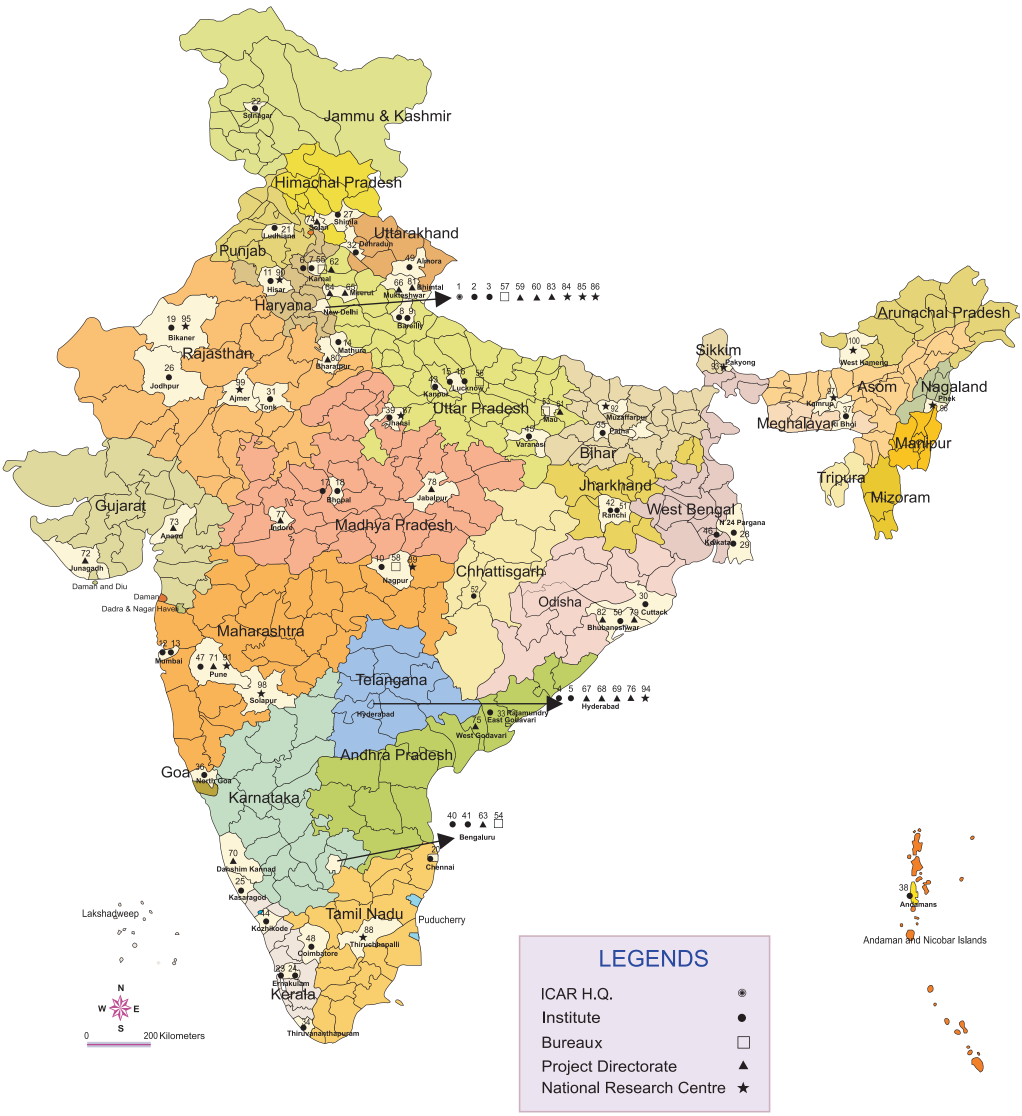
Vision 2050

Indian Institute of Wheat and Barley Research

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



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Vision 2050

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संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो–तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट–परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान–जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन–2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

राधा मोहन सिंह

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Indian Institute of Wheat and Barley Research (IIWBR), Karnal has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years ahead, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

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Preface

India is a privileged country to attain and retain the status of second largest producer of wheat in the world and register a historic production of 95.85 million tonnes during 2013-14 with a growth of around 3% over the previous year and productivity of 3.15 t/ha. The target for wheat in India is projected around 140 million tonnes by 2050 considering its growing demand for consumption and trade due to burgeoning population. There is also a need to keep the wheat price and supply affordable for the large Indian populace below the poverty line.

With changing food habits and availability of better quality products in the market at accessible prices, the choice before the consumer increases and so does the level of consumption. This will promote the growth of food industries and the movement of wheat in the value addition chain. Indian farming is witnessing a total change and crop diversification through vegetable, pulses, oilseeds and fruit farming is becoming essential since these commodities have greater consumer demand and better price. Therefore, development of modern genotypes suitable for intensive agriculture is going to become a prime concern. Exploiting hybrid vigour, innovations through molecular tools and proper intelligence system for marketing and pest risks are some of the possible approaches to further increase the yield potential of wheat. It is essential that the factor productivity be improved and needful steps should be taken to reverse the deteriorating soil health, nutrient deficiencies, and falling C:N ratio. Time is ripe for developing malt barley matching international standards as barley production is catching up and is slated to become an important commercial crop in years to come. The present perspective plan for wheat and barley research in the country has highlighted the emerging issues, challenges and opportunities.

The ever increasing population of the Indian sub-continent has necessitated the well-thought and planned efforts to face the challenges of increased food demand with diminishing resources. Keeping this in mind, the formulation of perspective plan with a visionary approach for next four decades became inevitable. The vision document highlights historical landmarks, recent achievements, concepts for new research projects to develop and promote innovative and need based scientific technologies to cater the demand of continuously evolving social and economic arenas in the background of the explicit analysis of our opportunities and future working environment.

The All India Coordinated Project on Wheat and Barley has a number of centres in diverse agro ecological areas. The project has active multidisciplinary research centers housed in the various State Agricultural Universities (SAUs) and these centers get financial support to meet 75 % of the annual expenditure from the union government and the remaining from their own states. This cost sharing brought about a cohesive, purposeful and result oriented network to develop varieties and appropriate production and protection technologies. The present document is focused on a research program which envisages developing wheat varieties with a productivity of 7 t/ha in NWPZ, the wheat bowl of India and 5 t/ha in Central & Peninsular zones in a scenario of no further expansion of area under wheat cultivation. The superior wheat varieties should have tolerance to rusts, Karnal bunt, foliar blights as well as abiotic stresses of salinity, terminal heat and water logging.

The research work on barley has geared to develop better malt type barley for industrial application in brewing, distillation and high energy foods/drinks. Due to increased industrial demand the barley crop will be known as cash crop in the coming years. Some industries are adopting contractual farming and giving premium price for better malt producing varieties. Besides this, barley is also an important crop for feed and fodder purposes and therefore emphasis will be given to develop dual purpose varieties.

The Indian Council of Agricultural Research (ICAR) having taken into cognizance the previous efforts, struggle to increase the productivity, concern to augment and sustain what has been achieved, issued the directives and guidance to develop the vision for research mandate to be adopted in the forthcoming decades.

It had been a pleasure opportunity to take up the task of developing the present document that will serve as a guideline for attaining the wheat and barley requirements by 2050. As a Director, I extend my sincere thanks to all the scientists of ICAR-IIWBR and coordination programme for their valuable inputs to bring this document in the present shape. I acknowledge and appreciate the contributions from Dr. BS Tyagi, ICAR-IIWBR; Dr. NS Bains, PAU, Ludhiana and Dr. Sendhil R, ICAR-IIWBR. I am sincerely thankful to Dr. S. Ayyappan, Secretary, DARE and DG, ICAR for his enumerable guidance imparted during the process of drafting this document. I take a privilege to acknowledge the contributions of Dr. Swapan K. Datta, Former DDG (CS) and Dr. J.S. Sandhu, DDG (CS) for giving valuable advice in finalizing this document. Thanks are also due to Dr.RP Dua, Former ADG (FFC) and Dr. Dinesh Kumar, Principal Scientist (ICAR) for their critical input and motivation.

(Indu Sharma)
Director
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Context

Wheat is an essential commodity for human civilization and is planted annually in an area of around 220 million hectares (m ha) across the world. Wheat provides 21% of the food calories and 20% of the protein for more than 4.5 billion people in 94 countries. In India wheat is the second most important cereal crop and plays a key role in food and nutritional security. Wheat research in India began in a systematic way more than a hundred years ago. The coordinated system of multi-location research to address the needs of different agro-ecological zones in wheat has been in operation for more than fifty years now. During this period India witnessed the dramatic successes of the green revolution and has been able to rise from a deficit state to a self-sufficient one going on to have surplus production at times. India harvested a record 95.85 million tonnes (mt) of wheat during the crop year 2013-14 with a productivity level of 3146kg/ha. This is indeed an important and reassuring milestone. Future however is an uncharted territory, particularly with the fast pace of change we are witnessing in the social, economic and technological arenas of the nation and the world. Serious challenges continue to be posed by the need to feed a large and growing population and have been accentuated further by natural resource crunch and looming spectre of climate change. The identified challenges serve as cornerstones of the 2050 vision. Besides obvious challenges, a basic robustness of the wheat research and production system is envisaged to tide over unforeseen circumstances and exigencies. This exercise however needs to be bench marked with the present role and status of the organisation as discussed briefly below.

