Current research status and future challenges to wheat production in India

Sapna Grewal and Sonia Goel*
National Research Centre on Plant Biotechnology, Pusa Campus, New Delhi 110 012, India

Received 3 October 2013; revised 18 November 2014; accepted 29 February 2015

Wheat is a dominant crop in temperate countries and is being used as human food and livestock feed. The success of wheat depends partly on its adaptability and high yield potential, and also on the gluten protein fraction, which confers the visco-elastic properties that allows its dough to be processed into bread, pasta, noodles and other food products. In terms of human diet, it contributes nutritional factors, beneficial phytochemicals and dietary fibre components. The present review deals with current and future concerns that include sustaining the wheat production and quality with reduced inputs of agrochemicals, and developing lines with enhanced quality for specific end-uses, notably for biofuels and human nutrition.

Keywords: Breeding, nutrition, transgenic, wheat

Introduction

Wheat, rice, maize, sorghum and millets constitute the predominant basis of human nutrition worldwide and require a major research effort to increase their productivity and sustainability in the face of high food prices, climatic changes and natural resource depletion. India has an urgent need to increase wheat production to meet the growing demands under the constraints of depleting natural resources and environmental fluctuations. Year after year problems are becoming more intense thereby highlighting the need to focus research on areas like drought tolerance, disease resistance and quality production. Blend of innovative approaches and breeding strategies can improve the drowning conditions in the future1. Wheat is one of the most important staple food crops grown over 200 m ha in varied range of environments throughout the world. Green revolution made a remarkable progress in increasing wheat production and the credit goes to Dr N E Borlaug who developed some high yielding dwarf varieties. In order to meet the daunting task of increasing yield potential in a sustainable way, India needs to improve the overall “breeding efficiency”2. The present review is focused on the ongoing research areas in India, challenges ahead and a possible way out to deal with the crucial issues strategically so as to proportionate the demand and supply ratios.

What Made Wheat so Successful?

Wheat contributes more than 50% of calories to the people on national level. Bread wheat contributes approximately 95% to the total wheat production, while another 4% comes from durum wheat and 1% from dicoccum wheat2. World wheat production for 2013-14 was projected at a record 708.89 Mt, up 53.69 Mt or 8% from 655.2 Mt in 2012-13, whereas global wheat consumption was projected at a record 706.47 Mt by USDA. In the last forty years in India, more than 200 wheat varieties are released for cultivation in the six mega wheat growing environments. Most of these varieties are released for cultivation under irrigated, high-fertility and timely-sown conditions3. Wheat consumption in India predominantly takes place in the form of homemade chapattis or rotis ( unleavened flat bread) and custom milled atta (whole meal flour), while worldwide it is consumed mainly as bread.

Wheat popularity and success can mainly be attributed to the following factors:

- Wide adaptation of wheat to diverse environmental conditions and presence of a strong visco-elastic storage protein complex called gluten are the main factors making wheat the most important food crop in the world.
- High protein content of wheat makes it an important source of human diet and, in addition, wheat grain is also used to manufacture alcoholic beverages (Table 1)1.
- Flour milling gives bran, which is used in livestock feed, and the germ is a valuable
addition to feed concentrate. Grains are fed to livestock whole or coarsely ground. The wheat plant is also used as a pasture feed before stem elongation, a practice that permits plant regeneration.

Wheat straw is also used as a source of fibre. There are many other products of wheat from the food industry like wheat germ oil, wheat gluten and wheat starch, which have industrial applications.

The “Whole” Truth about Wheat

The health benefits of wheat depend entirely on the form in which it is consumed. Hence to receive maximum benefit from the wholesomeness of wheat, it is important to choose wheat products made from whole wheat flour rather than those that are refined and stripped off their natural goodness. These benefits are few when wheat has been processed into 60% extraction-bleached white flour. The standard procedure for preparation of most wheat products includes only 60% of the original wheat grain and removal of the rest 40%. Unfortunately, the 40% that gets removed includes the bran and the germ of the wheat grain, which is the most nutrient-rich part of wheat. In the process of making 60% extraction flour, over half of the vitamin B₁, B₂, B₃ and E, folic acid, calcium, phosphorus, zinc, copper, iron and fibre are lost. Although some processing is necessary for palatability, safety and even nutrient bioavailability, there has been interest in the potential health benefits of high fibre food products for several years.

