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Review Article

Barley research in India: Retrospect & prospects

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Abstract

Barley is one of the founder crops of old world agriculture and was one of the first domesticated cereals. It is fourth largest cereal crop after maize, wheat and rice in the world with a share of 7 per cent of the global cereal production. The crop is considered as poor man's crop and better adaptable to problematic soils and marginal lands. It is not only useful for malting, feed and food purposes but also its β-glucans is helpful in lowering the risk of cardio-vascular diseases. Prior to the inception of AICRP on Barley, pure line selections in the indigenous land races were employed, which resulted in the development of several barley varieties like NP 13, NP 21 (New Pusa), C 251, K 12, K 18, K 24 (Kanpur, UP), BR 22 & BR 32 (Sabour, Bihar), T4, T5, C 138 and C 164 (United Punjab). The All India Coordinated Barley Improvement Project (AICBIP), involving ICAR and SAU centers was initiated in 1966-67 to do the collaborative research. During the IXth five year plan, both barley and wheat coordinated projects were merged and combined programme was named as "All India Coordinated Wheat and Barley Improvement Project" in 1997 and this arrangement is being continued since then. Keeping in mind the priorities as abiotic, biotic stress, dual, malt and food purposes, a total of 122 barley varieties and 15 genetic stocks, agrotechnologies and disease and pest management strategies have been developed from the barley improvement programme and are described in this review article.

Key words: Barley, malt, feed, food, disease, markers

1. Introduction

Barley (*Hordeum vulgare* L.) is an ancient cereal grain, which upon domestication has evolved from largely a food grain to a feed and malting grain (Baik and Ullrich, 2008; Pourkheirandish and Komatsuda, 2007). It is considered fourth largest cereal crop in the world with a share of 7% of the global cereal production (Pal *et al.,* 2012). It belongs to grass family poaceae, tribe triticeae and genus *Hordeum*, comprising nearly 350 species. Out of which *Hordeum* consists of about 32 species including the wild and cultivated one. Barley is a diploid with 2n= 14 chromosome. The cultivated barley (*Hordeum vulgare* ssp. *vulgare*) is one of the oldest of the cultivated plants. However, origin of cultivated barley is disputed. Aberg (1940) postulated that six rowed wild barley (*Hordeum vulgare* ssp. *agriocrithon*) found in Tibet was the progenitor of cultivated barley and Harlan (1976) suggested that barley was domesticated in south west Asia from a two rowed wild barley (*H. vulgare* ssp. *spontaneum*). Barley can grow in a wide range of environments than any other cereal, including extremes of latitude, longitude and high altitude (Vangool and Vernon, 2006). It is frequently being described as the most cosmopolitan of the crops and also considered, as poor man's crop because of its low input requirement and better adaptability to drought, salinity, alkalinity and marginal lands (FAO, 2002). Barley is also a model experimental system because of its short life cycle and morphological, physiological, and genetic characteristics.

Barley is cultivated in India since ancient times and is considered as a sacred grain. In India, barley is cultivated on about 6.95 lakhs ha area with production of 17.43 lakhs tons and productivity of 2508 kg/ha (Anonymous, 2013). The major barley growing states in india are Rajasthan, Uttar Pradesh, Haryana, Punjab, Madhya Pradesh, Uttarakhand, Himachal Pradesh, Bihar, Jammu and Kashmir, West Bengal, Chhatishgarh and Sikkim. Among states, Rajasthan occupied the highest area and production of barley, 3.67 lakhs ha and 10.17 lakhs tons respectively, followed by U.P. and Haryana. However, maximum productivity is recorded in the Haryana (3642 kg/ha). In Punjab, barley production got a major boost up during 2012-13 and reached about 70, 000 tons against the 47,000 tons in 2011-12 (http://www.moneycontrol.com, 2013).

2. Barley usages

Barley grain is used as feed for animals, malt for industrial uses and for human food. Barley straw is used as animal fodder in many developing countries including India (Fig.1). Barley straw is also used for animal bedding and as cover material for hut roofs. Barley is also used for green forage and either directly fed to the animal or used for silage. It also has immense potential as quality cereal especially for nutritional and medicinal point of view (Cavallero *et al.,* 2002; Newman *et al.,* 1989; Qureshi *et al.,* 1991). In developed countries barley is considered as a functional food and used in many bakery products and recipes. In India, its utilization as food crop (mainly hull less type) is restricted to the tribal areas of hills. The barley products like "Sattu" (in summers because of its cooling effects on human body) and Missi Roti have been traditionally used in India (Verma *et al.,* 2011). However, barley is predominantly consumed as food crop in the semi-arid regions of Africa (Morocco, Algeria, Libya and Tunisia), Middle East (Saudi Arabia, Iran, Iraq and Syria), highlands of Nepal, Ethiopia and Tibet, Andean countries of South America (Peru and Chile) and in some Asian countries (China and North Korea) (Akar *et al.,* 2004).

Malt is the second largest use of barley and malting barley is grown as a cash crop in a number of developed and developing countries including India. Among cereals, barley is most preferred for malt, as its husk protecting the coleoptile (acrospire) during germination process and provides aid in filtration, firm texture of grains and its amylase activity makes it unique for malt recovery. Malt is used mostly in beer, hard liquors, malted drinks and flavorings in a variety of foods. Barley malt can also be added to many food stuffs such as biscuits, bread, cakes and desserts (Akar *et al.,* 2004). The utilization of barley for malting and brewing industry has picked up recently with an increase of consumption of beer and other malt based products in many countries including India.

Fig 1. Utilization of barley for different purposes in India

With the changing lifestyles and increasing urbanization, the diseases like coronary heart disease, diabetes etc are on the rise all over the world. One of the ways suggested to control these diseases is changes in the dietary habits. Besides this in past few years it has been shown that inclusion of nutraceuticals such as soluble dietary fibres can help in controlling the blood cholesterol and glucose levels besides providing benefits to gut health. Barley grains possess higher amounts (3-7%) of one such dietary fibre called beta glucan. The mixed linkage (1-3; 1-4) beta glucans have been shown to lower postprandial blood glucose and lower the LDL cholesterol and is approved in many countries as health benefitting soluble fibre (Behall *et al.*, 2004; Fadel *et al.*, 1987; Braaten *et al.*, 1991; Pins and Kaur, 2006). Barley is also a rich source of tocols, including tocopherols and tocotrienols, which are known to reduce serum LDL cholesterol through their antioxidant action (Baik and Ullrich 2008, Qureshi *et al.* 1986).

2.1 Crop scenario: During 2012-13, globally barley was grown on nearly 49 million hectares area with a production of around 132 mt. The area was decreasing around the world until mid nineties but after that there has been stabilization, though the productivity is improving. In India presently the productivity is below the world average, but there has been a continuous gain in productivity through research efforts on varietal development and production technology. In India also, the trend of reduction in area under barley has been similar to world trend over the years (Fig. 2). However, during past 15-20 years the area under barley has almost stabilized with minor annual fluctuations depending upon the market prices and industrial demand.

The decline in area under barley can be broadly categorized in two phases. In first phase (the green revolution period) development of semi-dwarf wheat varieties with high yield potential made the farmers prefer wheat over barley. Since there was no such breakthrough in barley yield potential, the shift happened for wheat crop from barley being the crops of the same season. In the second phase (post green revolution era), the barley area again decreased significantly because of development of irrigation network, further increase in wheat area as major food security crop, popularization /demand of more remunerative oilseed crops like mustard for rainfed conditions and less demand for industrial utilization of barley. These factors confined barley to marginal, problematic soils as a rainfed crop, further adding to the decrease in the production of barley.

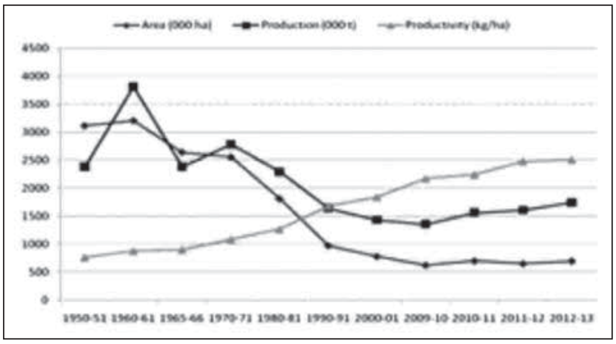

Fig 2. Trend of barley, production & productivity in India

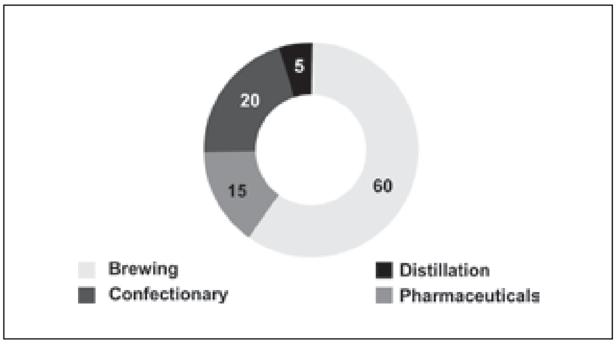

Fig 3. Utilization of malt in India

The increase in industrial demand of barley as raw material during early nineties resulted in hike in market prices and created a situation of short supply. In fact presently only about 25-30% of the total barley production is used in the manufacture of malt and malt extract, which is further utilized for brewing, distillation, baby foods, cocoa-malt drinks and medicinal syrups (Fig 3). Rest of the production is utilized as cattle feed and only a small portion in cereal food and in preparation of local beverages in the tribal areas. The available six-row barley possessed higher husk and less carbohydrate resulting in poor malting quality. This was mainly because of poor management of the crop as well as the inability of cultivars to bear the optimum management. Thus the continuous decline in barley area and production as well as reduced preference of farmers to grow barley under better management had triggered a shortage for good quality grain for malting in mid nineties. The Government of India has issued license to several new breweries, which created a demand for international quality malt as raw material for the breweries looking for the collaboration/ competition with multinational companies. The same trend is still continues and India is currently having highest growth rate/ increase in demand for beer in the world and several multinational companies have already established their set up in country to cater this demand. Further to promote the cultivation of malting type cultivars these companies have initiated “Contract Farming” in states like Punjab, Haryana and Rajasthan to ensure continuous supply of the raw material (malt barley grain) to meet the growing demand of malt for brewing and confectionary items.

In the recent years it has been observed that because of severe drought in the drier parts of northern plains, there is an acute shortage of green forage in the months of November to January. The common forage crops, berseem (*Trifolium spp*), oats (*Avena sativa*) and sugarcane require frequent irrigation, and can’t be grown under water scarcity condition. The dual purpose barley can be a better option as green forage as well as grain crop in dry areas. In the era of climate change, where shortage of water and rise in temperature are becoming limitations, barley cultivation can provide a viable alternative to farmers.