ICAR-IIWBR: Background and Progress

The All India Coordinated Wheat Improvement Project (AICWIP) began its operations in 1964 at IARI, New Delhi and was elevated to the status of Directorate of Wheat Research (DWR) in 1978. The Directorate moved to the present location at Karnal in 1990, and with addition of Barley Network it was renamed as All India Coordinated Wheat and Barley Improvement Project (AICW&BIP). In 2014, the DWR was upgraded and renamed as Indian Institute of Wheat and Barley Research (IIWBR). Thirty one funded centres, located in different SAUs, support multidisciplinary research on wheat and barley under the coordinated project. Besides the funded centres, more than hundred voluntary centres in SAUs are actively engaged in evaluation of genotypes. In addition, some testing sites are also provided by State Agriculture Departments and a few NGOs. These locations have been identified in such a way that distinct agro-climatic zones of the country (six mega zones under wheat cultivation, Fig 1) are represented.

Fig. 1 Wheat Growing Zones of the Country

Crop varieties represent a pivotal component of agro-technological packages. Work under AICW&BIP has resulted in the release of 412 wheat varieties, tailored for specific growing situations in the six wheat zones of the country. Starting with the first semi-dwarf introductions like Lerma Rojo, Sonora 64 and their further selections like Chhoti Lerma, Kalyansona and Sonalika, the programme went on to release varieties which became extremely popular and occupied large acreage. These mega varieties include C 306, HD 2009, WL 711, UP 262, HUW 234, HD 2189, WH 147, Lok 1, HI 617 (Sujata), HD 2285, HD 2329, PBW 343, Raj 3765, PBW 502, HD 2733, DBW 17, PBW 550, GW 273, GW 322, GW 496 in bread wheat and Raj 1555, PBW 34, HI 8498, PDW 291 and PDW 233 in durum wheat. Many varieties such as NP 4, Kalyansona, Sonalika, Sharbati Sonora, WL 711, HD 1220, HD 1931 'SIB', HD 2009, HD 2172, UP 262 etc., developed under the project stepped beyond after well national boundaries to be grown by farmers in other countries as well, besides several others used in wheat improvement.

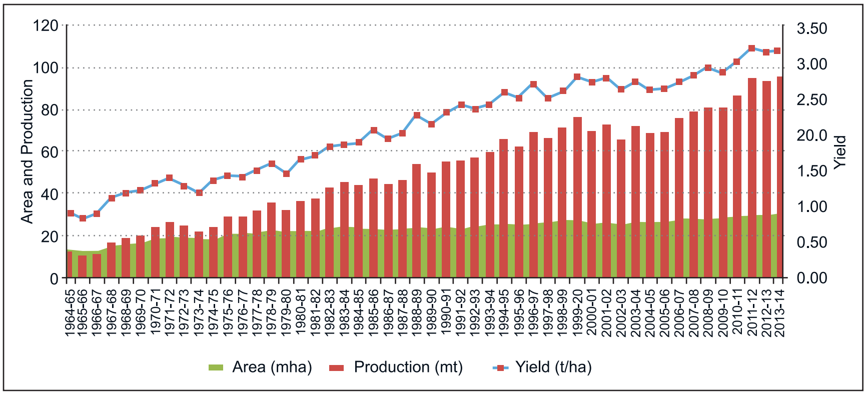

Fig. 2 Trends in area, production and yield for Indian wheat (1964-65 to 2013-14)

Looking more specifically at the production trend of last five years (Figure 3), one finds an unprecedented run of record productions culminating in the all-time high of 2013-14 (95.85 mt). The quantum jump of 2.34 mt (2.51%) registered in 2013-14 over the previous year is attributed to the marginal addition in wheat acreage (0.47mha) coupled with an increase in yield by 29 kg/ha. In the face of multiple challenges for further enhancing wheat production (detailed in next section), and burgeoning population growth, will it be possible to maintain this acceleration as we move to year 2050, and more importantly (in the context of this vision document), how?

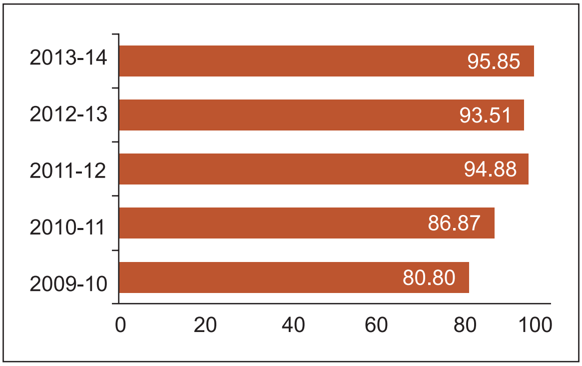

Fig. 3 Wheat production (mt) trend during the past five years

Barley

Barley is considered fourth largest cereal crop in the world with a share of seven per cent of the global cereal production. It uses range from malt and infant food to animal feed and fodder. It is predominantly grown as a food crop in the semi-arid regions of Africa, Middle East and Asia. In India barley presently occupies nearly 0.674 mha. The productivity of the crop is rising despite declining trend in area and production right from 1987-88 to 2013-14 (Figure 4).

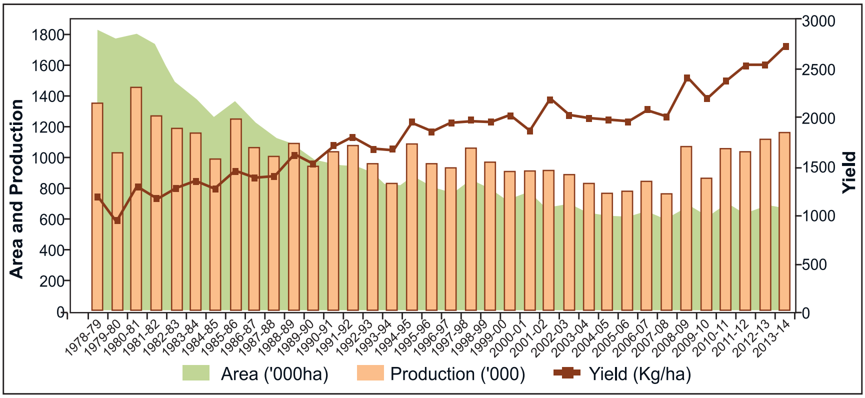

Fig. 4 Barley production in India (1987-88 to 2013-14)

The barley production registered a record 1.83mt during 2013-14 despite a fall in area by 3.11 per cent. However, productivity was all-time highest at 2718 kg/ha. Rajasthan leads in barley production and the top three states with respect to barley area, production and yield in 2013-14 are given in table 1.

Table 1 Top three states in area, production and yield of barley (2013-14)

Area ('000ha)	Production ('000t)	Yield (kg/ha)
Rajasthan (309)	Rajasthan (942)	Haryana (3923)
Uttar Pradesh (157)	Uttar Pradesh (450)	Punjab (3833)
Madhya Pradesh (87)	Haryana (153)	Rajasthan (3046)
India (673.50)	India (1830.65)	India (2718)

The barley component of AICW&BIP functions at seven funded centres with voluntary participation by some ICAR institutes and SAUs. So far, 92 varieties have been released for commercial cultivation and 15 genetic stocks registered with the NBPGR. The priority areas of research include development of barley for malt, feed and dual purpose. Traditionally, tall plant types were common in barley. The barley network programme successfully developed semi-dwarf, management responsive, lodging resistant cultivars with erect leaves, compact plant having thick stem and stiff straw. Varieties like BH 902, DWRUB 52, RD 2668, RD 2592, NDB 1173 and DWRB 73 are some examples for such plant type in malt and feed barley. Stripe rust and leaf blight are the major diseases of barley, although yellow and brown rust in NWPZ and brown rust and leaf spot are of importance in NEPZ. New high yielding varieties have resistance to such diseases. Resistance to CCN has been incorporated in some new cultivars. Varieties having good malting/ brewing qualities comparable to European malt barley cultivars have been developed. The recently released varieties DWRUB 52 and DWRB 73 (developed through hybridization of 2 row x 6 row types) hold promise as industrial barley with better yield, resistance and maturity duration as compared to earlier releases. Six row malt barley variety DWR UB 64 was the first one released for malt purpose.

The squeeze faced by barley as a traditional crop is in sharp contrast to its potential for industrial and nutraceutical use. In this regard, a significant shift is already in progress in barley research and development. Wheat in comparison is still tethered to its primary role of feeding the millions, but the context has undergone major widely acknowledged changes which have intensified in the last one decade. As with all successes, the green revolution fostered a powerful paradigm. The credence of this successful strategy continues to configure our thinking. Present ground reality and future projections however demand a new perspective, factoring in the fast pace of change and emergence of unprecedented challenges (taken up in the following section) to food security and sustainability. As early as 1969, Dr NE Borlaug predicted that reprieve provided by the green revolution is short lived (a few decades) and can only help us buy time to develop more sustainable systems for use of natural resources and managing population growth. In all probability this point of inflexion has now been reached. A wheat improvement paradigm with sustainability at its heart needs to be implemented. There in lies the rationale for a Vision 2050.

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Challenges

Increased demand for wheat: The current world population of 7.29 billion is projected to increase by almost one billion within the next 12 years, reaching 8.1 billion in 2025 and 9.6 billion in 2050 (UN report on World Population Prospects: The 2012 Revision). With such a great increase in global population comes the challenge of meeting global food demand. Global wheat utilization in 2014-15 has been estimated around 716 mt. If the demand growth rate were to remain constant, global wheat consumption would surpass 880 mt by 2050. This is about 23 per cent higher than the current level of production. While global demand can have implications for national wheat production, the trend in domestic requirement would surely be the guiding force for future research and policy regimes. As per the UN report, India's population is expected to surpass China's around 2028 when both countries reach 1.45 billion mark. While population of China is expected to decline beyond 2030, India's population will continue to grow, touching a peak 1.7 billion by 2050. Thus wheat production agenda will continue to address the population issue all the way to the chosen threshold of 2050. While population growth has been coped within earlier decades, the run up to 2050 becomes unprecedented in terms of absolute numbers involved, as well as the nature of threats to the carrying capacity of the system.

