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Widening the Genetic Base of Indian Barley Through the Use of Exotics

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Abstract: *The genetic base of improved varieties is becoming increasingly narrow due to the commonness of one or more parents in their ancestry. Thus, improved varieties may become vulnerable to the diseases, insect-pests and other stresses due to genetic similarity. Therefore, it has become imperative to broaden the genetic base of barley varieties. This genetic vulnerability, thus, can be avoided by using diverse and unrelated parents in barley breeding programme. Keeping this in view, an effort was made to study the role of exotic germplasm in the development of barley varieties vis-à-vis widening the genetic base of Indian barley. In India, much of the improvement of this crop has been obtained through the utilization of genetic resources available as land races of indigenous or exotic origin. Exotic germplasm of barley received from ICARDA continues to be an important base material for the development of barley varieties either as direct release as a variety or their utilization in the development of new barley varieties for improved yield and its components through hybridization programme. Through direct introductions varieties namely, LSB 2, HBL 113, Dolma, VLB 118, BHS 400 and BHS 380 varieties have been released and are cultivated in Northern Hill zone. These varieties have played a vital role not only in enhancing the productivity but have also strengthened the barley breeding research in India. To generate the wide genetic diversity, crosses were made between indigenous and exotic lines (I x E) and among the exotic lines (E X E). Thus, several barley varieties namely, BHS 169, DL 88, BH 393, NDB 1173 and VLB 56 have been developed by adopting hybridization followed by selection in the segregating generations for targeted traits.*

Keywords: Hordeum vulgare, *exotic, germplasm, barley.*

INTRODUCTION

Barley (*Hordeum vulgare* L.) was domesticated about 10,000 years ago in the Fertile Crescent of the Near East (Ceccarelli *et al.*1999). It is known as the most cosmopolitan crop and is grown in a wider range of environmental conditions as compared to other cereal crops. Barley is cultivated from 70°N in Norway to 46°S in Chile and from the sea level to high altitudes close to the Equator. In Tibet, Nepal, Ethiopia and the Andes, it is cultivated on the mountain slopes higher than other cereals. Because of its hardiness, barley is the only suitable crop to be grown under rainfed conditions in many countries. Barley is typically a crop of less favorable, low input, stressful environments, and the last crop possible before the steppe.

Barley is the fourth most important cereal crop after wheat, maize and rice in the world with a share of 7% of the global cereal production (Verma *et al.* 2012). It is grown in more than 100 countries (Sarkar *et al.* 2014) on about 49.78 million hectares with a production and productivity of 144.56 million tones and 2.9 t/ha, respectively (www.faostat.fao.org). Though, area under barley cultivation has decreased globally to the tune of 7.96 million hectares during the last one decade (2003 to 2013), its global

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production has increased by 2.19 million tones. This increase in production has been brought about by the substantial increase in yield levels from 2.47 t/ha in 2003 to 2.91 t/ha in 2013.

In India, barley is cultivated in about 0.67 million ha, producing nearly 1.63 million tones of grains with productivity of 2.45 tones/ha (Anonymous, 2015). The crop is mainly grown in Rajasthan, Uttar Pradesh, Haryana, Punjab, Madhya Pradesh and Bihar in plains, and Himachal Pradesh, Uttrakhand and Jammu and Kashmir in the hill states (Gupta, 2013). Barley is considered as poor man's crop as it requires low inputs like irrigation, fertilizer and insecticides, and can be grown in marginal lands (Alam *et al.* 2007, Sarkar *et al.* 2014). Barley is highly tolerant to drought, saline and alkaline conditions (Chanddola, 1999). It can be grown in varied topography like plains and hills and also cultivated under rain-fed and irrigated ecosystems. Moreover, barley can be cultivated where cultivation of wheat is not possible. In India, it is generally grown as a rain-fed crop which thrives well on residual moisture (Ceccarelli *et al.* 1999). Owing to the growing conditions of barley crop and the conditions this crop is adapted to, and also under the situations of ever changing climatic conditions; the increase in yields of this crop has not been so considerable.