Along with wheat bran, the wheat germ also deserves its health-food status. The germ is the vitamin and mineral rich embryo of the wheat kernel that is packed with important B-vitamins, high oil content and subsequently high amount of vitamin E, a powerful antioxidant that is important for immune system functions, cancer prevention and blood glucose control in both healthy and diabetic individuals. Increasing evidences are accumulating to show that fibre may actually reduces the risk of certain chronic diseases in humans like diabetes, cardiac diseases and certain types of cancers too.

Present Wheat Breeding Status and Statistics in India

As per the land use statistics 2010-11, the total geographical area of the country is 328.7 m ha of which 141.6 m ha is the net sown area (Annual Report 2013-14, Department of Agriculture and Cooperation Ministry of Agriculture, Government of India) (http://agricoop.nic.in/Annualreport2013-14/artp13-14ENG.pdf). Total area under wheat cultivation is nearly 26 m ha, of which 24.5 m ha is sown with bread wheat (T. aestivum) and nearly 1.5 m ha goes under durum (T. durum), whereas T. dicoccum covers less than 50,000 ha. This puts India at the second position among the wheat producing countries with approx 12% of the world's wheat production taking place here. Main wheat producing states are Punjab, Haryana, Uttar Pradesh and Rajasthan located in the North-western zone. According to the data provided in the annual report of Ministry of Agriculture, Government of India (2013-14), wheat production increased from 86.87 Mt in 2010-11 to 94.88 Mt in 2011-12 (Fig. 1), which is a record in itself. So the focus of Indian breeders need to shift from “Quantity” to “Quality” now as quality is far from being satisfactory. Breeders produce seeds for more than sixty wheat varieties each year, of which only fifteen varieties accounts for 80% of the crop.

Wheat varieties in India are categorised into six classes and their quality characters are listed in Table 2.

---

### Table 1—Nutritional components and characteristics of wheat cereal

<table>
<thead>
<tr>
<th>Nutrition facts</th>
<th>Manganese, phosphorus, magnesium and selenium are present in very large quantities. Also rich in zinc, copper, iron and potassium. Calcium present in small amounts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamins</td>
<td>Rich in vitamin B₆, niacin, thiamin, folate, riboflavin and pantothenic acid. Small amount of vitamins E and K are also present.</td>
</tr>
<tr>
<td>Calorie content</td>
<td>Calorific value: 339.0 calories per 100 g</td>
</tr>
<tr>
<td>Health benefits</td>
<td>Prevents breast cancer, gallstones, childhood asthma and heart risks. Reduces risk of high blood pressure, diabetes and high cholesterol.</td>
</tr>
</tbody>
</table>

---

*Fig. 1—Status of wheat production in India in the last one decade.*
Genetic improvement of wheat has received considerable attention over the last decade for the purpose of increasing the grain yield and minimizing crop loss due to various biotic and abiotic factors. To generate novel wheat cultivars with desirable characters, many in vitro technologies have been developed but large genome size (approx 17000 Mb) of wheat, inherent difficulties with gene delivery into regenerable explants and recovery of plantlets with the introduced transgene make this improvement process genetically challenging. Wild grasses, including relatives of wheat, have several desirable characters that can be introduced into both bread wheat and durum wheat. Biotechnological approaches can transfer defined genes from one organism to another, thereby increasing the gene pool available for improvement. Plant tissue culture is one such an area of plant biotechnology that involves the delivery, integration and expression of defined genes into plant cells that can be grown in artificial culture media to regenerate plants. The introduction of foreign genes coding for useful agronomic traits into commercial cultivars has resulted in saving precious time required for introgression of the desired trait from the wild relatives by conventional practices. Thus biotechnology has the potential to complement conventional breeding methods by reducing the time taken to produce cultivars with improved characteristics. Some of the latest areas of research and wheat improvement are discussed below.

### Nutritional Improvement in Wheat

Deficiencies of micronutrients, such as, iron, zinc, and vitamin A, afflict over three billion people. Currently, there is an increasing preference among consumers for food that contains not only traditional nutrients but also provide other compounds that are beneficial to health and well-being. Food systems that feed the world must be changed in ways that ensures a balanced nutrient supply in affordable way. At nutritional level, the main targets of improvement are to enhance the grain quality by: (i) increasing the protein content, (ii) increasing the essential amino acids, such as, lysine, (iii) increasing high molecular weight (HMW) glutenins to improve bread making properties of wheat flour, and (iv) modifying starch composition.

