eds) Proceedings of the 3rd International Wheat Genetics Symposium. Australian Academy of Science, Canberra, Australia, pp 591–599
23. Pugsley AT (1971) A genetic analysis of the spring–winter habit of growth in wheat. Aust J Agric Res 22:21–31

24. Reeves TG, Rajaram S, Ginkel MV, Trethowan R, Braun HJ, Cussaday K (1999) New wheats for a secure, sustainable future. CIMMYT, Mexico, p 28
25. Shoran J, Joshi HC (1986) Stability analysis for yield performance of winter and spring wheats in north-western hills. Agric Sci Digest 6:33–35
26. Shoran J, Tandon JP, Pandey BD, Pant PC, Joshi HC (1991) 'VL *GEHUN* 616' wheat for cut fodder and grain production in northern hills. Indian Farming 40:37–39
27. Shoran J, Hariprasad AS, Dube SD (1995) Wheat breeding research at VPKAS. VPKAS Tech Bull 7:36
28. Shoran J, Kant L, Singh RP (2003) Winter and Spring wheat: an analysis of combining ability. Cereal Res Commun 31:347–354
29. Stelmakh AF (1986) Typical alternative bread wheat and its genetic nature. *Syelskohozyaistvennaya Bil* (Moscow) 2:22–30 (in Russian)
30. Tandon JP, Rao MV (1986) Organisation of wheat research in India and its impact. In: Tandon JP, Sethi AP (eds) Twenty-five years of co-ordinated wheat research 1961–86. Wheat Project Directorate, All India Co-ordinated Wheat Improvement Project. Indian Agricultural Research Institute, New Delhi, pp 1–33
31. Van Ginkel M, Calhoun DS, Gebeyehu G, Miranda A, Tian-you C, Pargas Lara R, Trethowan RM, Sayre K, Crossa J, Rajaram S (1998) Plant traits related to yield of wheat in early, late, or continuous drought conditions. Euphytica 100:109–121
32. Wani SA, Khan MN, Zaffar G (2007) Progress of research for development of wheat in Kashmir—a review. Paper presented at the 46th All India Wheat and barley Research Workers Meet, 24–27 August. MPKV, Rahauri, College of Agriculture & Agharkar Research Institute, Pune, Maharashtra
33. Zargar GH (1999) Present status, constraints, prospects and research need in rice, maize and wheat in J & K for higher hills. Paper presented in "Brain storming session on improving productivity of wheat, maize and rice in higher hills," 22–23 October, VPKAS, Almora