Barley in India is mainly used as cattle and poultry feed (> 75%), followed by its utilization for malting and beverages (20%). Only 5% of the total barley produced in India is consumed as food and, thus, forms part of human diet. The rising health consciousness and barley being a valuable source of beta-glucan, this crop offers better opportunity for popularizing it as a food crop for human consumption either as its direct use or through blends with other cereals like wheat. Besides its uses as feed, food and malting, barley possesses medicinal properties as beta-glucan present in its seeds helps in lowering the risk of cardio-vascular diseases (Kumar *et al.* 2014).

In recent past, India has made an impressive progress in achieving self-sufficiency in food grain production by increasing productivity of several crops. However, forage production for livestock is limited (Singh *et al.* 2012). Barley has potential to produce high total biomass. Because of very fast growth in early stages of the crop and less water requirements, there has been an increasing interest in exploiting barley as dual purpose cereal which can permit forage production in early season in addition to the grain yield later on (Verma *et al.* 2007). This crop can be grown as a green fodder crop in rain-fed, arid to semi-arid conditions where other crops such as berseem, oats, sugarcane etc. cannot be grown due to scarcity of irrigation water (Kharub *et al.* 2013). In such situation, dual purpose barley becomes an option as green fodder as well as feed for domestic animals during winter months of November to January.

Barley is used for different purposes such as feed, malt, food, fodder and medicine. In addition, it is consumed as energy drinks like bournvita, horlicks, and biscuits, prepared by malt extract. It is also utilized in industrial uses for malt, bear, whisky, alcohol, vinegar *etc*. In rural areas of India, barley products like *sattu* and *missi roti* have been traditionally used as delicious food especially in the tribal areas of hills and plains (Verma *et al.* 2012). Barley has an advantage over wheat in terms of quantity and quality of beta-glucan, soluble fibre proteins, lysine and malt extract, and for its cooling and soothing effect (Vimal and Bishwakarma, 1998).

On the basis of grain type, barley is classified into two broad categories *viz*., hulled barley and hulless barley. In hulled barley the lemma and palea are fused to the pericarp where as in hulless the chaff is easily separated from the grain (Manjunatha *et al.* 2007). Out of them, hulless barley is a potential source of food (Bhatty, 1986). Advantages of hulless barley are that extra operation of pearling is not required; thereby, additional cost and loss of nutrients is avoided. It is considered as an important source of water soluble plant fiber essential in human diets to lower serum cholesterol. On account of high energy and digestibility, hulless barley is more preferred one for human consumption. Hulless barley forms an important part of food in hilly areas of Himachal Pradesh, Leh and Ladakh regions of Jammu and Kashmir in India (Verma *et al.* 2006). In recent years, barley has gained importance as an important food grain crop for human consumption due to its nutritional and medicinal values. In view of the important role of barley in the food and nutritional security of the country in general, and improving the economic security of the dry land farmers in particular, utilization of exotic barley germplasm is indispensable for genetic improvement and broadening genetic base of Indian barley.

UTILIZATION OF GERMPLASM FOR BARLEY IMPROVEMENT

Germplasm is a basic need for any crop improvement programme as it constitutes the reservoirs of valuable genes for high yield, quality, and resistance to biotic and abiotic stresses. It is the base of genetic variability enriched with valuable genes for disease and pests resistance; and the foundation for building a food and nutritionally secured country (Brahmi *et al.*, 2004; Yadav *et al.*, 2014). Success of utilization of genetic resources depends on their systematic screening, identification of donor parents for specific traits, selection of parental lines with trait(s) of interest for their inclusion in the hybridization programmes for varietal improvement with specific breeding objective(s). This will not only bring about genetic improvement of the crop but will also help broadening its genetic base. In barley, the genus *Hordeum* consists of 32 species and 45 taxa including diploid ($2n = 2x = 14$), tetraploids ($2n = 4x = 28$) and hexaploid ($2n = 6x = 42$) cytotypes (Bothmer *et al.*, 1995).

The majority of *Hordeum* species are perennials and different species have different reproductive systems (Bothmer *et al.*, 2003). The cultivated barley (*Hordeum vulgare* spp. *vulgare* L.) and its wild progenitor (*Hordeum vulgare* spp *spontaneum* C. Koch) belong to a single biological species which is annual and diploid with basic chromosome number $x = 7$. There is no crossing barrier between the wild and the cultivated ones.

