# Improving **Wheat** Productivity in Asia

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# Improving Wheat Productivity in Asia

*Editors*

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## The Organizers

**APAARI** (Asia-Pacific Association of Agricultural Research Institutions) is a regional association that aims to promote the development of National Agricultural Research Systems (NARS) in the Asia-Pacific region through inter-regional and inter-institutional cooperation. The overall objectives of the Association are to foster the development of agricultural research in the Asia-Pacific region so as to promote the exchange of scientific and technical information, encourage collaborative research, promote human resource development, build up organizational and management capabilities of member institutions and strengthen cross-linkages and networking among diverse stakeholders. To meet these needs, the Association: i) convenes General Assembly once in two years, holds regular Executive Committee meetings yearly and organizes consultations , workshops, trainings, etc., ii) collects, collates and disseminates research findings, iii) maintains links with other fora in the region and outside through meetings, participation and information exchange, and iv) promotes need based collaboration in research projects among member institutions, analyzing priorities and focusing on regional agricultural development. For details, please visit: *www.apaari.org*

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**JIRCAS** (The Japan International Research Center for Agricultural Sciences), an incorporated administrative agency under the Ministry of Agriculture, Forestry and Fisheries, plays a core role in international collaborations in the field of agriculture, forestry and fisheries research in Japan. JIRCAS has four main research programs, viz., i) international collaborative research, ii) dispatch and invitation of researchers, iii) research planning and evaluation, iv) cooperation with developing regions. Starting from April 2011, its five year third medium-term plan has commenced with the three main objectives, i) undertakes comprehensive experimental research for technological advancement of agriculture, forestry, fisheries and related industries in tropical and subtropical zones of developing regions, ii) collects, analyzes and publishes information of domestic and international research which are relevant to agriculture, forestry and fisheries as well as farming systems in these developing areas, iii) through the above, JIRCAS seeks to contribute solutions to global food and environmental problems as well as to the stable supply of agriculture, forestry and fisheries resources. For details, please visit: *www.jircas.affrc.go.jp*

# Contents

# Foreword

In Asia, rice and wheat are the two major staple foods ensuring the food security of almost 57 per cent of world's population and livelihood of 80 per cent of small holder farmers of the world. Recent concerns about food security and food price volatility have highlighted the critical role of cereals for both food and nutrition security of the poor and vulnerable. In Asia, attention has remained focused predominantly on rice as the region produces almost 80 percent of global rice. However, the importance of wheat in Asia - which supports the livelihoods and provides assured income to a large number of poor, small-scale farmers - has largely been overlooked.

World will need around 1090 million tons of wheat by 2050 to meet the growing needs from its current production level of 680 million tons. To meet this demand, developing countries should increase their wheat production substantially and more than 80 per cent of production increase in developing countries should come from vertical expansion. The production target has to be achieved especially when productivity growth in wheat has slowed down and the average productivity of Asia is even lower than global average.

To address above concerns, a regional consultation on “Improving Wheat Productivity in Asia” was jointly organized in Bangkok, Thailand on 26-27 April, 2012 by the Food and Agriculture Organization of the United Nations (FAO) and the Asia-Pacific Association of Agricultural Research Institutions (APAAR1), in collaboration with the International Maize and Wheat Improvement Center (C1MMYT), the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Japan International Research Center for Agricultural Sciences (JIRCAS). The consultation was attended by 53 participants representing national agricultural research systems (NARS), CGIAR Centers, FAO, APAARI, non-governmental organizations, farmer organizations and the private sector. It provided a platform to all the stakeholders to share their knowledge and experiences, learn from lessons, assess future trends and prepare a road map to accelerate the overall production and productivity of wheat, taking into consideration the impacts of climate change and (he declining natural resource base.

The consultation covered five technical sessions: i) strategy for increasing wheat productivity, ii) national/regional wheat scenario, iii) managing wheat diseases, iv) stakeholder dialogue, and v) addressing emerging challenges. In addition, two Working Groups on: a) research priorities and need assessment, and b) development initiative for inclusive growth were held to identify policy, research and development needs. The in-depth discussions helped in bringing out key recommendations to overcome (he challenges and enhance wheat production and productivity in the region.

We welcome the decision of the consultation to have a Regional Wheat Alliance (RWC) established to promote wheat production in the region through an integrated manner, ensuring required policy framework and e-networking. We firmly believe that this initiative will help in strengthening wheat research and development activities and their effective linkages in the region.

This publication includes the recommendations and extended summaries of invited papers presented in the regional consultation. We appreciate the valuable contributions of the speakers and other participants in making this event a success. It is expected that the investment in wheat research and development will receive high priority in future food security agenda at the national, regional and global levels. We hope that the recommendations of this important and rather timely regional consultation will draw attention of policy-makers, administrators, researchers, farmers and other stakeholders alike in implementing them to increase both wheat production and productivity in Asia.

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Regional Representative for Asia and the Pacific

**Raj Paroda**
Executive Secretary
APAARI

# Acronyms and Abbreviations

| | |
|---|---|
| ACIAR | Australian Center for International Agricultural Research |
| AICW&BIP | All India Coordinated Wheat & Borlaug Improvement Project |
| APAARI | Asia-Pacific Association of Agricultural Research Institutions |
| APR | Adult Plant Resistance |
| APRC | Asia-Pacific Research Committee |
| APSA | Asia and Pacific Seed Association |
| APSIM | Agriculture Production System Simulator |
| ARIA | Agricultural Research Institute of Afghanistan |
| ARI | Agricultural Research Institution |
| ANSOR | Afghanistan National Seed Organization |
| AR4D | Agricultural Research for Development |
| ASEAN | Association of Southeast Asian Nations |
| AUDPC | Area Under Disease Progression Curve |
| AVRDC | The World Vegetable Center |
| BADC | Bangladesh Agricultural Development Cooperation |
| BARC | Bangladesh Agricultural Research Council |
| BARI | Bangladesh Agricultural Research Institute |
| BGRI | Borlaug Global Rust Initiative |
| BISA | Borlaug Institute for South Asia |
| BMGF | Bill & Melinda Gates Foundation |

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|---|---|
| *Bp*LB | *Bipolaris* Leaf Blight |
| CA | Conservation Agriculture |
| CAAS | Chinese Academy of Agricultural Sciences |
| CCSHAU | Chaudhary Charan Singh Haryana Agricultural University |
| CEO | Chief Executive Officer |
| CGIAR | Consultative Group on International Agricultural Research |
| CHA | Chemical Hybridizing Agent |
| CIP | International Potato Center |
| CID | Carbon Isotop Descrimination |
| CIMMYT | International Maize and Wheat Improvement Center |
| CMS | Cytoplasmic Male Sterility |
| CRI | Crown Root Initiation |
| CRP | CGIAR Research Program |
| CSISA | Cereal System Initiative in South Asia |
| CSO | Civil Society Organization |
| CTD | Canopy Temperature Depression |
| CWANA | Central and West Asia and North Africa |
| DAE | Department of Atomic Energy |
| DDG | Deputy Director General |
| DAC | Department of Agriculture and Cooperation |
| DFID | Department For International Development |
| DG | Director General |
| DOA | Department of Agriculture |
| DNA | Deoxyribonucleic Acid |
| DRRW | Durable Rust Resistance in Wheat |

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|---|---|
| DSSAT | Decision Support System for Agrotechnology Transfer |
| ECOSA | Economic Cooperation Organization Seed Association |
| DWR | Directorate of Wheat Research |
| EGP | Eastern Gangetic Plains |
| EGPSN | Eastern Gangetic Plains Screening Nursery |
| EGPYT | Eastern Gangetic Plains Yield Trial |
| EIAR | Ethiopian Institute of Agricultural Research |
| FAO | Food and Agriculture Organization of the United Nations |
| FAT | Farmer Acceptance Test |
| FFT | Farmer Field Trial |
| FHB | Foliar Head Blight |
| FIRB | Furrow Irrigated Raised Bed |
| FLD | Front Line Demonstration |
| GAP | Good Agricultural Practices |
| GCARD | Global Conference on Agricultural Research for Development |
| GCC | Global Climate Change |
| GCISC | Global Change Impact Study Center |
| GCP | Generation Challenge Program |
| GDP | Gross Domestic Product |
| GFD | Grain Filling Duration |
| GFR | Grain Filling Rate |
| GH | Grain Hardness |
| GIBS | Genomic and Integrated Breeding Service |
| GIS | Geographic Information System |
| GM | Genetically Modified |

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|---|---|
| GR | Green Revolution |
| GSP | Grain Softness Protein |
| GPS | Global Positioning System |
| GWAS | Genome Wide Association Study |
| GWP | Global Wheat Program |
| HI | Harvest Index |
| HMW | High Molecular Weight |
| HMWGS | High Molecular Weight Glutenin Subunit |
| HSI | Heat Sensitivity Index |
| HYV | High Yielding Varieties |
| IARC | International Agricultural Research Center |
| IBIS | Indus Basin Irrigation System |
| IARI | Indian Agricultural Research Institute |
| ICAR | Indian Council of Agricultural Research |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| ICM | Integrated Crop Management |
| ICT | Information Communication Technology |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IFPRI | International Food Policy Research Institute |
| IGP | Indo-Gangetic Plains |
| INHERE | Institute of Himalayan Environmental Research and Education |
| ILRI | International Livestock Research Institute |
| INRA | National Institute of Agronomic Research |
| IPCC | Inter-Governmental Panel on Climate Change |
| IPR | Intellectual Property Rights |

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|---|---|
| IPM | Intergrated Pest Management |
| IRRI | International Rice Research Institute |
| ITPGFRA | International Treaty on Plant Genetic Resources for Food and Agriculture |
| IWIN | International Wheat Improvement Network |
| IWMI | International Water Management Institute |
| IWWIP | International Winter Wheat Improvement Program |
| JIRCAS | Japan International Research Center for Agriculture Sciences |
| KARI | Kenya Agricultural Research Institute |
| KBRL | Karnal Bunt Resistant Line |
| LBRL | Leaf Blight Resistant Line |
| LDC | Less Developed Countries |
| LMW | Low Molecular Weight |
| LWMGS | Low Molecular Weight Glutenin Subunit |
| LR | Lert Runt |
| MAIL | Ministry of Agriculture, Irrigation and Livestock |
| MAS | Marker Assisted Selection |
| MasAgro | Sustainable Modernization of Traditional Agriculture |
| ME | Mega Environments |
| MHA | Million Hectare |
| MAHYCO | Maharashtra Hybrid Seed Company |
| MOA | Ministry of Agriculture |
| MOAC | Ministry of Agriculture and Cooperation |
| MT | Million Ton |
| MTS | Membrane Thermo Stability |
| NARC | Nepal Agricultural Research Council |

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|---|---|
| NARS | National Agricultural Research System |
| NARES | National Agricultural Research and Extension System |
| NBPGR | National Bureau of Plant Genetic Resources |
| NCAP | National Center for Agricultural Economics and Policy |
| NEPZ | North Eastern Plains Zone |
| NGO | Non-Government Organization |
| NIASM | National Institute for Abiotic Stress Management |
| NPT | New Plant Type |
| NSC | National Seeds Cooperation |
| NUE | Nitrogen Use Efficiency |
| NUWYT | National Uniform Wheat Yield Trials |
| NWPZ | North West Plains Zone |
| NWRP | National Wheat Research Program |
| OPV | Open Pollinated Variety |
| PARC | Pakistan Agricultural Research Council |
| PAU | Punjab Agricultural University |
| PD | Project Director |
| PGR | Plant Genetic Resources |
| PPB | Participatory Plant Breeding |
| PPP | Public Private Partnership |
| PPVFRA | Protection of Plant Varieties and Farmers' Rights Authority |
| PSU | Public Sector Undertaking |
| PTOS | Power Tiller Operated Seeder |
| PVS | Participatory Varietal Selection |
| RAW | Regional Alliance on Wheat |

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|---|---|
| QTL | Quantitative Trait Loci |
| R&D | Research and Development |
| RCT | Resource Conservation Technology |
| RIL | Recombinant Inbred Line |
| RNFS | Rural Non Farm Sector |
| RWC | Rice Wheat Consortium |
| R4D | Research for Development |
| SAARC | South Asian Association for Regional Cooperation |
| SACAN | South Asian Conservation Agriculture Network |
| SAU | State Agricultural University |
| SCPI | Sustainable Crop Production Intensification |
| SDS | Sodium Dodecyl Sulphate |
| SI | Strategic Initiative |
| SR | Stem Rust |
| SMTA | Standard Material Transfer Agreement |
| SRM | Stem Reserve Mobilization |
| SSR | Seed Replacement Rate |
| SRR | Simple Sequence Repeat |
| THT | Terminal Heat Tolerance |
| TKW | Thousand Kernal Weight |
| TLS | Truthfully Labelled Seeds |
| TPE | Target population Environment |
| USAID | United States Agency for International Development |
| USDA | United States Department of Agriculture |
| WFS | World Food Summit |

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|---|---|
| WPEP | Wheat Productivity Enhancement Project |
| WRC | Wheat Research Center |
| WUE | Water Use Efficiency |
| WYC | Wheat Yield Consortium |
| YR | Yellow Rust |
| ZT | Zero Tillage |

# Executive Summary


Wheat is the second largest food security crop in Asia. Recent estimates indicate that world will need around 1090 million tons of wheat by 2050 from its current production level of 680 million tons. To meet this demand, developing countries should increase their wheat production by 77 per cent and more than 80 per cent of demand should come from vertical expansion.

Taking the above facts in view, FAO and APAARI in collaboration with CIMMYT, ICARDA and JIRCAS organized a "Regional Consultation on Improving Wheat Productivity in Asia" on 26-27 April, 2012 in Bangkok, Thailand to apprise the member countries on the current status of wheat research and development, share experiences, and develop strategies to enhance wheat production to meet the projected demand by 2050. The countries that participated in the regional consultation included Afghanistan, Australia, Bangladesh, China, DPR Korea, India, Iran, Mongolia, Nepal, Pakistan, Thailand and Uzbekistan. A total of 53 participants including the representatives of CIMMYT, ICARDA, JIRCAS, APAARI, FAO, regional NARS, NGOs, CSOs, farmers and the private sector attended. The two day consultation was divided into inaugural session, five technical sessions, two working group discussions and a plenary session.

A total of 26 scientific papers were presented which pertained to five thematic areas: i) strategy for increasing wheat productivity, ii) national and regional wheat scenario, iii) managing wheat diseases, iv) stakeholders dialogue on CRP 3.1 (Wheat), and v) addressing emerging challenges. Besides, two working groups were formed to discuss both research and development related issues.

The presentations on strategy for increasing wheat productivity addressed the major research efforts made for breaking yield barriers through germplasm sharing, pre-breeding, conventional breeding, collaborative/ regional testing, and use of new tools and techniques like precision phenotyping, biotechnology, etc. In order to address the emerging climate change scenario, greater focus was stressed on developing biotic and abiotic stress tolerant varieties and resilient management practices for wheat production system. The need to explore new opportunities of GM and hybrid wheat with more than 30 per cent heterosis was also highlighted.

The technical session on national/regional wheat scenario mostly covered the importance of exchange of germplasm with specific traits (biotic, abiotic stress tolerance) and their collective evaluation and sharing of results. For this, a need was felt to establish a regional platform/alliance for advancement and sharing of new

knowledge, germplasm, tools, techniques and practices, for example, stress tolerant germplasm, conservation agriculture based practices, use of small farm machinery, and capacity building, etc.

The disease management strategies were also discussed elaborately. It was highlighted that diseases are not confined within the borders of a particular country and hence, it was considered important to take collective and coordinated action at the regional level for survey, surveillance and early warning. It was also cautioned that emerging diseases are a concern which require institutions like FAO to take lead in terms of awareness that can mobilize resources to tackle the problem.

The session on stakeholders dialogue on CGIAR Research Program on CRP 3.1 (Wheat) which was officially launched in January 2012, was led by CIMMYT. It was pointed out that through the new CRP, an opportunity for collaboration and sharing research strategies and knowledge has emerged. As 50 per cent of wheat is grown in Asia-Pacific region, major support from this program should come to this region. A strong partnership around this program was recommended in order to reap the maximum benefits through involvement of all stakeholders.

In the last session on addressing emerging challenges, the resource persons advocated promotion of conservation agriculture (CA) and highlighted major issues under the conventional tillage based production systems and how CA can help in addressing these issues. Also, issues of adaptation and mitigation to climate change were discussed in detail.

The key highlights of regional consultation on wheat were summarized in the concluding session. Three major areas highlighted for focussed attention included policy, research and development for enhancing productivity of wheat in Asia. It was emphasized that there is a need to develop and popularize wheat cultivars that can withstand the adversaries of weather and soil. The global, regional and country specific research needs would require higher investments, close regional collaboration and mutual understanding to address future threats and constraints in order to ensure food security. Long-term research and development needs must also be kept in view. It was emphasized that food and nutritional security for the people of Asian region could be addressed through increased production of wheat and rice. There is also a need for enhanced focus on the use of alien species, hybrid technology and biotechnology. Environmentally sustainable small farm mechanization requiring support from all the stakeholders also needs to be given due attention. Therefore, regional cooperation among FAO, APAARI, CG Centers like CIMMYT and ICARDA, ASEAN and SAARC is extremely necessary to exchange ideas and learn from each other's experiences.

Various action points and recommendations pertaining to the establishment of a Regional Alliance on Wheat (RAW) through facilitation by FAO, APAARI and CIMMYT and to develop a Road Map for future directions for research, development and policy issues emerged. These proceedings cover the details of various deliberations and recommendations emanating from the regional consultation on wheat.

# Regional Consultation on Improving Wheat Productivity in Asia

## Introduction

Wheat is the second important source of food calories (21%) after rice and the largest source of protein (20%) to 4.5 billion population of the developing countries (Braun et al., 2010). By 2050, the demand for wheat in the developing world will be 60 per cent higher over current level (CIMMYT, 2011). In the Asia-Pacific region, it is the second staple food grain after rice and grown under diverse production systems and ecological settings. Though, wheat has been a key food security crop in the region, its role for food as well as nutritional security has been steadily increasing. During the past half a century, excellent strides have been made in global wheat production but during the past decade or so, the growth in wheat productivity gains has steadily been declining across major wheat production ecologies, posing challenges for the food and nutritional security of the region. Moreover, the instability and vulnerability in aggregate production and productivity of wheat further exacerbates the challenges.

The global wheat harvest during 2010-11 was about 682 million tons from 227 million hectare land with an average productivity of 3.0 tons per hectare. However, the productivity in Asian countries which occupied 45 per cent of acreage remained much below (2.23 t/ha) the global average and contributed only 33 per cent in global wheat production (FAO, 2010-11). The global population is projected to be 9 billion by 2050 of which the Asian countries alone will be inhabitating more than 55 per cent. Therefore, to meet the food demand of ever growing population, the food production in developing countries has to be increased by 77 per cent by 2050 essentially from the same or even less land and water resources. The Asian countries have to produce > 400 million tons of wheat by 2050. As there is no further scope for horizontal growth, most of the production gain (> 80%) has to come essentially through productivity enhancement and sustainable intensification. However, there is a wide variation in the productivity amongst the wheat growing countries of the world. For example, the productivity in Central Asia and Caucasus is 1.4 tons per hectare, while in the European Union, it is around 5.3 tons per hectare. In Asia, wheat productivity is 2.3 tons per hectare which indeed is very low as compared to the world productivity of 3.02 tons per hectare and bridging this gap alone can produce 80 million tons of additional wheat in the region that is expected to meet 2050 demand scenario. However, most Asian countries are experiencing yield plateau due to compound effects of low genetic enhancement, natural resource depletion, emerging biotic and abiotic stresses, volatile input costs and climate change effects. This emphasizes on the need to produce more from less favourable environments, on less and inferior quality land, and with less water and energy resources.

This warrants new thinking, direction and strategy for innovations in agricultural research for development (AR4D). For attaining major productivity gains while addressing the emerging challenges to keep pace with population growth, the "Three Pillar Strategy" that includes genetic enhancement, agronomic management and enabling policies, will have to play a critical role.

The genetic variability is the very basis of any crop improvement program and the wild relatives, landraces and genetic stocks are the important sources for new genetic diversity. However, with the use of conventional breeding tools and approaches, the genetic potential of available germplasm resources though exploited but the yield gains were less due to low investment. Hence, there has not been any quantum yield gain in the new varieties. Moreover, the current efforts on research for developing wheat hybrids are rather limited and without much success. This warrants reorientation of the wheat improvement strategies with greater emphasis on developing high yielding, stable, superior grain quality and more resilient genotypes through integrating conventional breeding and biotechnological tools. Hybrid technology has paid dividends in several crops including self-pollinated crops like rice which has led to rice revolution in many parts of the world. Hence, hybrid technology is one potential option for breaking the yield barriers in wheat. With the projected climate change effects on biotic stresses and new crop management scenarios, genetically modified (GM) wheat may play important role in future productivity gains and needs attention of researchers and policy makers for developing effective strategy for research on GM wheat.

To cope with emerging challenges of natural resource degradation, escalating input costs and declining farm profits while improving the productivity, the new agronomic management practices based on the elements of conservation agriculture and precision farming have shown promise under different production systems in diverse ecologies and farming situations. However, there has been significant genotype × management interaction which many times limits potential gains of either of components (genotype and management), if they are not compatible. Therefore, tailoring genotypes for different crop management scenario and production systems should also find place while reorienting breeding strategies to capture genotype x management interactions. Though seed is a basic and critical resource for crop production but despite the major efforts on developing new genotypes/ cultivars, the efficient and region-specific seed systems of these genotypes are lacking in most of the developing countries of the region. Hence, farmers do not have timely access to quality seed. Therefore, a suitable mechanism for region-specific seed systems needs to be in place to ensure good seed replacement rates and avoid any pest/disease out-break due to use of age-old and susceptible genotypes.