2.2 Barley improvement in India: The barley research in India has been progressed with development of varieties for different purposes such as feed, malt, fodder and hulless barley for varied agroclimatic conditions. However, major emphasis of barley breeding programme has been made on development of feed, malt and dual purpose varieties with high and stable yield, resistance to biotic stresses (yellow rust, leaf blight, aphids and cereal cyst nematode) and abiotic stresses (drought, salinity, alkalinity, rainfed, brackish water and diara lands). In addition, breeding for early maturity, bold and plump seeds and adaptation to specific environments has also assumed importance. A substantial progress in enhancing yield with reducing the losses from biotic stresses, increasing the seed size, lodging resistance and tolerance to salinity stress has been made by adopting the appropriate breeding approaches such as pure line selection, pedigree method, bulk method, backcross method, single seed descent method, mutation and biotechnological tools for molecular profiling.

The research programme for improvement of this crop was initiated in India, sometimes during 1916 with research activities such as;

i. Introduction of exotic barley germplasm and improvement through selection

ii. Collection of land races of barley and improvement through selection

iii. Development and popularizing package of practices to encourage its cultivation

iv. To recommend well tested varieties both hulled and hulless for cultivation.

Prior to inception of the AICBIP, a numerous varieties were selected from land races and developed the improved barley varieties with high yield along with other desirable traits. As a result of selection from land races a variety C 251 was developed during 1928 (Gupta, 2013). It combined high yield potential along with excellent malting quality and tolerance to saline/ alkaline conditions of soil. Other varieties developed and released were Type 4, Type 5, C 84, C 50, NP 100, barley local, BR 21, BR 22, BR 32, CN 292, CN 294, K 12 Balia barley, K 14, RS 17, KB 71, Ratna and PR 502. All these varieties were recommended on the basis of performance in their regional tests. Four hulless varieties namely CN 292, CN 294, Sindhu and Nurboo were directly selected from local materials. Varieties CN 292 and CN 294 were suitable for plain zone, whereas Sindhu and Nurboo were adopted for summer cultivation in Leh and Laddakh.

Table 1. Barley varieties released during recent years for feed and food purposes

Cultural practice	Variety	Year	Area of adaptation
Irrigated	RD 2552	1999	NWPZ, NEPZ
	NB-2 (NDB- 940)	1999	Uttar Pradesh
	BH 393	2001	Haryana
	RD 2592	2003	Rajasthan
	PL 751	2006	Central zone
	Jawahar Barley 1	2009	Madhya Pradesh
	BH 902	2010	NWPZ
	BH 946	2014	NWPZ
	HUB 113	2014	NEPZ
Rainfed (Plains)	PL 419	1995	Punjab
	K 560	1997	NEPZ
	Getanjali (K1149)	1997	Uttar Pradesh
	K 603	2000	NEPZ
	RD 2624	2003	NWPZ
	JB 58	2005	Madhya Pradesh
	RD 2660	2006	NWPZ
Rainfed (Northern Hills)	HBL 276	1999	Northern Hills
	BHS 352	2003	Northern Hills
	VLB 56	2005	Uttarakhand
	VLB 85	2008	Uttarakhand
	PRB 502	2009	Uttarakhand
	BHS 380	2010	Northern Hills
	UPB 1008	2011	Northern Hills
	VLB 118	2013	Northern Hills
	BHS 400	2014	Northern Hills

2.3 Barley improvement for feed and food purposes: Barley is a good source of feed and fodder. It is a key animals feed and fodder in dry areas of India (Kumar *et al.* 2013).

Majority of barley produced in India is utilized as feed for cattle and poultry and in few areas as food purposes. The Barley Network centers under AICW&BIP has got a major research component on the barley improvement for grain/ feed purposes.

A large number of varieties have been developed/ released either by CVRC for different zones or by respective SVRCs for specific states addressing different production conditions and agro-climatic situations by different centers under AICW&BIP. Incorporation of resistance to major diseases and pests along with improvement for grain yield has been the major objective of the programme after the reorganization of the network in 1990-91. Prior to this there was no organized system being followed for screening of resistance under artificially inoculated conditions at hot spot locations and only the natural incidence in yield evaluation trials was being recorded. Subsequently a large number of improved varieties with resistance to diseases were developed for feed and food purposes for different production conditions/ zones (Table 1).

Hulless barley or naked barley (*Hordeum vulgare* L. nudum Hook F.) is a form of domesticated barley with an easier to remove hull. It is consumed as both food and feed purposes. It is also used for making alcoholic beverages particularly in the high hills.

Hulless barley is preferred over hulled types because it allows easier removal of the hull and a fairy new industry has developed of selected hulless baley in order to increase the digestible energy of the grain, especially for swine and poultry (Bhatty, 1999a).

Hulless barley has been investigated for several potential applications as whole grain and for its value added products. These include bran and flour for multiple food applications (Bhatty, 1999b). Several research papers have revealed that soluble dietary fibre and β-glucan are of particular interest to the consumers due to their effect on blood cholesterol and blood glucose.

Keeping in mind the importance of hulless barley, some varieties have been released in India (Table 2) and breeding work is being in pace way.

2.4 Malting quality improvement: Barley is used for a wide range of end uses. The major portion of the produce is utilized for feed and food purposes and nearly 20-25% of the produce is consumed by the malting industry (Verma *et al.*, 2008). With the growing urbanization, more open economy and changing lifestyles demand for quality malt and malt products has increased in last two decades. Malt

Table 2. Resealed varieties of huskless barley in India

Variety	Parentage	Year of release	Salient feature
CN 292	Selection from local material of Pratapgarh	1954	Suitable for Jhansi, Meerut and Bundelkhand areas
CN 294	Selection from local material of Bulandshahar	1954	Suitable for Jhansi, Meerut and Bundelkhand areas
Dolma	Selection from USA (Introduction)	1974	Suitable for northern hills both high hills in summer and lower ranges during winters.
Karan 16	AZAM 1/ EB7576	1987	Semi dwarf, semi drooping, long lax ear, amber grain, susceptible to rusts
Geetanjali (K 1149)	K 12/K 572//10/ EB 410	1991	Six rowed, amber grain, free threshing
HBL 276	HBL 233/HBL 238	1999	Six rowed, good threshability, amber grain
Himadri (BHS 352)	HBL 240/BHS 504//VLB 129	2003	Six rowed, amber grain, resistant to rust, cold tolerant
Sindhu (NBL 11)	Selection from Sermo Tok	2005	Six rowed barley for rainfed cultivation at very high altitude areas during summer season.
Nurboo	Selection from NBL 11	2005	Six rowed, barley for rainfed cultivation at very high altitude areas during summer season.

is being utilized for brewing, distillation, baby foods, confectionaries, cocoa-malt drinks and medicinal syrups with the major share going to brewing. The annual requirement of barley for malting purposes is on rise in recent years. Though no authentic data are available in this regard, however the rough estimates depending upon the capacity of the major malting units indicate that total quantity of barley needed annually for malting purposes is nearly 240,000 MT. An expected growth @ 10% per year in barley for industrial purposes is estimated with several new malting and brewing units are entering in the field. The malt utilization for different uses has also changed in recent years, with an increase in proportion of malt being used for brewing and decrease in distillation. The current estimates indicate that now approximately 30% malt is used for energy drinks/pharmaceuticals & confectioneries, 8% for whiskies and the balance (around 60-62 %) is used by breweries.

Research on malt barley improvement in the country was initiated with the several two-row malt varieties introductions like Peatland and Pedigree (USA), Manchuria (Germany) and Odessa (Russia) which were evaluated at IARI, New Delhi along with indigenous varieties like Type 4, C 251 and NP 113. These exotic collections were found to be inferior for traits like 1000 gw and protein content. Also the differential requirements for brewer's and distiller's malt were not clear. With rise in industrial demand for malting, malt barley improvement programme was again taken up in early nineties. Two more introductions ALFA 93 and BCU73, both two row, good malt type varieties were released by CVRC in 1994 and 1997, respectively, for commercial cultivation in North Western Plains Zone (NWPZ) under timely sown conditions. However, late maturity, weak straw, poor grain filling under heat stress and low yield levels still remained major concern for their popularization among farmers, in absence of any premium by industry for quality. Some six-row type cultivars were released subsequently (RD 2503 for NWPZ, K 551 for NEPZ and DL 88 for Peninsular Zone) for cultivation under irrigated timely sown conditions having good malting qualities amongst six-row barley. In the mean time minimum standards were also fixed for various malting quality traits of barley grain and malt in India as a guideline to breeders in mid nineties. There are number of grain and malt traits, which are considered essential/important by malting and brewing industries (Verma *et al.*, 2005). Therefore, it was considered essential to start concerted efforts on development of indigenous malting quality varieties to suit Indian climatic conditions. A 'National Core Group on Malt Barley Development' was constituted in 1995 comprising of barley research workers and industry representatives. The group finalized the minimum standards of barley grain and malt qualities, as a guideline to barley breeders and all concerned agencies, taking into consideration the European Brewery Convention (EBC), American Malt Barley Association (AMBA) and ISI guidelines (Verma *et al.*, 2005) during its first meeting in December 1995 at Karnal. These standards are being adhered by the programme while selecting / approving any barley variety as malt barley in the network evaluation and release (Table 5). These efforts resulted in the development of first indigenously bred two-row malt barley variety (DWR28) in the country, which was released by CVRC for commercial cultivation in North Western Plains Zone.

The continuous efforts for making improvement in quality and yielding ability resulted in two more high yielding two-row malt varieties (DWRUB 52 and RD 2668), which have been released in 2007 by CVRC. This variety is the first two-row variety continuously giving equivalent yield levels in coordinated trials. Recently an improved variety for timely sown conditions namely DWRB 92 has been identified for recommendation to CVRC (Table 3 & 4).

In the era of climate change, where shortage of water and rise in temperature are becoming limitations, barley cultivation provides a viable alternative to farmers. In order to widen the scope of malt barley cultivation in the late sown conditions of northern plains in rotation with cotton, pearl millet, sorghum, maize and sugarcane crops, two new varieties, DWRB 73, DWRB 91 (two-row type), and DWRUB 64 (six-row type) have been released for commercial cultivation in 2011 to 13. These varieties gives good grain yield with acceptable malting quality under even late sowing conditions and will help in increasing barley cultivation in such areas. Another two row malt barley timely sown variety DWRB 92 has been released in the year 2013. These varieties have opened up another area of cultivation in non rice-wheat belt and give better grain yield and quality for malting, thus industry can exploit their potential for commercial malting without much competition with wheat for area in the same season.

The development of improved varieties for quality purposes always requires identification of important traits affecting quality in a particular growing environment. Since nowhere in India, barley gets equivalent grain filling period with mild temperatures like Europe and other countries which grow better malting quality barley (Verma *et al.*, 2005) there was a need to study barley malting quality parameters under Indian environments.