By 2050, more than 50% of Indian population, that is, about 900 million will live in cities. Thus, about 500 million will get added to the present urban population by 2050. Apart from pressure on land due to expanding cities, improved standard of living would also generate greater demand for wheat, either through enhanced consumption, or preference for wheat based products or more importantly as a result of shift towards meat based diets. The growth in consumption has already stayed ahead of population growth in the last 50 years (Table 2) indicating the role of above trends.

A widening of the food security net is anticipated under the new legislations or other such measures. As per the National Food Security Ordinance drafted recently, it is proposed that a rationed amount of wheat will be made available to 67 per cent of India's population at ₹ 2/ Kg. Such measures aim to reach out to disadvantaged sectors and address the serious issue of 'hunger amidst apparent self-sufficiency'. IFPRI's Global Hunger Index 2014, which takes into account undernourishment and child mortality, classifies the situation in India as 'serious'. As per HUNGaMA Survey 2011, 42% of children aged below 5 years in India are underweight, which is twice the figure for Sub-Saharan Africa. Thus, going by the health and nutritional status of the Indian population, the requirement for food remains far from adequately met even with judicious distribution of current production. Thus the twin issues of 'hidden demand' arising out of lack of purchasing power and 'hidden hunger' owing to nutritional inadequacy of available food are serious challenges which may not get properly represented in projections of future demand. Hunger is a blot on India's nationhood which our vision for wheat in 2050 will address with a well-planned strategy.

Table 2 Estimated growth (%) in production, per capita availability, consumption and population

Period	Cereals Production Growth			Growth in Per Capita Availability of Wheat	Consumption Growth of Wheat	Population Growth
	Rice	Wheat	Coarse Cereals			
1960-61 to 1969-70	1.19	6.82	1.51	2.80	4.98	2.15
1970-71 to 1979-80	1.90	4.31	1.11	1.42	3.75	2.38
1980-81 to 1989-90	3.62	3.58	0.35	1.44	3.98	2.23
1990-91 to 1999-00	2.02	3.57	-0.01	0.41	2.42	1.87
2000-01 to 2009-10	1.59	1.89	2.43	0.14	1.62	1.49

Note: Net availability of food grains is estimated to be gross production (-) seed, feed & wastage (-) exports (+) imports, (+/-) changes in stocks. The net availability of food grains divided by the population estimates for a particular year indicates per capita availability of food grains in terms of kg/year.

Climate change: Climate change scenarios paint a somber picture, particularly for the Indo-Gangetic plains. The favourable wheat acreage of the country comprising most parts of NWPZ and some parts of NEPZ which represent irrigated, high yielding environments may shrink upto 51% and acquire constraints akin to the less favourable Central and Peninsular zones on account of rising temperature and falling water availability. Some acreage from warmer and less favorable Central and Peninsular zones may even disappear. The Intergovernmental Panel on Climate Change predicted a 20% reduction in annual wheat production by 2030. The gist of most studies on climate change lies in a 20-30% yield loss, assuming a temperature increase of 2-3°C in various wheat growing regions of the country by 2050. The unmitigated effects of even a partial realization of these projections can be devastating. The stark absence of margins and maneuverability as epitomized by high population density and saturation of arable land resource add greatly to our vulnerability. The specter of depleting water availability can prove to be a single potent trigger for collapse of crop production in the wheat bowl of the nation. Having decimated renewable ground water, submersible pumps now mine fossil water in important wheat growing regions like Punjab and Haryana. A water table fall of 70 cm per year has occurred in several parts of Punjab. Receding Himalayan reservoirs and diminishing natural recharge in the Indo Gangetic plains does not augur well for the tripling of irrigation water demand by 2050 in India as estimated by the National Commission on Integrated Water Resources Development (NCIWRD).

Cultivation of wheat, originally a temperate plant species, in subtropics and tropics of India amounts to stretching its adaptation beyond its natural habitat. Wheat area is expected and can be increased by growing it in non-conventional states like Asom, Tripura, Bengal, Andhra Pradesh etc. However, it may not be able to cope with further strain imposed by climate change without fundamental interventions at genetic as well as management level.

Lag in technology implementation: Presently, there are considerable gaps between the realized and realizable wheat production particularly in eastern, central and peninsular parts of India (Table 3). The gaps in yield as assessed from front line demonstrations (FLDs) against check varieties vary among states and there is a scope for bridging the gaps with adoption of recommended package of practices.

Table 3 Yield gap for quinquennial ending 2013-14

State	Yield Gap (q/ha)	State	Yield Gap (q/ha)
Asom	5.66	Chhattisgarh	11.88
Bihar	5.25	Gujarat	3.26
Himachal Pradesh	4.64	Haryana	2.11
Jammu & Kashmir	5.13	Karnataka	5.37
Jharkhand	8.74	Maharashtra	4.01
Uttar Pradesh	5.55	Madhya Pradesh	9.79
Uttarakhand	8.12	Punjab	3.77
West Bengal	4.35	Rajasthan	6.17

The gaps are also reflected in large deviations in state yields from the national average. The situation for 2013-14 is depicted in Figure 5 with negative dips from national average (3146 kg/ha) being disproportionate to ecological and management constraints.

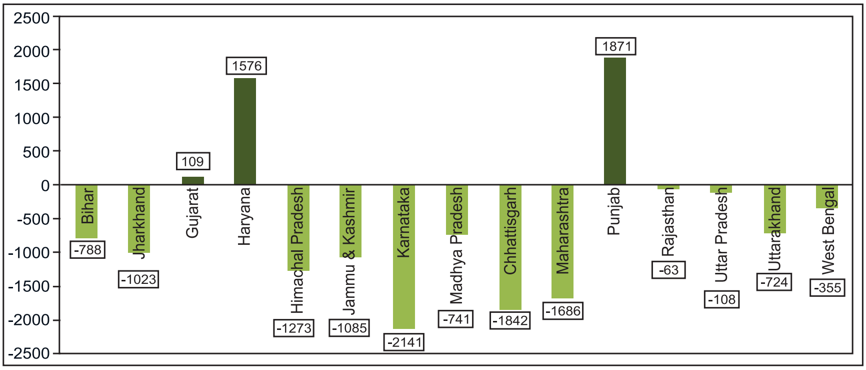

Fig. 5 Deviation of state yield in kg/ha from national average yield 2013-14

Generation of new technology without adequate bridging of technology gaps can push us back in our effort to maintain the desired growth trajectory and thus presents a serious challenge. A reinforcing cycle of technological advancement and its effective implementation at farmers' field has an accelerating effect on technological development. Widely improved channels for dissemination of information as well as efficient mechanisms for delivery of state support hold great promise for bridging technology gaps. In the context of 2050, it is the magnitude of the gap that needs to be continuously minimized, while the nature of gap would keep changing as existing ones are expected to be closed.

Zone specific challenges: In different parts of the country the problems vary and a summary of constraints in different zones is given in the Table 4. With intensive agriculture, using high yielding varieties of crops, and raising more than one crop in a year, deficiencies of several essential micronutrients have also become wide spread. In the intensive rice-wheat rotation of NWPZ, zinc deficiency had become rampant by 1980s. While soil application of zinc has had an ameliorative effect, manganese and iron deficiencies have become more common particularly

Table 4 Wheat production constraints in different wheat growing zones of India.

Zone	Current and potential constraints
Northern Hills Zone (NHZ) and North Western Plains Zone (NWPZ)	Yellow rust, brown rust, loose smut, Karnal bunt, *Ug* 99 race of black rust, (probability of occurence) micronutrient deficiencies, reduced water availability, *Phalaris minor* (Mandusi), *Chenopodium album* (Bathua), *Rumex dentatus* (Jangali palak), termite, frost damage, terminal heat stress.
North Eastern Plains Zone (NEPZ)	Leaf blight, seed availability, water logging, brown rust, *Phalaris minor* (Mandusi), *Chenopodium album* (Bathua), *Rumex dentatus* (Jangali palak), high temperature at maturity, late sowing, Zn deficiency.
Central Zone (CZ) and Peninsular Zone (PZ)	Lack of irrigation facilities, water stress, early and late heat stress, shorter crop period, brown and black rust, leaf blight.
Southern Hills Zone (SHZ)	Aphid, small holdings, all three rusts, bird damage.

manganese on coarse textured high pH soils. Oxidation of soil applied Mn and Fe makes it harder to manage and hence foliar applications are recommended.

Among the diseases, stripe rust in NWPZ has shown a major resurgence after breakdown of resistance in mega variety PBW 343 and also owing to global phenomenon of evolution of pathotypes adapted to high temperature. In recent years, the ambit of rust resistance has acquired a wider strategy than screening of breeding material in hand. The rust challenge needs to be met through pre-emptive gene pyramiding, characterization of emerging pathogens and their races molecular analysis of pathogen evolution with particular emphasis on rust, judicious application of chemicals and a host of other strategies. Karnal bunt poses another serious challenge. India being the second largest producer of wheat, the country should be capable of active participation in international market, considering the fact that wheat trade is likely to double to 240 mt or more by 2050. International quarantine restrictions against Karnal bunt can however virtually block India's trade prospects.