Several region specific technologies and innovations are in advance stages of experimentation but the lack of a regional common platform for sharing these technological advancements and information and lack of trained human resources at different levels and scales are the major deterrent in accelerating the pace of adoption of new technologies for their impact on enhancing wheat productivity in the region. Hence, greater partnerships for regional learnings, information and technology sharing (for example, CRP 3.1 on Wheat) are a must for harnesssing potential benefits of the technologies in the homologous ecologies/regions. Also, there is need for a complete shift in our approach from R&D to R4D as there exists large gaps between research and development and hence we need to effectively translate research into appropriate technology packages that are adaptable to local situations and production systems. Technology development *per se* will not be able to make transformations if a mechanism is not in place for enabling policy environment, effective communication, extension and capacity building for greater uptake and farm level impact of these technologies. Information Communication Technologies (ICTs), for example, cell phone based SMS services with quality and farmer friendly information can help in real time access to information by the large number of farmers. Innovation systems and pathways for participatory adaptation of technologies should form the integral part of technology development and delivery process to develop consensus among different stakeholders and define recommendation domains of the technologies. Also, enabling policies for resilient practices and environmental services to farmers should find a place in new AR4D agenda.

Against this background, a "Regional Consultation on Improving Wheat Productivity in Asia" was jointly organized by the Food and Agriculture Organization of the United Nations (FAO) and the Asia-Pacific Association of Research Institutions (APAARI), in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Japan International Research Center for Agricultural Sciences (JIRCAS) at Bangkok, Thailand on 26-27 April, 2012. The consultation was attended by 53 participants representing national agricultural research systems (NARS) from Afghanistan, Australia, Bangladesh, DPR Korea, India, Iran, Mongolia, Nepal, Pakistan, Thailand and Uzbekistan, CGIAR Centers, FAO, APAARI, non-governmental organizations, farmer organizations and the private sector. The consultation provided a platform for all the stakeholders to share knowledge and experiences, learn from lessons, assess future trends and prepare a road map to accelerate the overall production and productivity of wheat, taking into consideration the impacts of climate change and the already limited natural resource base.

The consultation was organized into five technical sessions: i) strategy for increasing wheat productivity, ii) national/regional wheat scenario, iii) managing wheat diseases, iv) stakeholder dialogue, and v) addressing emerging challenges. In addition, two Working Group sessions: 1) research priorities and need assessment, and 2) development initiative for inclusive growth were held to identify policy, research and development needs. The in-depth discussions were held in different sessions and the outcomes of the discussions were summarized in the plenary session.

## Objectives

The specific objectives of the regional consultation were as follows:

- To provide a regional platform to share experiences and assess national/ regional priorities for enhancing wheat production in the region
- To develop a common strategy to address emerging problems in the region
- To develop mechanisms to facilitate the exchange of knowledge and products and to learn from each other's successes and failures
- To develop a 'Road Map' for enhancing wheat productivity and production in Asia for improved livelihood of resource poor smallholder farmers

## Inaugural Session

The regional consultation commenced with the welcome address by **Dr. Raj Paroda**, Executive Secretary, Asia-Pacific Association of Agricultural Research Institutions (APAARI). In his welcome address, Dr. Paroda highlighted that wheat in Asia is not only a staple food but also important for nutritional security of the region. He mentioned that it is a matter of pride to be associated with wheat programs at global level that brought laurels to the world population particularly in Asia with several countries becoming self sufficient in terms of wheat production. However, the decelerating productivity growth rate of wheat which has came down to less than 1 per cent is not matching with the population growth of 1.8 per cent. For attaining the projected global demand of 1090 million tons of wheat by 2050, the annual production growth has to be 1.6 per cent which essentially has to come from productivity enhancement as there is no further scope for horizontal expansion. Therefore, the three pillar strategy of genetic enhancement, agronomic management and enabling policy has to play critical role to meet the growing demand on a sustainable basis. This calls upon the prioritization of research and development agenda for enhancing productivity while addressing the emerging challenges of wide management yield gaps, deteriorating natural resources, complexities of biotic and abiotic stresses and changing climates.

Dr. Paroda mentioned that there are number of options available for breaking the yield barriers in wheat provided that the issues of narrow genetic base and major biotic stresses such as stripe and stem rust diseases are dealt with integrating conventional breeding with molecular tools and with greater synergy among the stakeholders. He further emphasized the need of optimization of production systems and resource endowments to harness enhanced productivity with efficiency while addressing the impact of projected climate change. New strategies including integrating molecular tools with conventional breeding for quality improvement and value addition in wheat for enhanced nutritional security should also be given thrust under the changing scenario of food habits and globalization of agriculture.

Dr. Paroda further emphasized that agronomic management practices not only for wheat but in a systems perspective have to play key role under the emerging natural resource constraints and changing patterns of demand and supply balances of inputs (water, nutrient, labour, energy, etc.) that have direct bearing on the farm profitability. The conservation agriculture

(CA) based management practices have paid dividends in wheat systems of Asia and are getting attention of farmers and policy makers and planners. But, the breeding strategies are still commodity focused and under conventional tillage based practices due to which the full potential of these technologies is not realized. The breeding strategies, therefore, need to be reoriented to capture genotype × management interactions. The CA based technologies which are currently being adopted on nearly 2 million hectares can be adopted on atleast 12 million hectares to address the challenges of deteriorating soil health, declining water tables, labour and energy shortages. However, local adaptation through participatory approaches, innovation networks, capacity building and knowledge sharing mechanism needs to be in place for accelerated adoption of these knowledge intensive technologies by the smallholder farmers. Therefore, to meet the growing wheat demand for the ever increasing population on a sustainable basis in the region while adapting to climate change effects, not only the technology development but also efforts on convergence, partnerships and enabling policy environments are critical.

**Dr. Masa Iwanaga**, President, Japan International Research Center for Agricultural Sciences (JIRCAS), Japan, in his special address mentioned that wheat is a widely grown crop covering diverse climates, soil types, and production conditions and is an integral part of food chain in Asia due to its history and product use. He further emphasized that wheat crop is sensitive to climate change and is also vulnerable to diseases like rusts, etc. The stagnating yields, regional yield gaps, and shrinking profitability that exist even in the developed countries are the cause of concern to all of us. He also highlighted that fertilizer use efficiency and value chain components in wheat systems are to be addressed adequately to meet future food demand in the region.

**Dr. Thomas Lumpkin**, Director General, International Maize and Wheat Improvement Center (CIMMYT) in his chairman's remarks presented the scenario of wheat crop in India, pattern of cereal consumption in Asia and China vis-à-vis per capita consumption in both developing and developed countries. He highlighted that wheat trade by 2050 will be primarily controlled by US, Canada, Australia, Black Sea region, China and Argentina. The global changes would require researchers to look at water, energy, climate change, food demand, diversity and nutrient efficiency in a holistic manner. Dr. Lumpkin said that large yield gaps in wheat in Eastern Gangetic Plains of South Asia need special attention to produce additional wheat with available technological options. He concluded his remarks by the statement that the biodiversity, tolerance to abiotic and biotic stresses, photosynthetic efficiency, decision support tools, small farm mechanization and precision farming, and supply of good quality seed at right time and place will give solutions to many of the present day constraints. Dr. Lumpkin further added that the Borlaug Institute for South Asia (BISA) has been jointly established by Indian Council of Agricultural Research (ICAR) and CIMMYT and this institute will have research focus on these issues.

**Mr. Hiroyuki Konuma**, FAO Assistant Director General and Regional Representative for Asia and the Pacific, in his inaugural address, highlighted that wheat and rice are the staple food crops and main source of energy globally particularly for vegetarian population. He emphasized that growing concerns for production and productivity gain in major wheat growing countries are to be addressed locally as well as regionally, since many of the problems are common across countries. The enhanced production has to come from less water, less lands and less chemicals by promoting ecologically sustainable approaches for different production systems. There are many challenges due to climate change, soil degradation, fertilizer cost, heat and drought, productivity stagnation and emerging new biological threats. There is a slow down in productivity growth in whole Asia except China. Against this backdrop, this regional consultation is very important and timely. Dr. Konuma was of the opinion that there exists a vast potential of achieving the target production of wheat, provided that the research and developmental efforts are carried forward in right direction.

Dr. Konuma showed a concern that increasing temperature is a major threat and hence, breeding strategies will have to be reoriented to develop wheat varieties which are tolerant to temperature fluctuations and have resistance to new virulent diseases and pests. Therefore, concerted efforts on the part of researchers, extension workers, farmers and policy makers are needed to improve soil health, input use efficiency and the yield potential of wheat crop in the region.

He concluded that we have a good opportunity during the next two days to review and discuss major issues for increasing productivity and production in different countries in Asia with emphasis on managing biotic and abiotic stresses in view of changing climatic scenario. The task of fulfilling the increasing demand for food in general and for wheat in particular is very challenging under the current scenario of climate change, productivity stagnation and emergence of new diseases and insect-pests. Mitigating these challenges requires understanding of the reasons associated, options available and designing an effective strategy with new technologies, enabling policies and establishment of new networks and collaborations. In view of this, it is necessary to put more concerted efforts for the improvement of wheat production and productivity and thus calls for an urgent action to review the current scenario of wheat production and to develop strategies to enhance productivity for sustained food and nutritional security. Dr. Konuma further emphasized that close partnership, regional efforts, FAO's priority for Asia's food production and representation of various wheat growing countries in this consultation will be very helpful in ensuring the food and nutritional security of Asia.

**Subash Dasgupta**, Senior Plant Production Officer, FAO Regional Office for Asia and the Pacific delivered the vote of thanks.

## Technical Sessions

### Technical Session I. Strategy for Increasing Wheat Productivity

**Chair:** *Dr. S. Nagarajan*

**Co-Chair:** *Mr. Mirdad Panjsheri*

**Rapporteur:** *Dr. Gyanendra Singh*

In this session, five presentations covering the global and regional perspectives on strategies for increasing wheat productivity were made by the representatives from Consultative Group on International Agricultural Research (CGIAR), National Agricultural Research Systems (NARS) and private sector organizations. Brief summary of the presentations and major highlights of the session are given below:

**Dr. Hans J. Braun**, Director, Global Wheat Program, CIMMYT while making his presentation on regional scenario of wheat in Asia, highlighted that Asia is the largest producer of wheat (280 m t) but has highly variable national yields ranging from 1.4 tons per hectare in Kazakhstan to 5.6 tons per hectare in Saudi Arabia. He further mentioned that major Asian wheat producing countries that were involved in the green revolution are today self-sufficient in wheat production with a few exceptions. But, meeting the projected 60 per cent higher wheat demand by 2050 in the developing world (mostly in Asia), where yield growths during 1995-2006 remained around 1 per cent, is a major challenge as this will lead to short fall in the needed 25 per cent increase to keep prices at the current level. He further emphasized that the climate-change-induced heat and water stresses and natural resource degradation are estimated to reduce wheat production in developing countries where 60 per cent wheat is produced. In this regard, he highlighted the need for new studies on consumption patterns, forecasting production statistics and also demand supply issues. Dr. Braun talked about the stagnating yields and developing strategies to enhance yield gains through germplasm enhancement and sharing, international testing, parental characterization, conventional breeding, exploitation of distant gene pools, double haploids, genomic selections, synthetics, application of physiology, developing hybrid wheat, improved agronomy, disease resistance and enabling policies. He also emphasized the challenges in wheat quality improvement and value addition under the global climate change scenarios. He highlighted that future productivity gains will come through systems approach and it is high time to develop and provide a good gene package of high yield, stability, wide adaptation, disease resistance and quality. He stressed that high yield potential and drought tolerance for improved water use efficiency need more attention. There is a need to have network of phenotypic platforms to generate reliable and repeatable data, and better understanding of heat and drought tolerance. While concluding his presentation, Dr. Braun emphasized on higher investments by both private and public sectors on wheat research and development.

**Dr. R.C. Sharma**, International Center for Agricultural Research in the Dry Areas (ICARDA), on behalf of Dr. S. Rajaram, presented the strategy for increasing wheat productivity highlighting the projections of wheat for Central and West Asia and North Africa (CWANA) and South Asia in the light of global production. While highlighting the importance of wheat in the developing countries, he stressed that small shortage in wheat supply can cause big price shocks particularly in developing countries and make market highly volatile. He further mentioned that genetic gain in wheat during the last thirty years has been about 1.5 per cent per year. However, to meet the growing demand, this needs to be raised to at least 2.0 per cent per annum. The major challenge of yield barriers is to be tackled through hybrid wheat, exploitation of alien gene pool, improved water use efficiency, enhanced heat and drought tolerance, application of genomics, transgenics, and developing new wheat genotypes using new tools and advanced technologies.

**Dr. K.C. Bansal**, Director, National Bureau of Plant Genetic Resources (NBPGR), ICAR, India made a presentation on germplasm conservation through use and role of biotechnology in wheat improvement and covered various issues to make better use of available and new germplasm. He expressed that it is time to initiate pre-breeding activities across institutions to address the constraints for wheat productivity. Dr. Bansal said that a paradigm shift in the functional model, genome wide selection studies, trait-based reference collections, variability assessment for specific traits and providing value added germplasm to breeders are some of the options that are to be adopted using an integrated and holistic approach.

**Dr. Usha Barwale Zehr**, MAHYCO, India presented the progress of work on hybrid wheat and herbicide tolerance at MAHYCO and shared the status of hybrid wheat research, constraints, challenges, opportunities and options to make use of hybrid wheat technology for increasing productivity. Dr. Barwale informed that MAHYCO is currently marketing one hybrid in Central and Peninsular India and many more are in the pipeline. She further mentioned that for commercial cultivation of hybrid wheat, there is a need of economically viable level of heterosis. Though, there are many challenges for the hybrid wheat production but it appears to be economically viable for small scale farmers. It was highlighted that herbicide resistance against some weeds is reported and a team of scientists is working on introducing glyphosate tolerance in wheat using both GM and non-GM approaches. It was pointed out that for such studies, several cycles of testing are required before the product is ready for commercialization.

**Dr. A.K. Joshi**, CIMMYT, Nepal presented the status of regional collaboration for wheat research in Asia. He pointed out that for livelihood security, wheat in Asia is very crucial as each 1.0 per cent growth in wheat can reduce poverty by 0.5-1.0 per cent. However, for attaining this growth in wheat while addressing the serious issues of resurgence of super races and germplasm exchange, regional collaborations are critical. Citing the example of Mexico-Kenya shuttle breeding program for managing stem rust problem, he stressed on the need for creating such networks at regional level through regional and international collaboration. He further, highlighted that in view of emerging challenges (climate change, new pathotypes, post-harvest losses, socioeconomic issues) and opportunities (hybrid wheat, biotechnology, conservation agriculture, etc.), the regional collaboration is very critical not only for sharing germplasm but also for knowledge and capacity enhancement.

## Key Highlights

- For enhancing wheat productivity, major research efforts need to be made on breaking yield barriers through pre-breeding, conventional breeding, germplasm sharing, collaborative regional testing, and new tools and techniques like phenotyping, biotechnology, etc.
- To address the emerging climate change effects, greater focus should be on developing biotic and abiotic

stress tolerant varieties and resilient management practices for wheat systems.

- There is a need to explore new opportunities for developing and using GM and hybrid wheat with more than 30 per cent heterosis through collaborative and a mission mode approach to address the major challenges of hybrid wheat, for example, greater genome size (17GB), non-availability of diverse cytoplasm sources, assembling favourable genes from diverse genetic resources, high seed rate and production cost, etc.
- The available germplasm need to be characterized and used to contribute genes for specific traits related to stress tolerance and high yields.
- Reorientation of breeding strategies is extremely necessary to capture genotype × management interactions.
- Integrated approach of agronomic, genetic and physiological interventions need to be deployed for future productivity gains.
- There is a need to develop appropriate mechanism for regional surveys and surveillance for the occurrence of new races of pathogens and pests and to develop location-specific management practices with special reference to conservation agriculture adapted to smallholder farmers.
- Inter-regional cooperation needs to be established/strengthened for exchange of germplasm, production technology and information. Also, there is a need for regional collaboration for enhancing investment in research and development.
- There is a strong need to strengthen capacity building in frontier areas to develop core competence and socioeconomic studies for assessing regional demand-supply scenario to design right policies for increasing profitability.

## Technical Session II. National/ Regional Wheat Scenario

**Chair:** *Dr. Thomas Lumpkin*

**Co-Chair:** *Dr. Shahid Masood*

**Rapporteur:** *Dr. S.S. Singh*

In this session, the regional and national wheat research and development scenario were presented by wheat research leaders from regional NARS from the Asian countries. The brief summary of each presentation and major highlights of the discussion during the session are presented below:

**Dr. M.J. Uddin**, while presenting the wheat scenario in Bangladesh, mentioned that agriculture sector is the back bone of country's economy contributing 21.7 per cent to gross domestic product (GDP) and engaging 48 per cent of labour force in agriculture and agro-based industries. Bangladesh is facing problem of rapid population increase and reduction in agricultural land area and there is very little scope to bring more area under cultivation. Wheat area decreased by 50 per cent from 0.773 million hectares in 2000-01 to 0.374 million hectares in 2010-11. Similarly, wheat production has also gone down from 1.67 million tons in 2000-01 to 0.972 million tons in 2010-11. However, in case of productivity, there is increase from 2.16 tons per hectare in 2000-01 to 2.60 tons per hectare in 2010-11. The Wheat Research Center under Bangladesh Agricultural Research Institute (BARI) is responsible for conducting research on wheat crop and in the past 50 years, it has released 28 varieties of which the recently released varieties are high yielding with tolerance/resistance to biotic and abiotic stresses. Emphasis is now being laid on industrial quality and two varieties, BARI Gom22 and BARI Gom24, possessing high gluten content were released in 2005. BARI Gom27 was found to have adult plant resistance to Ug99. Resistance to leaf rust in high yielding varieties is governed by seven major genes including adult plant resistance gene *Lr34*. The good level of tolerance to spot blotch has been observed in new varieties. Dr. Uddin also informed that good research work is in progress in soil and crop management including optimization of fertilizer requirement and its placement options. Acid soils are being amended through application of dolomite lime and other aspects of soil management such as nitrogen use efficiency (NUE), straw and soil fertility have also been taken care of. Conservation agriculture is becoming a reality due to adoption of machines by farmers such as power tiller operated seeder, power tiller operated bed planter and zero till drill which save time, energy, water and seed and reduce the production cost.

Dr. Uddin mentioned that there exists a huge gap in yield mainly due to late planting of wheat in rice-wheat cropping system, sterility due to micronutrient deficiency and depletion of organic matter, etc. Leaf blight is the major disease of wheat in Bangladesh followed by leaf rust, head blight and black point. Rodents and birds are the other major biotic constraints in wheat production. Among the abiotic stresses, high temperature at the time of grain filling is the most damaging as 50 per cent wheat area is planted late due to late harvesting of rice in rice-wheat crop rotation. There is a great loss in production due to less water availability at critical crop growth stages and also water logging due to rains at seedling stage causing stunted growth. Spike sterility due to boron deficiency and soil acidity in north-western part of Bangladesh are also responsible for significant yield losses. In southern region, high salinity at sowing time is causing problem in the expansion of wheat area.

To address the challenges including climate change, Dr. Uddin suggested for developing high yielding varieties with tolerance to abiotic stresses, resistance to biotic stresses and possessing high input use efficiency. There is a need for maintaining continuity for survey and monitoring of new diseases and new pathotypes. He emphasized on strengthening conventional breeding programs through the use of molecular tools, ensuring crop management for enhancing productivity, conservation agriculture, participatory varietal selection and quality seed production and its horizontal spread to farmers' fields for enhancing wheat productivity. He informed that productivity of wheat crop in Bangladesh can be enhanced in future through vertical increase in yield by developing new varieties, quality seed, timely seeding, recommended doses of fertilizers and irrigation, and use of improved management technologies.

Dr. Uddin further mentioned that in order to sustain and increase wheat production in Bangladesh, more efforts should be made to expand wheat area where annual precipitation is reducing due to global climate change. Simultaneously, artificial recharge of ground water table should be done. There is scope for increasing 0.3-0.4 million hectare area in southern region. Further, strengthening collaborative research programs with international organizations especially in the fields of breeding for abiotic and biotic stresses including biotechnological research needs to be taken up vigorously. More emphasis is needed on participatory adaptive research and rapid dissemination of new varieties and technologies to the farmers.

**Dr. Alain P. Bonjean**, on behalf of Dr. Zhong-hu He, Chinese Academy of Agricultural Sciences, presented the status report on wheat production and technology improvement in China. He informed that China is leading in production as well as consumption of wheat in the world. The country is self-sufficient with production of 118 million tons of wheat from 24 million hectare area under 10 agro-climatic zones of the country. The average productivity was 4.7 tons per hectare during 2011 with increasing trend every year. The area covered under wheat crop has come down from 30 million hectares to 24 million hectares due to priority given to other crops for the purpose of increasing diversity. The major constraint in wheat production is the shortage and quality of water. He informed that the major diseases of wheat are sharp eye spot and take-all and there is not a single variety under cultivation which is resistant to these diseases. The other constraints in wheat production are small holdings, competition between cash and grain crops, global warming, lodging due to increase in seed rate under zero tillage, labour shortage, etc. Top priority in breeding high yielding varieties has been given to the use of world germplasm, increasing grain weight, plant height and high harvest index. Emphasis has also been given on developing synthetics and hybrid wheat but with less success. Efforts have also been made for promotion of conservation agriculture including water saving technologies and developing good quality wheat varieties suitable for noodles and other end use products.

Dr. Bonjean mentioned that the efforts are being made to develop genetically modified wheat with resistance to biotic and abiotic stresses, high yield potential and good end use quality. The government is quite positive in providing support in various ways such as increase in price, funding for research and extension, mechanization and quality seed availability. Future strategies suggested are to increase yield potential under less inputs, improvement in processing quality, promotion of mechanization, public-private-partnership in seed industry, developing two line wheat hybrids, marker assisted selection and genetic transformation to achieve target of producing 120-130 million tons of wheat by 2030.