Hence spontaneous and artificial crosses are easily attained (Asfaw and Bothmer, 1990). A number of promising genetic resources have been reported for different characters comprising resistance to biotic and abiotic stresses, malting quality etc. (Gulati and Verma, 1988).Wild species have already proven to be very fruitful source of genes for improvement of Indian barley. Wild barley has successfully been used as a source of major genes for rust and scald resistance (Feuerstein *et al.* 1990 and Abbott *et al.*1992). The National Bureau of Plant Genetic Resources, New Delhi, serves as the base collection for India and Indian Institute of Wheat Barley Research (IIWBR), Karnal maintains the active or the working collections of about 8000 accessions for utilization by the barley researchers (Verma *et al.* 2006). The germplasm involving exotic, indigenous and wild species conserved in mid-term storage at IIWBR, Karnal, are being utilized in the development of barley varieties for improving desirable traits and adaptability. To encompass exploitation of genetic variability in the barley breeding programmes, Elite International Barley Germplasm Nursery (EIBGN) is constituted with exotic lines of barley and this nursery is evaluated every year for adaptability and suitability at IIWBR, Karnal and cooperative centers of AICWandBIP. Similarly, National Barley Genetic Stock Nursery (NBGSN) is constituted with specific traits *viz.*, high yield, high tillering ability, good malting quality, high beta-glucan and protein, diseases and insects resistance. The donor lines are identified from these nurseries and are utilized as parents in hybridization programmes for improvement of barley for specific traits.

DEVELOPMENT OF BARLEY VARIETIES THROUGH INTRODUCTIONS

A plant variety or species is taken into an area where it was not grown earlier, even within a country, is known as introduction. When the introduced variety is well adapted to the new environment, it is released for commercial cultivation without any change in the original genotype. There are several examples of successful barley introduction in India during sixties and early seventies (Table 1). To strengthen the research on malt breeding, malt varieties introduced in India are Peat Land and Pedigree (USA), Manchuria (Germany) and Odessa (Russia). Clipper, a two rowed and semi winter type malt variety introduced from Australia and was released for commercial cultivation in 1972. However, this variety could not catch up with the farmers due to its poor grain yield, late maturity and poor support from industry as compensation for lesser yield, but this variety had good grain quality. During 1974-75, three introductions namely, Golden Promise, Universal and Midas were made from U.K. and evaluated with six rowed barley check variety Jyoti. Similarly, two more introductions Alfa 93 and BCU 73 (Rekha) both two rowed varieties with good malting quaity were released by the Central Variety Release Committee in 1994 and 1997, respectively for commercial cultivation in North Western Plain Zone (NWPZ) under timely sown conditions (Verma *et al.* 2006). In addition, several barley varieties have been released by direct introductions such as LSB 2 (USA 94), HBL 113 (Zyphee), Dolma (Selection from USA 115), and BHS 400 (selected from 34th IBON 9009) and are cultivated in Northern Hill Zone (NHZ).

Thus, international barley network for genetic enhancement of barley has proved to be an excellent vehicle to take advantages of exotic varieties/ breeding lines. Besides direct introduction as varieties after extensive testing, the exotic germplasms are being used as donor parents in crossing programme for improvement of yield and its components. Introduced varieties have played a vital role in not only enhancing the productivity but also in strengthening the barley breeding research in many countries including India.

UTILIZATION OF EXOTIC GERMPLASM FOR CREATION OF GENETIC VARIABILITY AND EXPLOITATION IN BREEDING PROGRAMME

In conventional plant breeding, new varieties are developed from a primary adapted pool of elite germplasm. In the past decades, intensive breeding of crop varieties has further narrowed the gene pool, especially in barley. Due to limited genetic variation among modern varieties, efficient use of genetic variation available in wild relatives of modern cultivars is, therefore, necessary for continued improvement. In India, improvement of barley mainly depends on sources available in land races of indigenous or exotic origin.

In the first half of the 20th century, barley breeders worked on the indigenous genetic variability available in different agro-climatic regions of the country. By utilizing this genetic variability several pure line varieties were developed from indigenous land races for different traits like grain yield, yield components, tolerance to cold, drought and salinity. The indigenous lines were tall with weak culm, susceptible to diseases and lax ear. To generate the wide genetic diversity, crosses were made between indigenous and exotic lines ($I \times E$) and among the exotic lines ($E \times E$). Thus, several barley varieties have been developed (Table 2) by adopting hybridization followed by selection in the segregating generations for targeted traits (Verma *et al.,* 2006).