Table 3. Barley varieties released in India for malting purposes for timely and late sown conditions

Variety	Year	Production condition	Area of adaptation	Developed at
Alfa 93	1994	Irrigated (TS)	NWPZ	DWR Karnal
BCU 73	1997	Irrigated (TS)	NWP, NEPZ, PZ	DWR Karnal
DWR 28	2002	Irrigated (TS)	NWPZ	DWR Karnal
DWRUB 52	2007	Irrigated (TS)	NWPZ	DWR Karnal
RD 2668	2007	Irrigated (TS)	NWPZ	ARS Durgapura
DWRB 92	2013	Irrigated (TS)	NWPZ	DWR Karnal
DWRB 73	2011	Irrigated (LS)	NWPZ	DWR Karnal
DWRUB 64	2012	Irrigated (LS)	NWPZ	DWR Karnal
DWRB 91	2013	Irrigated (LS)	NWPZ	DWR Karnal

Verma and Nagrajan (1996) reported that malting barley traits are not independent and are also influenced by environmental conditions in India. Ram and Verma (2002) studied the β-glucan content and wort filtration rate in 100 barley lines grown at two locations and there was non-significant effect on β-glucan content but the effect was significant on wort filtration rate. The β-glucan content varied from 2.9 to 7.1 % (DWB) at Karnal location.

Table 4. Quality parameters of malt barley varieties grown in north-western plains of India*

Variety (Season)	Test weight (kg/hl)	Thousand grain weight (g)	Bold grain (%)	Thin grain (%)	Husk (%)	Grain protein (%)	Hot water extract (%)**
BCU 73 (TS)***	64.0	58.5	90.9	2.2	11.0	9.6	77.9
DWR 28 (TS)	62.0	58.0	93.5	1.5	11.4	10.2	79.7
DWRUB 52 (TS)	65.6	47.6	86.8	1.8	11.2	10.7	80.8
RD 2668 (TS)	62.9	44.8	71.8	4.2	10.1	11.4	80.4
DWRB 73 (LS)	62.1	51.6	83.8	2.9	11.4	12.3	79.1
DWRUB 64 (LS)	59.8	42.9	86.3	2.3	12.0	10.0	77.4
DWRB 91(LS)	64.5	56.4	90.4	2.5	11.1	11.2	80.0
DWRB 92 (TS)	64.0	53.0	93.0	1.0	11.4	11.9	79.0

**Average over locations/year under AICW&BIP (For BCU 73 & DWR 28 years 2000-01 & 2001-02 reports; for other varieties 2010-11 & 2011-12 reports for DWRB 92 data for 2012-13 report also included), ** Malt was prepared in the Automatic Micro-malting system, ***TS=Timely sown; LS=Late sown*

The hordein protein profile study indicated a positive association of D-subunit with hot water extracts (Ram and Verma, 1998). Singh *et al.* (2005) studied the malting quality of eight genotypes in Kanpur (Uttar Pradesh) and found that protein content was inversely correlated with starch, insoluble carbohydrates and predicted extract value. Sarkar *et al.* (2008) investigated the grain and malting quality of 131 barley genotypes and identified several sources of different quality traits. They suggested that more detailed study on genetic diversity for malting quality traits may help in identifying more genotypes of interest in future. Verma *et al.* (2008) studied the correlation between hot water extract and several grain and malt parameters in 131 genotypes.

They suggested that hectoliter weight, thousand grain weight, hull content and malt friability can be used to predict hot water extract. Genetic diversity studies for malting quality were conducted on 72 Indian barley varieties released during last 60 years (Verma and Sarkar, 2010) and varieties grouped accordingly. The genotypes for high and low beta glucan content and protein content have been identified (Kumar *et al.*, 2012)

2.5 Improvement for abiotic stress tolerance: In India, barley is generally cultivated in harsh environments like drought, cold, salinity/alkalinity and marginal lands. Its cultivation is also confined to the rainfed areas and problematic soil conditions (Gupta, 2013). Soil salinity is a major abiotic stress which not only delays but also reduces flowering and yield of plants (Bernstein and Hayward, 1958). Reductions in yield under salinity have been reported in wheat and barley (Asana and Kale, 1965). In India, salt affected soils occupy about 6.74 million hectares (cssri. org) and represent a serious threat to its ability to increase food production to meet the expanding needs. Barley is a naturally salt tolerant crop (Hassan *et al.* 1970). Gill (1975) studied on effect of soil salinity on grain development and grain filling in barley and it was noticed that barley cultivars differed widely in yield attributes under normal and under saline conditions. To mitigate this problem, one of the cheapest sources is to develop the salinity tolerant varieties. It is prerequisite to search the donor parent for salinity tolerance from exotic/indigenous germplasm lines and varieties of barley. The landraces of barley through conventional breeding may be used to incorporate genes for salinity tolerance. The other approach is to utilize the wild species namely foxtail barley (*Hordeum jubatum* L.) for salinity tolerance (Israelsen *et al.* 2014).

However, it's a highly challenging task to screen materials for such conditions due to very high variability in the field condition affected by salinity and alkalinity. As a result the field screening for salinity tolerance sometimes can't be fully reliable, because of non-repetitive performance due to the soil heterogeneity. To have more efficient evaluation, we may have to look for the *in vitro* screening for salinity- alkalinity tolerance to supplement the regular

Table 5. Barley varieties for cultivation under saline-alkaline soils

Variety	Year	Production condition	Area of adaptation
DL 88	1997	Irrigated (TS & LS)	NWPZ, NEPZ
RD 2552	1999	Irrigated (TS)	NWPZ, NEPZ
N Barley-1 (NDB 209)	1999	Irrigated (TS)	Uttar Pradesh
N Barley-3 (NDB 1020)	2001	Irrigated (TS & LS)	Uttar Pradesh
NDB 1173	2004	Irrigated (TS)	NWPZ, NEPZ

research efforts. The efforts of barley research workers under AICWBIP have resulted in development and release of many tolerant varieties (Table 5), which give good yield level under such unfavorable conditions (Verma *et al.*, 2012).

2.6 Improvement for dual purpose barley: Barley grain has been traditionally used as animal feed and grain crop for human consumption in India. During the late seventies a few varieties like Azad, K 141 and Ratna, were also recommended for single cut for green forage. However, such line of research was not given much emphasis in the period to follow. In recent years due to increasing scarcity of green forage availability in the arid and semi arid region, it was observed that barley can be utilized as an alternative source of green forage in the drier parts of states like Rajasthan, Haryana, Punjab, MP and UP . Also in case of hills, most of the farmers are growing barley in apple orchards mainly for utilization as green forage. The Barley Network took a new initiative during last few years to look at the possibility of utilizing barley as a dual purpose crop to meet the requirements in association with AICRP-FC, Jhansi. It was found that barley crop can be given one cut (at 50-55 days after sowing in plains and 70-75 days after sowing in hills) for green forage and the regenerated crop can be utilized for grain purposes. A new series of yield trials was initiated from 2003-04 crop seasons for dual-purpose barleys in plains and hills zones to identify suitable genotypes. Already released feed type varieties RD 2035 and RD 2552 have been found equally good to be used as dual purpose type. Two more new varieties (RD 2715 for central zone and BHS 380 for NH zone) have been released by CVRC as dual purpose barley as forage cum grain crop (Table 6). However, there is a need to continue working on this area to develop better variety to be used as dual purpose barley. There is also a need for evaluation of the forage quality traits to improve the overall suitability as green forage. Thus barley can serve as supplementary crop for augmenting the green forage demand in the arid/ semi arid areas of northern plains under limited irrigations and in hills under rainfed conditions. It also gives satisfactory levels of grain yield from the regenerated crop, which can also be utilized as feed for cattle feed or for human food.

Table 6. Dual purpose barley varieties released in India

Variety	Year	Production condition	Area of adaptation
RD 2035	1994*	Irrigated	NWPZ
RD 2552	1999*	Irrigated	NWPZ
RD 2715	2008	Irrigated	Central zone
BHS 380	2010	Rainfed	Northern Hills

**These varieties were released as grain type earlier but recently observed as also good for dual purposes*

2.7 Molecular advances for barley improvement: Molecular approaches have been taken as tools for number of applications ranging from localization of a gene to improvement of plant varieties by marker-assisted selection. Barley is a well-studied crop in terms of genetics, genomics and breeding. A broad range of resources including EST sequence data, studies on transcriptome, proteome, and metabolome, and genome sequencing consortium have been developed during the last two decades. This has been assisted by a large number of mapped molecular markers, BAC libraries, mutant collections, DNA arrays, and efficient doubled haploid development and transformation protocols (Varshney et al, 2007). International Barley Genome Sequencing Consortium (IBSC) has constructed the high-resolution draft DNA sequence that has revealed structure and order for most of the genes and has provided the functional portions of the genome (http://barleygenome.org). Genome analysis based on molecular markers has generated a vast amount of information and a number of databases are being generated to preserve and popularize it (http://barleygenomics.wsu.edu.).

In India barley research gained a lot of momentum from this development in recent years to meet the future challenges imposed by a changing environment and to satisfy the soaring demand for malt barley. Most of molecular studies targeted the problems of disease incidences and insect pest infestations in barley sowing regions of India. The progress made in barley using molecular strategies resulted in molecular characterization of genomic regions involved in disease and insect pest resistance. Inheritance study of spot blotch resistance identified three resistance genes on *Rcs-qtl-5H-1*, *Rcs-qtl-5H-2* and *Rcs-qtl-1H-1* in cross IBON18/RD2508. These genes were found closely linked to three SSR markers BMS 32, BMS 90 and HVCMA during single marker linear regression analysis (Tyagi *et al*, 2008). Three molecular markers (Ebmac 705, Bmag 606 and Bmag 225) on 3H chromosome were validated for leaf blight resistance using exotic and indigenous barley genotypes (Jain *et al*., 2013). In another study, cross DWR 49/ RD 2508 was investigated for inheritance of leaf blight resistance. Eleven molecular markers Bmac 213, ABG 058, Bmag 125, Hv 5s, GBM 1208, GBM 1444, GBM 1506, GMS 1, GBM 5012, Ebmac 827 and Bmag 369 specific to chromosome 1H, 2H, 3H, 5H, 6H and 7H were found closely linked to leaf blight resistance (Jain *et al*., 2014). In accordance with these findings, leaf blight resistance in barley has complex quantitative inheritance at adult plant stage in Indian conditions. Most of the Indian barley varieties are susceptible to leaf blight disease and an integrated approach is recommended with host resistance as a major component to target genomic regions involved in leaf blight resistance (Singh *et al*., 2005). Therefore, these findings may be useful in developing marker assisted selection strategy for incorporating leaf blight resistance in Indian barley.

Corn leaf aphid (*Rhopalosiphum maidis)* is an important insect problem of barley crop in India. A study was conducted to determine the inheritance of resistance and to identify molecular markers of resistance in the barley *(Hordeum vulgare* L.) line EB921. This genotype was found resistant during phenotypic characterization for CLA resistance in barley (Yadav, 2003). A RIL population of cross Alfa93/EB921 was used to identify molecular markers linked to the genomic region that provides resistance against corn leaf aphid (CLA) in barley. Two markers KV1/KV2 (1H) and SCSSR15864 (7H) retained significance during chi square test analysis (Malik *et al.,* 2012). However, recombination fractions were calculated with the MAP MANAGER version QTXb20 using the Kosambi mapping function to locate closely segregating molecular marker and only KV1/KV2 was found to be relatively close to CLA resistance gene with a genetic distance of 19.7 cM. This suggested that CLA resistance was conferred by a single dominant gene on 1H chromosome in barley (Personal communication). Verma *et al.* (2011) also reported single gene inheritance in EB921 during genetics study of CLA resistance in barley. While work for closer marker continues to identify closer and more efficient markers, barley breeders should be obviously benefited by using this marker for their selection of CLA resistance in barley.