**Dr. Indu Sharma** presented the status report of wheat improvement in India. She mentioned that the country had record production with 85.93 million tons of wheat from 29.5 million hectare area during 2010-11. India is cultivating three species of wheat, namely, *Triticum aestivum*, *T. durum* and *T. dicoccum* which contribute 95 per cent, 4 per cent and 1 per cent, respectively towards total wheat production. The area under wheat cultivation is divided into six agroclimatic zones. The short duration and high temperature tolerant wheat varieties are being cultivated in central and southern peninsular region. The strength of the country's wheat improvement is the All India Coordinated Wheat and Barley Improvement Project (AICW&BIP) which conducts multi-location and multi-disciplinary trials in all the six zones of the country and has so far released 382 varieties of wheat (377) and triticale (5) for commercial cultivation. There are many constraints in increasing the yield gain which includes narrow genetic base of the available germplasm, increase in ambient temperature due to climate change, water availability at critical stages in some area, changing pest dynamics, high cropping intensity resulting in delayed planting of wheat crop, etc. However, the efforts are being made to enhance productivity through hybrid wheat research, changing plant architecture for high biomass with greater physiological efficiency and stabilizing production through incorporation of genes and their combinations for resistance to diseases especially rusts in newly developed varieties. Molecular markers are being used in breeding programs at some cooperating centers in the country. The perfection of conservation technology in wheat production has resulted in wide utilization of zero-tillage, furrow irrigated raised bed technology, rotavator, happy seeder and laser land leveller by the farmers, thereby achieving record production continuously for the last three years. The concerted efforts are also being made to develop varieties rich in micronutrients such as beta carotene, zinc, iron, etc., and better grain quality for end use products. The quality seed availability to farmers is a major task to harness genetic potential of new varieties and also to narrow down the yield gaps in different agro-climatic zones of the country.

**Dr. Abdolali Ghaffari** presented the status report on wheat in Iran and mentioned that the area covered under wheat crop in 2011 was 6.7 million hectares of which 2.7 million hectares is irrigated and 4.0 million hectares is rainfed with total production of 13.5 million tons in 2011. Iran is generally known for arid and semi-arid climate. Three types of wheat, viz., winter, facultative and spring are being grown in both irrigated and rainfed situations under different agroclimatic zones. There are 28 agroclimatic zones of which 50 per cent receive less than 250 mm rainfall every year, while drought and intense cold are always a limiting factor in wheat production. Stripe rust and Sunn pest are major diseases and pests, respectively. Russian wheat aphid is becoming a problem in cold areas, while common aphid has become a problem in temperate and warmer areas. Other diseases like *Fusarium* head blight and *Septoria* are also gaining importance. The stem rust race Ug99 was reported in 2007 from Broujerd and Hamadan. However, several newly released wheat varieties are found to be resistant to Ug99. The conservation agriculture has not been given due importance in Iran. However, zero-till drills which are less in number are being used as minimum tillage options. Priorities for increasing wheat production are conservation agriculture, early maturing varieties, disease and pest resistant varieties particularly Sunn pest resistant, use of marker aided selection in breeding programs and dissemination of new technologies to the farmers. The major emphasis is needed in developing good agronomic practices.

**Dr. Dhurba Bahadur Thapa**, presented an insight into the wheat scenario of Nepal on behalf of Dr. Dil Bahadur Gurung. He indicated that Nepal has wide diversity in landscape, altitude, topography and temperature. Temperature and rainfall are the main factors affecting agriculture. Wheat ranks third after rice and maize in area and production in the country. The average productivity of wheat is 2.30 tons per hectare. Its contribution to national food security is about 25 per cent and consumption rate has increased at a rate of 2 per cent per annum since 1972. The major factors for increasing wheat production are development of high yielding varieties with resistance to biotic and abiotic stresses along with availability of quality seeds. During 2010-11, Nepal produced 1.75 million tons of wheat from an area of 0.76 million hectares. Dr. Thapa further mentioned that 33 varieties have been released since 1962 including 13 varieties introduced from India and Mexico. Due to climate change, the major constraints in enhancement of productivity are water and fertilizer application, temperature during grain filling and disease incidence. To cope up with the emerging challenges, wheat research program has been strengthened with the objective to breed varieties resistant to biotic and abiotic stresses in addition to higher yield in collaboration with regional and global institutions. Also, emphasis has been laid on developing suitable conservation and crop management technologies, use of molecular tools and public-private-partnership (PPP) in technology generation and dissemination.

**Dr. M. Shahid Masood** in his presentation on country report of Pakistan mentioned that among cereals, wheat was grown on the largest area of 8.90 million hectares with production of 25 million tons and productivity of 28 tons per hectare during 2010-11. About 70 per cent area is irrigated and 76 per cent of the total wheat production comes from Punjab province. The wheat research was strengthened by the Pakistan Agricultural Research Council (PARC) through effective linkages among 26 national and 3 international centers. He mentioned that major priorities of wheat research are breeding varieties with tolerance to abiotic stresses such as drought, heat and salt, tolerance to biotic stresses (rusts and powdery mildew), earliness and good grain quality. The zero-tillage is becoming common in rice-wheat system, while relay cropping is being undertaken in cotton-wheat cropping system. There is also increased use of biotechnology in wheat research in order to reduce time frame in developing varieties, genetic transformation for drought and salt tolerance using simple sequence repeat (SSR) markers and deoxyribonucleic acid (DNA) finger printing of traditional and improved cultivars. He informed that public, private and informal seed sectors are involved in seed production and its distribution. Several collaborative projects with international organizations are also in place for wheat research and development of which Pak-China Phase II Project is focussing on development of hybrid wheat.

**Ms. Tuul Dooshin** presented the country report of Mongolia on behalf of Dr. Baryartulga L. Khagvasuren. She highlighted the impact of climate in Mongolia which is continental in nature with an average rainfall between 200-400 mm and average temperature ranging from -30°C to +30°C. Therefore, the growing season is short with low irrigation and high evaporation rate. During 2011, wheat production was 0.45 million tons from an area of 0.30 million hectares with average productivity of 1.53 tons per hectare. Focus of Mongolian Government is on production and supply of high quality seeds of high yielding varieties adapted to arid climate. The concept of new varieties and seed policy is always a significant issue for the crop sector development and its efficiency. During the past 50 years, 81 wheat varieties including 9 of durum wheat have been released of which 6 varieties covered 72 per cent area during 2011. The major challenges faced by the country are climate hazards causing low productivity, financial problems and land locked nature resulting in high cost of transportation of agricultural products and introduction of innovative technologies. She informed that in future, Mongolia is planning to import farm implements, fertilizers, agro-chemicals and also to upgrade and develop irrigation systems in order to increase domestic agricultural production.

**Dr. Mirdad Panjsheri** presented agricultural production scenario in general and wheat in particular in Afghanistan. He mentioned that out of 4 million hectares total cultivable land area, 45 per cent (1.8 m ha) is irrigated and 55 per cent is rainfed. The total population of the country is 27 million out of which 85 per cent is dependent on agriculture. Wheat is the staple food and therefore, food security and employment generation depends on this crop. As a result of continuous disturbances over the last 30 years, the economy of Afghanistan has shattered due to lack of infrastructure, farm machineries and competent human resource in agricultural research. The significance of wheat crop may be judged from its requirement of 5.18 million tons out of total cereal requirement of 6.30 million tons. However, the production during 2011 was 3.39 million tons with deficit of 1.79 million tons. Wheat acreage is 2.23 million hectares with productivity of 1.52 tons per hectare. The efforts are being made to modernize irrigation systems through construction of 30 new medium and large dams and 2,000 small water reservoirs. Agricultural Research Institute of Afghanistan (ARIA) has 12 departments of which crop improvement department is engaged in introduction of technologies especially wheat varieties from international organizations. The challenges are enormous which include lack of competent man power, farm machineries and agricultural equipments, investment, credit systems for farmers and market. ARIA has challenge to come up in agricultural research and developmental activities using modern technologies with the support of international organizations for food security of the country. At the end of his presentation, Dr. Panjsheri made a request on behalf the Afghanistan Government to all the international institutions for their generous support in agricultural research and development programs of the country.

**Dr. R.C. Sharma**, while presenting report on the status of wheat improvement in Central Asia, mentioned that the Central Asia comprises five countries, viz., Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan with total area of 400 million hectares where wheat, barley, rice and maize are major cereal crops with production of 25.5 million tons. Kazakhstan and Uzbekistan are self sufficient in wheat production, while other countries are also giving high priority to increase wheat production to become self-sufficient. Wheat was produced on 16.13 million hectares with the production of 21.04 million tons and productivity of 1.3 tons per hectare compared to whole Asia which was 2.88 tons per hectare during 2010. Winter wheat occupies larger area than spring wheat. Since independence in 1991, Uzbekistan is leading in wheat productivity with 4.74 tons per hectare due to its national commitment and strong linkages with ICARDA and CIMMYT towards enhancement of productivity and production. Dr. Sharma informed that the major constraints to wheat productivity enhancement in Central Asia are biotic stresses (stripe rust, leaf rust, Sunn pest and cereal leaf beetle), abiotic stresses (drought, heat, salinity and frost) and socioeconomic constraints like funding, infrastructure, manpower, seed, technology adoption and policy. Stripe rust is main threat in winter wheat production causing up to 30 per cent yield reduction and the region has faced 5 stripe rust epidemics in the years 1999, 2003, 2005, 2009 and 2010. The winter wheat varieties, Hazrati Bashir, Gozgon and Elomon released in 2010 in Uzbekistan are resistant to stripe rust. Soil salinity is increasing due to availability of less water required for leaching of salts. Sunn pest resistance is missing in all the popular varieties and hence is a major challenge in wheat productivity enhancement. There is an urgent need for increasing area under stripe rust resistant varieties, improving input use efficiency, narrowing yield gaps, crop diversification by inclusion of legumes in the cropping system, enhancing wheat research investment and increasing the number of competent young researchers.

## Key Highlights

- The major thrust needs to be given on sharing germplasm with specific traits (biotic, abiotic stress tolerance) and their collective evaluation and sharing of results.
- Stripe rust has emerged as one of the major diseases in the region and hence there is an urgent need to put a mechanism in place for preventive measures through organizing joint survey and surveillance activities and deployment of resistant varieties.
- Collaborative evaluation of advanced lines of wheat from all the wheat growing countries in Asia needs to be undertaken.
- There is a need to develop regional platforms/networks for advancement and sharing of new tools, techniques and practices, for example, stress tolerant germplasm, conservation agriculture based practices and machinery, capacity building, etc.
- The nutritional quality issues need to be addressed through biofortification using appropriate strategies including, use of novel germplasm, breeding, molecular tools and management practices.
- Augmentation of research on genetically modified wheat should be given greater focus for enhancing tolerance to heat, drought and salinity stresses to address the climate change mediated yield losses.
- There is a need to develop region-specific effective seed systems to enable the farmers to have easy access to quality seed of potential and locally recommended varieties in time.
- There is a need to develop innovation systems and networks involving public and private sector organizations, NGOs, farmer organizations and service windows for local adaptation, participatory learning and large scale delivery of improved technologies.
- There is a need for higher investment with convergence by public and public sector undertakings (PSUs) on research and development in wheat at the national, regional and global level.
- Strong collaboration with national and international organizations needs to be established for achieving food security.

## Technical Session III. Managing Wheat Diseases

**Chair:** *Dr. Ronnie Coffman*

**Co-Chair:** *Dr. Robert Park*

**Rapporteur:** *Dr. Etienne Duveiller*

Six presentations covering primarily the disease scenario and their management in Asia were presented in this session. The brief summary and key highlights of the discussions during the session are given as under:

**Dr. Ronnie Coffman** made a presentation on 'Borlaug Global Rust Initiative (BGRI) for Managing Wheat Rusts' which involves more than 20 centers world-wide. Rust surveillance had been very effective since 2008 and gene discovery including from wild relatives has led to the identification of 32 new resistance genes. Marker assisted techniques progressed in recent years and marker assisted selection (MAS) is increasingly used by breeders. Breeding efforts based on minor genes had been very effective under the leadership of CIMMYT. The seed multiplication and delivery needs to be given priority attention as the old and obsolete varieties need to be replaced with the new high yielding varieties. Therefore, donors also should come forward to make sure that quality seed reaches the farmers. The 'Durable Wheat Rust Research' community shares information through the BGRI website which may be consulted for more details.

**Dr. K. Vijayaraghavan** supplemented the information and presented the progress of work in South Asia. He talked about gene pyramiding and deployment and illustrated the efficiency of screening in early generations in aggressive hot spots in Kenya and Ethiopia. Data are very fragmented and needs to be analyzed. It serves as a toolbox for rust monitoring.

**Dr. S. Nagarajan** made a presentation on wheat diseases and climate change in Asia and emphasized the role of Central Asia on rust survival and distribution after the shift in crops, namely, the reduction of area grown under cotton and the increase in spring wheat which is more efficient in water use. Climate change is affecting the disease scenarios through changes in crop sequences. He also showed that some genes may lead to increased severity with higher temperatures whereas other genes will be affected by lower temperatures.

**Dr. Robert Park** in his presentation on managing wheat rusts by using minor genes highlighted that the genes tend to be durable and there is a need for more detailed studies to understand how minor genes operate. Dr. Park underlined that past durability does not guarantee durability forever. Thus, pre-breeding efforts need to continue. Gene pyramiding is very important and needs greater thrust. There are also exceptions and some genes i.e. *Sr.*12 behaves like minor genes, which should be kept in view.

**Dr. E. Duveiller** presented a paper on management of wheat diseases in Asia and highlighted the revised priorities for wheat disease resistance and control in the Asian context. The three rusts are global diseases that need to be addressed on priority but foliar blight is the most difficult disease to be resolved in South Asia. *Fusarium* head blight is important in China where the awareness for food safety (less mycotoxin) needs to be enhanced. Wheat blast recently reported only in South America is an emerging disease. However, risk awareness and attention should be given in other continents due to lack of resistance. It does not come from rice. The disease epidemiology needs further understanding and the source of resistance must be identified. He also stressed on breeding for disease and pest resistance and highlighted the need for characterization of source germplasm and breeding for wide adaptation.

**Dr. F. Dusuncelli** shared the experiences from FAO in the integrated management of rust diseases. He emphasized on the need for farmer field schools, training of plant protection officers and creating awareness of stakeholders through relevant meetings bringing people together. There is a need for more information on fungicide availability, efficacy and registration. He also stressed on the need for greater collaboration at regional and global level.

## Key Highlights

- Diseases are not confined within the borders of a particular country and hence it is important that collective and coordinated actions are taken at regional level for survey, surveillance and early warning.
- Emerging diseases are a concern which requires institutions like FAO to take lead in terms of awareness that can mobilize resources to tackle the problem. Addressing wheat blast should receive greater attention.
- Using fungicides is not a reasonable option but more information on fungicide in less developed countries is needed. Legislation and compound registration differ significantly between countries. There is a need for a centralized database including what is registered and is available in each country. This is a real need and challenge. FAO should coordinate the development and maintenance of this database.
- There is a need for capacity building on marker assisted selection in NARS to increase the application of molecular markers in breeding programs for disease resistance in Asia.
- National Agricultural Research Systems (NARS) should join hands for regional coordination for research and development (R&D) in wheat diseases especially in Central Asia.
- An international wheat pathologist should be based in Central Asia to train scientists and the language barrier should be overcome.
- Regional meetings should be organized to exchange experiences between Central Asia and South Asia on regular basis.

## Technical Session IV. Stakeholders Dialogue on CRP 3.1 (Wheat)

**Chair:** *Dr. Raj Paroda*

**Co-Chair:** *Dr. Hans J. Braun*

**Rapporteur:** *Dr. A.K. Joshi*

This special session was organized for stakeholders consultation on CGIAR Research Program (CRP 3.1 on Wheat) led by CIMMYT. Dr. Hans J. Braun, Director, Global Wheat Program (GWP), CIMMYT gave an overview of the CGIAR Research Program (CRP) to set a platform for discussion and feedback of the stakeholders.

The Session Chair, Dr. Raj Paroda while setting the context highlighted that as a result the launch of CRPs due to part of CGIAR change management process, there are more opportunities for collaboration and sharing new research strategies and knowledge. The feedback of stakeholders that involves participants from public, private, NGOs, farmers, CGIAR, and Agricultural Research Institutes (ARIs) will be immensely helpful not only in developing the work plan for AR4D but also in convergence of investments and resources among the wheat community, Dr. Paroda expressed satisfaction that many countries and institutions were represented in the meeting including farmers and NGOs from South Asia.

**Dr. Hans Braun**, spoke on objectives, strategies and stakeholders involvement in CRP 3.1 (Wheat). He informed that CRP 3.1 was officially launched in January 2012 in a meeting at Mexico in which around 300 stakeholders from all over the world participated. He explained the objectives and expectations from this program and informed that in the next few weeks, the partners and stakeholders in different countries will be contacted for getting their feedback on priorities and collaboration interest. He further informed that through this program, CIMMYT is looking for greater impact on poverty reduction. There is a big challenge to boost farm level productivity and hence, we need to act urgently. Therefore, there is a need for much better coordination and avoiding duplication by ensuring that all partners complement each-other. It is important to know where wheat is grown in developing countries and where wheat is really consumed. This will complement middle to high income country investments in national wheat research. There are 2.5 billion poor wheat consumers and 1.2 billion wheat dependent consumers in the world that are to be targeted.

Dr. Braun also explained that the document on 'CRP 3.1 on Wheat' was developed in a transparent way, the feedback was received from 340 institutions and there were consultations with major wheat producing countries. He informed that there are 10 strategic initiatives (SIs) to be taken-up in this program. SI 1 is technology targeting for impact. This will target to increase the effectiveness and impact of wheat research on food security, poverty reduction and gender equity. The approach and outputs include gender audit of wheat strategy, strategic analysis and targeting of new wheat specific technologies, institutional innovations and policy focus on the poor. Other important issues are special tools like rust mapper and wheat atlas. Future of wheat in Sub-Saharan Africa will also be attended since wheat consumption in this region is going up but wheat production is not increasing. SI 2 is on sustainable wheat based system. It will ensure transfer of technology, and address the yield gaps. This initiative involves the hub concept – innovation network, benchmark site for research on the impacts of conservation agriculture (CA) and focal point for regional capacity building. The structure to work together has to be based with farmers. Hubs will be used to test the best-bet technology, demonstration platform, trainings/ demonstrations, platform for relevant research, to integrate the production chain around a common objective and will work as feedback loop to researchers. It will engage in strategic research – value chain analysis, productivity, soil quality, water use efficiency, carbon and nitrogen cycling, trace gas emissions, crop growth and development, phytopathology – soil born diseases, tan spot and *Septoria*. There are 7 hubs in rice – wheat and 2 in cotton-wheat areas. New multiutility and multi-crop CA planters will be developed and tested for rice-wheat and cotton-wheat systems. Dual purpose wheat, genotype × system × tillage and system based innovative seed systems will also be addressed. The Cereal System Initiative for South Asia (CSISA) hubs are expected to impact 4 million farmers. Likewise, MasAgro has been launched in Mexico by Mexican Government so that technologies are transferred to the farmers. The target of MasAgro is to increase the yield of maize by 80 per cent and that of wheat by 20 per cent in next 10 years. ICT is also a high priority.

SI 3 is for increasing the use efficiency of vital inputs such as nitrogen, phosphorus and water. Value proposition is to enable 15 million smallholders in irrigated areas to produce wheat with less fertilizer and water. SI 4 is for high yielding wheat varieties. The proposition is to maintain a 0.9 per cent per annum growth rate through genetics. The other 0.9 per cent gain will come from better agronomy and protection from diseases. CIMMYT and ICARDA will not be able to do it alone and hence, cooperation of national partners is important. Hot spot regions for screening will be deployed much more than before. The outputs expected by 2016 include developing elite lines capable of maintaining productivity in South Asia and other heat stressed regions, enhanced drought tolerance, durable resistance, 20 per cent higher Zn and Fe and 5 per cent gain in grain protein. This SI will also work on developing parental stocks for salinity and salt tolerance, develop population for specific traits and regions, enhance participation of NARS partners in International Wheat Improvement Network (IWIN), molecular marker and genotyping platform continually optimize and validated for increased application efficiency. In SI 5, a durable disease and pest resistance in wheat and enhanced host resistance will be targeted for diseases (mainly rusts) that cause economic loss on 5-50 million hectares and to pests and viruses that affect 2-10 million hectares each. Also, it is not only about breeding for resistance but also for finding agronomic solutions like crop rotation. SI 6 pertains to stable yields in the face of climate change, induced heat and drought stress. It has been established that impact of climate change is already equal to -5.5 per cent for wheat. This SI will work to restore wheat productivity in areas vulnerable to climate change – South and Central Asia. BISA will play major role for heat tolerance and wheat lines with 15-30 per cent higher yields will be developed. Drought is possibly the most important abiotic stress. However, even in irrigated conditions, wheat has to have drought tolerance due to competition of water with high value crops. Synthetic derived lines extract more water from deeper soil profile and hence they are important. Physiology and breeding efforts will need greater collaboration. Airborne tools which can cover several hundred plots will also be used for remote sensing.

In SI 7 on breaking the yield barrier, new ways of achieving the targets will be applied. A "Wheat Yield Consortium" has been established to work on enhancing photosynthetic efficiency, extra biomass translated to grains, physiology and molecular breeding. This initiative will look for effective public-private partnership. There is a need for a holistic approach to bring all leading groups and partners together. It also includes sustainable seed systems to accelerate impacts on high priority basis. SI 8 on seeds of discovery is for tackling the black box of genetic resources. Very few world collections have been utilized so far. Mexican Government is extending support of 5 million dollars annually for global food security. Mexico wants to publish what is in store in germplasm so that it can be used for public good. All available accessions with CIMMYT will be sequenced and after careful analysis will look for more variation. Priority traits are heat drought, wheat blast, tan spot, spot blotch, stripe rust, stem rust, Karnal bunt, Sunn pest, etc. SI 9 is for strengthening the capacity of developing world – wheat institutions and specialists. The time has come when the perception about agriculture and wheat needs to be changed. There is a need for advocacy to make it attractive. Agriculture is not the problem, but it is solution. A new generation of wheat professionals and farmers will be created. In SI 10, wheat will focus on high quality partners – research and development - having common values. The presentation was followed by in-depth discussion.

**Dr. Raj Paroda** briefly summarized the highlights of presentation and opened the floor for discussion. He invited all stakeholders and farmers for participation in the discussion. Dr. Mahboob Hossain, Chief Executive Officer (CEO) of BRAC, Bangladesh, one of the largest NGO in the world, informed about his organization and its programs and activities. He informed that BRAC has 9 Programs in Bangladesh including agriculture, climate change and food security. This NGO also collaborates with CGIAR and other International Centers, namely, International Rice Research Institute (IRRI), International Potato Center (CIP), WorldFish and The World Vegetable Center (AVRDC) and has informal relationship with CIMMYT mostly for maize Program. BRAC has a large seed system and covers about 30 per cent hybrid market of maize. Unless wheat productivity is increased, chance of increasing its area in Bangladesh is very less. A comparative advantage study indicated that import is cheaper than increasing production. If wheat yield is increased upto 3.5-4.0 tons per hectare, then wheat can compete with other crops. He highlighted the role of BRAC in seed system, farmer participatory work and also women involvement. Also, the CRP 3.1 (Wheat) must address climate change effects. Dr. Paroda suggested that BRAC can help in testing new varieties, and their seed production and assessment.