Genome wide molecular marker strategies can strengthen genetic solutions to Karnal bunt problem in particularly, as sufficient groundwork exists in the form of populations and stocks. Similar progress for leaf blight is available and an effective genetic strategy can be implemented considering the importance of this disease for NEPZ. In fact there are several second tier diseases including loose smut and powdery mildew which can benefit by their inclusion as breeding objectives in the marker driven, efficient programmes of the future. Weeds and abiotic stresses are also listed in Table 4. All these constraints pose zone specific challenges to wheat production and its future enhancement. Solutions, evidently, have to cut across disciplines and approaches as discussed in later sections.

Human resource challenge- creating the 'integrator scientist': Besides formal training in various disciplines, the on-job environment is critical in refining scientific temper and acquisition of practical and analytical skills. Quality of the scientific staff is the key to find solutions for the challenges listed above. Problem solving needs 'integrator scientists', a term often used by Dr. Borlaug to describe scientists with an ability to understand reality by virtue of their multidisciplinary insight, capacity for innovative thinking and willingness to participate even in the solution implementation process. The institutional challenge lies in fostering such human resource talent so as to make huge infrastructural investments fully effective.

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Operating Environment

An enumeration of the components of operating environment is essential for placing an institute and its working in relevant context. This provides the foundation for further analysis and would facilitate the objective of developing a vision for the future.

Technology Development and Adoption

Coordinated research model which again is the legacy of the 1960s continues to be the defining element of the operating system notwithstanding the expansion and strengthening witnessed over the decades.

- **An effective, well-oiled technology evaluation system** constitutes a major strength of the system. Every year around 500 entries contributed by the wheat breeding centres are tested in around 450 varietal trials under different cultural conditions at about 130 locations.
- **Well established system for biotic stress resistance is in operation** whereas significant groundwork has been accomplished for abiotic stress resistance. Prioritization of quality aspects remains sub-optimal, in deference to overwhelming productivity concerns and a procurement channel aiming almost exclusively at national food security.
- **New varieties continue** to be the primary vehicle of technological advance. This situation is most likely to perpetuate into the future as well.
- **Exploratory research activities,** particularly the handling of early tentative phases of research, continue to be less well demarcated as a coordinated activity.
- **Funded and voluntary centres of the AICW&BIP** project at SAUs serve as research partners and fit seamlessly into the coordinated project network. SAUs represent the generators as well as users of technology for their respective states. SAUs are also instrumental in creating the regional focus and thus keep the programme oriented to real needs on the ground.
- **Biotechnological solutions are now actively sought** and their potential is well acknowledged. Molecular markers have emerged as a powerful breeding tool. Its large scale application has however

been thwarted due to low throughput and higher cost. Technologies have evolved rapidly and we are on the cusp of an era of molecular breeding. Transgenic wheat, though largely ignored by public programmes in the present hostile opinion environment is likely to be of great importance in our run up to 2050.

Seed Technologies and Production

Linkage with the seed chain through DAC and seed agencies is a major conduit of technology transfer. A responsive and dynamic seed chain ensures timely and appropriate deployment of varieties. Future refinements would allow the system to explore varietal micro niches, thus minimizing the ill- effects of stagnating monocultures.

Resource Conservation Technologies

Resource conservation issues have gained importance in last decade and are likely to move to centre stage in the coming years. Resource conservation technologies (RCTs) have economic and environmental consequences and are finding increasing adoption at the farm level. A related development is mechanization for precision of farm operations and labour saving. Future evaluation of varietal candidates and management practices is expected to be performed in the context of RCTs

Off-season wheat crop is an integral part of the R&D system and is based on exploitation of high altitude areas in the Himalayas and Nilgiri hills

The current operating environment is characterized by a preponderance of public institutes in wheat R&D in the country, historically but there are clear signs of an emerging private sector involvement. The R&D paradigm continues to be, by and large, the one that was adopted in the green revolution phase.

International Collaborations

- Strong ties with International Agricultural Research Centres (IARCs) particularly CIMMYT and ICARDA with ready access to germplasm developed at these centres has characterized the technology pipeline. Significant varietal and germplasm influx into the coordinated system has resulted from this collaboration. Technology adaptation for other components of the package e.g., RCTs seems to require greater local inputs and fine tuning.
- The collaboration with CGIAR centres will now include Borlaug Institute for South Asia (BISA) as well, which is coming up with ICAR support at three locations in India.

- Besides CGIAR centres, the ICAR-IIWBR and the AICW&BIP have active collaboration with many international organizations/ institutes like, USDA, ACIAR, ISCB, ADB, DFID, University of Zurich, PBI UK, BBSRC UK, State Key Laboratory of Crop Biology China, Kihara Research Institute Japan, INRA France and Cornell University US etc. Close linkages with other Government departments/organizations like DBT, DST, CSIR, NCL, ARI, SAU's and other ICAR institutes exist.

Several aspects of the operating environment are evolving, with some slated for rapid change. A dynamic interplay of these changes would define the future role of the Directorate and nature of research and coordination programmes in IIWBR.

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Opportunities

A broader genetic base for sustained progress in wheat and barley breeding

The Germplasm Resource Unit at the Institute maintains more than 11000 germplasm lines of wheat which include indigenous collections, donors from trials/nurseries, genetic and cytogenetic stocks, wild species and close relatives, and exotic collections. Another set of about 20000 germplasm lines have been stored under natural conditions at IIWBR Regional Station, Dalang Maidan (HP). The different research centres also maintain working collections (an estimated pooled figure of approximately 26,000) and utilize them in creating new variability. Germplasm from many countries e.g., USA, Canada, Australia, China, Syria and South Africa has also been acquired. While wider genetic input has all along been considered as desirable, wheat breeders have largely stayed away from this prospect owing to practical difficulties. Systematic efforts on building up germplasm collections and identification of potential donors for various traits have set up a new opportunity for wheat scientists. Another hindrance in utilization of distant genetic resources is the much longer duration of breeding process before commercially relevant materials can be created. Improved facilities for embryo rescue, rapid generation advance and marker facilitated monitoring of alien gene introgression besides development of breeding schemes based on integration of these techniques have significantly accelerated gene transfers. Space for pre-breeding work has also been created by demonstration of commercial success of several alien rust resistance genes besides large scale deployment of alien chromosome arms such as 1B/1R in varieties such as PBW 343. Wheat's hexaploid nature itself offers the greatest opportunity for wider genetic input by providing a well buffered receptacle for diverse and even alien chromosome segments.

Marker assisted breeding

Integration of molecular markers in wheat improvement represents one of the most important technological advances for dramatically improving the efficiency of the breeding process. During the projected period, we could be in position to utilize new technologies like RNAi, Targeted mutagenesis, Micro RNA, Cis-trans techniques in wheat and barley imporovement. It offers several new opportunities such as:

1. Pre-emptive breeding for rust resistance
2. Marker assisted background selection (MABs) for rapid rectification of mega varieties
3. Marker assisted selection (MAS) for resistance to 'second tier diseases' which have not been brought under resistance breeding efforts so far
4. Genome wide selection approaches for handling complex traits including yield and tolerance to abiotic stresses
5. Molecular marker based monitoring of evolutionary and short term pathogen dynamics for devising effective control strategies

Wheat genome sequence and associated genomic tools

The fast unraveling sequence information under various national and international projects offer unprecedented opportunities for reinventing wheat and taking it to a new status as a crop. We have an opportunity to identify new specific genes for traits for example 'Deeper Rooting 1' (DRo1) QTL controlling root growth angles and DREB genes. This will help in architecting the suitable plant types for smaller ecological niches. Some of the more immediate opportunities may be listed as:

1. Allele mining on the basis of probing germplasm sets for specific gene sequences
2. Innumerable new molecular markers in genomic regions of choice to facilitate large scale cloning of new genes
3. A plethora of approaches for understanding the function of each and every gene
4. Understanding temporal and tissue specific gene expression in response to developmental and environmental cues
5. Uncovering molecular basis of complex adaptation syndromes including tolerance to various abiotic stresses
6. Designing of a genome wide perfect marker system based on SNPs in entire gene space of the species

Potential of wheat transgenics and possibilities of greater public acceptance

Presently the development and release of wheat transgenics have been lagging behind world over and public opinion for its acceptance remains, at best, divided. As of 2013, 34 field trials of wheat transgenics have taken place in Europe and 419 have taken place in the US. Modifications tested include those to create resistance to herbicides, insects, fungal pathogens (especially fusarium) and viruses, tolerance to drought, salinity and heat, increased content of glutenin, higher protein content, increased heat stability of phytase, increased content of water-soluble dietary fiber, increased lysine content, improved qualities for use as biofuel feedstock, production of drugs via pharming, and yield increases. Thus we see a broadening of the transgenic wheat agenda with some activity even in Europe, conventionally associated with strong anti-GM sentiment. Rothamsted Research, UK, has applied for release of transgenic wheat genetically modified to produce a hormonal chemical compound that acts as an alarm signal to move aphids from the crop or deter them from landing on it. This chemical, the pheromone sesquiterpene (E)-β-farnesene (EBF), is produced by aphids when they are being attacked by predators and parasites. As this transgenic addresses an environmental concern, it is expected to encounter less resistance. Notwithstanding the recent furor over unexpected detection of 'Round Up Ready' wheat plants in an Oregan farm in US, there are indications of a revival of interest in wheat transgenics in public as well as private sector.

The opportunity provided by wheat transgenics particularly in context of tolerance to heat, drought and other adverse environments where wheat gene pool may fall short of the required variation cannot be ignored, particularly by the public sector research.