In crops including barley, evaluation of genetic diversity appears essential to make optimal use of germplasm for effective breeding. The genetic variability in Indian germplasm of cultivated barley was reported using

SSR markers and morpho–physiological traits such as plant height, ear attitude, waxiness, purpose of cultivation, 1000 grain-weight and disease resistance to yellow rust, spot botch and aphid (Jaiswal *et al*., 2010). The UPGMA analysis for 16 SSR markers showed a high level of diversity among all the barley genotypes during hierarchical clustering. This may be due to their geographical pattern, agronomical characters, growth ertiliz and different pedigree. SSR markers BMS 40, BLYRCAB, BMS 30, HVCMA and HVM 3 gave high polymorphic information content (PIC) and could provide an effective way to increase the efficiency of germplasm evaluation and to identify duplicate accessions in the barley germplasm collection. This study determined the utility of molecular marker diversity as a tool for gene discovery and biologically meaningful classification of barley germplasm.

Marker assisted selection (MAS), is expected to increase genetic response by affecting efficiency and accuracy of selection. MAS now plays a prominent role in the field of plant breeding and it holds true for barley also. Indian barley varieties were screened with molecular markers reported to be closely associated with disease resistance and malting quality (Verma *et al*., 2012). Markers for rusts resistance, GMS61 (*Rph*12-5H), HVM11 (*Rph*19-7H), HVM67 (*Yr*-4H); for powdery mildew resistance MGB402 (*Mla*-1H) and for malt quality attributes ABC302.3 on 5H (grain protein), Ebmac415 on 2H (malt extract), HVM67 on 4H (wort content) were reported efficient for selection of respective traits. These markers may be further used for germplasm screening for disease resistance and malt quality during barley breeding program. Nevertheless, the economic and biological constraints such as a low return of investment in small-grain cereal breeding, lack of diagnostic markers, and the prevalence of QTL-background effects hinder the broad implementation of MAS.

Until now molecular markers have had limited success in Indian barley breeding programs and application of MAS remained limited. With the recent advancement of barley genomics a stronger impact on breeding strategies is expected in future. Chip-based high-throughput genotyping platforms and the introduction of genomic selection will reduce the current problems of integrating MAS in practical breeding programs. A new whole-genome breeding strategy for barley has to be developed to make full use of the ever increasing knowledge about barley genomes and their ertiliz. With the growing demand of malt barley for commercial purposes, there is a huge scope for malt barley in India. Therefore, there is a dire need of long-term investments in the public sector in form of consortium or network program for barley to reap benefits of available molecular information and latest technologies in barley genomics and transgenic.

3. Development of resource management technologies

Till early sixties agronomic investigations on barley in India centered mostly on varietal evaluation and mixed cropping trials. With initiation of All India Coordination Project on Barley in late sixties, experiments on most of the important agronomic aspects like seed rate, method and time of sowing, fertilizer and irrigation requirement of barley were undertaken. During early seventies more emphasis was laid on dry land barley research and later a new line of research on malt barley management was undertaken. All these efforts led to useful recommendations for better crop management. Later, the research efforts were diverted to solve the specific and location oriented problems in barley production. The problems in hulless, hulled and malt barley are different from each other. Not only this, the problems and limitation in irrigated, dry land, saline/ alkaline, acidic, single and double cropped situations, timely and late sown conditions are quite different from each other. Research on resource conservation techniques and input management was initiated in 2006-07. Varieties were evaluated for different tillage options. Inputs like seeds, fertilizer and irrigation were optimized for new genotypes. Investigations in production technologies for dual purpose barley were initiated during 2005-06 and recommended date/stage of cutting for fodder, ertilizer application (dose and time), irrigation and varieties for the specific purpose.

3.1 Selection of variety: The selection of suitable variety is the prime aspect of production technology. Barley is grown in different growing conditions viz. irrigated or rainfed, timely or late sown and problematic soils having salinity or sodicity. Traditionally grown barley varieties were tall and weak stemmed and generally lodge even under relatively low soil fertility conditions. Therefore, researches on varietal improvement have restructured the plant type to take full advantage of higher level of soil fertility and irrigation. New advanced lines were evaluated for different growing conditions in different zones and accordingly advanced lines and checks were recommended for different sowing conditions as reported by Anonymus 2013. Recently released malt barley varieties are DWRUB 52, RD2668 and DWR 28 for timely sown irrigated conditions and DWRB 73 and DWRUB 64 for late sown conditions (Kharub and Chander, 2012). In order to widen the scope of malt barley cultivation in the late sown conditions of northern plains in rotation to cotton, pearl millet, sorghum, maize and sugarcane crops, a new variety, DWRB73 has been recently released for commercial cultivation . This variety gives good grain yield with acceptable malting quality under late sowings up to mid-December and will help in increasing barley cultivation in such areas. In addition the development of six-row cultivar DWRUB 64 as malt barley has also provided an option for cultivation at non paddy areas in rotation with crops like cotton, maize, pearl millet, sorghum and sugarcane etc., where sowings get delayed till mid-December, with good yield and grain quality for malting Verma *et al.,* 2012.

3.2 Time of sowing: The best time for sowing barley depends upon the altitude of the field. Time for sowing barley is naturally adjusted in such a way that during germination of seed, soil has sufficient warmth to initiate germination and there exist prolong cool dry weather for development and growth of the plant, finally weather turning warm or hot dry at maturity. Accordingly, at hills, crops are sown earlier than in plains (Uttar Pradesh, Rajasthan, Haryana, Punjab and Madhya Pradesh) i.e. mid-October to mid-November, when mean daily temperature falls to 23-25°C which is conducive for seed germination.

Delay in sowing beyond November 15 causes marked reduction in grain production (Table 7) mainly due to reduced tillering and reduced number and weight of grains per ear. Delay in sowing also raises the protein content in the grain and thus adversely affects the malting quality of the grain.

Early sowing of winter wheat is likely to expose the crop not only to higher temperature but also a critical day length for flowering. On the other hand late sowing of wheat and barley might expose the crop to higher temperature after and during heading resulting in reduced number of ears per square meter and number grains / ear. Higher temperature during vegetative stage results in poor tillering, growth and development. Singh *et al.*, (1989) found that grain yield of barley decreased at delayed sowing from 10-25 December and 10 January.

Table 7. Effect of date of sowing on different varieties in NWPZ

Variety	Yield (q/ha) in different date of sowing				Mean
	D1	D2	D3	D4	
BH 902	40.08	38.03	37.13	33.58	37.20
RD 2552	38.13	36.81	36.48	34.00	36.35
DWRUB 52	40.19	40.75	37.25	34.11	38.08
RD 2668	38.46	38.16	35.43	33.56	36.40
Mean	39.21	38.44	36.57	33.81	37.01
CD (0.05)	DOS (A) 0.98	Varieties (B) 0.98	B within A 1.96	A within B1.96	

Anonymous, 2013, DOS: starting from last week of October to Last week of November (10 days interval)

Agarwal and Arora (1980) reported that vegetative stage of the crop reduced with delayed sowing, continuous low temperature during vegetative stage and temperature at maturity adversely affected the plant height and also the spike formation which ultimately reduced straw yield.

In cotton-wheat crop rotation areas, malt barley can be sown up to 15th December but with specific variety (Kharub and Chander, 2012).

3.3 Soil and its preparation: Barley thrives well on well-drained, medium fertile, deep-loam soils with neutral to mild salinity (7-8 pH). Highly fertile soils are not conducive for barley cultivation. Being salt tolerant, it is the best option in sodic soils. Its cultivation has become possible on saline coastal areas of Sunder ban in West Bengal and saline black soils of canal irrigated areas of northern Karnataka. Acidic soils are not suitable for barley cultivation, and liming is must in these soils for better yields. The soil should not be very fertile as the crop lodges very severely and drastic yield loss is observed. It is susceptible to water logging. Goyal *et al.* (2012) reported that out of five varieties of *Hordeum vulgare*, BH 924 and RD 2508 are the good salt tolerant varieties in comparison to others.

3.4 Seed rate and spacing: The seed rate of barley depends upon its test weight, germination percentage, spacing, sowing time and method as well as soil fertility status.

Table 8. Seed rate and Spacing of Barley under Different Production Condition

Production condition	Seed rate (kg/ha)	Spacing (cm)
Irrigated timely sown	100	23
Irrigated late sown	125	18
Rainfed plains	100	23
Rainfed hilly region	100	23

Recent agronomic experiments suggest that seed rate of 100 kg/ha for irrigated timely sown conditions in medium fertile soil and 120 kg/ha for irrigated or rainfed late sown conditions in poor soils is optimum (Table 8). The seed of barley should be sown to a depth of 5-7 cm at a distance of 22-23 cm. In case of two-row malt barley varieties, line to line spacing should be 18cm to get optimum grain yield and quality (Kharub and Chander, 2012).

The spacing and seed rate depend on the nature of variety. A variety having good tillering habit can also be grown at wider spacing and reduced seed rate but a variety having shy tillering require to be grown at closer spacing with slightly increased seed rate to harness the maximum productivity (Table 9).

Table 9. Productivity (q/ha) of DWRUB52 under different row spacing (Av. of 3 years)

Spacing (cm)	Date of sowing		
	Normal	Late	Mean
18	49.74	35.94	42.84
20	49.02	35.95	42.48
23	48.12	35.12	41.62
Mean	48.96	35.66	42.31
CD (0.05)	Sowing Time (A) 6.13 Spacing (B) NS B with in A NS A within B 3.57		

Anonymous , 2010

3.5 Fertilizer management: As per early sixties recommendation, fertilizer application to the barley crop is negligible and its requirement depends upon soil test report, climate and variety. Nitrogen is essential for high yield, particularly on soils with low organic content but the excess use of nitrogen cause lodging, adversely affects the yield. On an average, phosphorus and potassium requirement of barley is 30 and 20kg/ha which are adequate to maintain soil fertility. It was reported that split application of potassium (with planting and at 8 weeks after planting) can decrease the risk of lodging. With the increase in yield over the last couple of years, mainly due to genetic improvement, improved production practices and optimum irrigation scheduling, it appears that a total nitrogen application of 90 kg/ha for malt barley, depending on the soil texture and rotation system seems to be sufficient for optimum yield and quality. An additional 20 kg N/ha is also recommended on very sandy soils, where leaching of nitrogen is a major problem. Split application of nitrogen fertilizer is more important under overhead irrigation and sandy soils than under flood irrigation and heavy clay soils. A split of half of the total nitrogen with planting and the rest half 5- 6 weeks after emergence, seems to give the best results. On very sandy soils where leaching is a problem and a history of low nitrogen content in the grain is experienced, the topdressing can be applied at a later stage but not later than the flag leaf stage. The agronomic practices that were most beneficial for malt barley production are early seeding and application of N fertilizer at appropriate rates (Kharub and Chander, 2012).