**Ms. Sonali Bisht**, heading an NGO called Institute of Himalayan Environmental Research and Education (INHERE) working in the Himalayas (Uttarakhand, India), informed that their focus is on livelihood and food security, seed production, processing of produce, capacity building and other human resource development programs. They had been trying to engage communities with field trials, climate change adaptation trials and seed production. She wanted to know the kind of NGOs selected and their role in CRP. Dr. Hans Braun informed that the role of NGOs will vary according to countries and activities in different countries. CIMMYT works in Afghanistan for seed production. CIMMYT is very open and will be interested in working with any NGO.

**Mr. Manoj Munjal**, a farmer from Haryana, India informed that most of the area in Karnal district of Haryana State is under rice-wheat system. The farmers need training program and new improved seeds. They also want solution of stripe rust, which is the main problem now. In view of rise in average temperature, heat tolerant varieties are also required. He also shared his experience on conservation agriculture in wheat systems that helped them not only in increasing productivity and reducing cost of production but also in adapting to climate change effects (terminal heat in wheat) and for this, good farm machinery will also be of great help to farmers.

**Mr. Ram Ji**, a farmer from Nepal, informed that wheat planting is often late in Terai of Nepal. So the farmers need varieties that can give high grain yield even if planted late. Participatory variety selection (PVS) approach has proved very helpful and this approach needs greater emphasis.

**Mr. Hasraf Sarker**, a farmer from Bangladesh, informed that 30 per cent of wheat in the country is grown in Rajshahi. He further informed that he gets wheat yields up to 5 tons per hectare, produces seed and has been practicing conservation agriculture which can be a model to other farmers of the region. Dr. Paroda suggested that outscaling of conservation agriculture (CA) is needed which is evident from the impressive yield obtained by a farmer in Bangladesh. In addition, there is a need to look for good niche areas and exchange visits of farmers between the countries for sharing their experiences.

**Mr. Usman**, a farmer from Pakistan mentioned that farmers in Pakistan have lot of talent but they get very little support from the Government. Inputs are costly or not available and electricity is very costly. Water is scarce and running tube wells is not easy. Subsidy has also been stopped by the Government. So, in addition to input availability, the farmers need capacity building and knowledge sharing. Dr. Paroda commented that a policy issue has emerged which is part of SI 1. Dr. Mirdad Panjsheri from Afghanistan informed that in his country, drought is the major problem. In addition, farmers need machinery, subsidy for seed industry development and other technical assistance as being given by FAO. They also need seed certification training for better quality control of seed. Dr. Paroda mentioned that there is great potential for increasing wheat production through regional collaboration. CIMMYT can help through the development of new varieties and pre-breeding programs. Duplication of efforts needs to be avoided since FAO is also doing a lot in seed sector. International Center for Agricultural Research in the Dry Areas (ICARDA) is also working in some countries. Therefore, there is a need to have a holistic approach in a complimentary mode. Dr. Hans Braun informed that CIMMYT has a good collaboration with FAO and ICARDA.

**Dr. Rafiqul Islam Mondal**, Director General, Bangladesh Agricultural Research Institute (BARI) informed that scope of expansion of wheat in Bangladesh is limited due to strong competition with other crops. There is some scope of expansion in coastal areas and other vacant lands having high pH. Also, the Government is discouraging boro rice in north-west Bangladesh due to declining water table and this area can be put under wheat cultivation. Seed production is another important issue since, compared to rice, wheat needs higher quantity of seed. Farmers face the shortage of seed availability at the time of planting. There is a need to strengthen seed production and capacity building of farmers and other stakeholders so that they can produce and save good quality seed. High yielding wheat varieties with heat tolerance are crucial to sustain wheat production. Bangladesh has strong linkages with CIMMYT for wheat research but the collaboration needs to be strengthened with other centers for other crops. Dr. Jaim, Director of Research, BRAC, Bangladesh, informed that in CRP 3.1 (Wheat), the main focus is on improving food security but not improving livelihood of farmers which needs to be given greater attention. He stressed that livelihood of small farmers must be attended urgently. Seed problem is a serious issue and women's involvement in seed storage also needs attention. Linking farmers to market is important and should be appropriately addressed. Dissemination of knowledge and market intelligence needs to be given due attention. There is also a need to catalyze the policy makers.

**Ms. Sonali Bisht** from Institute of Himalayan Environment Research and Education (INHERE) suggested that besides linkage with market, the backward linkage is also important which relates to affordability and accessibility of inputs to farmers. There is need to have foresight for supply-demand scenario which has implications for tomorrow. Dr. Paroda informed that Malaysia is a good example to demonstrate that importing food grains is not a good strategy. They shifted from grain production to the production of rubber and date palm but now shifted back to food grain production.

**Dr. R.R. Hanchinal** highlighted that seed system needs strong attention since availability of seed at right price, time and place is very important. He informed about the good model of participatory seed production developed at the University of Agricultural Sciences, Dharwad, India and suggested that seed village program was highly successful. Certification is sometimes a problem and so truthfully labelled seed (TLS) can be used. Use of ICTs in seed production systems and proper seed storage were also considered important issues. Dr. Masa Iwanaga, President, JIRCAS, wanted to know the procedure for joining one or more initiatives of wheat program. Dr. Hans Braun clarified that survey is going on to analyze the priorities which will be reviewed by a committee and the procedure will be known very soon. Dr. M.L. Jat, CIMMYT suggested that system research is important keeping in view the needs of farmers. Also, there is a need to bring out 'Wheat Systems Atlas' as the research on wheat crop alone will not be able to provide complete solution.

**Dr. Raj Paroda**, informed that in Northern India, growing wheat after December in sugarcane systems is not paying more and we have better options available, for example, spring maize that gives up to 7 tons grain yield per hectare.

**Dr. N.C.D. Barma** from Bangladesh informed that incidence of wheat rust was quite high in the crop season during 2011-12 and stripe rust was seen for the first time in Bangladesh. They need help from CIMMYT and BGRI for rust screening in India and to reorganize their hybridization program. Seed system is being strengthened in Bangladesh and they are giving preference to farmers' seed production as truthfully labelled seed. Dr. Paroda suggested that FAO can support seed program through their technical program which is also linked with CRP. Mr Fazil from FAO agreed to extend FAO's full support for wheat research programs.

**Dr. Hans J. Braun** summarized the major issues as follows:

- Seed production of suitable varieties needs urgent attention. Dissemination of Ug99 resistant varieties through United States Agency for International Development (USAID) project is a good example. Seed replacement takes time and therefore, pre-release seed multiplication is important. Policy makers were convinced about the pre-release seed multiplication. The project got real cooperation in six countries to allow pre-release multiplication. Many countries were not doing it before as seed multiplication was used to be done after the varieties are released. This is costly exercise as there could be drop outs, but was highly successful.
- For wheat rusts, there is a need for organizing one more meeting. A good monitoring system exists but policy makers are difficult to be convinced to stop multiplying susceptible varieties. Syria was hit by wheat rust for two years in a row due to cultivation of susceptible varieties. Now susceptible varieties are being stopped. Likewise, Ethiopia is also now releasing only rust resistant varieties.
- Bangladesh has areas where rice–rice cropping system is followed with 90 days gap. For such areas, there is need for super early wheat varieties.
- In Afghanistan, the seed sector is now being increasingly addressed and a few new projects are under consideration.
- One of the most important objectives is to address the issues of resource poor farmers. There is impact targeting and value chain analysis; Hubs will also play significant role in their own way.

The Chair, Dr. Raj Paroda concluded that this is a good opportunity for all of us to build strong partnership. Asia-Pacific region grows 50 per cent of wheat and, therefore, major share of funds from CRP 3.1 should come to this region. The initiatives that are already there must get partnership in the program so that there is greater synergy for outputs. Policy issue is important for future of wheat in some countries. For resource poor farmers, supply-demand scenario has to be kept in view and institutional support in the region should be available e.g. National Center for Agricultural Economics and Policy (NCAP) in India and IFPRI. APAARI has earlier endorsed this program. Partnership for research in wheat should also be developed with advanced research centers like JIRCAS and Sydney University where there is good leadership. Breaking the yield barrier will be a challenge and seed has to be given a high priority.

Capacity building is equally important and partners have to be involved effectively. Addressing the concern of climate change must find high priority. The stakeholders should come forward to be partners who help in many ways but there is a need to identify right partners. There is good scope of deploying participatory approach in many countries. There are important policy issues such as - investments to support wheat research in different countries so that we know how much is being spent in wheat research and development in different countries. This data can make the case for countries that are spending less on wheat compared to others. Dr. Paroda further suggested that effective partners are important and hoped that there will be good representation from Asia-Pacific region on the management committee of this CRP.

## Key Highlights

- Seed systems need to be strengthened in almost all developing countries.
- Capacity building of farmers, scientists and other stakeholders including women needs to be strengthened.
- There is a great need to adopt farmer participatory approaches in implementing the activities under CRP 3.1 (Wheat).
- Greater thrust needs to be given on the development of varieties possessing resistance to diseases, particularly durable resistance, heat tolerance, short duration, water-use efficiency, and other traits that can address adaptation to climate change.
- Policy aspects need to be given greater thrust particularly with respect to linking farmers to market and providing them market intelligence and other vital inputs.
- Cropping system research along with conservation agriculture must be given greater attention.
- Building strong partnership with advanced research institutes in the region and also among national research institutions and with farmers and other stakeholders be given due emphasis

## Technical Session V. Addressing Emerging Challenges

**Chair:** *Dr. Masa Iwanaga*

**Co-Chair:** *Dr. R.R. Hanchinal*

**Rapporteur:** *Dr. M.L. Jat*

Six presentations addressing the major challenges were made in this session. The brief summary of each presentation and the key highlights of the discussions during the session are summarized below:

**Dr. M.L. Jat** made a presentation on promoting conservation agriculture (CA) and highlighted major issues under the conventional tillage based production systems and how CA can help in addressing these issues. He cited the example of delayed planting of wheat in eastern Gangetic Plains of South Asia that leads to large yield losses. Optimizing cropping systems through targeting appropriate crop varieties of both rice and wheat with conservation agriculture based management practices plays a key role in advancing planting of either crop, escapes terminal heat and attains higher yields. He mentioned that adoption of conservation agriculture based management practices and their component technology for local adaptation is a must. There is a need to develop regional and sub-regional networks for 'basic-strategic-applied research-capacity building-knowledge sharing-delivery continuum' to serve as learning centers. The herbicide resistant wheat has to play important role under changing management scenario and has to find place in the breeding programs of the national systems as well as CGIAR and ARIs. Special focus should be laid on capacity building at different levels (researchers, extension agents, service providers, farmers, etc.) and scales (local, regional, international level). For accelerated adoption of CA based management practices, the emphasis should be on creating full time and value chain service window to serve the twin purpose of providing real time services and facilitate technology led small-scale rural business. Laser land levelling in India is one successful example of such kind which provides employment to rural youth to the tune of 3.5 million person days/year at current number of laser units (more than 10,000 in India). Public-private partnerships should be strengthened through pooling resources for common goals of reaching farmers with better understanding and synergy on technologies, prioritization of investments and linking different programs for greater impact. Systematic database-management, curation, access, sharing mechanism and use should form integral part of R&D. He concluded that an effective mechanism should be developed for common regional platforms, knowledge sharing and consultations.

**Dr. Mustaq Ahmad Gill** made a presentation on enhancing wheat production and productivity through resource conservation technologies in Pakistan and emphasized that major technical and socioeconomic challenge is adoption of conservation agriculture techniques. He said that socioeconomic factors are significant barriers being faced by smallholder farmers to increase wheat production and productivity. Pakistan has rice-wheat rotation in sizable area where average wheat yield is between 2.2-4.0 tons per hectare depending on holding size. The large number of wheat growing farmers in Pakistan practice rice-wheat crop rotation and are smallholders having huge potential that remain untapped to enhance wheat productivity. The major wheat productivity limiting factors include lack of improved agronomic practices, non-availability of quality seeds, limited access to conservation tillage and farm machinery, uncertain crop support price, and lack of effective research and technology backup to majority of farmers in the country. The feedback information from the case studies suggests that the wide variation in wheat production and productivity amongst farmers particularly smallholders and large farms can be bridged through amelioration of socioeconomic constraints. In conclusion, he highlighted that there is need to develop suitable farm policies and strategies for large scale adoption of resource conservation techniques and to provide a road map that can enhance wheat productivity and farmers' livelihood in rice-wheat areas of Pakistan.

**Dr. S. Naresh Kumar** addressed the issues of adaptation and mitigation to climate change. Under the business as usual scenario, the projected increase in temperatures due to climate change effects is likely to affect the crop production by 10-40 per cent by the end of current century in the Indian sub-continent. The projected impact of climate change on wheat indicates that if suitable adaptation measures are not taken, with every rise of 1°C temperature throughout the growing period, a loss of production in India alone will be to the tune of 4-5 million tons per year. The losses could be as high as 19.0 and 27.5 million tons with respective increase in temperatures by 3°C and 5°C. The post-anthesis temperature is crucial factor for the maximum kernel weight in wheat and each 1°C rise in temperature above the optimum can cause a 3-5 per cent reduction in grain weight which ultimately translates in yield and quality losses. The terminal heat/ high temperature stress leads to reduction in grain growth duration which is the major cause of loss in productivity. The decline in the rate of grain growth is mostly due to a decrease in the rate of starch accumulation. In addition, rapid leaf senescence is one of the major causes of yield reduction as it impedes supply of photosynthates for grain development. He mentioned that tolerance to heat stress is a difficult trait due to genetically and physiologically complex traits which are highly influenced by the various environmental factors during growth and development of grains. He also emphasized on understanding the target environments which is vital for designing wheat for high temperature environment as adaptation of genotypes is often location specific. Genotype × management interaction has to play key role in thermal tolerance. Taking into consideration the underlying complexities in mechanisms of tolerance to high temperatures and individual contribution of several traits so far reported, an appropriate strategy should be developed to identify the genes and stack them in suitable genetic background that matches with the target environment and resource management practices. There is a need to intensify food production systems through establishing and strengthening technology and input delivery systems and linking farmers with market. Also, there is a need to promote conservation agriculture based crop management technologies for improved land and water management, improved resource use efficiency and adaptation to climatic extremes. He was of the opinion that the time has come to develop suitable policies to provide incentives to farmers for resource conservation and use efficiency, pricing of resources, and giving credit for transition to adaptation technologies.

**Dr. J. Rane**, in his presentation on developing terminal heat tolerant wheat, highlighted various areas that can have possible influence on wheat yields under changing climate. Dr. Rane highlighted the precision phenotyping and its importance with particular reference to physiological interventions. He was of the opinion that persistent efforts through genetic, physiological and breeding approaches need to be made so as to develop wheat genotypes tolerant to high temperatures. For this purpose, several traits associated with thermal stress tolerance, their influence on grain yield and combining quantitative trait loci (QTLs) through combination of conventional breeding approaches and molecular tools are needed. He emphasized on understanding the complex mechanism, and developing appropriate strategy and suitable resource management practices to enhance yield potential of future wheat genotypes to mitigate possible impacts of climate change.

**Dr. R.K. Gupta** made a presentation on improving quality traits and informed that with the diversified uses of wheat for industrial purposes, systematic efforts should be made for breeding wheat cultivars for quality traits by selecting parents and advancement of generations and target them in different regions in accordance with product specific quality requirements of that region. The projected climate change will have effects on the quality of wheat. For example, gluten strength has less influence by the elevated $CO_2$ but protein content for flour decreases significantly with increased $CO_2$ concentration. Also in general, there is some increase in protein content at high temperature, but there is change in the glutenin/gliadin ratio and thus adversely affects quality. Therefore, new breeding strategies should have these considerations in view in addition to climate resilience and yield.

**Dr. H.S. Gupta** made a presentation on current status and future strategies for seed production in Asia. He stressed on the need to encourage seed enhancement mechanism and technologies for more viability of seed and also develop regional cooperation in quality seed supply, for example, APSA (1994) and SAARC Seed Forum (2010). He further mentioned that there is a need to develop a common variety list and harmonized quality assurance system for SAARC countries for seed supply. In self-pollinated crops, small farmers tend to produce and use farm- saved seed to the tune of 60-70 per cent, except in warm and humid areas where the vigour and viability of seed decline rapidly. In the global scenario of climate change, farmers are frequently facing newer challenges of abiotic and biotic stresses. Thus, there is a greater need to replace old varieties with new improved ones. Hence, adoption of new varieties can be achieved only by increasing the seed replacement rate (SRR). In conclusion, he proposed the following strategies for increasing seed production: (i) maintenance of seed chain:breeder-foundation-certified, (ii) involvement of public sector agencies-self-pollinated and high volume crops, (iii) encouragement to private sector, (iv) farmers' participatory seed production, (v) better and fast institutional mechanism for seed certification, and (vi) developing efficient seed distribution network.

## Key Highlights

- Large management yield gaps in wheat exist particularly in Eastern Gangetic Plains of South Asia and the major factors contributing this are poor crop establishment and delayed planting. Conservation agriculture based technologies and appropriate cultivar choices in wheat systems have helped in bridging the yield gaps and hence needs strategies for accelerated adoption.
- Conservation agriculture practices provide opportunities for resilience in production systems, sustainable intensification through optimization of cropping systems and conservation of natural resources.
- The basic elements of CA remains the same, however, for realizing potential benefits, the recommendation domains of the component technologies (water, nutrient, weed, cultivar choices, seed rate, depth etc.) need to be defined through participatory adaptation to meet local needs.
- Significant genotype × management interactions have been observed and hence the breeding strategies need to be reoriented in order to capture G × M interactions and define the domains of the genotypes and realize potential yields.
- As immediate strategy to cope with climate change effects, the farmers should be assisted with establishment of weather services, agro-advisories, insurance and community banks for seed and fodder.
- Research programs need to be strengthened for enhancing adaptive capacity on climate change monitoring and warning systems.
- Intensive efforts are required for developing nutritionally superior wheat varieties enriched with iron and zinc using molecular tools as well as agronomic manipulations.
- Breeding strategies should be reoriented to develop micronutrient enhanced wheat cultivars without compromising tolerance to abiotic/biotic stress, crop productivity, and acceptable end-use quality.
- Greater thrust needs to be given on developing value chain for wheat products and linking farmers to market.
- There is a great need to increase seed replacement rate (SRR) through developing robust seed systems.

To attain this, there is a need to encourage public-private-partnership and implement seed village/valley concept in farmer participatory mode for local seed systems.

- Investments in modern technologies e.g. conservation agriculture, precision agriculture, sensor based polymer coats, flash treatments (electronic magnetic/heat/electron, etc.) are very high and hence partnerships with technology providers and seed growers need to be adequately strengthened.

## Working Group Discussions

Focussed discussion to identify research priorities and need assessment on research and development initiatives for inclusive growth were organized involving key resource persons in related fields and were moderated by an eminent expert. The key issues and recommendations emerged from the two working group discussions are summarized below:

## Working Group 1. Research Priorities and Need Assessment

**Facilitator:** *Dr. H.S. Gupta*

The first group involving 28 participants from Asian countries, CIMMYT, ICARDA, APAARI and FAO had in-depth discussion on prioritization and need assessment for future wheat research in Asia. The key issues/recommendations emerged are summarized below:

### *Augmenting genetic capacity for enhancing productivity and adaptation*

- Increasing biomass and harvest index (HI) for improved grain yield
- Development of terminal heat tolerant varieties with high revival capacity
- Strengthening biofortification of wheat
- Developing and strengthening research program on hybrid wheat
- Development of synthetic wheat varieties
- Developing transgenic (multiple stress tolerant) varieties
- Initiating efforts for converting wheat from $C_3$ to $C_4$ crop
- Developing twin strategy (genotype × management) for increasing input use efficiency of water and nutrients
- Enhancing system productivity through developing sustainable intensification strategies with focus on conservation agriculture and precision farming
- Promoting mechanization for timeliness of operations
- Greater thrust on developing effective seed production systems

### *Leveraging policy options to enhance productivity*

- Strengthening inter-institutional and regional (inter-country) cooperation for information/knowledge/technology sharing in Asian region.
- Promoting the exchange of varieties with simplicity of IPR guidelines
- Developing strategies for bridging inter- regional yield gaps

***Informatics and computational biology with focus on phenotyping***

- Establishing mechanism for developing, managing and sharing database for wheat systems
- Developing knowledge system on wheat through portal development
- Enhancing use of information communication technology (ICT) for effective dissemination of technology to the end user

***Human resource development***

- Strengthening capacity building at different levels (students, researchers, extension agents, farmers, policy planners) and scales (field to international) in frontier areas of research and development with special reference to Central Asian countries and Mongolia
- Promoting exchange visits of scientists, students, farmers and policy planners

## Working Group 2. Development Initiative for Inclusive Growth

**Facilitator:** *Dr. S. Dasgupta*

The second group comprising 25 participants met to discuss and finalize issues and recommendations related to development initiative for inclusive growth. The group identified various policy issues, input supply system related needs, investment for a small farm mechanization, efficient management of natural resources, strengthening extension system and capacity building. The key issues/recommendations emerged are summarized below:

***Policy***

- Making wheat development an integral part of national policy and ensuring strong political commitment from the government to implement the policy
- Promoting conservation agriculture for sustainable intensification of wheat systems
- Promoting scientific land use planning
- Providing incentives for new niches for the expansion of wheat areas
- Focusing attention on climate resilient agriculture
- Strengthening conservation of plant genetic resources through use
- Focusing on research and enhancing investment in research and development
- Putting special emphasis on needs of smallholder and resource poor farmers and women while developing technologies

***Seed supply system***

- Focusing on quality seed production at farmers level through contract farming
- Providing equal priority to both formal and informal seed sectors
- Establishing community/village level seed banks
- Strengthening partnership program with informal sector to produce quality seeds
- Increasing seed replacement rate
- Promoting small scale mechanization
- Enhancing funding in wheat sector from national sources

***Small farm mechanization***

- Ensuring availability of adaptable technologies suitable for smallholder farming conditions
- Developing entrepreneurship to produce technologies at local level
- Developing indigenous and location-specific technologies

***Natural resource management systems***

- Increasing use efficiency of inputs mainly water and nutrients
- Developing mechanism for carbon credits and incentives for environmental services
- Integrated management practices for agro-chemicals and natural/ indigenous resources

***Strengthening extension systems***

- Developing innovation systems and networks through active participation of all stakeholders at all levels of technology development, adaptation and scaling out strategies
- Strengthening public extension systems
- Developing private extension systems
- Enhancing the role of CSOs, NGOs and farmers in extension systems
- Strengthening knowledge sharing mechanisms among different change agents through developing regional knowledge banks
- Linking farmers to markets
- Developing infrastructure and institutions to promote technology transfer
- Establishing South-South linkage and cooperation at regional level
- Establishing farmers' network at regional level

***Capacity development***

- Organizing informal vocational trainings for the farmers
- Strengthening education and learning process at grass root levels
- Linking women and youth with small enterprises

## Plenary Session

**Chair:** *Mr. Hiroyuki Konuma*

**Co-Chairs:** *Dr. Thomas Lumpkin,*
*Dr. Raj Paroda*

**Rapporteur:** *Dr. Bhag Mal*

The key highlights of different Technical Sessions and the Working Groups were presented by the Rapporteurs/ Moderators. The reflections and remarks by the Chair and Co-Chairs and the key recommendations relating to research, development and policy emerged are given below:

**Mr. Hiroyuki Konuma**, Assistant Director General and FAO Regional Representative for Asia and the Pacific, in his concluding remarks emphasized on three major areas, viz. policy, research and development, for enhancing productivity of wheat as wheat is one of the two most important staple foods in Asia. This region is facing problems of shortage of arable land and water due to increasing population pressure and on top of it, there is increasing threat from climate change affecting the wheat production through biotic and abiotic stresses vis-à-vis food security of the region. He emphasized on wheat improvement through conventional and molecular approaches in order to develop new high yielding wheat varieties in shorter time frame having resistance/tolerance to biotic and abiotic stresses that adversely and significantly affect the wheat productivity. There is increasing need to develop wheat varieties suited to zero till condition and have increased water and nutrient use efficiency due to continuous dwindling of natural resources in Asia. Dr. Konuma indicated that rice-wheat system is the most popular covering larger acreage and thereby affecting soil health and ground water adversely. Hence, diversification of cropping systems is essential. There is an urgent need for adoption of resource conservation technologies and farm mechanization. He stressed on effective linkages between wheat research and extension for faster dissemination of modern technologies benefiting resource poor farmers through increased income and also livelihood security. In order to enhance wheat productivity in Asia where fluctuation in temperature and rainfall is a regular phenomenon in changing climatic situations, there is need to develop medium and long-term forecasting model for sustainable production.