Demand for wheat with specific processing and nutritional attributes

The domestic demand for raw wheat, bread, biscuit and pasta at 2050 has been estimated at 125, 2.7, 3.5 and 0.25 mt respectively based on the projected population of 1.7 billion. Population pressure, increasing rate of urbanization and changing life styles are expected to fuel a manifold increase in demand of processed wheat products. Requirement for new products, such as various types of semi-processed or ready to eat chapaties may become predominant. Overall, it represent opportunities offered by an enlarged market. As a response, and as per economics of value addition, product specific varieties would need to be developed. Unlike this processing quality driven opportunity, nutritional quality is likely to acquire great importance in case of wheat meant for public distribution system.

High micronutrient density and protein content may become mandatory for wheat entering this channel. The third opportunity, similar to the one generated for processed food products will be driven by expansion of wheat exports from India. Durum wheat, for instance may emerge as a strong export option. Only by virtue of quality, India can think of stepping boldly into international wheat trade arena. The uniqueness of the Indian Dicoccums presents yet another opportunity.

India is the only country in the world growing *T. dicoccum* over 50,000 ha area. It is a highly premium priced commodity on account of its unique nutritional and therapeutic value. Dicoccum varieties are low yielding, and highly susceptible to yellow rust. Therefore, improvement in yield and resistance while retaining the special quality of its products becomes imperative.

Emergence of malt barley as an important industrial crop

The national consumption of malt based baby food, energy drinks, chocolates, and other confectionary items is on fast rise in urban areas and spreading in rural areas as well. Similarly, the consumption of beer and malt whiskies is increasing at a fast rate. The investment from the MNCs (like SAB Miller, Australian Foster group and several others) especially in the brewing sector has given a boost in production as well as quality consciousness and increased competition for local giants like United Breweries and others. The requirement of international grade raw material (barley or malt) has increased several folds and is expected to increase further. In such situations, the crop will certainly be looked as industrial cereal rather than a crop for poor and under managed areas. The export of barley grain for malting purpose, malt or even malt extract for nearby countries which mainly depend on import of these items from much distant places like Australia and Canada, can be another prospect. This can be met only through organized production and segregated procurement from specified areas to meet the required specifications. It is estimated that the current requirement of nearly 250000 tonnes of barley for malting may increase three fold to 0.75 mt by 2025. The cultivation of barley as feed crop is expected to decrease and whatever non-malt barley is cultivated shall be either for fodder/ dual purposes or specialty products like sattu.

Demand for scale appropriate mechanization and precision farming tools

Diminishing availability of farm labour coupled with economic as well as environmental incentives offered by RCTs are likely to promote mass adoption of mechanization and precision farming tools provided scale-appropriate machinery is available. Some of the problems of affordability are already being addressed by emergence of community based sharing and hiring systems for farm machinery. Such business models are expected to spread in more wheat growing regions. The entire agro-technological package would, thus need to keep evolving in response to the changes in systems of cultivation.

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Goals / Targets

The area under wheat is expected to decline by around 5-6 mha by 2050 on account of non-agricultural activities as well as alternate crops. Demand for wheat however will continue to rise due to various reasons discussed earlier. India need to produce about 140 mt of wheat by 2050 (domestic demand + public stock + export for different destinations), which is more than 46% over the present production level. Average yield levels in NWPZ would have to exceed 7 t/ha and average national productivity needs to touch 5 t/ha to meet the projected target. Having stated the target, it is necessary to outline main strategies for achieving it.

Upgrading to new-era wheat breeding programmes

Increased productivity targeted above, unlike as in the past, will have to come from more restricted use of fertilizer, irrigation and other inputs, in deference to growing resource crunch and environmental concerns. Climate perturbations pose an unprecedented challenge to the crop improvement strategy. Wheat cultivation in India, much of it made possible by already stretching the original adaptation of the species, is particularly vulnerable. The wheat bowl of North-Western plains is seriously challenged by the twin threat of heat and drought. Climate change may also has impact on pathogen and pest incidence. Foliar blights are anticipated to gain importance in North Western plains and aphids may graduate from minor to major pest status. Among the prevailing major diseases, the recent stripe rust breakout has taken a toll of the available varietal repertoire, demanding a closer relook at the host-pathogen dynamics and a hiked up breeding effort.

Tolerant varieties are sought to tackle pervasive micronutrient deficiencies under intensive agriculture systems. On the top of this, a modern wheat variety is expected to be adapted to resource conservation technologies (such as zero tillage or bed planting), confer additional nutritional benefits (e.g., micronutrient dense grains) and be amenable to processing into various products. The need for diverse and multiple genetic ameliorations in the future is likely accompanied by shortening time frames. All these add up to a tall order for a crop with notoriously narrow genetic base, notwithstanding the earlier breeding successes.

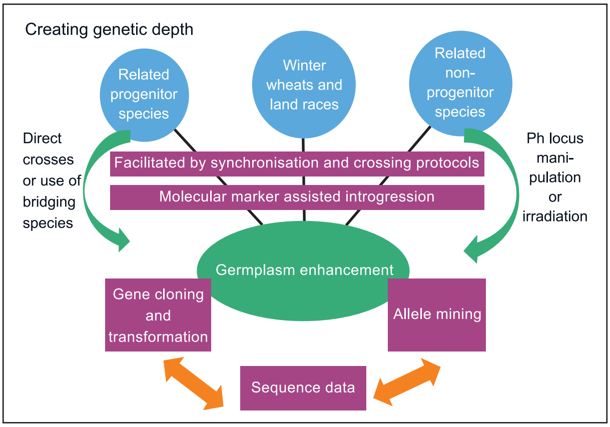
Breeding programmes in the conventional mode would not be able to measure up to these challenges. The need for an accelerated breeding programme which integrates the conventional strategy with a wide spectrum of the available and emerging molecular-genetic technologies is inescapable. Hallmarks of such a new-era breeding programme would be:

- An ability to handle a multitude of traits and objectives by virtue of depth of germplasm generated and utilized.
- Accelerated breeding processes, capable of delivering varieties to the farmers' fields in a significantly shorter time frame.
- Precise and rapid mobilisation of genes for intelligent deployment in genotypes suitable for various cultivation contexts.
- Advanced information management system for allelic, haplotypic and genealogical data of the breeding programme.

IIWBR and partners are now in process of adopting this ideal approach for traits like rust resistance with the help of markers. Effective tagged genes of alien as well as cultivated origin including Yr5, Yr10, Yr15, Yr17, Yr18, Yr36, Yr39, Yr40, Yr C591, Lr19, Lr24, Lr28, Lr37, Lr57, Lr58, Sr22, Sr26, etc., are being used extensively. This system now needs to be extended to more complex traits including physiological efficiency for enhanced productivity and tolerance to abiotic stresses. This however, demands a major reorientation and upgradation of the system with the bellowing features.

- **Scaling up:** The plant material development has to be on a breeding scale. Consequently, corresponding infrastructural upscaling would be necessary.
- **Acceleration:** As genes have to be mobilized from remote donors all the way to commercial cultivars, only an accelerated mode of breeding would be effective. High throughput of all major processes thus becomes necessary.
- **Strategic exploration:** Sustained success of the wheat breeding work depends on regular breakthroughs based on simultaneous exploration of several strategic research options.

The upgradation may be structured around two functional units; one aimed at germplasm enhancement and the other at acceleration of the genetic and breeding processes. While a major part of the alien and exotic germplasm potential lies untapped and need to be worked at more vigorously, transformation and allele mining can complement this source particularly for the bottleneck and novel traits. The components of the first functional unit aimed at broadening the genetic base are represented below:



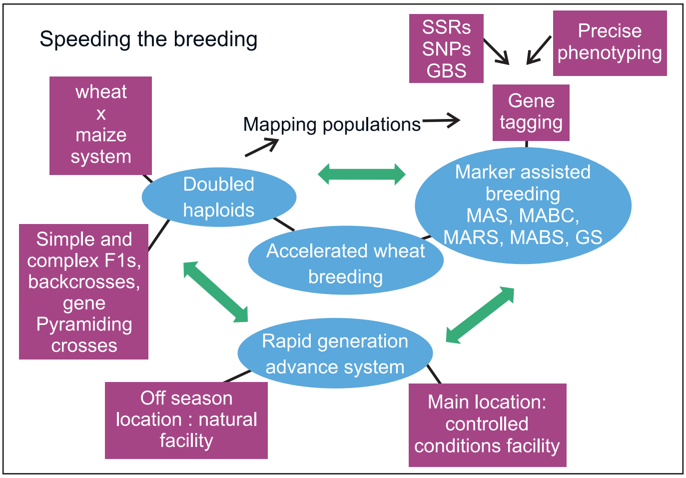
A large number of synthetic hexaploids and germplasm endowed with genetic richness for high grain weight, delayed senescence (stay green habit), HMW glutenins, resistance to KB and yellow rust; tolerance to heat & drought, salinity and water logging have been identified and will be continuously emphasized for introgression of these traits into high yielding wheat varieties. The potential of winter x spring wheat crosses has been widely demonstrated by the release of 'Veery' lines. The gene pools of winter and spring wheats have remained genetically isolated due to their different growth requirements and this variability nevertheless needs to be harnessed on a larger scale in the Indian wheat programme. The winter wheats have high biomass production, superior tolerance to stresses besides long ears and good grain features. The winter x spring hybridization programme has been initiated with the aim to transfer the high yielding traits into spring wheat background suitable for NWPZ targeting a yield level of 7 t/ha.The wild progenies and related genera of wheat offer large number of genes for resistance/ tolerance to various biotic and abiotic stresses (Table 5).