### Enhancing Protein Content and Improving Amino Acid Profile of Wheat

Though the protein content of cereals is lesser (7-14%) compared to that of legumes (20-40%), they account for about 45% of the daily per capita protein supply in the world and approx 63% in developing countries, which clearly illustrates the importance of cereals in our daily life. Protein quantity as well as quality are important and are affected by the levels of nitrogen and sulphur in the plant as it develops through the season. Nitrogen and sulphur are well known to play crucial role in affecting protein profile of wheat as they are a part of most amino acids. Wheat is found to be lacking in some of the essential amino acids like lysine, tryptophan and threonine. Lysine mutants have already been made in barley, maize and sorghum but due to polyploidy nature of wheat, this work could not get much success in wheat. Singh et al have done some good work in this area. They have identified a seed storage protein in wheat and named it triticin, which is found to be lysine rich. Further, work has been done to enhance the expression of original/modified triticin gene using more efficient promoter and to increase the gene copy number for improving bread making quality by enhancing lysine content. This research area of improving protein and amino acid content can surely help in improving the nutritional status of such an important cereal crop, which is the staple diet of millions.

### Genetic Transformation of Protein Subunits

Wheat grain contains a protein aggregate called gluten, which is highly hydrated and viscoelastic. It...
endows the wheat dough with its unique properties of dough making. High molecular weight glutenin subunit (HMW-GS) plays a major role in determining the viscoelastic properties, thereby determining bread making qualities. HMW glutenins are necessary to create strong dough, which traps tiny bubbles of carbon dioxide gas formed naturally by yeast during mixing and subsequent rising, thereby enabling the dough to rise. Dough strength and its ability to contain gas bubbles is known as viscoelasticity and is an important characteristic of wheat grain with respect to its end product quality.

Gluten proteins, e.g., gliadin, glutenin, albumin and globulin, give wheat products unique extensibility and processing properties. When managing the protein quality, the main aim is to get the plant to produce protein that contains the HMW, long chain gluten proteins. A number of HMW-GS as well as LMW-GS (low molecular weight glutenin subunit) genes have been introduced into bread and pasta (Triticum turgidum) wheat by genetic transformation\textsuperscript{22}. Leon and co-workers were successfully able to develop transgenic wheat lines expressing additional copies of HMW-GS genes, 1Ax1, 1Dx5, 1Dy10 by particle bombardment\textsuperscript{23}. They further extended this work ahead and altered the rheological and pasting properties of dough by expressing those HMW-GS genes\textsuperscript{24}.

**Wheat Starch**

The amount of starch contained in a wheat grain may vary between 60 and 75\% of the total dry weight of the grain. Starch is a mixture of two polymers—the almost linear amylose molecules and the heavily branched amylopectin molecules. The ratio of amylose to amylopectin is relatively constant, at about 23. Work has been done in this area to characterize and get better understanding of various components of starch biosynthesis in order to make rational design of novel starches and alteration in starch levels in other crop plants\textsuperscript{25}.

Study of wheat starch biosynthesis has been possible with the discovery of wheat with null alleles or mutations for the different starch biosynthesis enzymes\textsuperscript{25,26}. The generation of modified starches through genetic engineering has also been reported\textsuperscript{25}. This has extended the variation in wheat starch properties and expanded the possibilities for novel end uses. While insufficient food calories is one of the major causes of malnutrition in developing countries, an excess of digested calories leads to obesity and other diseases in developed countries\textsuperscript{27}. Starch with elevated amylose contents is of interest because they provide resistant starch with positive impact on human health. Aiming to increase the relative content of amylose in wheat grains, a RNAi construct, designed to silence the genes encoding the two starch-branching isozymes of amylopectin synthesis, were expressed under a seed-specific promoter in wheat. This resulted in increased grain amylose content to over 70\% of the total starch content.

**Abiotic Stress and Progress in Research**

Abiotic stresses, such as, extreme temperatures and water availability, high salt, and deficiencies or toxicity of minerals, severely affect productivity of cereal crops worldwide. Wheat is grown in adverse environments, especially high temperature and low water availability, gets greatly affected in terms of yield. There is ample variation available in abiotic stress tolerance in germplasms of wheat and its wild relatives, which are not fully exploited due to complexity of wheat genome and lack of understanding of its molecular basis of stress response. Functional genomics that involves approaches, such as, gene expression profiling and identification of responsive genes/alleles, followed by mutant analysis or transgenic approaches to assign the function of specific gene or its product protein is the new tool to deal with this issue.