Under irrigated conditions half the quantity of nitrogenous fertilizer and full quantities of phosphatic and potassic fertilizers should be placed at 8-10 cm depth in the soil before sowing, while preparing the land. The remaining quantity of the nitrogenous fertilizer may be applied with first irrigation i.e. 30-35 days after sowing. Under rainfed conditions the entire dose of all the fertilizers should be placed 8-10 cm deep in the soil before sowing. In the case of saline soil and barley grown for malting and brewing, the entire doses of all the fertilizers are applied at sowing. In order to reduce use of chemical fertilizer and sustainable production, 5 t FYM + 75 % of chemical fertilizer can be used in barley. The rainfed crops are seldom manured directly. It is the preceding crop in the rotation which receives the manure. In irrigated crop, about 10-15 tons of FYM or compost should be applied about a month before sowing. The application of organic matter to soil besides providing essential nutrients to the crop also helps in overcoming salt problems of saline and alkali soils and moisture conservation.

Nitrogen is the most important element for realizing potential yield of any crop as requirement for nitrogen is the highest among all the essential plant nutrients and this nutrient is most limiting under Indian conditions. The photosynthetic assimilates are reflected in terms of yield of crop. Nitrogen is also the main constituent of amino acids which are precursors to protein. So, malt barley grain yield, grain protein and kernel plumpness are the characteristics strongly related to available nitrogen. Increased fertilizer level upto 80 kgN, 50kg P and 30kg K per ha. increased total dry matter (Table 10). Similar trends of the effect of fertilizer were also observed in barley by Hooda and Kalra (1981), Misra *et al.* (1982), Verma and Singh (1989).

Choudhary *et al.* in 2013 reported that foliar spray of 0.5% $FeSO_4$ at tillering + flowering significantly increased the N,P,K and Fe up-take indicating an increase of 16.7, 17.9, 11.1 and 16.0%, respectively over control. This might be due to increased supply of Fe and good response by the plants leading to enhanced translocation of nutrients to reproductive structures *viz.,* spikes and grains.

3.6 Water management: Barley is a drought tolerant winter season crop and thus requires less irrigation. However, the dwarf fertilizer responsive cultivars do require irrigation. In 2002-03, 62.2% of the total barley area was under irrigation. Besides a pre-sowing irrigation for crop establishment, the crop also requires irrigation at 3 critical stages *viz.* active tillering (30-35 DAS), flag leaf (60-65 DAS) and milking stages (80-85 DAS).

Table 10. Revised recommendations of the fertilizer application in barley

Zone/State	Production conditions	N : P : K (Kg/ha)	
		Old	Revised
NHZ	Rainfed	20:20:0	40:20:20
NWPZ and NEPZ	Irrigated timely sown	40:20:0	60:30:20 (feed barley)
			90:40:20 (malt barley)
	Irrigated Late sown	40:20:0	60:30:20
	Rainfed	20:20:0	40:20:20
Dual purpose in plains and hills	Irrigated/ rainfed	-	75:30:20 (plains)
			60:30:20 (hills)

Under limited water resources, i.e. available for one irrigation only, it should be applied at active tillering stage. If water is available for two irrigations, crop should be irrigated at active tillering and flowering stages. In saline soils, frequent irrigations are given to dilute the impact of salts. Heavy irrigation in March should be avoided to prevent lodging. Hull-less barleys with 10-15 longer duration than hulled varieties require one additional irrigation at grain filling stage for proper grain filling and to overcome hot winds damage.

This holds true for malt barley also as this crop should not suffer from moisture stress at any stage. Fodder barley requires irrigation and top dressing of N immediately after first cut (60-65 DAS). Heavy irrigation should be avoided as it causes lodging, severe yellowing as well as reduction of tillering. Irrigation scheduling must be according to evapo-transpiration needs and as per growth stage. It is, however, very important that irrigation is not stopped too early to ensure an even ripening (Kharub and Chander, 2012).

Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity.

3.7 Tillage methods/ method of sowing: Different management practices influence the productivity, protein content and other quality parameters, which have direct bearing on the malt quality of barley grain. The agronomic practices for malt grade barley are altogether different from its grain crop. Tillage methods have a major influence on aeration, moisture and temperature of soil which in turn affect the yield and quality of crop. Under Agra, Durgapur, Hisar and Karnal condition, barley sown by different methods (flat, bed and FIRBS) resulted no difference in grain yield of malt barley (Anonymous, 2004). Methods of sowing failed to influence significantly the grain quality characters.

Barley grain yield and 1000-grain weight were higher in zero tillage as compared to conventional tillage (Anonymous 2006). Highest grain yield was recorded from ZT crop followed by CT and BP. Grain yield of ZT crop was 3.4 and 6.0% higher than CT and BP (Singh *et al.,* 2013). Maximum stirring number i.e. minimum a-amylase activity and diastatic power was obtained under BP. The highest malt recovery and yield was obtained with ZT followed by CT and BP. The highest grain hardness, husk and protein were observed in bed planted crop followed by conventionally tilled and zero tilled crop. However, the highest test weight, starch content and kernel plumpness was obtained in zero tilled crop followed by conventionally tilled and bed planted crop. The best method of sowing is with a seed drill or dropping seed with a Chonga attached to a deshi plough. Dropping seeds in open furrows behind a deshi plough and broadcasting are found to be inferior to line sowing with seed drill.

3.8 Weed management: Weeds have been prevailing on the earth ever since the man started domesticating/cultivating plants and animals around 10,000 B.C. Weeds have been recognized as a delinquent since then and the battle against weeds is a never ending one and often the costliest agronomic input for successful crop production. The reduction in productivity depends upon the type of weed flora and weed density (Balyan and Malik, 1989; Balyan *et al.*, 1991). Among weeds, grass weeds, particularly the Littleseed canary grass (*Phalaris minor* Retz.) and wild oat (*Avena ludoviciana* Dur.) are the most serious problems of wheat and barley under irrigated conditions (Balyan *et al.*, 1991; Singh *et al.*, 1995). Due to the strong competitiveness, these weeds can cause yield reduction in the range of 15 to 50% in barley (Gill and Brar, 1975).

The crop has early vigorous growth and by active tillering stage, it completely covers the soil resulting in smothering of weeds, but weeds can lower the yield significantly Irrigated barley with high fertilization usually suffers from severe weed competition. The major weeds are *Anagallis arvensis* (*Krishna neel*), *Avena fatua* (wild oat), *Chenopodium* *album* (*bathua*), *C. murale , Cirsium arvense* (*kateli*), *Melilotus alba* and *Melilotus indica* (*senji*), *Euphorbia heliscopia, Spergula arvensis, Convolvulus arvensis, Rumex dentatus, Asphodelus tenuifolius, Lathyrus aphaca, Vicia sativa, Phalaris minor and Avena ludoviciana*. Weeds usually pose greater problem in irrigated areas.

Plant height has a direct correlation with weed competition and yield loss; semi-dwarf and hull-less cultivars of barley were found less competitive than full height and hulled cultivars This is true for wheat also where grassy weeds (*Avena ludoviciana* and *Phalaris minor*) are more competitive than broadleaf weeds and tall cultivars compete better than dwarf ones (Balyan *et al.,* 1991, Singh, 2007). Under normal conditions, both broadleaf and grassy weeds infest the crop. Isoproturon and 2,4-D were the only herbicides recommended for weed control in barley; however, due to resistance to isoproturon in P. minor, this herbicide has limitations of use (Singh, 2007; Ram and Singh, 2009). Not all wheat hebicides are selective for barley (Singh and Punia, 2007).

Pinoxaden was found to provide effective control of grassy weeds in barley (Singh and Punia, 2007; Chhokar *et al.,* 2008). Singh and Punia in 2007 reported that Clodinafop and fenoxaprop inflicted 20 to 53 per cent and 28 to 40 per cent crop injury, respectively two weeks after treatment (WAT). Isoproturon and 2,4-D ester 1.0 kg/ha and tribenuron 30 g/ha suppressed the crop initially, but it was not significant and crop recovered. Atlantis (mesosulfuron+iodosulfuron) 10.8 to 21.6 g/ha resulted in 50 to 65 per cent injury 2 WAT; injury reduced to 36 per cent 8 WAT, but not at higher rate (67%). Similarly, Total (sulfosulfuron+metsulfuron) at 32 g/ha inflicted 65 and 45per cent injury 2 and 8 WAT, respectively. Pinoxaden was found to be most advantageous grass weed killer for barley without any crop damage; clodinafop and fenoxaprop injury, though disappeared after four weeks may not be desirable due to their inconsistent results against *Phalaris minor* in wheat under rice-wheat growing zones. Isoproturon and fenoxaprop can be used in barley as early post-emergence against grass weeds if there is no resistance to these herbicides in *P. minor*, whereas pinoxaden can be used against both *Avena ludoviciana* and *P. minor.*

Metsulfuron and carfentrazone can effectively be used for the control of broad leaf weeds in barley and as tank mix with grass herbicides for broad spectrum weed control. Carfentrazone has slight edge for the control of *Convolvulus arvensis, Rumex dentatus* and *Malva parviflora* compared to metsulfuron. On the other hand, carfentrazone efficacy was lower on *C. album*, *A. tenuifolius*, *L. aphaca* and *M. indica* compared to metsulfuron and provideds a choice to the grower to select broadleaf herbicides as per field infestation of important broadleaf weeds.

Chhokar *et al.* (2008) reported no toxicity on any of the 18 barley genotypes screened for their sensitivity to pinoxaden (30 and 60 g/ha). Pinoxaden @ 30 g/ ha effectively controlled isoproturon resistant P. minor in barley and provided 21.6per cent higher yield compared to isoproturon application. However, 2, 4-D used to control broadleaf weeds in wheat is less effective against some broadleaf weeds (Punia *et al.,* 2006).

Cropping systems: Owing to drought resistance and short duration, barley find place in several inter and sequential cropping systems. Under rainfed conditions, barley is inter or mixed cropped with pea, rajmash, chickpea, linseed etc. In crop rotations, it follows *kharif* cereals (rice, maize, pearlmillet, jowar), legumes (pigeonpea, cowpea, groundnut) and commercial crops (cotton, potato, sugarcane). In diara lands of eastern Uttar Pradesh, vegetable-barley rotation is followed. Under adequate irrigation, short duration pulse or fodder succeeds barley. Barley being a short duration crop, can be grown successfully after harvest of kharif crops. Some of the crop rotations are generally used.