Table 5 Species with traits for utilization in wheat improvement

Desirable Traits	Sources
Heat tolerance	*Ae. peregrina ,T .longissimum, Ae. kotschyii*
Drought tolerance	*T. polonicum, T. longissimum, Ae. kotschyii, T. sphaerococcum*
Salt tolerance	*T. sharonense, Ae.ovata, Ae .kotschyii*
Powdery mildew resistance	*Ae. speltoides, T. longissimum*
High tillering	*T. carthalicum*
Grain weight	*T. carthalicum, T. polonicum*
High protein	*T. dicoccoides, Ae ovata, T. longissimum*
Baking and pasta quality	*Ae. tauschii*

For the sake of acceleration, doubled haploids (DH), rapid generation advance facility and markers have a complementary role. The second functional unit of the new-era breeding programme is represented schematically below:

Wheat breeding can benefit greatly from system of single step homozygosity based on doubled haploid (DH) production, thus cutting out the protracted selfing phase. It strengthens the 'breeding option' in face of sudden biotic and abiotic challenges. Overall efficiency of the breeding programme improves on account of precision of evaluation (being based on fixed, homozygous material) and exclusively additive nature of genetic variation- resulting in a much higher genetic advance. Wheat x maize system of doubled haploid production provides an excellent route to instant homozygosity and is finding use in wheat breeding programmes in Canada, Australia and Japan. A high throughput DH laboratory is being set up at IIWBR and is expected to speed up gene tagging as well as breeding work.



A second vital component of accelerated breeding is provided by the Wheat Summer Nursery situated in the Lahaul Valley of Himachal Pradesh. This facility was established in 1966 with the aim of generation advancement and multiplication of very important wheat material. The location permits the screening against yellow rust and powdery mildew. The use of this facility is being extended to cover a major part of the breeding material and for performing crosses between new lines emerging from testing during the main season. Dalang Maidan also serves as an excellent site for natural germplasm storage. It is proposed to strengthen this component further.

The new-era breeding programmes aims to integrate conventional and biotechnological aspects as outlined above. It also need to embrace new breeding objectives as discussed in the next section.

The trait focus

Armed with an upgraded breeding system, and working through hundreds of individual experiments or genetic manipulations at the Institute and SAU centres, it would be possible to realize the following general elements of our vision.

Productivity: A multi-pronged, exploratory strategy for productivity enhancement, over and above all the mandatory components such as resistance to biotic and abiotic stresses would be followed. Major gains for productivity have mainly accrued from strategic breeding interventions e.g., dwarf wheats and winter x spring wheat derivatives. The ability to precipitate a major productivity gain is a tough but most prized target. Primarily three strategies would be employed for which extensive ground work exists. These involve, (i) wide genetic input for introgression of untapped productivity alleles (ii) physiological breeding, and (iii) hybrid wheat. The three approaches are not mutually exclusive and can have synergistic overlaps. No way, productivity is to be viewed in isolation of other traits.

Rust resistance: Rust resistance is the most critical genetic input made by a wheat breeding programme. Yet yield losses due to rust on the farmers' fields continues to happen. Assisted by markers, all the way from resistance gene identification to deployment, the vision is to graduate an exclusively pre-emptive system. Deliberate and intelligent deployment of rust resistance genes can bring down yield losses and use of chemicals to a mere trickle. The most important part of this strategy is the in-house ability to scout new, effective genes followed by their mobilization and pyramiding in commercially acceptable and durable combinations. So far, this kind of deliberate deployment has not been achieved and is a cherished ideal. Towards this end as discussed earlier, a large set of Yr and Lr and a few Sr genes are being actively followed in the breeding programme. A large number of populations with cultivated and wild donors are being analysed for a regular stream of new genes.

Second tier diseases: Traditionally, breeders shy away from handling second tier diseases, which then have to be managed with chemicals or simply ignored. Upgraded marker capability holds the promise of bringing these diseases into the ambit of resistance breeding. Our vision is to use this strategy with Karnal bunt (which is an important disease in North India) and other typical second tier diseases like loose smut and powdery mildew. Resistance to cereal cyst nematode, with its tough screening technique, can also be effectively incorporated using several available or newly tagged resistance genes. Extensive ground work done at the IIWBR and other centre for molecular tagging of Karnal bunt and loose smut resistance strengthens this approach.

Quality: The challenge before us is to use in the first instance, available tagged genes for quality traits to create commercial cultivars with specific end uses. Such cultivars are not being regularly and deliberately generated in India and this can prove restrictive for development of processing industry. Marker assisted monitoring of recombination events can ensure transfer and assemblage of all these genes in the desired genetic backgrounds. Genetic variation for bread making quality in Indian environments, however, continues to be deficient necessitating further search for appropriate donors.

Input use efficiency and abiotic stress tolerance: These traits are virtually intractable for breeding by conventional means. In case of input use efficiency and abiotic stress tolerance, techniques such as DH and MAS almost become a pre-requisite and the need of phenotyping modules has been emphasized. These would have to be designed to suit our specific requirements. Genotypic differences for nitrogen use efficiency (NUE) have been detected in cultivated wheat stocks and the leads are being followed up. Tolerance to micronutrient deficiencies is high in Triticales (conferred by rye genome). Water use efficiency (WUE) rather than drought tolerance is another desired trait in the context of natural resource crunch. Traditional (C 306 etc.) and exotic lines have been involved in crosses as donors. Heat tolerance is the key to productivity under Indian wheat growing environments. Traits and donors have been demarcated and populations developed. Intensive marker as well as phenotyping inputs are proposed. Precise phenotyping, both in case of biotic and abiotic stress tolerance, is the key to marker discovery. Screening systems need to be created with precision as a target but without sacrificing scale and robustness. The system for screening against major biotic stresses such as rusts and Karnal bunt are well developed and routinely being used. Screening for tolerance to two major abiotic stresses in wheat: heat and drought however need significant technical and infrastructural input and hence more than 20 poly houses are required at the Institute.

Physiological indices based on canopy temperature, osmotic adjustment, carbon isotope discrimination, gas exchange, stem reserves, light interception, photosynthesis etc. are finding increasing use for evaluation and selections in the field. To evaluate the lines, certain phenotypic in relation to drought tolerance have been identified as carbon isotope discrimination, stomatal conductance, root architecture, proline content, lipid peroxidation and antioxidant enzymes. This strategy can be taken a step further with the use of molecular markers. A major benefit from the use of molecular markers for abiotic stress tolerance would be the possibility of overcoming phenotyping problems associated with variable, inconsistent stress in the field which is often confounded with other abiotic and biotic stresses. Primary constraint in this regard is the lack of established/proven QTLs for heat and drought tolerance in wheat. Appropriate donors and mapping populations would be necessary. The critical requirement, however, is the appropriate phenotyping modules. Along with precise phenotyping, the marker based approach can be strengthened further by breaking up the stress tolerance response into components and underlying biochemical mechanisms so as to drive a more direct association with the molecular markers.

Upscaling agro-technological packages

Adoption of minimum or zero tillage and laser leveling have opened this area wider for farmers and researchers. Issues like- 'should flood irrigation be done away with in the future?' have gained credibility. Several initiatives such as the following are already in place:

- Site specific nutrient management for targeted yields
- Integration of crop residues, bio-fertilisers and other organic sources with inorganic fertilisation
- Tillage techniques like FIRBS for increasing nutrient use efficiency
- Need based nitrogen application using remote sensing based handheld sensors for efficient N management
- Studies on effect of nutrient deficiencies on grain and straw quality vis-à-vis human and animal health

Further refinement and adoption of conservation and precision agriculture tools, particularly with regard to tillage and irrigation practices are pivotal targets for future sustainability of wheat based cropping systems. Thus, major efforts would go into tailoring the package of practices around these new tools in conjunction with development of scale appropriate machinery matched with novelties of the local situation. The need for a matching varietal component has already been discussed.

Special initiatives

National Repository of Wheat Rusts and Seeds of Differentials

Presently, about 100 cultures of different rust pathogens are being maintained at IIWBR Regional Research Station, Flowerdale, Shimla. As the number of variants are expected to grow, a bigger and long term preservation facility is proposed. Also a repository of pure and well authenticated seed of differentials would be set up at this centre.

Monitoring Puccinia astriiformis Virulence across National Borders

Stripe rust *(Puccinia astriiformis)* is the most important disease of wheat in the countries of Middle East and South Asia (MEASA) and Iran, Iraq, Pakistan and India are part of a contiguous epidemiological zone. Transcaucasia region is another major stripe rust zone. A regional network of Asian countries within these zones for addressing this issue will be promoted.

Integrated Pest Management

Till now, the wheat ecosystem is relatively free from pesticides (as compared to several other crops). Disease surveillance, virulence typing, gene deployment and use of PGPR/PGPF like organisms, would be assembled into eco friendly IPM approaches. Effect of bio-agents alone and in combination with reduced dosages of chemicals will be studied on management of wheat diseases and insect pests.

Pest Risk Analysis (PRA) for Global Trade

Anticipated global weather changes may lead to new diseases or changes in existing epidemiological patterns. This requires preparedness in terms of ready PRA systems for various important wheat diseases such as Fusarium head blight, Karnal bunt and rusts etc. IIWBR has been able to provide a PRA system for Karnal Bunt and would be inclined to carry it further to other diseases that facilitates export to different destinations for a better foreign exchange.