**Heat/Temperature Stress**

Many parts of North-western plain zone, including parts of Rajasthan and Haryana, are exposed to high temperature due to dry winds coming from Thar desert. Higher mean temperature particularly immediately after anthesis reduces the yield significantly\textsuperscript{28}. Development of heat tolerant genotypes is the cheapest means of combating the heat and high temperature stress. New lines should be developed having high yielding attribute in addition to their adaptability to warmer climates. Heat tolerance can be incorporated by enhanced membrane thermostability, significant canopy temperature depression, increased stay-green habit and better stem-reserve mobilization rates\textsuperscript{29}. Effect of heat stress on grain starch content in diploid, tetraploid and hexaploid wheat species was studied by Chinnusamy and Chopra\textsuperscript{30} and they found that hexaploids had the highest grain starch content and the lowest heat susceptibility index, followed by tetraploid and diploid species. Based on their observation, future
research work on improving nutritional status can be specifically targeted towards hexaploid wheat. Studies at gene level has also been done where temperature related stress genes in bread wheat were targeted for understanding the mechanism of regulation of these genes by Khurana et al. Effect of high temperature was observed on wheat plants (Triticum aestivum cv. CPAN 1676) by subjecting them to heat shock at 37°C and 42°C for 2 h, and responsive genes were identified through PCR-select subtraction technology. Worldwide research is going on with the help of next generation sequencing to isolate sRNA responsible for heat stress in wheat. Many heat tolerant varieties like DBW 14, DBW 16, Raj 3765, Lok 1, GW 322, etc have been popularized on larger scale in India and research is going on to develop more such heat tolerant wheat varieties.

**Drought-Tolerance**

Drought resistance is now an essential trait for wheat because water is a limiting factor, especially, as the world faces the effects of global climate change. Declining water table is also adding to the trouble and, therefore, apart from water conservation technologies, breeding of varieties that can tolerate low-water conditions are an increasingly higher priority. Synthetic wheat has been developed by crossing tetraploid durum wheat with Aegilops tauschii, the ancestral donor of the D genome in hexaploid wheat, which has shown good tolerance to drought stress. Using these synthetic wheats, the breeding programme in CIMMYT (International Maize and Wheat Improvement Center), Mexico has made a notable progress in developing bread wheats adapted to drier environments. This successful research project can make significant contribution in tackling issues of crop loss and food shortage. Another study on the effect of chloroplast antioxidant system onto stress tolerance in wheat was carried out by Sairam et al. They found direct relationship between the tolerance level of the genotype to moisture and temperature stress with its antioxidant enzyme system. So workers can use this information to target their research in the area of modifying enzymatic pathways, which can lead to an increase in crop’s resistibility in future.

Genetic and genomic tools to improve drought tolerance are well described by Fleury et al. in detail. They analyzed advances in the genetics and genomics of drought tolerance in wheat and barley where a specific environment was targeted and appropriate germplasm and environment was selected, based on definition of morpho-physiological and molecular mechanisms of tolerance of the parents. This information was used to create structured populations and develop models for QTL analysis and positional cloning. Most QTLs for drought tolerance in wheat and its close relative barley have been identified through yield and yield component measure. Transgenic wheat lines for enhanced biomass yield under water deficit conditions were developed by Sivamani et al. by particle bombardment of barley gene HVA 1 encoded for late embryogenesis protein (LEA), which accumulates during seed desiccation.

Genomic associations were observed for drought tolerance on the short arm of wheat chromosome 4B. A consistent genomic region associated with drought susceptibility index (qDSI.4B.1) was mapped on the short arm of chromosome 4B, which also controlled grain yield per plant, harvest index and root biomass under drought. Markers tightly linked to this genomic region in combination with other important regions on group 7 chromosomes can be used in marker-assisted breeding for drought tolerance in wheat.