Paddy-barley, Jawar-barley, Maize-barley, Cotton-barley, Bajra-barley, Groundnut-barley, Urd-barley, Guar-barley and Cowpea-barley. Barley is being grown in three distinct type of soil groups mainly sandy loam, loam and medium & heavy black soils. In sandy soils the crop is mainly grown as irrigated crops after Bajra, Guar, Til, Cotton and Groundnut crops. In loam soils barley is planted after Kharif pulses like Moong, Urd, Maize & Bajra. In medium to heavy soils barley is planted after Soybean, Urd, Groundnut, Maize, Jowar and Small Millets. In saline area, Barley is also planted after rice. If barley is grown in cereal -cereals rotation i.e. Maize–Barley, Jowar–Barley, Bajra–Barley, Rice–Barley. The nutrient removal is only from upper layer of soil i.e. 6" depth soil. If such cropping system is followed for longer period, it creates nutrient deficiency & nutrition imbalance. Due to nutrient removal from a particular zone with the soil depth 6", which ultimately results in poor yield of the cropping system.

Most economic cropping system in relation to barley still need to be worked out depending upon the agro-climatic condition. Directorate of Wheat Research, Karnal has initiated scientific work on introduction of barley after direct seeding of rice.

3.9 Dual purpose barley: It was found that barley crop can be given one cut (at 50-55 days after sowing in plains and 70-75 days after sowing in hills) for green forage and the regenerated crop can be utilized for grain purposes (Table 11). A new series of yield trials was initiated from 2003-04 crop season for dual-purpose barleys in plains and hills zones to identify suitable genotypes. Already released feed type varieties RD2035 and RD2552 have been found equally good to be used as dual purpose type. Two more new varieties (RD2715 for central zone and BHS380 for NH zone) have been released by CVRC as dual purpose barley as forage cum grain crop (Verma *et al.*, 2012).

Dual purpose barley have tremendous scope in the country. They have definite potential in the North India Gangetic Plains, Hills and even in central India. It fulfills the forage as well as grain requirement. The crop gives 200- 250 q/ha of green fodder in one cut after 55 days of sowing and than 30-35 q/ha of barley grain for feed purpose. Increased seed rate by 25 per cent helps in harvesting more green fodder per ha without reduction in grain yield. In NWPZ & NEPZ, one cut at 55 days after sowing is optimum because there is not much reduction in grain yield over cut at 40days. At the same time fodder gain was not enough to compensate the yield reduction at 70 days cut. In Hills, 70 days cut was optimum for green fodder and grain. Dual purpose trial under late sown (December sowing) conditions could not found feasible due to very less productivity of feed and fodder.

Table 11. Fodder and grain yield of different varieties in different agro-climatic conditions

Zone / Production conditions	Variety	Yield (q/ha)	
		Forage	Grain
NWPZ irrigated, timely sown	RD 2035	228	27.6
	RD 2552	216	27.7
NEPZ irrigated, timely sown	Azad	190	33.8
	RD 2552	233	34.7
CZ	RD 2715	160	27.7
NHZ rainfed, timely sown	HBL 276	52.8	12.0
	BHS 169	53.0	15.7

Barley for green forage and grain can be grown in semi arid and arid climatic conditions where no other green forage is available in winter months due to shortage of irrigation water or low rains. The new varieties have been developed zone wise for dual purpose barley. The time of cut for green fodder was optimized and cutting 55 days after sowing was found optimum in plains and 70 days in Hills (Table 12). Multi location experiments resulted that seed rate of 120 kg/ha and fertilizer dose of 75N:30P:20K kg/ha are optimum for dual purpose barley. Dual purpose barley provides nutrition rich green fodder for the livestock at the time of scarcity and at the same time also provides acceptable quality grain for human consumption.

On an average, 180-240 and 24-35 q/ha of green fodder and grains, respectively can be produced from dual purpose barley crop (Verma *et.al* 2008, Anon., 2010).

Table 12. Grain and forage productivity (mean of different varieties/ locations)

Cut/Uncut	Yield (q/ha)	
	Grain	Forage
Uncut	43.2	0.0
Cut 40 DAS	38.7	83.6
Cut 55 DAS	41.2	172.7
Cut 70 DAS	33.8	195.3

3.10 Intercropping/ mixed cropping in barley: Prasad *et al.* (1988) reported that wheat as well as barley produced significantly longer and more ears/m and higher grain yield in mixed stands than in their pure stands. The 2 : 1 wheat : barley mixed stand gave the highest grain yield; 35 % relative yield advantage over mid-monoculture yield. The 1 : 1 seed blend mixture was inferior to 1 : 1 (Wheat : barley row ratio) mixed stand. Anonymous in 2013 reported that maximum net profit was realized with intercropping of barley and mustard (6:1).

3.11 Conservation agriculture: There appears to be no alternative but to increase agricultural productivity (*i.e.* crop yield per unit area) and the associated total and individual factor productivities (*i.e.* biological output per unit of total production input, and output per unit of individual factors of production such as energy, nutrients, water, labour, land and capital) to meet the global food, feed, fibre and bio-energy demand and to alleviate hunger and poverty. However, until now, agricultural intensification from intensive tillage-based production systems generally had a negative effect on the quality of many of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature. Land degradation in the country is posing a big threat to the natural resources, resulting in almost 5 billion tons soil and 6 million tons of nutrient loss every year. This degradation of the land resource base has caused crop yields and factor productivities to decline and has forced farmers, scientists and development stakeholders to search for an alternative paradigm that is ecologically sustainable as well as profitable. Another challenge for agriculture is its environmental foot print and climate change. Agriculture is responsible for about 30% of the total greenhouse gas emissions of CO_2, N_2O and CH_4 while being directly affected by the consequences of a changing climate. India and South Asian countries are dependent on agriculture for livelihoods of 60% of their population and the emergence of CA and other resource conserving technologies may be the key to sustaining and increasing production in the future. These new management systems will hopefully reverse the degradation of soils that has been occurring over the past 30 years and help to promote improved soil health, the key basis for sustainable production. This indicates the scope for making further effort improving yield level feed & fodder type barley in India.

3.12 Farmers participatory research: Increase of the area under barley crop will depend on income generated through this crop. Farmers participatory research can be an useful tool to develop farmers friendly technology with their close association. DWR, Karnal has initiated work on this aspect. The advance production technology to reduce cost of cultivation and to increase productivity are demonstrated on farmers' field. Field days and kisan gosties are held. Any drawback experienced in the technology is removed with fruitful discussion with the farmers. Improved technology is with the farmers with in a short span.

3.13 Public private partnership: India's beer consumption rate is growing at a robust 10 percent each year. This growth has driven demand for malting barley–a key ingredient in beer–to new heights. However, the majority of the 1.5 million tons of barley produced each year in India is feed grade: ideal for cattle but not for malting. Because this lower-quality barley does not command a premium price in agricultural markets, farmers do not consider it a priority crop. Therefore, many farmers do not invest in government-certified seeds and other inputs and training that would help yield a higher-quality crop. As a result, beer manufacturers uses barley that is available, although lower-quality barley drives up the processing costs for brewers. Recently United breweries and SABMiller India realized that by contract farming, better quality barley to create better quality malt can be procured and it also reduced the production costs. The program provides rural smallholder farmers in one of India's main barley-growing regions with access to the seeds, agronomical advice, and the training they need to enhance the quality of their crops. Farmers participating in the program receive hands-on customized support from agricultural specialists who provide farmers with tips and information on barley cultivation, such as proper irrigation, fertilizer usage, and harvesting. They also have access to conveniently located "Progress through Partnership" centers where government-certified seeds, fertilizers, and pesticides can be purchased. Directorate of wheat, Karnal also took steps to promote PPP mode.

3.14 Diseases and insect pest management: Barley is exposed to various diseases and insect pests responsible for heavy reduction in yield and quality. Though barley is attacked by many pathogens but few are economically important in India, which need attention through resistance breeding or chemical control. In India, stripe rust / yellow rust (*Puccinia striiformis f.sp. hordeii)* and leaf rust/ brown rust (*Puccinia hordei)* are major problems in NWPZ, while in NEPZ leaf rust and leaf blights are common. In NH Zone, stripe rust and powdery mildew are serious problems. In recent years, stripe rust has become the most damaging cereal rust in cool climate across international locations (Yadav, 2003). Barley stripe rust has the potential to greatly affect the barley industry in India due to the races with shorter life cycles, capable of producing more urediniospores and adapted to warm temperature. Stripe rust appears early in season that other two rusts. Symptoms include yellow orange pustules develop on leaves and eventually grow together forming stripes. The orange pustules contain spores that re-infect barley. Losses to stem rust / black rust (*Puccinia graminis tritici*) in barley have been very rare in many areas because the disease occurs in late season. Leaf rust develops rapidly between 15 and 22°C in the presence of free moisture.

During earlier days, the *Helmithosporium* leaf blights were considered as a minor disease as most of barley was under rainfed cultivation in dry areas, but due to change in climate and cropping patterns and adoption of new technologies the disease levels of leaf blight have increased. The spot blotch (*Bipolaris sorokiniana)* is gaining importance in regions where the day temperature increases during March. Initial leaf infections in the field result from airborne conidia produced either on wild grasses or on plant residue in or above the soil. Extended periods of warm of 20°c (>16hrs), moist weather are conducive to epidemic development. Yield losses of 10-20% may occur when environmental conditions are favourable for 1-2 weeks after plants have headed; losses may be as high as 20-30% when favourable conditions persist for 3-4 weeks (Singh, 2004).

In case of malt barley cultivation, application of more fertilizers under irrigated condition results in more foliage growth favoring build up of pathogens. In late sown barley, the vegetative stage coincides with warm and humid conditions during February and March, which provides good spread of blights. In recent years, leaf blights assumed an important yield limiting factor in barley cultivation causing very heavy losses. The net blotch (*Pyrenophora teres)* is also recorded in NEPZ occasionally. Severe infection kills leaves prematurely and mainly causes reduced seed weight. It may also reduce number of ears and number of grains per ear. Yield reductions of 20 to 30 per cent can occur and grain quality may also be affected. Powdery mildew (*Erysiphe graminis f. sp. Hordei)* development is optimal at temperatures between 15 and 22°C and is markedly retarded above 25°C. Barley is most susceptible during periods of rapid growth. Dense stands of susceptible cultivars, heavy nitrogen fertilization, high humidity and low temperatures favours disease development.

The loose smut (*Ustilago tritici)* infected heads emerge as a mass of dark brown powdery spores replacing the entire head of plants with little development of floral bracts and awns. Smutted heads often emerge earlier than healthy heads. Spores are dislodged and scattered by wind when the delicate membranes surrounding them break. The pathogen survives from one season to the next only as dormant mycelium within the embryo of infected barley seed and the seed treatment with systemic fungicide Carboxin eradicates the pathogen. The covered smut (*Ustilago hordei)* infected heads remain intact until harvest and the disease is externally seed borne.

Among insect pests, barley foliar aphid (*Rhopalosiphum maydis)* can cause damage early in the season and yield loss through direct feeding damage. Heavy infestations can cause a reduction of the number of grains per ears and thus a noticeable reduction of the yield. Usually found on the lower leaves, but if numbers increase they may spread all over the plant. If conditions are suitable, aphid populations can build up rapidly and cause direct injury to plants. Foliar sprays with Confidor @ 20 g a.i./ ha at the appearance of foliar aphids and later at 15 days intervals till physiological maturity is very effective. The cereal cyst nematode (CCN) causes small swellings along the roots, from which many small roots will develop and CCN affected plants become stunted occurring in patches. Root systems are shortened and development retarded..