Developing Hybrid Wheat

Amelioration of serious bottlenecks like low heterosis for yield due to absence of defined heterotic gene pools and incomplete fertility restoration are the primary targets. Better understanding of diversity patterns and focus on hitherto less exploited genetic resources is a viable strategy for the former constraint while the second one can be best removed by employing marker assisted pyramiding of fertility restoration (Rf) genes.

Focus on Abiotic Stresses – Heat, Drought, Salinity in North East and Central India

Nearly 2.5 mha area under bread and durum wheat in central India is grown under residual moisture regimes and suffers from stress of drought, heat and salinity. Rapid physiological screening based on stem reserve mobilization, cell membrane thermo stability and canopy temperature depression, chlorophyll fluorescence etc. of diverse sets of relevant germplasm in the short run and more fundamental molecular manipulation in the long term, form part of this initiative. There will be emphasis on developing varieties with double null nutations like Nap hal.

Interface with Industry

A big opportunity to convert a sizable quantity of wheat into value added products remains relatively underexploited. An interface with the industry therefore is crucial to orient varietal development to industrial needs, to encourage new entrepreneurs and enhance investment in this area.

Technology Promotional Activities

Various technology promotional activities such as Farmers' Days, Seed Day, Traveling Seminars, use of print and electronic media to disseminate knowledge will be used to educate the farmers and scale up the level of adoption of the latest wheat and barley technologies. Video films and IT tools will be used for better diffusion of technologies.

Commodity Market Intelligence System (CMIS)

Future shifts in current wheat procurement policy would bring into greater focus the role of market intelligence systems. The Commodity Marketing Intelligence System (CMIS) model will be an informatics model aimed towards developing a reliable and integrated system, wherein all the information associated with marketing is readily available. This informatics model will be based on – multi-database information system; knowledge-based expert system; geographical information system; and on-line distributed query capabilities. Informatics for agricultural marketing information system requires coordinated inter-sectoral approach and application of appropriate information technology tools in the area of agricultural marketing (involving storage, packaging and infrastructure), agricultural extension and transfer of technology, agro-meteorology, agri-business, quality assurance and agricultural inputs viz. seeds, fertilizers, manures.

Weed Management

Among biotic stresses, weeds play an important role in deciding the productivity of any crop. Unfortunately, they are more resistant to abiotic stresses and their nutrient absorption capacity is also better than the wheat crop. An understanding of weed succession and weed dynamics in relation to various cropping systems, agro-techniques, soil and climate of the agro-ecological system is being generated and following initiatives are being carried into the future:

- Evaluation of alternate herbicides and herbicide mixtures for resistance inactivation
- Molecular basis of herbicide resistance and markers for herbicide resistance
- Integration of effective non-chemical measures like competitive varieties, crop rotations, tillage practices, residue retention etc. with chemical measures
- Exploiting the feasibility of biological control i.e. mycoherbicides
- Studies on chemical weed control for companion and intercropping systems
- Identifying the possibility of allelopathic wheat cultivars for weed management

Varieties Suitable for Diversification

High priority is in place for new tillage practices which aims for minimization of cost of cultivation and also to save depleting precious natural / economic resources. However, initial studies have shown that there exists genotype x tillage interaction and hence, better performing genotypes, specifically suited to a particular tillage option such as zero tillage, Furrow Irrigated Raised Bed (FIRB) planting and cultivars suitable for rotavator tillage technology will be needed. An early generation screening of potential crosses shall be made to identify suitable genotypes for specific tillage options.

Water Management

Though wheat requires only 4-5 irrigations, the consequences of water shortage on production can be substantially high. The need of the hour is to adopt integrated water management practices which require the judicious use of good quality water and conjunctive use of brackish water. Following strategies need to be adopted to address this problem:

- Laser land leveler for efficient water usage
- Surface residue retention to conserve soil moisture
- Need based nitrogen application using NDVI sensors etc. for checking the ground water pollution.
- Diversification/Intensification through alternative crops like maize, soybean etc. through FIRB technology for increasing water use efficiency.

Barley as Human Food

The barley products like "Sattu" (in summers because of its cooling effects on human body) and missi roti (for its better nutritional quality) have been traditionally used in India. One of the common uses of barley malt is preparation of diuretic syrups and other medicines in addition to high energy baby food with easily digestible sugars and proteins. The barley water helps in better urine filtration / increased kidney efficiency due to its high enzymatic constitution.

Thus, barley in modern times can serve as a very good nutritional as well as medicinal food where the use of traditional food products has been declining with the increase in fast food culture. The work on development of food barley either naked or hulled type to be consumed after pearling needs more emphasis in some areas especially in hills and tribal parts where still barley is an important component of human diet.

Application of Remote Sensing and GIS

The recent approaches of Remote Sensing and Geographic Information System in conjunction with weather parameters will be used for simulation modeling to determine the potential irrigated wheat yields and the N and water requirements to achieve targeted yield in various land units. Moreover, it can be used to simulate productivity and sustainability options of rice-wheat cropping system. The principal objective of developing these models is to determine climatically potential yields as well as to analyse the effect of climatic variables and management of water and nitrogen availability on productivity of wheat. In general, it will decipher the trends in water and nitrogen uptake, dry matter growth and productivity. In particular, the productivity as affected by various climatic constraints and management treatment will be simulated.

Reversing soil nutrient depletion

The intensive tillage coupled with crop residue burning and continuous mining of soil has led to the depletion of soil organic matter as well as essential plant nutrients. The situation is further complicated by imbalanced fertilisation leading to expression of multiple nutrient deficiencies. Zn is already recommended and there are more frequent occurrence of deficiencies of Mn, Fe, Cu, Mo and B in the rice-wheat system. More than 35% soils are also deficient in sulphur and the K status has also reached a threshold in many soils since farmers are mainly applying nitrogen and phosphorus to the crops. Following strategies are proposed to reverse the adverse effects on soil:

- Adoption of resource conservation technologies like zero tillage and conservation agriculture - minimum soil disturbance to conserve soil organic matter.
- Residue management - Incorporation or surface residue retention to enhance the soil organic matter.
- Developing new and improving the available machinery for residue management and conservation agriculture.
- Introduction of leguminous crops like moong bean to regain & build up the soil health.
- Green manuring to increase soil organic matter.
- Balanced use of fertilisers - Application of NPK in proper proportion along with need based application of Zn, Mn, Fe, Cu, Mo and B.

Seed initiatives

The seed of new varieties will be produced in large quantities in the very first year of its release and distributed to the farmers on 'Seed Day'. This will hasten varietal adoption among the farmers and provide quick feedback to the plant breeder. Seed dissemination will be promoted further by adopting a few villages for the production of seed of new varieties in each district. Progressive farmers in 'Seed Villages' can be provided training on seed production. Technical training to private seed producers and government officials involved in seed production would add further strength to seed initiatives. Smart Techno-village choosing a village respectively for wheat & barley and demonstrating all production technologies in that village.

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Way Forward

India believes that agriculture is the mainstay and crux for economic development. Wheat and barley crops supplements food security, nutrition security, health and to reduce poverty in terms of calorie intake. In the context of global climate change and weather anomalies, 'climate smart agriculture' gains significance. Producing 140 mt of nutrient rich, value-addition enabled wheat by 2050 in an environmentally sustainable, economically profitable and socially equitable manner is the prime goal of the IIWBR. This target can be split into an additional wheat production by about 11mt at the growth rate of 9 per cent for every decade (Figure 6). Similarly in the case of barley, the past production trend and target are shown in figure 7. This challenge is discussed in context of likely trajectory of the institutes' future growth and role.

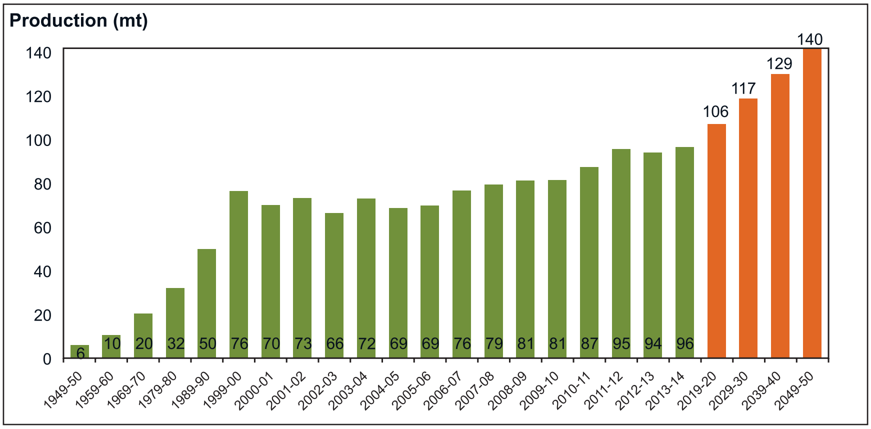

Fig. 6 Past level of wheat production and target by 2050

Starting largely with coordination work, the IIWBR has grown to acquire twin roles of coordinating national wheat and barley improvement network on one hand and addressing important research issues related to the two crops on the other. Thus, the coordinated programme is as much a conduit for sharing of scientific research as for testing of varieties and other wheat technologies. This arrangement has grown organically over the years and has imparted strength to the system. In recent years, the science component has made huge strides and it is a challenge to operate at the cutting edge. Retaining all the previously performed activities, the institute would take up a larger research mandate. This is perceived to impart a greater strength to the strategic and exploratory research component which has received less than optimal attention in the current dispensation. The activities could continue to meld seamlessly as earlier in the interest of integrated functioning and a more fruitful engagement of the scientific staff. The unprecedented biotic and abiotic problems arising due to climate change need to be tackled with a sound scientific strategy. The immense pressure on the wheat programme is likely to intensify till post-2050 era when India's population is likely to stabilize. Emergence of barley as a crop for industrial processing with complex nutritional and processing attributes also calls for intensification of the scientific strategy. Being a major crop, wheat is at the fore-front of application of biotechnology. Breeding of wheat by 2050 would depend heavily on molecular methodologies. The envisaged organizational change would improve the working and impact of the institute. The scientific back up provided by the institute would allow smaller centres in the network to be more effective. It would be ideal to have a regional sub-centre of the institute, preferably in the NEPZ in tune with its enormous but untapped potential.