Recombination breeding involves crossing between the parents of choice followed by pedigree or mass pedigree selection in the segregating generations for targeted traits, is widely used breeding strategy in barley improvement. Unlike the pure line selection that is limited to identification of the best in the existing variability, recombination breeding is an approach to create genetic variability and recombine desired characters for any given condition. Depending upon the objectives bulk method of selection and back cross breeding is also used.

Pedigree method is most commonly used in barley improvement. In fact, it involves selection of the heterozygous offspring produced by crossing. In this method, selection is practiced from second generation of hybrids (F_2) and the chances of success increases with every successive generation. An optimum level of homozygosity for several selected characters can be expected to be attained in the F_5 generation. From this generation, a breeder takes decisions solely on the basis of visual evaluation of plants and performance within a family. In F_5 generation but not later than $F_{6,}$ genetically stabilized families are propagated by commercial sowing and all the seed from plants is harvested together. The final selection of the best family is usually performed at the level of F_8 or F_9 generation. The families, thus selected, constitute breeders material. Off season nursery at Lahul and Spiti is also utilized for advancement of breeding material.

IDENTIFICATION OF SOURCES FOR RESISTANCE TO BIOTIC STRESSES

Biotic stresses are important biological factors causing considerable damage to crop production and deteriorate quality of the end product. The

Table 1
Barley varieties released directly by utilizing exotic germplasm

Variety	*Parentage*	*Area of adaptation*	*Production condition*	*Salient features*	*Developing centre*
Clipper	Introduction from Australia	Haryana, Rajasthan and Delhi	Irrigated condition	2 rowed, good for malt quality	IARI, New Delhi
LSB 2	Introduction as USA 94	NH ZONE	Rainfed condition	6 rowed, early maturing semidwarf	Palampur (PAU Centre)
Dolma	Selection from USA 115	NH Zone	Rainfed conditions	6 rowed, hullesssemidwraf, high yielding, resistance to yellow rust	CSKHPKV, Bajaura
Alfa 93	Aurora/Queen// Beka (introduction)	NWPZ	Irrigated timely sown	2 rowed barley for malting and brewing	IIWBR, Karnal
HBL 113	Selection from Zyphzee	NH zone	Rainfed, timely sown	2 rowed hulled barley, resistant to rusts	CSKHPKV, Bajaura
Rekha	WUM 143 (YAGAN)	NWPZ, NEPZ and PZ	Irrigated Timely sown	2 rowed, early maturing, better grain and malt quality	IIWBR, Karnal
BHS 400	34th IBON 9009	NH Zone	Rainfed, timely sown	6 rowed, feed barley with tolerance to yellow and brown rust	IARI, Shimla
PL 807	IBON 13	Punjab	Irrigated, Timely sown	6 rowed, feed barley with reisstance to yellow, brown rusts, loose smuts leaf blight and stripe disease.	PAU, Ludhiana
BHS 380	VOILET/MJA/7/ ABN-B6/BA/GAL// FZA-B/5/DG/ DC-B/PT-BAR/3/ RA-B/BA/3/4/ TRYIGAL	NHZ	Rainfed	Resistance to leaf and stripe rusts and good resistance to blight and powdery mildew	IARI, RS, Shimla
VLB 118	14th EMBSN-9313	NHZ	Rainfed, timely sown	Resistance to yellow rust	VPKAS, Almora

Table 2
Barley varieties released by utilizing exotic line as a parent in the crosss

Variety	*Parentage*	*Area of adaptation*	*Production condition*	*Salient features*	*Developing centre*
BHS 169	Kailash × Briggs	NH Zone	Rainfed, timely sown	Very good tillering, bold grains, high yielding, resistant to yellow and brown rusts	IARI, Shimla
Geetanjali	K12/K572/10// EB 410	U.P.	Rainfed	Huskless, 6 rowed, amber grains, free threshing	CSAUA and T, Kanpur
DL 88	BG 1X MEX 5-13	NWPZ (Late sown) and PZ (timely sown)	Irrigated conditions	6 rowed, resistance to leaf blight and faster growing	IARI, New Delhi
BH 393	California Mariout/ Ratna	Haryana	Irrigated conditions	6 rowed with early maturing, better grain, resistant to yellow rust	CCSHAU, Hisar
NDB 1173	BYTLRA3(94-95)/ NDB 217	NWPZ and NEPZ	Saline soils	6 rowed, high grain yield and resistant to leaf blights	NDUA and T, Faizabad
VLB 56	Morroco/VLB 1	Uttarakhand	Rainfed, timely sown	6 rowed, feed barley	VPKAS, Almora