**Dr. Thomas Lumpkin**, Director General, CIMMYT, Mexico highlighted that the favourable climate for higher production may not be a regular feature and therefore, there is a need to develop and popularize wheat cultivars that can withstand the adversaries of weather. The global, regional and country specific research requires more investment in wheat, close collaboration and mutual understanding to address future threats and constraints to ensure food security. He also stressed on developing strategies for outscaling of conservation agriculture producing more from less area and lesser inputs for which good agronomy needs to be continued. He also mentioned that long-term research and development needs must also be kept in view.

**Dr Raj Paroda**, Executive Secretary, APAARI in his concluding remarks was emphatic on food security and nutritional security for the people of Asian region. He stressed on the possibility to increase wheat productivity by 1 ton per hectare in 75 million hectare area in Asia (except China). In order to achieve this target, there is need for adoption of aggressive approach for genetic enhancement through use of modern technologies and natural resource management. He also emphasized on the need for enhanced use of alien species, hybrid technology and biotechnology. Major efforts are needed in outscaling resource conservation technologies to produce more at less costs, improving soil health, and reducing environmental pollution in order to enhance productivity and production of wheat crop. He mentioned that environmentally sustainable small farm mechanization requires support from all the stakeholders. Therefore, regional cooperation among FAO, APAARI, ASEAN and SAARC for close interactions is extremely necessary to exchange experiences and learn from each other. Involvement of private sector and youth is also very important. Also, South-South and North-South partnership is needed for greater collaboration. International organizations like CIMMYT should provide facilitation role towards strengthening wheat improvement activities in these countries. Public-private-partnership in Asia needs promotion aggressively in quality seed production, greater investment in conservation of natural resources and farm mechanization. He emphasized on strengthening extension services for faster dissemination of technologies where NGOs can also play significant role. He gave a call for building up a "Regional Alliance on Wheat (RAW)" for catalysing policy makers through FAO.

**Dr. Bhag Mal**, Consultant, APAARI extended vote of thanks to the organizers, co-sponsors and the participants attending the regional consultation.

## Recommendations

The wheat growing countries of Asia, especially China, India and Pakistan have played critical role in ensuring food security in Asia. In this context, the Green Revolution in South Asia had been a great success story. The world would need around 1090 million tons of wheat by 2050 from its current production level of 680 million tons. This production target has to be achieved especially when productivity growth rate in wheat has declined and the same is even lower than global average in Asia. Hence, improving productivity of wheat is of immediate concern for the Asian wheat growing countries. In this context, there exists large untapped potential for doubling wheat productivity in the region. However, it is also clear that business as usual will not work. The first revolution in wheat was primarily through germplasm enhancement (single pillar). For second revolution, we shall need a 'three pillar' strategy, involving germplasm enhancement, agronomic management and enabling policies.

The major recommendations related to wheat research, development and enabling policies, as emerged during the discussions in the regional consultation, are given below:

### I. *Research related recommendations*

- The reversal of slowdown in genetic gains (breaking yield barriers) needs concerted efforts through effective use of germplasm. Germplasm enhancement/pre-breeding through the use of trait-specific germplasm from genebanks (seeds of discovery) need to be strengthened for developing new plant architecture and advancement of generations using conventional breeding supplemented with biotechnological tools and collaborative regional testing. CGIAR Centers such as CIMMYT and ICARDA should facilitate as well as accelerate the pre-breeding initiatives.
- The breeding programs in wheat need to be strengthened adopting conventional breeding, biotechnology and marker assisted selection. Research on development of synthetic wheat, use of double haploids, hybrid wheat and GM wheat (herbicide tolerant, water and nutrient use efficient) needs a focused and mission mode approach involving all active stakeholders and the CG Centers. There is also a need to establish hybrid wheat consortium at the regional level in order to accelerate the pace of research in this direction.
- Greater thrust needs to be given to breed varieties with multiple/durable resistance against major biotic and abiotic stresses using novel germplasm and molecular tools. Pyramiding genes for resistance to rusts must be given

a high priority attention. Minor genes based multiple resistance also needs to be given preference.

- As a long-term strategy to address the vulnerability of wheat to changing climates and projected shrink in favourable wheat mega environments, photosynthetic efficiency of wheat plant needs to be enhanced. Hence, concerted long-term strategy for conversion of $C_3$ wheat to $C_4$ should be in place. Advanced international institutions, viz., CIMMYT, ICARDA and JIRCAS, in collaboration with regional institutions such as Borlaug Institute for South Asia (BISA), and the stronger NARS should play important role in this basic research area.
- There is a greater need in the present context to develop resilient plant types with better root architecture having improved efficiency in the uptake of nutrients and water, better nutrient partitioning and higher nutrient density grains.
- Special efforts need to be made on bioinformatics and research programs to understand/explore physiological basis of stress tolerance (drought, terminal heat, etc.) and nutritional quality.
- Trans-boundary diseases and pests surveillance regional research networks need to be established to address possible outbreaks of new races of diseases having potential threats, especially in case of stripe rust, leaf rust, foliar blight, stem rust (Ug99), etc. for their effective management.
- Greater thrust needs to be given to regional approach on the development of varieties possessing resistance to diseases, particularly durable resistance, heat tolerance, short duration, water use efficiency, nutrient use efficiency, high nutritional and end-use quality (biofortification). Institution like BISA should have major mandate for this.
- The shuttle breeding programs need to be accelerated for which facilitation role of international centers will be highly critical.
- Renewed efforts need to be made for research on developing and defining resilient wheat production systems having greater synergy with resource endowments particularly to meet the needs of small holder farmers under varied ecologies to harness enhanced productivity with efficiency, while addressing the issues of natural resource degradation and projected impact of climate change. For climate change resilient varieties, new types of genes are required to be incorporated into the varieties. Conservation agriculture based crop management technologies should also form the integral part of this strategy.
- Concerted efforts need to be made for research on dual purpose wheat varieties, crop residue cover needs and crop-livestock interactions in relation to conservation agriculture under irrigated and rainfed ecologies. Such wheat varieties will enable farmers to address their concerns for lack of good quality fodder for their milch animals.
- There is an urgent need for enhancing farming system based productivity through promoting agronomic (water, nutrient, weed management), genetic and physiological interventions and also to introduce resource conservation technologies at small farm level.
- There is an urgent need for basic and strategic research on integrated use of

crop modelling, sensors, geographic information system (GIS), remote sensing, decision support systems and ICTs for climate change monitoring, in-season estimates of crop performance (input application), advance forecasting (pest, disease, weather, yield) and early warning at different scales (local, national and regional level).

- There is a need to address also the issue of quality seed production, storage and supply, through greater public-private-partnership. Also, the seed village concept in farmers participatory mode and establishment of the seed banks in different wheat growing regions will help in achieving higher wheat productivity.

## II. *Development related recommendations*

- Thrust needs to be given to assessment of field level attainable yields using best practices in different agro-ecologies, production systems and farmer typology and define the recommendation domains of the potential technologies for bridging the yield gaps. There is an urgent need to outscale available technologies adopting eco-region specific approach/ strategies.
- Greater thrust needs to be given now on 'resilient agriculture innovation systems' through developing best-bet 'seed-to-seed' technology modules (new seeds, mechanization/CA, improved input management, etc.). Such best practices are to be outscaled under diversified situations using most effective input delivery systems.
- Concerted efforts are needed to develop databases and knowledge and service banks to facilitate women and youth entrepreneurship for effective dissemination of improved technologies including small farm machinery, new seeds, tools, techniques and custom hire services at farmers' door-step.
- Focused attention is needed on capacity building at different levels (research scholars, researchers, extension agents, service providers, farmers, women and farm youth) and scales (local, regional, international level) through informal vocational trainings and capacity building. Special efforts are needed for enhancing capacity of stakeholders especially from Central Asian countries and Mongolia in the areas of breeding, seed production, conservation agriculture, survey, surveillance and monitoring of diseases and pests, etc. A regional mechanism needs to be in place to facilitate the exchange visits of farmers, scientists and policy makers for knowledge sharing. Leadership of FAO in this regard will be highly appreciated.
- Under the projected climate change scenario, the uncertainties and risks of abiotic and biotic stresses are likely to be intensified. Therefore, there is a strong need to develop a suitable mechanism for adoption of resilient varieties targeting high variety replacement rate (VRR) through increased seed replacement rate (SRR) using effective seed chain by ensuring greater public-private-partnership (PPP).
- There is an urgent need to develop infrastructure on post-harvest management, storage, value chain for wheat products, and market infrastructure for linking farmers to market through developing long-term

export strategy in order to provide remunerative prices to the farmers and enhance their income.

- Many farmers of the region are harvesting very high yield levels of wheat. The best practices adopted by such farmers have to be understood and synthesized to know the factors contributing to such high yields and devise appropriate strategies to disseminate the same to other farmers in the region.
- Suitable mechanism needs to be developed to minimize technology dissemination losses and time lag through the non-traditional extension system. Custom hire services need to be encouraged through creation of technology agents (private, entrepreneurs, NGOs, farmers, etc.) to complement the traditional extension that have become relatively less efficient.
- There is an urgent need to define the successful models of public-private partnerships and develop 'technology led business models' for yet greater synergy, outputs and long-term sustainability.

## III. *Policy related recommendations*

- There is an urgent need to establish a "Regional Platform/Alliance on Wheat" in order to share knowledge, germplasm and technologies. Such a platform will help in capacity building in core competence areas and for organizing periodic consultations and review. For this, required support from FAO, CG Centers (CIMMYT, ICARDA) and, APAARI will be necessary.
- The "Regional Alliance on Wheat (RAW)" is much needed for the collaboration in research, development and extension. There is also a need to build the North-South and South-South partnership for required technological breakthrough. The RAW should will facilitate these two processes. There is a need to facilitate the exchange of useful germplasm between countries within the region in order to strengthen their respective breeding programs. Such initiative might be established under the umbrella of RAW. The germplasm can be transferred between countries through the standard material transfer agreement (SMTA) adopted by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). This can be facilitated by the Borlaug Institute for South Asia (BISA), through adoption of suitable policies and procedures.
- The CGIAR Research Program on Wheat (CRP 3.1) should help in building RAW for intensifying wheat research and development in the wheat producing countries in Asia.
- In Asia, there is a need to have a clear policy framework and regulatory mechanism in place to undertake research on developing hybrid wheat, genetically modified (GM) wheat and varieties with specific traits not used before in breeding programs.
- Appropriate policy support should be in place to encourage higher investments for agricultural research for development (AR4D). Suitable policy actions in line with GCARD Road Map and Bangkok Declaration need to be taken to double the investments on wheat research and development in Asia. Also, there is a need for greater

synergy and convergence of research and development schemes and funds for greater impact and increased wheat production.

- Eco-regional niches will have to be defined for both horizontal and vertical growth in wheat production through strategic decisions on investments/incentives considering resource endowments, consumption forecasts, regional food demand and supply chain and possible implications of changes in diet patterns linked to economic development.
- In view of new threats due to changing climate, concerted efforts are required to create awareness and mobilize resources to tackle future problems. Enabling policies need to be put in place for linking farmers to markets by empowering them with required market intelligence and region-specific input/output delivery system, knowledge networks, agro-advisories, weather services, insurance and community banks for seed and fodder. Also policies are needed for compensating smallholder farmers for their environmental services like promotion of conservation agriculture.
- For the use of fungicides, more information is needed about the legislation and compounds' registration in place in different countries. There is a need for centralized database including what is registered and available in each country. FAO could be approached for the development and maintenance of such database.
- There is a an urgency to encourage investments in modern technologies/innovation systems e.g. conservation agriculture, precision agriculture, farmer cooperatives, single-window input services, community based/region-specific seed systems, incentives to farmers for carbon credits, environmental services, improved grain quality, etc.
- The institutional mechanism and required infrastructures in some of the Asian countries are not adequate e.g. Afghanistan, Mongolia, Bhutan, etc. This needs urgent attention of the national, regional and international community to establish and strengthen institutional capacity to support wheat research in such countries in the region.
- There is over production of wheat in some countries, while others are deficient in the production resulting in import from other countries. It is, therefore, extremely necessary that a suitable regional policy is in place to balance the import-export of wheat for long-term food security in Asia. In this context, RAW would help in needed policy advocacy.
- There is an urgent need for greater involvement of private sector through provision of enabling policies especially in areas such as upstream research e.g. GM wheat, hybrid wheat, small farm mechanization and cost-effective input delivery system for which appropriate models need to be identified and promoted on priority.
- A holistic and coordinated approach for research and development on wheat needs to be adopted and duplication of efforts are to be avoided to economize on scarce resources. Also, more focused policy issues should be in place to address the needs of farmers, traders and consumers in the context of supply/demand scenario.

- Quality seed is extremely important input and hence the seed health aspects need to be given high priority. Policy makers in wheat growing countries need to be convinced such that continuous growing of wheat varieties, susceptible to diseases, is discouraged. Also, there is a great need for regional cooperation in supply of quality seed for which an appropriate mechanism/strategy needs to be developed. FAO could facilitate having a regional program on seed development and training in countries such as Afghanistan, Nepal, Bhutan and Mongolia.

## Conclusion and Future Road Map

Wheat in Asia-Pacific region is the second largest staple food crop grown widely in different ecological conditions. Despite, significant achievements in improving wheat production by different countries, the productivity level is still far behind the required target to feed the growing population and have improved livelihood security in Asia. There is yield stagnation leading to instability and vulnerability in aggregate production and productivity. Even the productivity level is below the global average productivity. Hence, there is an urgent need to intensify current efforts and develop suitable strategies for research, development and policy to enhance both production and productivity of wheat for sustained food and nutrition security in Asia. Against this background, a regional consultation on improving wheat productivity was organized in Bangkok which was attended by the representatives from Asian NARS, CIMMYT, ICARDA, JIRCAS, APAARI, NGOs, farmers and the private sector. There were intense discussions in different sessions and working groups on enhancing productivity of wheat that enabled the development of a Road Map for enhancing wheat productivity by the smallholder farmers in Asia. Decision was also taken to establish "Regional Alliance on Wheat (RAW)" for greater collaboration for research, development and extension. It was strongly felt that there is great need for developing North-South and South-South partnership for effective collaboration. Various action points pertaining to the Road Map, future directions for research, development and policy issues and the recommendations emerged for enhancing productivity, profitability, food and nutritional security and sustainable livelihood in the region.

# Extended Summaries of Invited Papers

# 1. Regional Scenario of Wheat in Asia

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Asia is the world's largest producer of wheat with 280 million tons and an average yield of 2.9 tons per hectare (excluding Russia). Southern and Eastern Asia produce 114 million tons each, Western Asia 29 million tons and Central Asia 23 million tons (FAOSTAT, 2010). Average national yields are highly variable. The highest yields are obtained in Saudi Arabia (5.6 t/ha, all irrigated) China (4.7 t/ha, mostly irrigated) and Uzbekistan (4.5 t/ha, mostly irrigated), while yields are the lowest in Central Asia (Kazakhstan, 1.4 t/ha, mostly rainfed). Asia is also the home to more than 50 per cent of the global population and by 2050, every fourth citizen will live in South Asia.

Wheat is the most important protein source and after rice the second most important calorie source world wide. In Asia, its importance varies greatly with more than 50 per cent of all calories coming from wheat in Central Asia. In 2007, Asian countries imported nearly 40 million tons of wheat, mostly non-traditional wheat growing countries or countries with limited wheat production: Japan (5.2 mt), Korea (3.1 mt), Indonesia (2.6 mt), Malaysia (2.4 mt) and the Philippines (2.4 mt). It needs to be emphasized that all major Asian wheat producing countries that were involved in the Green Revolution are today self-sufficient for wheat production with the exception of Afghanistan, Iraq and Yemen. Due to very significant price fluctuations for wheat over the last five years, many countries seek to remain self-sufficient for major staples and wheat plays an important role in this.

Demand for wheat in the developing world is projected to increase by 60 per cent by 2050 (Rosegrant and Agcaoili, 2010) and much of this increased demand is expected in Asia. However, in the world's 20 principal wheat-producing countries, which account for 85 per cent of all wheat, yields rose annually by only 1.1 per cent during 1995–2006 (Dixon *et al.,* 2009), excepting China, where growth is still above 3 per cent per annum. Based on a 1.0 per cent global yield growth rate, wheat production will be only 15 per cent higher by 2025. This falls well short of the 25 per cent increase needed to keep prices at the current level (Rosegrant and Agcaoili, 2010).

At the same time, climate-change-induced temperature increases are estimated to reduce wheat production in developing countries (where around 66% of all wheat is produced) by 20-30 per cent (Easterling *et al.,* 2007; Lobell *et al.,* 2008; Rosegrant and Agcaoili, 2010). Wheat production will also suffer the effects of stagnating or decreasing on-farm productivity, falling irrigation water supplies, declining soil fertility, and threats from emerging diseases and insect-pests. In irrigated cropping systems in Asia (wheat-rice; wheat-cotton and increasingly wheat-maize) wheat is often the crop with the lowest economic value and farmers optimize yields of other crops. Consequently, wheat is sown late and at maturity more exposed to high temperatures e.g. in the rice-wheat system of eastern India, remote sensing studies have shown that at least 60 per cent of the wheat area is planted late. Improving wheat's adaptation to high temperatures in these systems would considerably benefit subsistence farmers. In a survey among farmers in developing countries regarding the impact of global climate change (GCC), farmers were not so much afraid of the impact on increasing temperature *per se*, but of the impact of climate extremes or irregularities on the timing of cropping operations, e.g. delay in sowing due to late rains. The impact of GCC on diseases and pests is reported elsewhere in this publication. Developing wheat cultivars that are adapted to variable sowing times and wheat cultivars with short growth duration become, therefore, one of the highest priorities for wheat breeders in low latitude Asia.

Between 25 and 30 million hectares of wheat in tropical and subtropical areas (including China, Bangladesh, Nepal, India, Pakistan, Ethiopia, Sudan, Egypt, and North Africa) are subject to yield losses from heat stress. This area will increase substantially, according to current trends and predictions about global warming. South Asia's Indo-Gangetic Plains region is especially at risk. This breadbasket created by the Green Revolution currently accounts for 15 per cent of global wheat production and is inhabited by 900 million people, or one-seventh of the world population. It is now considered optimal for wheat farming but, even with carbon fertilization, between 26 per cent and 51 per cent of this breadbasket may be transformed by 2020-2050 from being the most favourable, high-yielding wheat production zone to a heat-stressed, short-season production zone. In India alone, the heat-stressed wheat area is expected to triple by 2050 and temperatures are projected to rise as much as 3-4°C by the end of the century. The greatest impacts will be in the Eastern Gangetic Plains, an area with high levels of rural and urban poverty (Braun *et al.,* 2010).

The compounding impact of receding groundwater table and increasing irrigation cost, could result in the politically risky prospect of South Asia having to import as much as one-quarter to one-third of its wheat by 2050. Together, West Asia and North Africa have the highest per capita wheat consumption; their imports as well as yield losses and year-to-year production swings will increase due to rising temperatures, more severe weather extremes, and decreasing water availability.