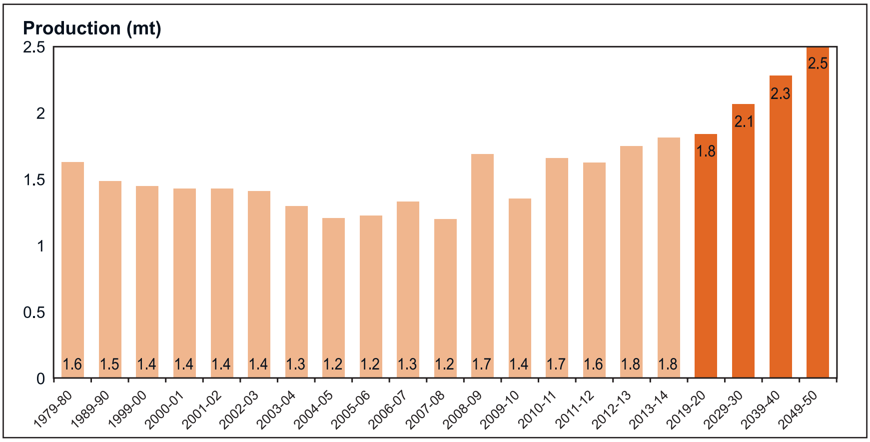

Fig. 7 Past level of barley production and target by 2050

Biotechnology to help precision breeding

The approach in assisting targeted selection of major genes and quantitative traits to transform breeding programs into highly-efficient, modern variety development, harnessing genome information and its integration with wheat phenome need to be utilised. The integration of new generation technologies involving NGS and Bioinformatics in a genomics core of wheat along with data analysis & management to enhance genotyping, SNP discovery, QTL Mapping & MAS would enable to undertake genetic engineering activities for yield and tolerance to biotic stresses, through DNA assembly, genome editing, cloning, amplification etc. leading to transgenic wheat with suitable tests for mass public acceptance. To enhance the light interception and efficient use, transforming C3 wheat to C4 requires special skill and expertise.

State of the art laboratories

IIWBR aims to invest in state of the art research infrastructure through setting up of central labs at Karnal for high throughput molecular marker analysis, DH production and quality analysis. There is an urgent need for high-throughput for physiological/genetics experiments to address the climate change and food security related issues. Currently a wide range of high-throughput techniques exist for the measurement of genome, the transcriptome and metablomics, however, relating these to the phenotype of plants is key to identify and characterize of genes underlying important traits. Technological advances now exist for high throughput phenotyping (employing robotics, non-destructive image analysis and super computers) and a centralized phenomics hub facility forms a part of IIWBR future plans.

Efforts to unravel and understand crop genomes have been boosted in the recent years by unprecedented developments in so called Next Generation Sequencing (NGS) technologies that present exciting new opportunities for crop genetics and breeding. With basic wheat genome sequence on the anvil, NGS technologies offer the great possibilities for gene expression analysis. As sequencing costs continue to fall, it is feasible that reduced-representation or even whole-genome re-sequencing could become the method of choice for genotyping of germplasm collections and breeding populations alike. Genome-wide DNA sequence data generated by using NGS shall quickly outpace our ability to obtain high quality phenotype data that accounts for strong environmental effects on complex traits.

One stop solution

The nodal role of IIWBR for any matter related to wheat and barley in the country assumes the proportion of a national service. Being connected to the entire wheat & barley R&D at national level besides linkages with international organizations, will help IIWBR to provide a 'single stop solution' to most of the queries and issues raised by the stakeholders. It is thus imperative for IIWBR to maintain high visibility, provide easy accessibility and earn high trust by virtue of its non-partisan and transparent dealings. Greatest priority would be accorded to the needs of the smallholding farmers. Augmenting their needs and insulating them from the shocks of low production and market prices would have to be given extra care. There would be increased opportunity for growth in trade of wheat & barley and their value-added products in the coming years. More entrepreneurs may be attracted in domestic supply and trade which may bring in the culture of contract farming for specific trait varieties.

Inter-institutional linkages

New linkages with national and international institutes would be made to harness the advancements in science. Strong complementarity would be sought with the upcoming BISA. Inter-institutional cooperation with SAUs has to be further strengthened for making the coordinated system of research more effective and result oriented. Collaboration with ISRO and Indian Meteorological Department will help to realize benefits of GIS for wheat & barley production. The private companies would be associated as important partners in research and seed production.

Information technology

The recent advances in computer technology and data management system have vastly augmented the ability to store, access, distribute and process large quantities of information at low cost. Large amount of data/results generated through field experiments, laboratories analysis and collection, will be properly documented in the form of database. A strong database will be developed on sound and scientific lines on various aspects like pedigree management, genetic resources, crop protection system, geographical information system, statistics on fertilizer usage, results of the coordinated trials etc. This will provide timely and accurate information for future research and planning. Computer networking through ERNET, LAN etc. using satellite, digital communication will be utilized for the rapid exchange of information contained in the database within and outside the organizations engaged in wheat & barley research in India and abroad.

Avenues for sustained funding

All out fund raising efforts at the ICAR and national/ international levels will be pursued. Wheat qualifies eminently for private philanthropic support in a country like India where battle against hunger is still to be won. Such opportunities therefore could also be explored.

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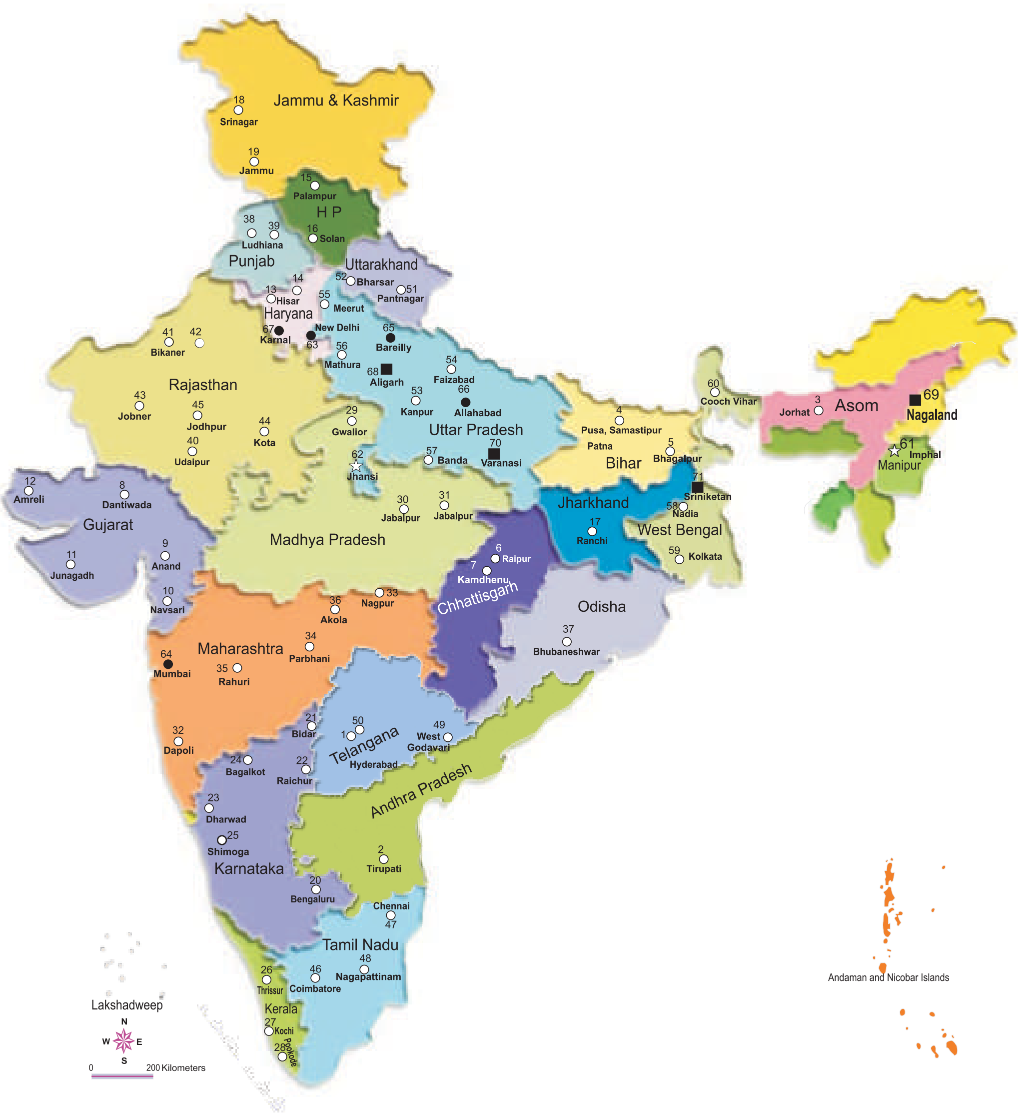

LEGENDS

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Central Universities with Agricultural faculties	■
Central Agricultural Universities	☆
Deemed Universities	●

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