modern barley varieties are more productive and offer greater protection against diseases and insect-pests. However, most of them have one or two common resistant genes and are, therefore, vulnerable to epidemic breakdown of resistance. In India, barley suffers mainly from diseases such as rusts (stripe, leaf and stem rust), leaf blights (spot and net blotch), smuts (loose and covered smut), powdery mildew and molya disease. Amongst them, yellow rust caused by *Puccinia striiformis* f.sp. *hordei* is the most important disease in barley cultivation area of North Western Plains of India, where it may create turmoil in susceptible varieties leading to heavy losses in yield. This disease also causes huge production losses in northern hills. Jorgensen (1987) reported that major genes have been the most widely used for resistance to this disease as these provide effective control of the disease and it is easy to incorporate this kind of resistance. Four major resistance genes, namely Rps1, Rps2, Rps3 and Rps4 have been identified and used in barley breeding all over the world (Jorgensen, 1987). In India, resistance breeding has been based on confirmed sources available in land races of indigenous or exotic origin. Yadav and Kumar (1999) in their study on evaluation of exotic and indigenous barley for resistance against Indian pathotypes of *Puccinia striiformis* f.sp.*hordei* reported that resistance was found more commonly in the exotic materials, as seven out of 75 exotic accessions exhibited no infection to a mixture of isolates. In their study, they registered three exotic entries *viz*., BCU 24, BCU 25 and BCU 26, which were completely free from yellow rusts. However, these entries were susceptible to aphids. Other exotic accessions, namely BCU 51 and BCU 127 were also completely free from yellow rust infection and showed multiple disease resistance. Khan *et al.* (2013) evaluated more than 3000 barley germplasm accessions including indigenous and exotic genotypes and were found to be resistant for yellow and brown rusts. Selvakumar *et al.* (2013) evaluated a total of 127 barley genotypes at seven locations in India under artificial epiphytotic conditions for identification of resistance sources to yellow rust. They found that 27 genotypes were resistant at adult plant stage across the locations and 31 genotypes exhibited resistance at seedling stage to all the five races. Out of the 127 genotypes evaluated, 10 genotypes revealed resistance to yellow rust at both seedling and adult plant stages for two years across all five races of yellow rust. Out of these 10 resistant barley genotypes, three genotypes namely BHS 392, PL 844 and VLB 119 were derived from exotic breeding materials (Table 3). In order to identify the new sources of resistance to yellow rust in barley, Sarkar *et. al.* (2003) screened 607 barley germplasm accessions under artificial inoculation with races 24, 57, G and M for four consecutive years (1999-2003). Based on field screening 47 accessions were found to be resistant in more than two years. They noticed in their study that seventeen germplasm accessions of exotic origin were resistant to yellow rust. Thus, lines identified as resistant to yellow rust can be utilized as donor parent in resistance breeding programme to minimize the losses due to yellow rust and can also be used in genetic studies for identifying new genes for resistance.

Table 3
Sources of resistance to yellow rust of barley

Genotype	*Centre*	*Parentage*	*Origin*
BHS392	IARI, Shimla	ZIGZIG/PETUNIA2// PETUNIA2	Exotic
PL844	PAU, Ludhiana	30th INYT-904	Exotic
VLB 119	VPKAS, Almora	16th HBSN-9632	Exotic

Spot blotch, a foliar disease caused by *Bipolariss sorokiniana* (earlier *Helminthosporium sativum*), commonly occurs in barley growing regions of the world. This disease is particularly found in severe conditions in warm and humid environments of the subtropics where barley is now being cultivated. Yield losses caused by spot blotch may range from 10 to 30% in susceptible genotypes of barley (Fetch and steffenson, 1994), although it may exceed beyond 30% under highly favorable conditions.