**Salt-Stress**

Domestication and breeding has narrowed the gene pool of modern wheat, leaving it susceptible to environmental stress. Salty soils lead to cultivation problem because buildup of sodium in leaves affects photosynthesis, which is critical to the plant's survival. The salt-tolerant gene (TmHKT1; 5-A) excludes sodium from the leaves. It produces a protein that removes the sodium from the cells lining xylem. A lot of attention is directed towards using this gene to transform wheat genotypes. Scientists from CSIRO Plant Industry have introduced a salt-tolerant gene into commercial durum wheat, showing spectacular results in field tests. At Waite Research Institute, University of Adelaide, Australia, scientists have worked towards understanding how the gene delivers salinity tolerance in the plants. They studied the function of the salt-tolerant genes in the laboratory and their effect on increased grain yield in the field. This was the first study to confirm that the salt-tolerant gene can increase the yield in a field with saline soil, while other similar studies have only looked at the performance of gene under controlled conditions in a laboratory or greenhouse.

In India, The Central Soil Salinity Research Institute (CSSRI), Karnal has focused on doubled haploid breeding techniques and genetic engineering
for increasing salt tolerance in wheat by incorporation of tolerance from related but poorly adapted genotypes into elite bread and durum wheat cultivars. Genetic variation for salt tolerance in some bread and pasta wheat genotypes and effect of NaCl salinity on wheat cultivars has also been studied to find out different markers, which can be helpful in selection of varieties in different breeding programmes.

Breeding Wheat for Resistance to Biotic Stress

Wheat is also attacked by a number of viral, bacterial and fungal pathogens, as well as insect and nematode pests. Introgression of genes from wild relatives has exhibited resistance to pests and pathogens in wheat. These genes have been successfully utilized over the years for the generation of resistant varieties of wheat. Availability of novel transgenes those encode for anti-microbial peptides, defense-related proteins and enzymes for the production of anti-microbial compounds in crop plants has been a reality nowdays. Their use greatly enhance the possibility of engineering crop plants for resistance to pests and pathogens. Growing resistant wheat cultivars is the most economical and environmentally safe approach to eliminate the use of fungicides and to reduce crop losses. Most of the work in this area has been focused on developing protection against fungal pathogens.

Developing Resistance to Common Diseases

The major wheat diseases prevailing in India are rusts, including leaf rust, yellow rust and stem rust, Karnal bunt, foliar blights, powdery mildew and loose smut. Diseases like head scab, foot rot and flag smut are of limited importance. Leaf rust, caused by *Puccinia triticina*, is one of the most damaging diseases of wheat worldwide. Pyramiding several rust-resistance genes into one adapted cultivar is one new strategy these days. Three highly effective alien genes for leaf rust resistance; Lr 24, Lr 28 and Lr 9 were selected for pyramiding in the background of a susceptible but well adapted bread wheat variety HD 2329 by Charpe et al. When this variety was screened against virulent pathotype 77-5 (121R63-1) of leaf rust, a high degree of seedling and adult plant resistance was observed. The availability of a combination of the three major rust resistance genes in desirable background would facilitate the strategic deployment of wheat varieties to achieve durable resistance. These studies have paved a path to combat the rust issue in wheat.

Work on RFLP mapping of resistance to rust and loose smut has begun recently. Panjab Agriculture University has developed artificial inoculation technique for screening against pathogens. This technique was then used in carrying out systematic breeding work on Karnal bunt. Wheat was transformed with the bar gene encoding the barley yellow mosaic virus coat protein and pathogenesis-related (PR) proteins. This genetic transformation resulted in the development of new improved resistant wheat. Pellegrineschi and co-workers evaluated the PR proteins, such as, the thaumatin-like protein (TLP) from barley, chitinase and 1,3,β-glucanase. Stable integration of these genes in the genome and inheritance in the progeny were determined by phenotypical analyses that challenged the plants against a wide range of pathogens. Their results indicated increased resistance of transgenic wheat plants to *Alternaria triticina*.

Herbicide Tolerance

Herbicides are pesticides used to kill unwanted weed plants and their use is one of the main reasons for green revolution in India. Herbicides have a major disadvantage of killing the main plant varieties along with the weeds, which result into greater loss. Herbicide tolerant varieties provide new options for the control of major weeds, which are constraining agricultural production. In North-western India *Phalaris minor* is the most serious weed against which isoproturon has been used but its continuous use has caused resistance in the weeds. Now broad spectrum herbicide “Basta” is being used to control *P. minor*. Herbicide-tolerant transgenic wheat was produced by microprojectile bombardment technique, which could provide effective control against *P. minor* through the use of herbicide Basta.