Under AICW&BIP, barley entries are screened under various nurseries viz., Initial Barley Disease Screening Nursery (IBDSN), National Barley Disease Screening Nursery (NBDSN) and Elite Barley Disease Screening Nursery (EBDSN) respectively) for resistance against various diseases, aphid and CCN in different cooperating centers (Selvakumar *et al*., 2013). Presently, there are 14 centres involved in disease/ pest evaluation under AICW&BIP representing all barley growing zones. Each centre has specific responsibility for screening the different nurseries under barley network. Experiments on chemical control of leaf and stripe rusts and blight have also been conducted at various locations to evaluate various fungicides for management of diseases.

3.15 Pathotypes analysis and seedling resistance test: DWR regional station at Flowerdale is responsible for maintenance and regular supply of pathotypes of three rusts of barley in addition to identification/ pathotyping of races from samples collected during the crop seasons across the country. In stripe rust, there are five pathotypes available viz., M (1S0), G (4S0), 24 (0S0-1), Q (5S0) and 57 (0S0) and all NBDSN & EBDSN entries are being screened for SRT with these pathotypes individually. In case of leaf rust, pathotypes H1, H2, H3, H4 and H5 are being maintained and new entries are being tested against the mixture for SRT analysis. For stem rust, five pathotypes viz., 11 (79G31), 40A (62G29), 117-6 (37G19), 122 (7G11) and 21A-2 (75G5) are available but the entries are going to be screened with mixtures of pathotypes. These SRT screening arrangements have being made in order of relative importance of the three rusts in barley.

In general, use of resistant varieties which are now available with minimum number of sprays of chemicals is suggested for management of barley disease as it would be more economical. Singh *et al.* (2010) identified an IPM module for management of barley diseases and insect pests. Under AICW&BIP, seed treatment with Vitavax Power @ 3g/kg of seed followed by seed treatment with Gaucho @ 0.06 g a.i./kg of seed at sowing followed by foliar sprays of Tilt (25 EC) @ 0.1% at the appearance of rusts and foliar blight and later at 15 days intervals in case if need arise till physiological maturity and Foliar sprays of Confidor @ 20 g a.i./ ha is recommended at the appearance of foliar aphids and later at 15 days intervals till physiological maturity.

4. Future challenges in barley production

4.1 Area constraints: Although barley area in India has more or less stabilized nearly 650- 700 thousand ha over last decade after substantial decline from 3.5 m ha during seventies. But still the challenge remains to sustain this level and to make further improvement in area to meet the increasing demand for industrial utilization, by making available high yielding better quality varieties. Also there will be increasing demand for feed and forage type barley varieties especially in the era of climate change, where water availability will become a limiting factor for growing more water requiring crops.

4.2 Demand for quality raw material for malting: In India barley is now becoming more and more important as commercial crop for industrial raw materials for malting and brewing. Although the proportion in malting utilization is less at present but it is expected to increase with changing scenario in south-east Asia with respect to rapid growth for beer and other malt based product consumption. The concept of "contract farming" has become a reality now in states like Punjab, Haryana and Rajasthan, where new two row malt type cultivars are being cultivated / promoted by brewing industry, with premium prices for quality. Improvement in yield levels in such two row cultivars has made them *at par* with traditional six-row feed barley cultivars, under optimally managed conditions. However, still there is a great need of popularization of such cultivars through joint efforts of industry as well as state department functionaries. The production system for such new cultivars through joint efforts shall boost the malt barley cultivation through increased availability of quality seed.

For development of improved cultivars for malting and food purposes, there is a need to identify sources for grain quality traits for use in breeding programme. Further the biochemical and molecular basis of malting and nutritional quality of barley under subtropical climate of India needs to be investigated for the use of breeders/ biotechnologists.

4.3 Increasing area under problematic soils: The most commonly observed fact is that farmer will always prefer to grow wheat in resource rich conditions and push barley to problematic soils with minimum input. There is a big challenge to make yield breakthrough in barley varieties for abiotic stresses like salinity, drought and heat tolerance for near future under the changing climatic conditions. The new initiatives can be taken in this direction by evaluation of germplasm collections to discover better sources of tolerance to such stresses. These confirmed sources of abiotic stresses will be ready for use in the future breeding programmes to address these important issues.

4.4 Supplementing the demand for feed/forage : It is visualized that barley is going to be an important crop in semi-arid region for supplementing the grain feed as well as for green forage, due to its limited water requirement and faster growth at early stages. The progress has been made in this regard through association of AICRP-FC, Jhansi by developing/identifying dual purpose barley varieties for such areas. However, still there is a need for better biomass and nutritional quality of the barley forage. Germplasm evaluation for such traits is the need of the hour to identify good sources for further improvement in this field.

4.5 Resource management in changing climatic scenario: The most important aspect of study in barley agronomy still remains to be covered is the detailed nutrient and moisture utilization pattern under different situations supported by physiologic and economic studies. No doubt, barley's input requirement is low, but how to raise the input efficiency in crop production is another challenge. Plant type of two-row fertilizer responsive malt barley varieties has widen the scope of raising the production potential of this crop, through agronomic research in near future. Agronomic research on malt barley, hulless barley, feed and forage barley, barley for saline lands needs to be undertaken on priority. There is need to develop lodging resistant varieties as barley is prone to lodging under high input application. There is also a need for taking up the experiments on furrow irrigated raised bed (FIRB) system in barley, especially with new plant type varieties to avoid lodging, as well as for faster irrigation, which can be of much use in larger seed production plots in particular.

4.6 Disease / pest management in changing cultural practices and climates: Incorporation of varietal resistance for prevailing disease has been the main objective of the barley improvement programme under barley network. The joint efforts of the breeders and pathologists have resulted in development of resistant / tolerant varieties. The two major aspects for resistance breeding were rusts and leaf blights. The relative emphasis may differ according to area of cultivation (zones) and production conditions in years to come. In case of northern hills zone (NHZ) resistance to yellow rust is and will continue to be the primary requirement for new varieties, since it will cut down the inoculum load for plains. In lower hills again leaf rust is very important and resistance is always essential. In addition powdery mildew is another important disease needs to be focused in coming future. In case of north western plains zone (NWPZ) resistance to both yellow and brown rusts are critical for new varieties. Recently with introduction of irrigated barley cultivation in NWPZ, the levels of leaf spot in various parts has increased except the semi arid belt of Rajasthan. The spread of inocula of leaf blights through seed from eastern areas has further complicated the situation. In north eastern plains zone (NEPZ) leaf rusts, spot and net blotch are major problems in warmer and humid climate. The changing climatic conditions are likely to increase blight diseases on much larger scale. Since the inocula can survive through crop residue in soil, this can further complicate the situation. Therefore we may have to follow more strict norms of field resistance in new cultivars to avoid disease build up and spread.

4.7 New stable sources of resistance: Though the available barley varieties are showing some amount of resistance against all three rusts but unfortunately they lack good resistance to leaf blight. Thus there is a need for identifying sources of blight resistance from germplasm by screening with our leaf blight isolates. The sources of resistance from wild species and grasses have to be searched for incorporating the same into cultivated barley.

Barley cultivation in India was facing stiff challenges in terms of area with wheat in winter season, as the crop was considered less remunerative due to less MSP and market price, resulting in drastic reduction in area and production. Recent changes in situation triggered by the industrial demand for malting and brewing has given it a new lease of life and it is becoming a commercial crop.

These developments have resulted in initiation of contract farming by industry on larger scale in Punjab, Haryana and Rajasthan. The new challenges for production and protection technologies in addition to the genetic improvement are being envisaged because of its shift to optimally managed conditions. We may also have to look for lodging resistance through new plant type in addition to the requirements of genetic resistance to biotic and abiotic stresses and better grain quality. The changing climate and depleting natural resources are general problems of crop production and barley cultivation can be a good option to mitigate with such challenges.

References

1. Aberg E. 1940. The taxonomy and phylogeny of *Hordeum* L. Sect. *Cerelia.* Ands. with special reference to Tibetan barleys. *Symbolae Boanica. Uppsala* **4**:1–156.
2. Agrawal SK and NR Arora. 1980. Effect of sowing dates and seed rates on growth and yield of barley varieties. *Indian Journal of Agronomy* **25(1):** 65-70.
3. Akar T, M Avci and F Dusunceli. 2004. Barley: Post-harvest operations. *http://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_BARLEY.pdf.*
4. Anonymous. 2004. *All India coordinated wheat and barley improvement project, Progress report,* Directorate of Wheat Research, Karnal, India, pp. 4-11.
5. Anonymous. 2006. *Annual progress report,* Department of agronomy PAU, Ludhiana.
6. Anonymous. 2010. *Annual progress report of barley network* 2009-11. Directorate of Wheat Research, Karnal, India.
7. Anonymous. 2013. *Progress report of All India coordinated wheat and barley improvement Project* 2012-13. Vol. VI. Barley Network. Directorate of Wheat Research, Karnal, India.
8. Asana RD and VR Kale. 1965. A study of salt tolerance of four varieties of wheat. *Indian Journal of Plant Physiology* **8**:5-22.
9. Baik BK and SE Ullrich. 2008. Barley for food: Characteristics, improvement, and renewed interest. *Journal of Cereal Science* **48**: 233–42.
10. Balyan RS and RK Malik. 1989. Influence of nitrogen on competition of wild canary grass (*Phalaris minor* Ritz.) in wheat (*Triticum aestivum* L.). *Pestology* **13**:5-6.
11. Balyan RS, RK Malik, RS Panwar and S Singh. 1991. Competitive ability of winter wheat cultivars with wild oat (*Avena ludoviciana*). *Weed Science* **39**:154- 158.
12. Behall KM, DJ Scholfield and J Hallfrisch. 2004. Diets containing barley significantly reduce lipids in mildly hypercholesterolemic men and women. *American Journal of Clinical Nutrition* **80**: 1185-93.
13. Bernstein L and HE Hayward. 1958. Physiology of salt tolerance. *Annual Review Plant Physiology* **9:**25-46.
14. Bhatty RS. 1999a. β-glucan and flour yield of hulless barley. *Cereal Chemistry* **76**:314-315.
15. Bhatty RS. 1999b. The potential of hulless barley. *Cereal Chemistry* **76**:583-599.
16. Braaten JT, Wood PJ, Scott FW, Riedel KD, Poste LM and Collins MW. 1991. Oat gum lowers glucose and insulin after an oral glucose dose. *American Journal of Clinical Nutrition* **53:** 1425-30.
17. Cavallero A, Empilli S, Brighenti F and Stanco AM. 2002. High $(1\rightarrow3,1\rightarrow4)$-β-Glucan barley fractions in bread making and their effects on human glycemic response. *Journal of Cereal Science* **36**: 59-66.
18. Chhokar RS, RK Sharma and RPS Verma.2008. Pinoxaden for controlling grass weeds in wheat and barley. *Indian Journal of Weed Science* **40 (1&2)**:41-46.
19. Choudhary Shripal, LR Yadav, SS Yadav, OP Sharma, GL Keshwa. 2013. Integrated use of fertilizers and manures with foliar application of iron in barley (*Hordeum vulgare*). *Indian Journal of Agronomy* **58**(3):363-367.
20. Fadel JG, RK Newman, CW Newman and AE Barnes. 1987. Hypocholesterolemic effects of b-glucans in different barley diets fed to broiler chicks. *Nutrition Reports International* **35**:1049-58.
21. FAO. 2002. Food barley improvement. (*http://www.fao.org/ag/AGP/AGPC/doc/field/other/ act.htm*).
22. Gill HS and LS Brar. 1975. Importance of herbicides in the agriculture of Punjab and Haryana. *Pesticides* **9**:20-24.
23. Goyal A, S Pradhan and VK Bajaj. 2012. Screening of salt tolerance in different varieties of *Hordeum vulgare. World Applied Sciences Journal* **16 (7):** 926-932.
24. Gupta PK. 2013. Barley breeding. *Highlights of Wheat and Barley Research*: 67-71.
25. Harlan JR. 1976. Barley. In Simmonds NW (ed.) *Evolution of crop plant.* Longman, London pp. 93-98.
26. Hassan NAK, JV Drew, D Knudsen and RA Olson. 1970. Influence of soil salinity on production on dry matter and uptake and distribution of nutrients in barley and corn: II Corn (*Zea mays*). *Agronomy Journal* **62**:46-48.
27. Hooda RS and GS Kalra. 1981. Effect of nitrogen on dry matter production and uptake of nitrogen by barley under irrigated and rainfed conditions. *Agriculture and Science Digest* **1:**149-151.
28. Israelsen KR, CV Ransom and BL Waldron. 2014. Salinity tolerance of foxtail barley. *Weed Science* **59 (4):** 500-505.
29. Jain N, R Malik, V Pande, R Kumar and RPS Verma. 2013. Identification of genomic regions associated with leaf blight resistance in barley. *International Journal of Advance Biotechnology and Research* **4**(4):553-559.
30. Jain N, R Malik, R Selvakumar, R Kumar, V Pande and RPS Verma. 2014. Screening of barley germplasm for leaf blight (*Bipolaris sorokiniana)* resistance. *Indian Journal of Agricultural Research* **48**(1):67-71.