In India, spot blotch commonly occurs in North Eastern Plains Zone *viz*., Eastern U.P., Bihar, Jharkhand and Eastern part of M.P, where weather conditions are comparatively hot and humid during the crop season. In addition, it has become important disease of barley in North Western Plains Zone comprising of Punjab, Haryana, Western U.P., Delhi and Rajasthan (except the dry belt of Rajasthan). It might be due to application of increased irrigation and fertilizers in barley for better production of malt quality for industrial utilization as well as increased availability of these inputs resulting in the humid micro climate which is more conducive for leaf blight development (Verma *et al.*, 2013)). Spot blotch primarily occurs on the leaves and leaf sheaths of barley. Fetch and Steffensen (1999) reported the range of spot blotch symptoms occurring on seedling and adult plants with different levels of resistance. On adult plants, typical early symptoms that occur on susceptible host genotypes include brown pinpoint lesions surrounded by faint chlorosis. Subsequently, oblong or fusiform brown to dark brown lesions that are often bordered by chlorosis are formed. If moist conditions prevail late in crop season, infections can occur on the grains. To overcome this disease, development of resistant barley varieties is an appropriate option. Verma *et al.* (2013) evaluated 5458 barley accessions, comprising of both indigenous and exotic collections for resistance to spot blotch in field conditions during four crop seasons. In this study they found that 28 and 58 genotypes had resistant and moderately resistant reaction to spot blotch, respectively. The remaining accessions were found to be susceptible to highly susceptible to this disease. In some cases the extent of susceptibility was so high that these genotypes could not produce spikes and grains leading to almost 100% yield losses.

The germplasm collections maintained at IIWBR, Karnal repository comprise of local cultivars, breeding materials developed by different barley breeding centers of India and the lines selected from international trials/nurseries received from ICARDA. Good number of germplasm accessions has immediate breeding value and can be used as donor parents in different breeding programmes of barley improvement. These genetic resources involving indigenous and exotic accession are from different geographic regions of the world. Hence, these accessions are most likely to carry diverse genes for resistance making them useful in breeding programme.

Powdery mildew is a fungal disease caused by *Blumeria graminis* f. sp. hordiiThe use of resistant barley varieties can be an effective strategy for controlling powdery mildew. In this regards, several alleles for powdery mildew resistance has been identified in both cultivated (Jorgensen, 1994) and wild barley (Dreiseitl and Dinoor, 2004). Although, the effectiveness of many resistance alleles deployed in agriculture has been short-lived due to appearance of new virulence types.

Classical breeding for resistance to pathogens and pests mainly depends on identification of resistance genes in wild relatives of crops and then introgression of these genes into cultivated crops. Wild barley has successfully been used as a source of major genes for rust and scald resistance (Feuerstein *et. al.* 1990, Abbott *et al.* 1992). However, it takes years to derive the new resistant variety. Crop breeding entered into a new era with introduction of molecular techniques in 1980s. The new molecular techniques are available which can be utilized successfully for introgressing genes from wild species (Tanksley and Nelson, 1996).

BARLEY QUALITY IMPROVEMENT

Barley grain has a very versatile usage and the major uses include animal feed, malt, and direct use as food. The second major use of barley is in the malt industry after feed and fodder; however, the increasing awareness about the health benefits of consuming barley in our daily diets has opened new vistas before the barley researchers to popularize this crop as a food crop. Indian barley improvement programme is focused on different aspects of barley quality which are briefly discussed below.

MALT BARLEY IMPROVEMENT

For making superior quality malt, the barley grain must possess certain quality parameters. These include higher starch (> 60%), lower protein (9-11%), lower beta glucan (< 4.5%), lower husk (< 11.0%), reasonably good starch degrading activity (Table 4). Usually the two rowed barley having bold grains with lower protein and husk contents as compared to six rowed barley grains, are considered superior for malting purpose. The Indian standards for all these parameters have been fixed (Anonymous, 2014). Preliminary research efforts on malt barley started in 1969-70 when an Australian genotype, Clipper was introduced but it could not become popular. Another two rowed introduction Alfa 93 from Argentina was released in 1994 and Rekha (BCU 73) from Australia in 1997. These genotypes had desirable quality traits, but probably because of their lower yields as compared to six rowed barley, they also did not become much popular. A comprehensive breeding programme was started under Barley Network at ICAR-IIWBR (earlier Directorate of Wheat Research, DWR) in mid nineties and first indigenous malt barley two rowed variety DWR 28 developed by the barley breeders of IIWBR, Karnal was released in the year 2002. This variety has higher yield and good quality grains. However, yield gap between two rowed malt barley and high yielding feed barley varieties remained about 10% in NWPZ. Further efforts in this direction resulted in release of two varieties in 2007, DWRUB 52 and RD 2668. The variety DWRUB 52 has reasonably good yield comparable to popular six rowed varieties coupled with good grain quality.