Climate change will increase the risk of water deficits in most developing countries. Of the three major staple crops, wheat is the best adapted and most widely grown commodity under semi-arid conditions. The majority of the 90 million hectares of wheat grown in Asia is already experiencing temporary or permanent water scarcity, as a result of either inter- or intra-seasonal rainfall variation (in rainfed systems) or of temporary unavailability of irrigation water. Today, already more than 300 million people are fed with grain produced from over-pumping. Current irrigation systems are frequently inefficient and since water is often provided for free or at insignificant costs, farmers have little incentives to adopt more efficient systems. To produce 1 kilogram grain, wheat requires ca 900 litres water, maize 1,500 litres and rice 1,800 litres, whereby tremendous variation exists among irrigation systems and farmer's practices. Using optimum agronomic practices, best available wheat varieties and the irrigation technology, e.g. laser leveling or drip irrigation, the water consumption for wheat can be reduced by 30-50 per cent to an optimum of around 460 litres water per kg wheat grain produced. Considering that agriculture consumes globally more than 70 per cent of all sweet water and in Asia even more, investments in increasing irrigation efficiency is paramount and the greatest gains in increasing water use efficiency will initially come from improved irrigation technology (agronomy and irrigation systems).

Due to the relatively low value of wheat compared to other irrigated crops, wheat production is likely to expand in rainfed areas and the demand for water use efficient and drought tolerant lines will greatly increase. Since heat and drought often go together, this constitutes a strong argument for enhancing heat tolerance and improving wheat's water use efficiency. Significant advances in gene discovery and in understanding genotype environment interaction have been made through: development of precision phenotyping tools for a range of physiological traits design of a new generation of experimental populations; innovative approaches in statistical analysis and access to a vast database from international nurseries. Major efforts are now underway to evaluate large germplasm collections for traits that potentially can contribute to increased heat and drought tolerance. NBPGR (India) is evaluating the Indian wheat collection (26,000 accessions), CIMMYT is screening all its genebank wheat accessions (ca 150 000 accessions) and so does ICARDA (ca 50 000 accessions). Similar efforts are underway in several other countries. To develop databases that are compatible to each other and that allow comparing data – phenotypic and molecular – are, therefore, of paramount importance. A major objective of the G20 Wheat Initiative is to establish such standards for interested wheat programs.

Wheat is the crop to which the most nitrogen fertilizer is applied globally i.e. 19 per cent of all nitrogen fertilizer. Of the 90.9 million tons of nitrogen fertilizer used globally, 70 per cent is applied in the developing world, most of it in only three countries: China, India, and Pakistan. Nitrogen-use efficiency (NUE = kg grain / kg N applied) in developing countries is commonly only around 33 per cent, but it is economically feasible to increase this level to 65 per cent. In rainfed areas, NUE is intricately linked to rainfall and decision guides linked to weather information for farmers are critical to increasing efficiency. Phosphorus reserves for fertilizer are not unlimited, and peak phosphorus production is likely to reach as early as 2030, after which supplies will be much more difficult and expensive. Agronomic practices that lead to increased NUE, e.g. sensor technology, need to be widely used. Only then will growers benefit fully from the enhanced NUE of future wheat cultivars. To enhance NUE is a high priority for wheat improvement worldwide and at transgenic and non-transgenic options, e.g. introgression of genes from alien species that reduce nitrification through root exudates, are currently evaluated and wheat cultivars with greatly enhanced NUE should be available to grower by 2020.

In the future, more people will live in cities than on the country side which will have major implications for the wheat industry in Asia. While at present many Asian wheat programs pay little attention to wheat quality, quality traits relevant for industrial processing and in particular consistency of quality traits will become rapidly a major breeding priority. Wheat is a major source for calories, protein and nutrients in the diet of millions of resource poor people, and enriching wheat with micro-nutrients like Zn and Fe will have a big impact on reducing the 'hidden hunger'. Wheat cultivars developed under the HarvestPlus Project with 20 per cent enhanced Zn and Fe content in the grain are currently under evaluation in South Asia and are scheduled for release in 2013.

The challenges for wheat improvement in Asia are tremendous. The International Wheat Improvement Network, consisting of world-wide cooperating wheat research institutions was very successful and has prevented major famines since the beginning of the Green Revolution. This network is based on sharing of germplasm and data and also encourages exploration of evolving insights while promoting focused human resource development, workshops, and staff exchanges. However, the challenges ahead require even closer collaboration, since no single NARS or CGIAR Centers like CIMMYT and ICARDA have the in-house expertise and capacity required to tackle such highly complex traits like heat and drought tolerance or increasing the photosynthetic efficiency of $C_3$ crops like wheat. Similarly, the yield gap between farmers' fields and experimental stations is from 40-60 per cent and new technologies like precision agriculture need to be adopted and then adapted by smallholder farmers. Therefore, various major initiatives in wheat research have been started or planned, including:

- The Borlaug Global Rust Initiative (BGRI, led by Cornell University)
- The Cereal Systems Initiative for South Asia (CSISA, led by IRRI)
- The Wheat Yield Consortium (WYC, led by CIMMYT)
- Seeds of Discovery (led by CIMMYT)
- Wheat Initiative (led by INRA, France)

These initiatives bring together world leaders in their respective research areas to produce international public goods available for any wheat researcher worldwide. Until now, wheat research in Asia is mainly conducted by the public sector, while private sector investments have been small compared to other major staples. This may change in the near future as several multi-national breeding companies have expanded their wheat programs or started new programs which also target Asia. To meet the challenge to produce enough food during the coming decades, investments in wheat research need to be increased since in the absence of unprecedented, coordinated measures to raise wheat productivity, wheat consumers will pay more than twice of today's prices for their staple food by 2050 AD.

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# 2. Strategy for Increasing Wheat Productivity

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The global food security depends on adequate production of food grains as more than 70 per cent of energy intake comes from cereals which is the cheapest source. Recently, the per capita food grain production has shown declining trend. Also, the demand pattern is shifting from low priced cereals to high cost livestock products as source calories. This pattern necessitates increase in total grain supply involving decline in food demand but rising feed demand causing food-food competition intense. The small shortage can cause big price shocks particularly in developing countries and make market highly volatile. The food grain production in 2009 was 2,493.62 million tons globally compared to pulses (64.05 mt), oilseeds (162.49 mt) and roots and tubers (735.8 mt). Cereals occupy the largest arable area of 699.19 million hectares. The global wheat production in 2009 was 684 million tons. The demand for wheat in 2025 would be between 800-1,000 million tons. The momentum of productivity growth is slowing down. The genetic grains in the last 30 years have amounted to 1.5 per cent per year, while the genetic gains needed are 2.0 per cent per year. The global average yield needed in 2025 would be 4 tons per hectare to meet the demand of wheat.

The major production constraints globally and in India are foliar disease, low fertilizer doses, soil pathogens and late planting. The accumulated reduction in productivity could be as high as 25 per cent per year. The major challenges in increasing wheat productivity are breaking yield barriers, bridging yield gaps, reducing losses due to biotic stresses and improving adaptation under climate change. In the case of South Asia, avoiding storage losses is of paramount importance.

The priority areas of research and development to increase wheat productivity are investments in hybrid wheat, exploitation of alien and related species, water use efficiency, high temperature tolerance and pyramiding of disease resistance genes. In global setting, the stripe rust fungus (*P. striiformis tritici*) has caused enormous damage in wheat production. Unless it is addressed properly and timely, it has potential to destabilize wheat production from India to Morocco and Ethiopia to Kazakhstan. I believe this regional consultation on 'Improving Wheat Productivity in Asia' has the responsibility to warn NARS and governments of this threat. If there is one most important R&D agenda requiring attention of International Centers, NARS and donors, that would be stripe rust threat.

It is to emphasize that conventional tool of plant breeding would continue to play a major role in improving yields. This has been recently demonstrated by identification of varieties Super 172 and Super 152 by Shriram Fertilizer and Chemical Company (SFC) out of a set of germplasm provided by CIMMYT. These varieties represent on the average 10 per cent higher yield than currently and widely grown cultivar PBW 343. This is a real breakthrough. However, in India, wheat future depends on application of a set of technologies involving breeding, integrated pest management (IPM), water management, hybrid technology and genetically modified (GM) wheat. In conclusion, it is my strong conviction that India, China, and the countries of West and Central Asia need to follow a set of technological interventions which involve genetic, agronomic, chemical, nutritional, rotational and mechanization as it is now routinely done by Australian farmers.

# 3. Strategies for Enhanced Utilization of *Ex Situ* Wheat Genetic Resources to Boost Wheat Productivity: Indian Initiatives

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## Introduction

India contributes 13 per cent of the global wheat sown area and about 12.5 per cent of the global production (FAOSTAT, 2012). With the current average productivity at about 3.0 tons per hectare, efforts need to be strengthened for further increasing productivity to meet the India's increasing wheat demand, which is expected to be up to 101.7 million tons by 2025 (Ganesh *et al.* 2012). Moreover, India's overture at tapping global wheat surplus upsets the prices. Hence, the only way-out is to increase productivity and production. This necessitates breeding new varieties that help fight abiotic and biotic stresses, fit into new areas and cropping systems and provide a means to ensure food as well as nutritional security. The strategy undoubtedly revolves around exploiting the potential of germplasm including wild and related wheat species (Bansal and Sinha 1991a, b), and frontier technologies including genomics and informatics. In the following sections, our efforts in implementing the proposed strategy are illustrated.

## Constraints for Wheat Productivity Enhancement

### Changing climate

Climate change particularly with rise in mean temperature is manifesting in terms of moisture stress bouts and abrupt fluctuations in the temperature (terminal heat stress) during the wheat growing season particularly in north-west plain zone (NWPZ) and north-east plain zone (NEPZ).

## Shrinking water and land resources

Availability of cultivable area (Table 1) and timely availability of water have become serious constraints since the past decade. In India, economic expansion and urbanization have led to severe pressure on the agricultural land resulting in sharp decline rates in the availability of arable land.

### *Lack of pre-breeding efforts*

Development of donor lines by bringing desired traits from new gene pools remains an ignored activity. Pre-breeding becomes a greater challenge if the traits in question relate to abiotic stress tolerance. For instance, although heat tolerance can be improved by selecting and developing wheat genotypes with heat tolerance, pre-breeding may have to be based on secondary traits like membrane stability, canopy temperature depression, photosynthetic rate and grain weight under heat stress. Hence, more close integration of efforts and collaboration among geneticists, plant physiologists, molecular biologists and wheat breeders is required for achieving any tangible progress in wheat pre-breeding particularly in India.

**Table 1.** Availability of land for crop cultivation

| Criteria | World | Asia | India |
|---|---|---|---|
| Arable land* | 10.6 | 15.3 | 53.1 |
| Land area under crops* | 1.2 | 2.5 | 3.9 |
| Rate of decrease in per capita arable land (%) | 1.5 | 1.4 | 2.0 |

*Fraction of total available land (%); Source: FAO (2010)

## Major breeding constraints

### *Narrow genetic base*

Since the early 1930's, Vavilov advocated creation of a broad genetic base for wheat breeding that will include entire intra-specific variability of the species including the variability related to physiological and agronomic traits. Effective utilization of wheat resources requires comprehensive knowledge of their genetics and development of donors, particularly resistance to biotic and abiotic stresses, for breeding high yielding wheat cultivars resistant to multiple stresses. In spite of the efforts of CIMMYT and national breeding programs, experts tend to believe that genetic base of wheat cultivars needs further expansion if the demand for wheat were to be met in the face of biotic and abiotic stresses.

### *Lack of screening and phenotyping methodologies*

There have been standards and descriptors for characterization of gene bank accessions available and followed diligently. However, there are no uniform standards available and followed to carry out trait-specific evaluation. The shortcoming is magnified in case of germplasm screening for various abiotic stress tolerance traits. There are practical problems (technical, instrumentation and cost) in implementing the published methodologies for large scale germplasm screening.

## Exploring the Solutions

### Unlocking natural variation available in the gene bank through genomic technologies

- The lab-to-land gap in the productivity, inability of extant varieties to combat abiotic and biotic stress conditions in long run, need for quality improvement to address nutritional security, uncertainties of the imminent climatic change and yawning gap between the demand and supply necessitate looking for new genes.
- Varietal advancements are built exclusively on the available diversity. New genes are readily available in large number of *ex situ* collections that are collected and conserved over decades in the National Gene Bank at NBPGR. The million dollar question is how to unlock these genes? Traditionally, curators have been characterizing and evaluating the germplasm for identifying the phenotypic traits and donors.
- However, the current phenotyping methods are inadequate and it is not possible to evaluate the entire genetic diversity available in the National Gene Banks (Fig. 1). There is an urgent need to develop field based high-throughput phenotyping methods for various physiological and agronomic traits. In addition, large experimental farms, selection conditions (natural or artificial) and skilled manpower are few to meet the immediate requirements.
- Fortunately though, there are tremendous advancements in the technologies that can help understand the genetic make-up of the accessions in a precise manner. Today, these "genomic" tools have become high-throughput and affordable.
- With the help of modern genotyping and sequencing technologies, gene banks can generate genome-wide patterns of natural variation and associate the patterns with field-level phenotypic observations (Fig. 1).

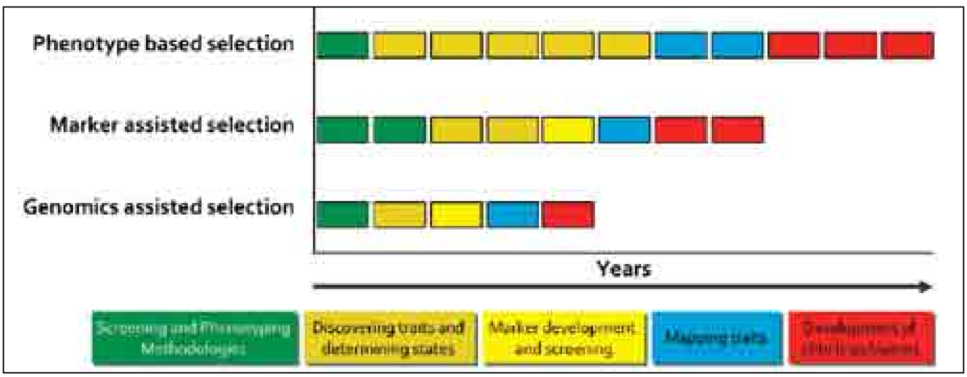


**Fig. 1.** Technology timeline for the utilization of plant genetic resources

(*Modified from Ulukan (2011)*)

## Collaborative efforts between gene banks

- Gene banks of different countries have specific crop-based long-term mandates that cannot be altered, and hence benefit from each other's experience (exchange of information and material).
- Gene banks specialize in specific PGR management aspects such as cryopreservation, seed physiology, herbarium, geographic information system (GIS) tools, taxonomy, *in vitro* culture, pre-breeding, informatics, etc., and hence benefit from each other's expertise.
- Collaboration can be in the form of: (i) collaborative projects, e.g. screening for terminal heat tolerance at different locations, and (ii) starting centers of excellence and exchange programs.

## India's Approach

The National Gene Bank housed at NBPGR holds about 400,000 accessions of which about 6 per cent belong to bread wheat. The wheat germplasm (22,000 accessions) at NBPGR is about 2.5 per cent of the worldwide wheat holdings. However, availability of material from international wheat nurseries for selection every year and incomplete characterization and absence of trait-specific evaluation of the wheat germplasm has led to inefficient utilization of wheat collections conserved in the National Gene Bank.

NBPGR has accorded the highest priority to characterization and evaluation of wheat collections conserved in the National Gene Bank. This activity assumes greater significance in the face of climate change and the need for wheat lines exhibiting tolerance to terminal heat and specific rust diseases.

This beginning nevertheless requires a specific paradigm shift in the functional model of NBPGR. The Bureau (applicable to all gene banks) needs to be transformed from a mere service organization into a vibrant research hub, that connects breeders, pathologists, physiologists and molecular biologists with a purpose of enhanced utilization of the germplam and productivity enhancement.

NBPGR has planned for broadening genetic base by (i) augmenting trait-specific germplasm from CIMMYT and ICARDA, and other gene banks; (ii) enhancing pre-breeding efforts in collaborative mode; (iii) test the feasibility of novel breeding approaches including multi-parent mapping populations; and (iv) employ genomic tools to complement the efforts (e.g. Genome wide association studies (GWAS).

## NPBGR's New Initiative

It is obvious that we need to begin with characterization and evaluation of entire germplasm available in the Indian National Gene Bank. NBPGR started with multiplying about 16,000 accessions of wheat germplasm in *kharif* 2011 (off-season) at IARI Regional Station, Wellington.

In a new initiative (Fig. 2), NBPGR has grown for the first time ~22,000 accessions of wheat germplasm conserved in the National Gene Bank, at three locations. In the first experiment, two sets of 22,000 wheat germplasm, first set under normal sowing (during 1-5 December, 2011 and a second set under late sowing were

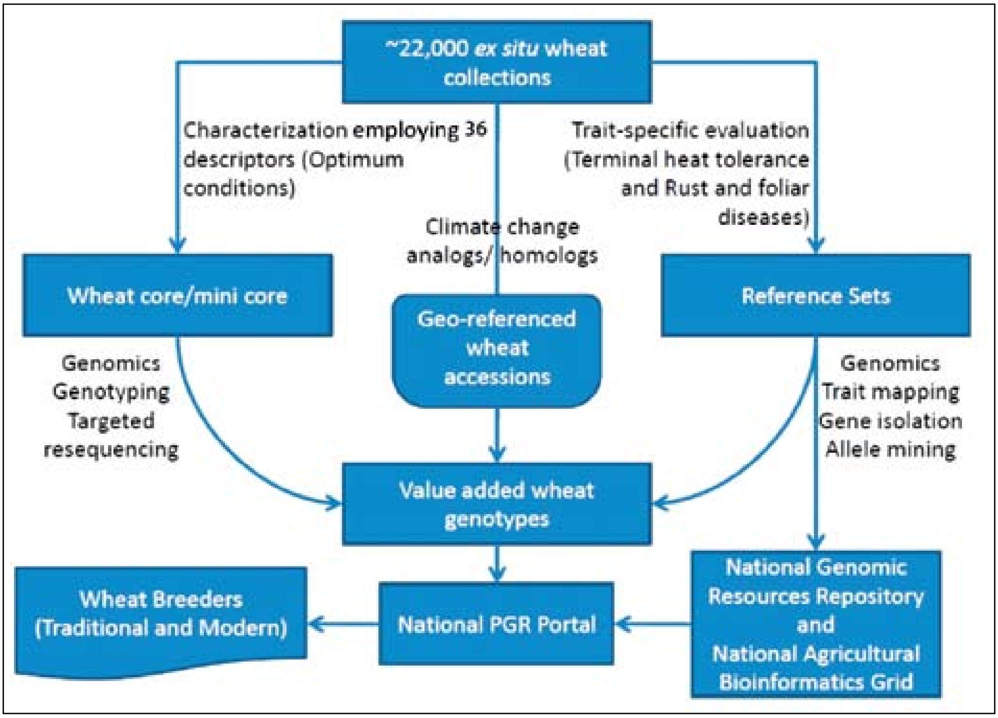


**Fig. 2.** Multi-pronged approach of NBPGR for characterization and evaluation of wheat germplasm held at National Gene Bank

planted in single row plots in augmented block design with 8 national checks for the respective species. A total of 17 agro-morphological characters and physiological traits associated with heat tolerance were recorded to screen the wheat germplasm against terminal heat tolerance. The traits included: thermo-tolerance, grain quality parameters, spikelet fertility, ear bearing tillers, total biomass, grain weight, harvest index, etc. Further, some of the physiological traits included leaf photosynthesis for higher biomass, radiation use efficiency, rate of dark respiration, canopy/leaf temperature, etc. In the second experiment to screen against rusts and other major foliar diseases, one set of 22,000 wheat accessions was sown during 11-22 November, 2011 in augmented block design with four susceptible checks at a hotspot (IARI Regional Station, Wellington). Data on rust and important foliar diseases were recorded at two stages. In the third experiment under optimum conditions (CCS HAU, Hisar), one set of 22,000 accessions was sown during 7-12 November, 2011 and 1-3 December, 2011 in three rows plots in augmented block design with 8 national checks (Kharchia-65, Raj-3765, DBW-17, C-306, DDK1025, DDK1029, UAS-415, DWR 1006) for the three wheat species. A total of 36 agro-morphological characters were recorded for development of a core-set to facilitate the utilization of wheat germplasm in wheat breeding program as well as molecular genetic analysis. Data will be shared with the wheat community soon after analysis and documentation is completed.

## Acknowledgements

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# 4. Hybrid Wheat at MAHYCO

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Wheat is an important cereal crop world-wide followed by rice. Globally, wheat is grown on 217 million hectare area with 621 million tons of production whereas the area under wheat in India is 28.9 million hectares with 80.7 million tons of production (Rajaram, 2011). With the increase in the demand for wheat, efforts are being made to increase the productivity of the crop. Development of hybrids in wheat by use of chemical hybridizing agents (CHA) is one of the options (Mahajan and Nagarajan, 1998). Since the report of cytoplasmic male-sterility (CMS) by Wilson and Ross (1962), efforts were made in development of CMS-based hybrids. China, India, France, Germany and South Africa have all reported activities in hybrid wheat breeding. At present, the area under hybrid wheat is ~ 300,000 hectares, where China is the leading country (Rajaram, 2011). He *et al.* (1998) reported that the Chinese national hybrid wheat network first emphasized the use of *T. timopheevii* CMS, but *Ae. kotschyi* and *Ae. ventricosa* were also being utilized. They reported that three hybrids based on *T. timopheevii* and six hybrids based on *Ae. kotschyi* had a 15 per cent advantage over commercial pure line cultivars.

In India, the work on hybrid wheat at Maharashtra Hybrid Seeds Co. (MAHYCO) Ltd. started more than two decades ago. Virmani and Edwards (1983) reported 15 different cytoplasm of the genera *Triticum* and *Aegilops*. MAHYCO is the only private sector institution in India working on hybrid wheat. At MAHYCO, efforts are being made to develop hybrids suitable for North-West Plain Zone, North-East Plain Zone and Central Zone. The first CMS-based hybrid was released in India (1996) by MAHYCO and proved the benefits of the heterosis in wheat. The area under hybrid wheat in India was about 2,400 hectares during 2005 (Matuschke and Quim, 2006). There is a need to identify heterotic cross combinations so that the productivity of wheat can be increased. The research is in progress for development of disease resistant parental lines in wheat. As rusts are important threats for wheat, development of rust tolerant lines is the priority.