Modified Wheat: Best Possible Solution to Beat the Heat

The production of maize and soybean are ahead of wheat because conventional efforts for wheat are not keeping in pace with the modernized techniques used to improve maize and soybean. Many alterations of the bread wheat genome have been done through homoeologous recombination with wild wheat (alien) species, which proved to be helpful to introduce disease resistance in wheat cultivars.

Transgenic Wheat

Transgenic wheat can be made by the method of transformation, which includes the method of
Gene Silencing—New Beginning and a Long Way to Go!

Gene silencing-related mechanisms were first noted as a surprise observation by plant scientists during the study of plant transformation experiments, in which the introduction of a transgene into the genome led to the silencing of both transgene and homologous endogenes. Since then, the biologists have made significant advancements in exploiting RNA silencing as a powerful tool for gene function studies and crop improvement. RNA-induced gene silencing or RNA interference (RNAi) is a conserved regulatory mechanism of gene expression that has been widely characterized in eukaryotic organisms. The RNAi mechanism has been exploited extensively and has become powerful functional genomics tool to silence virtually any gene of interest by introducing target gene sequences into cells or organisms. The subsequent detailed analysis of resulting loss of functions and altered phenotypes represent the most readily interpretable method for experimentally validating the roles of respective gene play. Virus-induced gene silencing (VIGS) is a technology that exploits an RNA-mediated antiviral defence mechanism. It involves creation of engineered viruses carrying sequences corresponding to the host gene to be silenced. Infection leads to synthesis of viral dsRNA, an intermediate step in viral replication. This activates the anti-viral RNA silencing pathway, resulting in down-regulation of the host gene transcript. VIGS has been used widely in plants for analysis of gene function and has been adapted for high-throughput functional genomics. Protection of plants from viral infection has been one of the first commercial outcomes resulting from the application of a gene silencing technique. Transgenic papaya (Carica papaya) with resistance to Papaya ringspot virus (PRSV) was among the first commercial releases and saved the papaya industry in Hawaii.

Some work has been carried out in wheat as well, but a lot more is desired. Regina and colleagues had worked on the modification of starch composition in wheat. They used hpRNA constructs to silence an isoform of a starch-branching enzyme to produce a high-amylose transgenic wheat line, which can have significant health benefits. While more research is required to establish specific roles of RNA silencing pathways in plant defence against nonviral pathogens and insects, it can be anticipated that gene silencing-based technologies could potentially be developed to control bacterial infection, fungal diseases and insect infestation of agronomically important crop species. Possible approaches include the overexpression or down-regulation of host-encoded gene silencing factors known to be involved in disease resistance pathways or knockdown of sRNA species already shown to be involved in plant defence pathways. The problem of complex genome in wheat can be minimized by optimizing methods for simple integration patterns, use of specific promoters and gene sequences isolated from other cereals.

Hybrid Wheat

United States and a couple of other countries commercialized the use of hybrid wheat in the 1970s. Seed production cost was extremely high and that is why it was never grown on a large scale. Accordingly most companies dropped their research programmes on hybrid wheat but India is an exception: the Maharashtra Hybrid Seed Company (Mahyco) launched hybrid wheat in 2001 and reported adoption of 60,000 acres in 2005. Strikingly, the company’s marketing focus is not on the irrigated wheat states of Northern India but on states like Maharashtra in the semi-arid tropics, where wheat is primarily grown for home consumption. The demand for hybrid wheat is price responsive, which indicates that if hybrid seed prices could be lowered for instance through efficiency gains, adoption rates could increase significantly. We can hypothesize that hybrid wheat could be one important option to tackle challenges faced by agricultural research in India. Since hybrid wheat has been in the market only since 2001, more research is needed to assess its effectiveness in various wheat growing regions of India and under different climatic conditions.

Biofortified Wheat

Biofortified wheat is nutritionally improved wheat, which can increase people’s intake of minerals, iron
and zinc. The International Centre for Wheat and Maize (CIMMYT) is leading the research efforts in collaboration with national agricultural research and extension systems in the South and West Asia. Half a billion people in South and West Asia are deficient in iron and iron deficiency anaemia rates in India are among the highest in the world with 79% of children and 52% of pregnant women being affected. This is mainly attributed to low bioavailability of iron in the diet. Biofortification efforts aim to improve the nutrient level of basic cereals crops and are a strategy proposed to improve micronutrient intakes in India.