The varieties released till 2007 were all for timely sown conditions. But in certain parts of the NWPZ, cotton is grown or an early crop of potato is planted and these crops are harvested in the end of November or first week of December which make the cultivation of this variety impossible. Therefore, need was felt to develop malt barley varieties which can fit well under the late sown conditions. In the year 2010 a two rowed barley variety DWRB 73 was released followed by another two rowed variety DWRB 91 in the year 2012. A major breakthrough was achieved in the year 2011 when the first six rowed malt purpose variety of India DWRUB 64, suitable for late sown conditions of North Western Plains, was released. For timely sown conditions, improved variety DWRB 92 was released in 2012 and subsequently two varieties DWRB 101 and RD 2849 were released in the year 2014.

Though Indian malt barley improvement programme has come a long way with a bouquet of varieties to sustain the malt barley industry in the country, but the shorter window of time available for maturing barley grains (35-40 days) under Indian conditions of sub-tropical climates result in higher husk, protein and beta glucan contents as compared to barley being grown under temperate climates. All these factors result in poor malt quality parameters as compared to international standards. Hence, concerted efforts are required to develop barley varieties suitable for malt purpose by using traditional as well as molecular tools.

FEED BARLEY IMPROVEMENT

Most of the varieties developed in India are meant for feed purpose only. Grain yield and disease resistance are the two major criteria being used for the development of feed barley variety. In this regard since the year 2011, protein content and certain other physical parameters of grain are being monitored in the AICWandBIP samples. One of the major bottlenecks for evaluating quality of feed barley is the non-availability of set of standards. However, certain parameters like starch content, low content of beta glucan, protein quality and quantity and fibre content can be used as selection criteria for developing feed barley varieties which should have better *in-vivo* digestibility.

FOOD BARLEY IMPROVEMENT

With the revelation of health benefits of beta glucans, barley is now considered as a health food as it is a rich source of tocols, including tocopherols and tocotrinols which are known to reduce serum LDL cholesterol through their anti-oxidant action (Baik and Ullrich, 2008). Regular consumption of barley grains with higher beta-glucan may decrease blood cholesterol and glucose levels. However, the commonly grown barley varieties are hulled and may not be suitable for food uses because of higher crude fibres. Removal of hull (husk), a process called as pearling, also removes the important nutrients from outer layers of the grain. Therefore, development of husk less barley varieties with higher grain yield and higher beta- glucan content is the need of the hour. Naked or huskless barley is part of regular food in tribal of higher Himalayas.

Huskless barley has a great potential in the country and can become an important ingredient of multigrain *atta* (flour), cookies, bread and *Daliya.* In this direction research efforts have been initiated at ICAR-IIWBR, Karnal, few germplasm lines (BCU 554, DWRB 30 and DWRUB 76) with high beta-glucan (> 6% dwb) have been identified for their utilization as donor parents to improve the beta-glucan content of Indian barley (Kumar *et al.*, 2015).

Table 4
Quality of some of the malt barley varieties grown in north-western plains of India

S. No.	Variety	Test weight (kg/hl)	Thousand grain weight (g)	Bold grain (%)	Thin grain (%)	Husk (%)	Grain protein content (%)	Hot water extract (%)
1.	BCU 73	64.0	58.5	90.9	2.2	11.0	9.6	77.9
2.	DWR 28	62.0	58.0	93.5	1.5	11.4	10.2	79.7
3.	DWRUB 52	65.6	47.6	86.8	1.8	11.2	10.7	80.8
4.	RD 2668	62.9	44.8	71.8	4.2	10.1	11.4	80.4
5.	DWRB 73	62.1	51.6	83.8	2.9	11.4	12.3	79.1
6.	DWRUB 64	59.8	42.9	86.3	2.3	12.0	10.0	77.4
7.	DWRB 91	64.5	56.4	90.4	2.5	11.1	11.2	80.0

Source: Anonymous 2012

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