There are other biotic stresses, which are becoming major bottlenecks in increasing wheat yield. Apart from rusts, weeds are major constraints in sustainable wheat production. The losses caused due to weeds vary depending on the weed species, their density and environmental factors. The average losses caused by weeds in wheat are about 25-30 per cent (Singh and Chhokar, 2011). Use of selective herbicides is one of the common practices for control of weeds. Glyphosate is a non-selective, systemic herbicide which gives broad spectrum control of weeds. Development of glyphosate tolerant wheat through transgenic breeding will help farmers to control all types of weeds.

## Challenges in Hybrid Wheat Breeding

The following challenges in hybrid wheat breeding need to be addressed on priority:

- Non-availability of diverse cytoplasm sources
- Assembling favourable genes from diverse genetic resources.
- Less genetic variability in germplasm
- Low range of heterosis
- High seed rate
- High seed production cost
- Heterotic gene pool
- Greater genome size (17Gb) which makes it difficult for molecular marker use
- Non-availability of fertility restorers in germplasm

The initial results with hybrid wheat have been positive and we continue to look at use of molecular breeding and additional germplasm sources to have more options for improved cultivars/hybrids farmers in the years to come.

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# 5. Regional Collaboration for Wheat in Asia

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## Introduction

Wheat is of immense importance for the food security in Asia. China and India, the two top wheat producers of the world, are in Asia and all together Asian countries contribute around one third of the global wheat production (FAOSTAT, 2012). The other major wheat producers in Asia are Pakistan, Turkey and Kazakhstan. India and Pakistan are the major producers in South Asia; Turkey, Iran and Afghanistan in West Asia; and China in East Asia. Asia is the home to half of the world's population with many developing countries facing the threat of climate change to sustain food security. The demand of wheat continues to grow in Asia due to non-stop increase in population and to some extent the changing food habits caused by growing urbanization and prosperity in many countries. Asian wheat production has to grow as predicted for global wheat production, which has to increase 2 per cent annually until year 2030 to ensure food security (Singh and Trethowan, 2007). But, this increase will be more demanding than the past since it has to be achieved under newer challenges of biotic and abiotic stresses. Since the population is mostly growing in developing countries where income levels and resources are quite low, the challenges are even more.

## Need and Scope of Regional Collaboration in Asia

The major issues that need attention to handle the challenges of wheat production in Asia transcend the legal and geographic boundaries of nations. The developing nations, their people and farmers affected by these issues, such as climate change and new virulence of rust races, have interdependent interests and often they are not in the best position to handle them on their own. In addition, the scope of regional collaboration is quite logical due to presence of similar kind of agro-ecological environments across countries, presence of similar cropping system (e.g. rice-wheat) in a big area, same type of biotic and abiotic stresses (the major being wheat rusts, drought and heat), matching economy and presence of variable level of research institutions with each having some strength to support the other. Some countries lack infrastructure for doing cutting edge science but their strategic location for testing the presence of a particular trait or as source of disease inoculums requires their compulsorily inclusion. Therefore, there is need to work together across countries and to develop pragmatic solutions.

The necessity of regional collaboration in wheat has assumed increasing importance in recent years due to emergence of serious issues that were not present previously. Some of these issues are: climate change effects, resurgence of super races of disease such as stem rust race Ug99, major yield losses caused by stripe rust in several countries, possibility of developing hybrid wheat and overcoming legal hurdle in germplasm exchange. Although there is no single model or approach to regional collaboration, previous experiences can be used to think and act regionally. The first important and critical step will be to determine the need for regional collaboration on a particular or more number of issues. It is not necessary that regional collaboration will work in all situations. Therefore, the best way to ensure its effective use will be to devote sufficient time for proper planning in a particular situation using success stories, if any, even if they are on a smaller scale. One of the successful examples of this planning was initiating shuttle breeding between Mexico-Kenya by CIMMYT using the earlier model of shuttle breeding within Mexico. The results obtained in the Mexico-Kenya shuttle are even better in breeding agronomically superior lines along with resistance to stem rust race Ug99.

## Existing Regional Collaboration in Asia

There are several regional collaborations already going on in Asia mainly through different projects of CIMMYT and ICARDA that connect different nations. The major ones are: i) Cereal System Initiative in South Asia (CSISA); ii) USAID Famine Seed Project; iii) HarvestPlus and iv) Borlaug Global Rust Initiative (BGRI).

CSISA project is funded by BMGF, USAID and World Bank and involves four CGIAR institutions (IRRI, CIMMYT, ILRI and IFPRI) with traditional public research and development partners to medium-and large-scale companies, farmers' organizations, and NGOs in four South Asian countries – India, Nepal, Pakistan and Bangladesh (CSISA, 2012). The purpose of the project is to decrease hunger and malnutrition and increase food and income security of resource-poor farm families in South Asia through the accelerated development and inclusive deployment of new varieties, sustainable management technologies, and policies with respect to wheat, rice and maize. This project provides an overall strategy and a new umbrella for contributing new science and technologies to accelerate cereal production growth in South Asia's most important regions where major cereals (including wheat) are grown. The improved cultivars of wheat selected under conservation agriculture practices are also being developed and management concepts for future cereal systems is being designed and evaluated, alongside policy analysis and advocacy, and capacity building at all levels. The first phase (2009-11) is already completed with significant achievements.

To mitigate the threat of Ug99 and other wheat rusts, a seed multiplication project 'Famine Seed Project' supported by United States Agency for International Development (USAID) was implemented in Nepal, Afghanistan, Bangladesh, Egypt, Pakistan and Ethiopia (Joshi *et al.*, 2011). The objective was to have sufficient seed of resistant lines to plant at least 5 per cent of the total wheat area by 2011. The major activities under this initiative, being implemented jointly by the national wheat programs, CIMMYT, ICARDA and BGRI are: i) identification of suitable Ug99 resistant varieties and their pre- and post-release seed production; and ii) delivery of seed to farmers to ensure their rapid dissemination. The project ended in March, 2012 and has made significant impact by enabling fast track release of agronomically superior Ug99 resistant wheat varieties in participating nations and by facilitating large scale seed production of these varieties.

HarvestPlus is a global biofortification initiative within the Consultative Group on International Agricultural Research (CGIAR) to breed and disseminate crops for better nutrition (Harvestplus, 2012). The goal of HarvestPlus is to reduce micronutrient malnutrition among poor populations in different countries including Asia thereby improving food security and enhancing the quality of life. The two major micronutrients being focused by HarvestPlus in wheat are iron and zinc and the two countries presently targeted in Asia are India and Pakistan. In the first phase, donor lines with high Zn and Fe were identified, while in second phase advanced lines have been developed that are under evaluation in South Asia engaging both public and private sector with the aim to release a variety by 2014.

Global Rust Initiative (GRI) was launched in 2005 and was later called the Borlaug Global Rust Initiative (BGRI) (BGRI, 2012). The objective of BGRI is to systematically reduce the world's vulnerability to wheat rusts, facilitate the development of a sustainable international system to contain the threat of wheat rusts, and continue the enhancements in productivity required to withstand future global threats to wheat (BGRI 2012). Many wheat producing countries of the world including those in Asia initiated activities in collaboration with CIMMYT, ICARDA and BGRI, to identify and develop suitable resistant cultivars before race Ug99 establishes. The enormous effort put in at CIMMYT and many other countries resulted in identification of promising sources of resistance, both race-specific and adult plant and agronomically superior wheat varieties were developed with diverse and durable resistance (Singh *et al.*, 2011). Consequently, Ug99 resistant varieties were released in many countries of South Asia and Africa and large scale seed dissemination was achieved (Joshi *et al.*, 2011).

In addition to above, other regional collaborative mechanisms exist in Asia with respect to wheat research and development. For instance, rust monitoring is being done through South Asian Association for Regional Cooperation (SAARC) nursery in South Asia. Likewise, joint survey and surveillance for rust and other diseases are also being done in South Asia and central Asian countries. The implications of wheat rust on wheat production in different countries at the national, regional and global levels are being discussed through different fora to formulate strategy to respond to the emergency occurrence of wheat stripe rust in current cycle 2011-12.

## The Way Forward for Regional Collaboration in Asia

Since food security will be of major concern in Asia, regional collaboration on emerging challenges will play a crucial role. The future germplasm requirements will be mostly dictated by stresses caused by climatic change, emergence of new pathogen races, shrinking resources, widespread adoption of resource conservation technologies, and quality requirements. Although germplasm requirements will vary from country to country and also within countries, most of the locations will need high yielding, adaptable genotypes with resistance to the three major rusts. In addition, heat and drought tolerant genotypes will be important in the future. Major wheat growing countries in Asia should look forward for collaboration seeking short and long term solutions for the major problems. While stem and stripe rust may demand greater attention, some countries can have collaboration for local issues such as spot blotch of wheat in South Asia (India, Nepal and Bangladesh) and Sunn pest for Central Asia.

Regional collaboration will be useful for knowledge sharing and assessment of regional priorities for enhancing wheat production in the region. This will help in developing a common strategy to address emerging problems by collaboration and by learning from each other's successes and failures. This in turn will lead to enhanced wheat productivity and production in Asia and thus improved livelihood of resource poor small holder farmers.

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# 6. Wheat Production for Food Security in Bangladesh

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## Introduction

Agriculture sector being the backbone of Bangladesh's economy continues to be the dominant driving force for growth and development of the national economy. It is the single largest contributor to national economy and also the largest source of employment. In fact, agriculture and agro-based commodities engage about 48 per cent of the labour force and account for about 7.34 per cent of the total export earning and the share of the sector to the total GDP is about 21.7 per cent (crop sector about 11.7%) (MoF, 2009). The contribution of rural non-farm sector (RNF) is 36 per cent which is driven by agriculture. Together the share of agriculture and RNF accounts for around 60 per cent of the GDP (FAO, 2008).

Bangladesh has to face a number of challenges for achieving sustainable agriculture and food security such as rapid population increase, shrinking agricultural lands and natural resources, etc. On top of these, climatic change and natural hazards make the situation worse. The opportunity of bringing more land under cultivation is lacking.

The projected population and the estimated food (rice+wheat) requirements for 2015, 2020 and 2030 are 156.70, 166.90, 195.53 million people and 25.943, 27.632 and 32.377 million tons, respectively. So far, near self-sufficiency in rice has been possible because of 8 times increase of boro area in 2006 compared to 1972 at the cost of area under other crops. If the statistics of all crops during this period is analyzed, it is observed that the area of boro rice, potato, vegetables and maize have increased significantly and all other crops have decreased and the same trend is in production also. The gap between production and requirement is huge for these commodities which needs to be narrowed to face the great challenges in meeting the food and nutritional security of the country.

Bangladesh is traditionally a rice growing country and wheat was a nontraditional crop in this country up to early seventies. Bangladesh has become a wheat growing country by mid eighties through a massive wheat production program that initiated in 1975-76. A rapid dietary change has also taken place so that wheat rose to prominence in diet within a time span of only a decade. With the growing demand of food and use of wheat in diversified ways, it stands as the second most important cereal crop next to rice in Bangladesh.

Wheat is rich in nutritional value than rice having high protein (12-14%), high fibre, minerals and vitamins. Wheat has very good industrial and commercial value due to its easy utilization and marketing and about 50 items of food products of wheat are available. Wheat straw is durable and used for thatching purpose, cottage industries, as pulp for paper mills and feed for cattle. Wheat crop needs less water than rice and can be grown without irrigation (in rainfed condition, or with residual moisture in heavy soil, or in the area where water table is shallow) where soil moisture is enough to complete its life cycle. In the crop fields, insect infestation is negligible. Disease infection is less in wheat crop and the modern varieties are tolerant or resistant to the major foliar diseases. Wheat cultivation needs very less or almost no use of pesticides. So, wheat is an environment friendly crop. Currently, Bangladesh is producing one million ton of wheat against the national demand of about 3.60 million tons. The consumption rate of wheat is increasing at the rate of 3 per cent per year. So, wheat is playing an important role to ensure food and nutritional security in the country. Therefore, to meet the growing demand of wheat, Bangladesh needs to import at least 2.60 million tons of wheat grain every year.

Wheat in Bangladesh is mainly grown in rotation with rice. About 85 per cent area of wheat is grown after harvesting of transplanted Aman rice. Wheat-rice-rice, wheat-fallow-rice, wheat-jute/legumes-rice, are the common wheat based cropping patterns in Bangladesh. Moreover, about 50 per cent of the wheat area (about 0.20 m ha) is late sown due to late harvest of transplanted Aman rice that encounters heat stress during grain-filling period. So, sustainability of the rice-wheat system has become a critical issue for agricultural research in Bangladesh.

Considering the population increase, present and foreseeable crop production constraints, availability of natural resources, agro-ecological conditions and government's policies related to agriculture, renewed research thrust was given to different commodities to generate technologies on a long term basis to meet the future challenges.

## Area, Production and Productivity of Wheat and Other Food Crops in Bangladesh

Rice is the predominant crop in Bangladesh occupying 78.25 per cent of the total cropped area. The rest 21.75 per cent area is covered by all other crops.

Presently, wheat is grown in 0.374 million hectares that occupies only 2.58 per cent of the total cropped area and 3.15 per cent of total cereal area (BBS, 2011). The wheat area and production in the country was further increased and reached to 0.85 million hectares in 1998-99. The production in that year was 1.9 million tons. This production was about 18 times more over the production of 1970-71 and double the production of 1980-81. This spectacular achievement in wheat production in the country was due to wide spread adoption of high yielding varieties, development of wheat production technologies and diffusion of these technologies to the farmers (Ahmed and Miesner, 1996). However, after 1999 both area and production of wheat started decreasing mostly due to crop competition with maize, potato, boro rice and vegetables. The potato cultivation has been increased tremendously during recent years. Moreover, increased cultivation of boro rice in the high land or medium high land is replacing wheat area. During 2010-11, the wheat area and production reduced to 0.374 million hectares and 0.97 million tons, respectively which is almost half of 1999 (BBS, 2011). The present production is only one-fourth of the national demand. The area, production and productivity of wheat, maize, potato and rice for the last 10 years are shown in Table 1.

The wheat area and production during recent years is almost static. However, the productivity has increased significantly in 2009-10 (2.93 t/ha) and 2010-2011 (2.60 t/ha) due to introduction of heat tolerant high yielding wheat varieties and adoption of wheat production technologies and dissemination of those to the farmers' fields.

## Past Accomplishments in Increasing Wheat Production and Productivity

Wheat research in Bangladesh was initiated in late 1960's. The Wheat Research Center (WRC), BARI has been conducting research to generate suitable technologies for the farmers to enhance wheat productivity and production in the country. Some of the important achievements are highlighted below:

### Variety development

The Wheat Research Center of BARI has so far released 28 varieties for commercial cultivation. Among these, Kanchan released in 1983 became the most popular and widely adapted, occupying about 80 per cent wheat area in the country. All the recently released varieties are moderately tolerant to terminal heat stress and resistant/ tolerant to leaf rust and leaf blight diseases. The development of new varieties with improved industrial quality is also getting due importance.

- BARI Gom 21 (Shatabdi) released in 2000 is now the predominant variety covering about 50 per cent of the total wheat area. Another two varieties, BARI Gom 23 (Bijoy) and BARI Gom 24 (Prodip) released in 2005 are popular among the farmers. These varieties can yield 3.5-5.2 tons per hectare depending on the growing environment. They are early to medium in maturity (105-112 days), semi-dwarf type with bold amber grains. BARI Gom 22 (Sufi) and BARI Gom 24 (Prodip) possess strong gluten and suitable for bread making.
- Two more new varieties BARI Gom 25 and BARI Gom 26 with high yield

**Table 1.** Area, production and yield of wheat, maize, potato and rice during 2001-2011

| Year | Area ('000 ha) | Production ('000 t) | Yield (t/ha) | Area ('000 ha) | Production ('000 t) | Yield (t/ha) | Area ('000 ha) | Production ('000 t) | Yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | **Wheat** | | | **Maize** | | | **Potato** | |
| 2000-01 | 773 | 1670 | 2.16 | 4 | 10 | 2.25 | 249 | 3216 | 12.92 |
| 2001-02 | 742 | 1610 | 2.17 | 20 | 64 | 3.23 | 238 | 2994 | 12.60 |
| 2002-03 | 706 | 1504 | 2.13 | 29 | 117 | 4.01 | 245 | 3386 | 13.80 |
| 2003-04 | 642 | 1252 | 1.95 | 50 | 241 | 4.80 | 271 | 3908 | 14.43 |
| 2004-05 | 559 | 976 | 1.75 | 67 | 356 | 5.33 | 326 | 4856 | 14.88 |
| 2005-06 | 479 | 735 | 1.53 | 98 | 522 | 5.31 | 301 | 4161 | 13.81 |
| 2006-07 | 400 | 737 | 1.84 | 151 | 902 | 5.97 | 345 | 5167 | 14.96 |
| 2007-08 | 388 | 844 | 2.18 | 224 | 1346 | 6.01 | 402 | 6648 | 16.54 |
| 2008-09 | 395 | 849 | 2.15 | 128 | 730 | 5.69 | 396 | 5268 | 13.32 |
| 2009-10 | 376 | 901 | 2.93 | 152 | 887 | 5.83 | 435 | 7930 | 18.24 |
| 2010-11 | 374 | 972 | 2.60 | 227 | 1552 | 6.84 | 460 | 8326 | 18.10 |
| | | **Aman rice** | | | **Aus rice** | | | **Boro rice** | |
| 2000-01 | 5713 | 11249 | 1.97 | 1326 | 1916 | 1.45 | 3764 | 11921 | 3.17 |
| 2001-02 | 5650 | 10726 | 1.90 | 1243 | 1808 | 1.46 | 3773 | 11766 | 3.12 |
| 2002-03 | 5685 | 11115 | 1.96 | 1244 | 1850 | 1.49 | 3846 | 12222 | 3.18 |
| 2003-04 | 5680 | 11520 | 2.03 | 1203 | 1832 | 1.52 | 3945 | 12838 | 3.25 |
| 2004-05 | 5282 | 9819 | 1.86 | 1025 | 1500 | 1.46 | 4066 | 13837 | 3.40 |
| 2005-06 | 5431 | 10810 | 1.99 | 1035 | 1745 | 1.69 | 4068 | 13975 | 3.44 |
| 2006-07 | 5418 | 10841 | 2.00 | 906 | 1512 | 1.67 | 4260 | 14965 | 3.51 |
| 2007-08 | 5050 | 9662 | 1.91 | 919 | 1507 | 1.64 | 4610 | 17762 | 3.85 |
| 2008-09 | 5500 | 11152 | 2.03 | 1066 | 1895 | 1.78 | 4718 | 17809 | 3.77 |
| 2009-10 | 5665 | 12207 | 2.15 | 985 | 1709 | 1.74 | 4709 | 18059 | 3.84 |
| 2010-11 | 5645 | 12791 | 2.27 | 1112 | 2133 | 1.92 | 4770 | 18617 | 3.90 |

potential were released in 2010 of which BARI Gom 25 is saline tolerant and BARI Gom 26 is tolerant to terminal stress and moderately resistant to stem rust race Ug99. BARI Gom 26 ranked first in yield among the genotypes included in Indo-Gangetic Plains screening nursery and trials tested in different locations of India, Nepal and Bangladesh. BARI Gom 27 and BARI Gom 28 are heat tolerant and give 15-20 per cent higher yield than Kanchan.

- Recently, two more high yielding varieties BARI Gom 27 (Francoline) and BARI Gom 28 have been provisionally released. Both possess CIMMYT lines background in the pedigree. BARI Gom 27 is resistant to leaf rust and has good level of adult plant resistance to the Ug99 race of stem rust. BARI Gom 28 is early in maturity and resistant to leaf rust.
- Breeding for high yield potential varieties is being given thrust to raise the present trend of genetic gain in yield.

The pedigree of the most important varieties among the 28 developed by Wheat Research Center of BARI for commercial cultivation are given in Table 2.

## Disease management

- WRC identified a good number of genotypes having tolerance to spot blotch under artificially inoculated condition and a few of these are being used in hybridization program. New wheat varieties have good level of tolerance to spot blotch.
- A good number of genotypes have been identified to be resistant to leaf

**Table 2.** Pedigree of recently released wheat varieties in Bangladesh

| Variety | Accession No. | Pedigree/ Cross | Year of release |
|---|---|---|---|
| BARI Gom 21 (Shatabdi) | BAW 936 | MRNG/BVC//BLO/PVN/3/PJB-81 CM98472-1JO-0JO-0JO-1JO-0JO-0R2DI | 2000 |
| BARI Gom 22 (Sufi) | BAW 966 | KAN/6/COQ/F61.70//CNDR/3/OLN/4/PHO/5/MRNG/ ALDAN//CNO BD(JE)349-X-0JE-9DI-10HR | 2005 |
| BARI Gom 23 (Bijoy) | BAW 1006 | NL297*2/LR25 | 2005 |
| BARI Gom 24 (Prodip) | BAW 1008 | G. 162/BL 1316//NL 297 | 2005 |
| BARI Gom 25 | BAW 1059 | ZSH 12/HLB 19//2*NL297 | 2010 |
| BARI Gom 26 | BAW 1064 | ICTAL 123/3/RAWAL 87//VEE/HD 2285 BD(JO)9585-0JO-3JE-0JE-0JE-HRDI-RC5DI | 2010 |
| BARI Gom 27 | BAW 1120 | WAXWING*2/VIVISTI CGSS01BOOO56T-099Y-099M-099M-099Y-099M-14Y-0B | 2012 |
| BARI Gom 28 | BAW 1141 | CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10 CMSS95Y00624S-0100Y-0200M-17Y-010M-5Y-0M | 2012 |

rust. In collaboration with CIMMYT, Mexico and India, six major leaf rust resistance genes have been identified in the cultivars and advanced lines of Bangladesh. The resistance genes are *Lr1*, *Lr3*, *Lr10*, *Lr13*, *Lr23* and *Lr26*, which have occurred either singly or in combination of two genes along with some unidentified factors for resistance. A slow rusting gene *Lr34* is also present in a few lines and varieties. New wheat varieties such as Sourav, Gourab, Shatabdi, Bijoy, BARI Gom 25, BARI Gom 26, BARI Gom 27 and BARI Gom 28 are resistant to the existing leaf rust races in Bangladesh. However, BARI Gom-24 (Prodip) released in 2005 has become susceptible to leaf rust particularly under late sown condition.