31. Jaiswal SK, SP Pandey, S Sharma, R Prasad, LC Prasad, RPS Verma and AK Joshi. 2010. Diversity in Indian barley (*Hordeum vulgare*) cultivars and identification of genotype-specific fingerprints using microsatellite markers. *Journal of Genetics* **89**: 46-54.

32. Kharub AS and S Chander. 2012. Production technology for malt barley. *A compendium of lectures on "Malting quality improvement in Barley, Sorghum & Corn. January 28-February 6, 2012.* DWR Compendium No. **5**:56-62.

33. Kumar D, S Narwal, RPS Verma, AS Kharab, V Kumar and I Sharma. 2012. Genotypic variability in β-glucan and crude protein contents in barley genotypes. *Journal of Wheat Research* **4(2):**61-68.

34. Kumar V, Kumar R, Verma RPS, Verma A and Sharma I. 2013. Recent trends in breeder seed production of barley (*Hordeum vulgare*) in India. *Indian Journal of Agricultural Sciences* **83(5)**: 576-578.

35. Malik R, R Kumar, RPS Verma**,** V Rana, A Verma and I Sharma. 2012. Molecular markers identified for corn leaf aphid *(Rhopalosiphum maidis)* resistance in barley using bulk segregants analysis. *Crop Improvement*, **Special issue**: 25-26.

36. Misra BN, BS Verma and KN Singh. 1982. N, P and K requirements of two-row barley. *Indian Journal of Agricultural Sciences* **52**:669-673.

37. Newman RK, SE Lewis, CW Newman, RJ Boik and RT Ramage. 1989. Hypocholesterolemic effect of barley foods on healthy men. *Nutrition Reports International* **39:**749-760.

38. Pal D, S Kumar and RPS Verma. 2012. Pusa Losar (BHS 380) – the first dual-purpose barley variety for northern hills of India. *Indian Journal of Agricultural Sciences* **82**: 164-165.

39. Pins JJ and H Kaur. 2006. A review of the effects of barley β-glucan on cardiovascular and diabetic risk. *Cereal Foods World* **51**: 8-11.

40. Pourkheirandish M and T Komatsuda. 2007. The importance of barley genetics and demonstration in a global perspectives. *Annals of Botany* **100**: 999–1008.

41. Prasad R, S Singh, SN Sharma and CP Singh (1988). Studies on pure and mixed stands of wheat and barley under dryland agriculture conditions. *Journal of Agronomy and Crop Science* **160(5):**335-338.

42. Punia SS, S Singh. RK Malik, D Yadav. 2006. Studies on herbicide mixtures in wheat. *Indian Journal of Weed Science* **38**:1–4.

43. Qureshi AA, WC Burger, DM Peterson and CE Elson. 1986. The structure of an inhibitor of cholesterol biosynthesis isolated from barley. *Journal of Biological Chemistry* **261**:10544–550.

44. Qureshi AA, N Qureshi, JJK Wright, Z Shen, G Kramer, A Gapor, YH Chong, G Dewitt, ASH Ong, DM Peterson and BA Bradlow. 1991. Lowering serum cholesterol in hypercholesterolemic humans by tocotrienols (palmvitee). *American Journal of Clinical Nutrition* **53**: 1021-26.

45. Ram S and RPS Verma. 1998. Barley storage proteins for varietal identification and malting quality. *Indian Wheat Newsletter* **4(2)**: 5.

46. Ram S and RPS Verma. 2002. β-Glucan content and wort filtration rate of Indian barleys. *Cereal Research Communications* **30**: 181-186.

47. Ram H and A Singh. 2009. Studies on efficacy of tank mix herbicides for the control of weeds in irrigated barley (*Hordeum vulgare* L.). *Indian Journal of Weed Science* **41**:167-171.

48. Sarkar B, RPS Verma and B Mishra. 2008. Genetic diversity for malting quality in barley (*Hordeum vulgare* L.). *Indian Journal of Genetics* **68 (2)**: 163-170.

49. Selvakumar R, RPS Verma, SC Bhardwaj and I Sharma. 2013. Sources of rust resistance in Indian barley genotypes. *BGRI 2012 Technical Workshop, September 1-4, Beijing, China.* p.112

50. Singh DP. 2004. Losses due to leaf spots caused by *Bipolaris sorokiniana* and net blotches by *Helminthosporium teres* in barley and their effective management. *Plant Disease Research* **19(2):** 173-175.

51. Singh S. 2007. Role of management practices on control of isoproturon-resistant littleseed canarygrass (*Phalaris minor*) in India. *Weed Technology* **21**: 339-346.

52. Singh S and SS Punia. 2007. Sensitivity of barley (*Hordeum vulgare*) to herbicides of different modes of action. *Indian Journal of Weed Science* **39(3&4)**:205-210.

53. Singh J, AS Malik and J Singh. 1989. Response of late sown wheat barley and lentil to irrigation levels. *Haryana Journal of Agronomy* **5(1):**52-56.

54. Singh S, RK Malik, RS Balyan and S Singh. 1995. Distribution of weed flora of wheat in Haryana. *Indian Journal of Weed Science* **27**:114-121.

55. Singh DP, R Singh, RPS Verma, B Sarkar and J Shoran. 2005. Status of resistance to yellow rust and leaf blight in popular varieties and sources of combined resistance to both diseases in barley. *Plant Disease Research* **20**:87.

56. Singh DP, KS Babu, SK Mann, SS Karwasra, IK Kalappanavar, RN Singh, AK Singh and SP Singh. 2010. Integrated pest management in Barley (*Hordeum Vulgare*). *Indian Journal of Agricultural Sciences,* **80**: 437-442.

57. Singh J, SS Mahal and A Singh. 2013. Yield and quality of malt barley (*Hordeum vulgare*) as influenced by irrigation, nitrogen and methods of sowing. *Indian Journal of Agronomy* **58 (3):** 354-362

58. Tyagi K, R Nandan, L Prasad, AK Joshi and R Chand. 2008. Inheritance and identification of molecular markers associated with leaf blight (*Cochliobolus sativus L.*) resistance through microsatellites analysis in barley. *Genetics and Molecular Biology* **31** (3):734-742.

59. Vangool D and L Vernon. 2006. Potential impacts of climate change on agricultural land use suitability: Barley. Department of Agriculture, Western Australia. *Report No*: 302.

60. Varshney RK, P Langridge and A Graner. 2007. Application of genomics to molecular breeding of wheat and barley. *Advances in Genetics* **58**: 121-55.

61. Verma RS and RR Singh. 1989. Dry matter accumulation pattern of malt-barleys (*Hordeum distichum* L.) as influenced by seeding rates and nitrogen fertilization. *Indian Journal of Agricultural Sciences* **24**:109-116.

62. Verma RPS and S Nagarajan. 1996. Environmental effects on malting quality of barley in India. In: Slinkard A, Scoles G and Rossangel B (eds.) *VII Int. Barley Genetics Symposium*, July 30-August 6, 1996. University of Saskatchewan, Saskatoon, Canada, pp. 44-46.

63. Verma RPS, RK Sharma and S Nagarajan. 2003. Influence of nitrogen and irrigation on malt and wort quality in barley. *Cereal Research Communications* **31**: 437-44.

64. Verma RPS, AS Kharub and B Mishra. 2008. Dual purpose barley for green fodder and grain in dry areas of India. Poster presented in *10th International Barley Genetics Symposium, Alexandria* during 5-10 April, 2008.

65. Verma RPS, AS Kharub, D Kumar, B Sarkar, R Selvakumar, R Singh, R Malik, R Kumar and I Sharma. 2011. Fifty years of coordinated barley research in India. Directorate of Wheat Research, Karnal-132001. *Research Bulletin No.* **27:** 46.

66. Verma RPS, V Kumar, B Sarkar, AS Kharub, D Kumar, R Selvakumar, R Malik and I Sharma. 2012. Barley cultivars released in India: Names, parentages, origins and adaptations. Directorate of Wheat Research, Karnal, India. *Research Bulletin No.* **29:** 26.

67. Verma RPS, RK Sharma and B Mishra. 2005. Future of barley for malt, feed and fodder in India. Directorate of Wheat Research, Karnal -132001. *Technical Bulletin No.* **9**, p 28.

68. Verma RPS, B Sarkar, R Gupta, and A Varma. 2008. Breeding barley for malting quality improvement in India. *Cereal Research Communications* **36**(1):135-145.

69. Yadav R. 2003. A combined source of resistance against corn leaf aphid and yellow rust in barley. *International Journal of Pest* **49**:293–296.