ICAR identifies seven promising wheat varieties for diversification. One among these is HI 8663, a new durum wheat variety with high β-carotene (6.5 ppm*) recommended for release in Southern parts of the country, i.e., Karnataka and Maharashtra. It can serve as ‘naturally biofortified food’ and can be used for nutritious chapatti and pasta preparations. It can aid in improving nutritional security because of its high and stable β-carotene, high sedimentation value, high protein content of 11.6 per cent and high levels of micro-nutrients. Also, it has higher levels of other important micronutrients like iron 47.0 ppm and manganese 28.0 ppm. VL 892 is a wheat variety developed by Vivekanand Parvatiya Krishi Anusandhan Sansthan at Almora, which provides better nutritional quality wheat owing to higher content of zinc, copper and manganese. A few of such nutritionally enriched varieties of wheat are listed in Table 3. Common agricultural strategies can be used to develop these high nutritional quality wheat like using micronutrient fertilizers, but this involves high cost. On the other hand, crop biofortification via traditional cross breeding offers a sustainable and low-cost way to provide essential micronutrients. Genetic biofortification involves classical breeding approaches to characterize and exploit genetic variation for mineral content, as well as new approaches involving gene discovery and marker assisted breeding. It is expected that adoption of micronutrient-dense wheat varieties will be driven by their improved agronomic properties, higher yield potential, resistance to new strains of rusts, and tolerance to climate change induced heat and drought stresses. So development of wheat grains with higher micronutrient levels is a challenging task for wheat breeders.

**Issues that Need to be Focussed in Future**

In 1990, Swaminathan used the term “Evergreen Revolution” to emphasize the need for enhancing productivity without harming the environment. According to him, in densely populated countries like India, China and Bangladesh, production increase has to come under diminishing arable land, irrigation water and increasing biotic and abiotic stresses. The major constraints are: shortage of quality seed during sowing time, high cost of seed and fertilizer, adulteration of fertilizer, high cost of weedicides, non-remunerative price of wheat, higher rate of interest, lack of timely and easily available credit, and lack of funds for the purchase of farm machinery. To meet the growing demand of food, India should focus on all these points. The breeding strategies too need a paradigm shift because the three components mainly responsible for green revolution in India, i.e., high yielding dwarf varieties, increased use of fertilizer and addition of irrigation facilities seem to be exhausting very fast. So we conclude that the most promising research goals, which can make a real difference at ground level, are: development of transgenics and marker assisted selection (MAS) for complex traits, use of alien translocation to enhance

<table>
<thead>
<tr>
<th>Variety</th>
<th>Research Institution</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI8663</td>
<td>Regional Station, Indian Agricultural Research Institute (IARI), Indore, Madhya Pradesh</td>
<td>Excellent grain quality, high stable yield and high resistance to stem and leaf rusts</td>
</tr>
<tr>
<td>PBW 550</td>
<td>Punjab Agricultural University, Ludhiana, Punjab</td>
<td>Combines high grain yield with high degree of resistance to leaf rust and stripe rust</td>
</tr>
<tr>
<td>HI1544</td>
<td>Regional Station, IARI, Indore, Madhya Pradesh</td>
<td>Better yield even under deficient irrigation availability</td>
</tr>
<tr>
<td>HD2932</td>
<td>IARI, New Delhi</td>
<td>Wide adaptibility</td>
</tr>
<tr>
<td>WH 1021</td>
<td>CCS Haryana Agricultural University, Hisar, Haryana</td>
<td>High degree of disease resistance and better quality characters</td>
</tr>
<tr>
<td>HPW 251</td>
<td>Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh</td>
<td>High degree of resistance against major diseases, such as, yellow rust, brown rust and loose smut</td>
</tr>
</tbody>
</table>
the yield potential, germplasm improvement, increase in efficiency at all levels of breeding and working on manipulations at the genetic level in wheat genome.

References
10. Murphy S & Burch D. Cereal secrets—The world’s largest grain traders and global agriculture, Oxfam Research Reports, August 2012. [www.oxfam.org]
23. León E, Marín S, Gimenez M J, Pistón F, Rodríguez-Quijano M et al., Mixing properties and dough functionality of transgenic lines of a commercial wheat cultivar expressing the 1Ax1, 1Dx5 and 1Dy10 HMW glutenin subunit genes, J Cereal Sci, 49 (2009) 148-156.
35. Sivamani E, Bahieldin A, Wraith J M, Al-Niemi T, Dyer W E et al., Improved biomass productivity and water use efficiency under water deficit conditions in transgenic wheat