- Regular screening of segregating generation and advance lines against Ug99 race of stem rust through shuttle breeding in KARI, Kenya is going on with the help of CIMMYT. Few high yielding lines showed moderately resistant reaction against Ug99 race of stem rust.

## Soil and crop management

- Optimization of fertilizer requirement for wheat has been optimized in different tillage options to enhance wheat productivity.
- Studies were conducted on productivity, soil fertility and nitrogen-use efficiency in wheat-mungbean-rice cropping pattern in different tillage options, straw management and N-levels.
- Fertilizer placements for different tillage options to improve wheat growth and yield have been standardized.
- Improvement and up-scaling of cereal cropping system through resource conserving technologies has been done.
- Wheat productivity enhanced with acid soil amendment through liming with dolomite lime [$CaMg(CO_3)_2$] to increase availability of P. Use of 'dolochun' a dolomite lime [$CaMg(CO_3)_2$] in low pH soil at 3 years interval @ 1.0 ton per hectare depending on soil pH enhances the availability of P and increased wheat yield by 20-25 per cent.

## Mechanization and conservation agriculture

- Power tiller operated seeder (PTOS) has been introduced for rice-wheat system that performs tilling, seeding in rows, and covering seed simultaneously in a single pass. It saves seeds, reduces water requirement, minimizes turn-around time and production cost. Local manufacturers already started its manufacturing.
- A seed-cum-fertilizer zero till drill machine has been developed that performs seeding and fertilizing at the same time. A number of crops can be sown along with wheat. Residue of previous crop can be managed easily. It is environment friendly with less degradation of the soil.
- A power tiller operated bed planter has been developed which performs bed formation and seeding operation in a single pass. This planter also allows seeding on permanent bed without breaking the previous bed. This system facilitates efficient irrigation, less lodging of crop, minimum rat damage and satisfactory yield. This bed planter is getting popular among the farmers.

- More than 300 operators, advanced growers, agricultural officers, NGOs are trained on operation, maintenance and trouble shooting of these resource conservation technologies (RCTs).

## Seed Production

Wheat Research Center of BARI produced nucleus seed for variety maintenance, breeder seed for supply to seed producing agencies and truthfully labelled seed (TLS). During 2010-11, nucleus seeds of 4 varieties Bijoy, Prodip, BARI Gom 25 and BARI Gom 26 were produced each in 0.25 hectare of land area. In total, 50 tons breeder seeds and 40 tons TLS were produced. During 2011-12, a total of 16 hectare land was under seed production of Prodeep, BARI Gom 25 and BARI Gom 26 with each 5 hectares each and Bijoy 1 hectare. A total amount of 50 tons breeder seed was supplied to Bangladesh Agricultural Development Corporation (BADC) this year.

## Constraints in Productivity Enhancement and Emerging Challenges

The reduction in wheat area is mainly due to rapid increase of maize cultivation in the last few years and extensive cultivation of potato, HYV boro-rice and vegetables in some areas. However, wheat cultivation is less costly, resource conserving and economically beneficial. The national average yield during 2001-2009 ranged from 2.16-2.93 tons per hectare. However, the wheat productivity started increasing since 2010 (2.93 t/ha) and the average wheat yield rose to 2.60 tons per hectare in 2011. During the current year, national average yield is expected to be at least 3.0 tons per hectare. However, the average yield in varietal demonstration trials during the last few years at farmers' field was 3.0-3.5 tons per hectare. The mean yield of new varieties so far recorded at research stations with optimum management is 4.5 tons per hectare, while the maximum yield with new variety and recommended management so far achieved in the farmer's field is 6.5 tons per hectare. So, huge yield gap remains between varietal yield potentiality and farmers' yield which should be minimized to enhance wheat productivity. There are many reasons behind such yield gap most of which are due to continuous rice-wheat rotation, late planting, depletion of soil nutrients, formation of plough pan restricting proper root growth, sterility in wheat due to micronutrient deficiency especially B, etc. Wheat planted late i.e. beyond 30 November (1$^{st}$ week of December for northern region) often encounters high temperatures during grain filling period resulting in reduced yield @ 1.3 per cent for each day delay (Saunders, 1988). The rate of yield loss is significantly higher in southern areas. Various biotic and abiotic constraints and other factors associated with decrease in wheat productivity are given below:

### Biotic constraints

Among the biotic constraints, some of the important diseases and insects are as follows:

***Bipolaris* leaf blight (BpLB):** Leaf blight or spot blotch caused by *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoemaker is the most destructive disease of wheat in the rice-based cropping systems in Bangladesh. It may cause moderate to severe yield losses (10-40%) depending on the variety, time of sowing and agronomic management. New wheat varieties have moderate to good level of tolerance to this disease.

**Leaf rust:** Leaf rust caused by *Puccinia triticina* Eriks. (*Puccinia recondita* f. sp. *tritici*) is considered as the second most important disease of wheat in Bangladesh but yield losses are usually small, but can be severe if a susceptible variety is grown and infection occurs early in the crop season. Recently developed wheat varieties are resistant to the existing leaf rust population in Bangladesh. However, Prodip released in 2005 has become susceptible to leaf rust particularly under late sown condition.

**Black point:** Black point of wheat is a disease of grain. It is considered as a major problem for production and marketing of wheat seed. In order of prevalence, the major fungi associated with the black point disease are *B. sorokiniana*, *Alternaria alternata*, *Curvularia lunata*, *Fusarium* spp. and *Cladosporium cladosporioides*. Severity of the disease increases if rain occurs or humid condition prevails during grain filling period. Seed germination is reduced depending on severity of infection, particularly when *B. sorokiniana* and/or *Fusarium* spp. are involved. Occurrence of black point may be avoided to a large extent if the crop is harvested (without delay after maturity) before rain or humid weather.

**Head blight:** Head blight or ear-head infection caused by *B. sorokiniana* is becoming an important disease of wheat in Bangladesh. It usually affects one or more spikelets of an individual ear-head. Severely infected spikelets do not bear any seed inside the florets. The disease is favoured by warm and humid weather during and after heading. None of the cultivars and advanced lines has been found to be completely free from the disease, but considerable variability in incidence of the disease exists among them. Spraying with Tilt 250 EC (0.05%), once at heading and another at 15 days later, can minimize the incidence of the disease. Studies have been initiated to generate detailed information on this disease.

**Rodents:** Rats cause serious damage to the crop throughout the growth period. Necessary measures should be undertaken to control the rats from the beginning. Rats could be controlled by using poison baits, traps, water, smokes, etc.

**Birds:** Birds causes seed and seedling damage up to 10-12 days after sowing and reduces the plant population to a greater extent. Measures should be ensured to drive out the birds up to 10-12 days after seeding to avoid the seed and seedling damage by birds.

## Abiotic constraints

**Heat stress:** High temperature is one of the major constraints of wheat production in Bangladesh (CIMMYT, 1995). Wheat is sensitive to temperature increases but the intensify of effects depends on variety, and stage of development. Increasing temperatures usually hasten crop development and shorten the grain filling duration, which severely reduces grain yield. Late sown wheat is more affected by heat stress. IPCC (2000) predicted 1.8-4.0°C temperature increase by the end of 21$^{st}$ century. In sub-tropical and tropical regions, wheat is often already near its limit of maximum temperature tolerance, so temperature increase of

1-2°C will reduce wheat yield in future. Therefore, high yielding varieties with greater adaptation to high temperature need to be developed for sustaining and increasing wheat production in this region. About 50 per cent wheat in Bangladesh is late sown due to late harvest of transplanted Aman rice and faces heat stress during grain filling period and produces smaller grains than in optimum sowing.

**Drought stress:** Water scarcity for irrigation is very common in many areas of Bangladesh and ground water table is rapidly declining. Even irrigated wheat is facing temporary drought stress in critical growth phases like tillering, booting and grain filling that reduces wheat yield. Global climate change may induce more droughts in future. So, emphasis should be given to develop varieties combining high yield potential with tolerance to severe drought.

**Water logging:** Wheat plant cannot withstand water logging at seedling stage especially at crown root initiation stage. Over irrigation at this stage followed by rain may cause water logging. It causes yellowing of leaves and stunted growth and results in low yield.

**Spike sterility:** Spike sterility frequently occurs in the light soil of north-western part of Bangladesh causing significant yield loss in some years. Sterility is presumed to be associated with low soil fertility, especially deficiency of boron. Some environmental factors such as low light intensity, high humidity, foggy weather at anthesis are likely to enhance spike sterility.

**Soil acidity:** Soils of north-western Bangladesh are light textured and acidic in nature (pH 4.5-5.0). It reduces the availability of P to the crops causing significant yield loss. WRC has recommended soil amendment through applying dolomite lime @ 1-2 tons per hectare once in 3 years. It enhances more than 20 per cent yield of wheat (Anonymous, 2010).

**Salinity:** It is a major constraint in expanding wheat in southern region where salinity during sowing time varies from 3.0 to as high as 15 dS/m. Most of the wheat varieties can tolerate salinity level of 6-8 dS/m at seedling stage. The variety BARI Gom 25 can tolerate salinity up to 10 dS/m at seedling stage (Saifuzzaman *et al.*, 2010). Therefore, varieties with higher degree of salinity tolerance at seedling stage should be developed for achieving good yield in saline belt.

## Approaches for Meeting the Challenges Including Climate Change

- Develop high yielding varieties with greater adaptation to changing climatic situation-terminal heat stress, drought, salinity, spike sterility, etc.
- Develop lodging resistant varieties having high input use efficiency
- Improved resistance /tolerance to spot blotch and leaf rust disease in new varieties
- Continued screening of germplasm against Ug99 race of stem rust in Kenya through CIMMYT collaboration as a measure to mitigate the future threat
- Survey and monitoring for new diseases and new races of pathogens
- Germplasm collecting and evaluation of exotic germplasm against specific stresses
- Strengthen physiological traits based breeding program

- Initiate molecular approaches to support conventional breeding
- Adopt participatory variety selection in target environment
- Increase varietal diversity
- Ensure optimum planting: introduce power tiller operated seeder, short duration Aman rice variety
- Improve salinity and drought stress management by residue incorporation, bed planting, etc.
- Ensure improved crop management to enhance wheat productivity
- Ensure soil fertility improvement: incorporate legume, crop residue management, conservation agriculture
- Enhance quick dissemination of quality seed of new wheat varieties to the farmers

## Efforts in Improving Wheat Production for Meeting the Future Targets

To meet the demand of the growing population, more than 2.0 million tons of wheat grain is being imported every year with high investment in foreign currency. Therefore massive production program needs to be undertaken in collaboration with WRC, BARI, DAE, BADC, NGO, etc. The technology adoption process also needs to be strengthened. Considering the above scenario, production target up to 2030 may be fixed as shown in Table 3.

## Future Strategy

There is a scope of vertical and horizontal expansion of wheat in Bangladesh. Also, there is a good scope to enhance production and productivity of wheat through appropriate strategies.

### Vertical expansion

At present, there is a huge yield gap between potential yield and farmers' average yield. Last year, the national average yield was only 2.60 tons per hectare, while the demonstration average yield during last several years is more than 3.0 tons per hectare. Therefore, national average yield could be raised to 3.5 tons per hectare quite easily by adopting the following measures:

- Quick dissemination of new high yielding varieties to the farmers

**Table 3.** Projected population, demand, production target in different years

| Projected population/demand/ production target of wheat | Years | | | | |
|---|---|---|---|---|---|
| | 2010 | 2015 | 2020 | 2025 | 2030 |
| Projected population (m) | 148.00 | 186.70 | 206.90 | 220.00 | 190.60 |
| Demand (mt)* | 3.50 | 3.85 | 4.00 | 4.37 | 3.37 |
| Target area (m ha) | 0.40 | 0.45 | 0.50 | 0.55 | 0.55 |
| Target average yield (t/ha) | 2.60 | 2.80 | 3.00 | 3.50 | 3.40 |
| Production target (mt) | 1.00 | 1.20 | 1.48 | 1.90 | 1.88 |

**Considering per capita consumption @ 55.28 g per day (20.18 kg/capita/year).*
**Production in 2008-09 was 0.85 million tons; population growth rate: 1.39 per cent.*

- Extensive farmers' training on modern wheat production and seed production technologies through participatory approaches
- Small scale mechanization should also be given emphasis to enhance wheat productivity in the country through timely operations for seed sowing and other management.

## Horizontal expansion

A vast area (about 0.8 mha) remains fallow in winter in southern region and Sylhet areas. Moreover, Barind area of Rajshahi region is a very dry area where about 70,000 hectare land remains fallow due to moisture stress during winter every year. In future, availability of water for irrigation will be severely reduced due to global climate change and depletion of ground water table. So, in these regions, boro rice should be replaced by wheat and the short duration Aman rice should be introduced in this area for planting wheat in normal time.

Therefore, wheat could be introduced in part of the areas with limited/light irrigation or with residual soil moisture. In that case, high yielding disease resistant varieties well adapted to the stress situations like heat, drought, salinity, etc. will be required in future.

However, appropriate wheat research and development program should be undertaken to sustain and increase wheat production in the country. The following strategic points may be considered:

## Genetic resources and variety improvement

- Collecting and evaluation of germplasm against biotic and abiotic stresses to identify resistant genes for utilizing in variety development programs
- Developing disease resistant varieties for leaf rust, leaf blight diseases with high yield potential
- Screening varieties against new race of stem rust (Ug99)
- Developing high yielding varieties tolerant to abiotic stresses like; heat, drought and salinity
- Developing lodging resistant and high input-use efficient varieties
- Developing varieties possessing improved industrial quality

## Biotechnology

- Marker assisted selection to identify and tag molecular markers for leaf and stem rust
- QTL mapping for heat, drought and salinity stresses for wheat

## Diseases and pest management

- Screening of genotypes under artificial epiphytotic and field conditions for major wheat diseases like leaf blight, leaf rust, etc.
- Screening varieties against Ug99 race of stem rust in KARI, Kenya should be continued
- Survey and monitoring for new diseases and new races
- Regular field monitoring to assess potential damage caused by insect-pests

## Crop management

- Introducing conservation agriculture to manage abiotic stresses like heat, drought, salinity (straw retention and residue management, bed planting)

- Choosing profitable cropping patterns to sustain and improve soil fertility
- Efficient irrigation scheduling to optimize water use
- Developing and refining improved management packages for attaining high yield goal

### Farm machinery

- Improving small scale farm machinery (PTOS, reaper, bed planter)
- Encouraging new entrepreneurs to design and fabricate efficient farm machinery
- Introducing resource conservation technologies (RCTs) at farm level

### Quality seed production

- Strengthening variety maintenance program to produce quality breeder seed of new varieties
- Ensuring the supply of quality seeds of the new varieties to the farmers and private seed producers

### Socioeconomic Studies

- Policy intervention to encourage wheat production in areas where underground water table is going down alarmingly instead of boro rice cultivation
- Undertaking economic study of profitability of wheat cultivation as compared to the competing crops

### International collaboration

- CSISA-CIMMYT collaboration for wheat breeding and technology transfer
- Ug99 Famine Fund Seed Multiplication Project (CIMMYT/USAID)
- Food for Progress Program in Bangladesh- Lime and Raised Bed Component (USDA/CU)
- Global Cereal Rust Monitoring under BGRI Initiative
- Sending advanced lines and segregating generations to KARI, Kenya for testing their resistance to Ug99 race and its variants of stem rust pathogen under BGRI/CIMMYT

## Conclusion

As winter loving crop, global climatic change will affect wheat production unless necessary measures are not taken well. Among the biotic factors, new races of diseases may become more virulent. Intensity of abiotic stresses like heat, drought, salinity, etc. will be enhanced affecting the productivity of wheat in future. Due to climate change in future, there will be scarcity of water during wheat season and crop will be exposed to more frequent droughts. Wheat production can be increased through vertical expansion by improving wheat productivity as well as horizontal expansion where feasible. There is a scope to increase wheat area in southern belt, in eastern part (Sylhet) and in Barind area (Rajshahi) where thousands of hectares of land remain fallow during winter. Therefore, the following recommendations may be considered to sustain and increase wheat production in Bangladesh:

- Water table is going down every year and the annual precipitation is also reducing due to global climatic change. So, water is going to be scarce in future. Wheat may become more important cereal than rice in such situation as wheat requires much less water than rice. So, more efforts should be made to expand wheat cultivation in such areas. Simultaneously, artificial recharge of ground water table also needs to be done.

- Since, there is very high crop competition in traditional wheat area, wheat can be expanded in barind area of Rajshahi, southern belt and greater Sylhet district, where abundant land remains fallow in the winter. Fallow land in southern Bangladesh during winter was estimated to be more than 400,000 hectares which is suitable for growing wheat (Rawson *et al.*, 2011).
- Collaborative research work with CIMMYT needs to be strengthened in the field of breeding varieties for heat stress, salinity, drought, etc. Continued support is needed to develop disease resistant variety especially against the virulent races.
- There is a need to strengthen more collaboration with directorate of agricultural extension and other agencies for rapid dissemination of new varieties and technologies to the farmers.
- Regional cooperation needs to be strengthened among the countries for technology generation.
- Human resource development *i.e.* training of wheat scientists is very much important to face future research challenges and needs to be given a thrust.
- Participatory adaptive research in farmers' field should be strengthened for upscaling of technologies and also for reducing yield gap.
- Well trained scientists and well equipped laboratory facilities are prerequisite to start biotechnological research. Collaboration with CIMMYT should be further strengthened in this regard.

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# 7. Wheat Production and Technology Improvement in China

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## Introduction

There is a long history of wheat cultivation in China, mainly in the mid-North of the country, starting about 5,000 years BC. Today, China is the largest wheat producer and consumer in the world and wheat ranks as the third leading crop in China after rice and maize. Wheat products are the major staple foods consumed in northern China although its consumption in southern China is also increasing rapidly. The relative cereal production in China, Asia and World in 2011 is given in Table 1.

From the establishment of P.R. of China in 1949 to the present, wheat continues to play an important role in food production and the country is globally self-sufficient despite very limited import-export. About 10 types of wheat agro-environments and cultivation zones exist in China. However, more than 70 per cent of Chinese wheat is produced in five provinces, i.e., Henan, Shandong, Hebei, Anhui, and Jiangsu. On the basis of sowing dates, autumn-sown wheat accounts for more than 95 per cent of production and acreage. Wheat-maize

**Table 1.** Cereal production in 2011

| Production (mt) | Wheat | Rice | Maize |
|---|---|---|---|
| China | 118 | 141 | 192 |
| Asia | 235 | 419 | 249 |
| World | 694 | 465 | 865 |

and wheat-rice rotations are the dominant crop systems in Yellow and Huai Valleys and Yangtze Region, respectively.

## Area, Production and Productivity of Food Crops including Wheat

In 2011-12, the China's wheat acreage covered 24 million hectares, among them 75 per cent located in the plains of Huang He and Huai plains where average yield in 2011 reached 4.7 tons per hectare with leading provinces of Henan and Shandong with 5.8 tons per hectare, producing simultaneously the same year on the same land 6.1 tons per hectare of maize, for a total country wheat production of 115 tons, nearly equal to U.E. 27's total production.

About 70 per cent of the national production was concentrated in the provinces of Henan, Shandong, Hebei, Anhui and Jiangsu, where 70 per cent of wheat is still consumed in mid-North China. In 2012, the Chinese milling industries gather 3,200 companies – only 4 giant ones crush between 5,000 to 18,500 tons per day, 50 more than 1,000 tons per day and the last ones much less.

Regarding the end-uses, 14 per cent of wheat is dedicated to seeds and industries, 10 per cent to feed and 76 per cent to food (31% steam bread, 31% noodles, 14% western bread, pastries and misc.).

## Past Accomplishments in Increasing Wheat Production and Productivity

Great progress has been made in Chinese wheat production over the last 60 years. Average yield increased annually by 1.9 per cent and production increased more than six times (Fig. 1).

Many factors contributed to this increase from 1949, including adoption of improved cultivars with eight rounds of varietal changes, expansion of improved crop management, significant increase in irrigation, fertilizers and mechanized

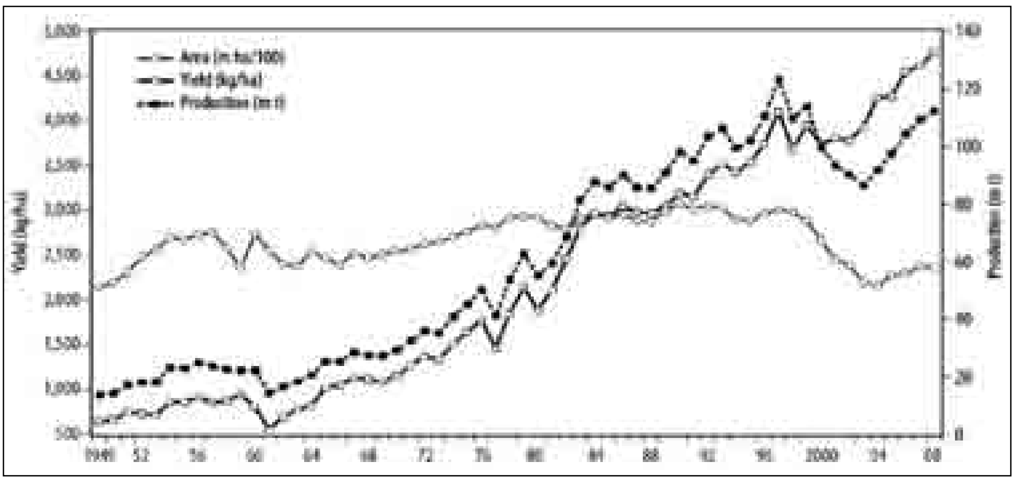

**Fig. 1.** Wheat area, average yield, and production in China (1950-2008)

operations, and improved rural policies since 1978. Agricultural policy reform in the early 1980s largely stimulated wheat production, and 123 tons of harvested grain was recorded in 1997. Farmers have replaced their wheat cultivars 6-8 times in the major wheat areas during the past 60 years. Wheat area, however, has declined from 30 million hectares to around 24 million hectares at present, largely due to the policy of increasing crop diversity, high yield and high profitability of maize, elimination of guaranteed pricing policies in South China and spring wheat regions.

## Challenges and Opportunities

The main current production constraints are as follow:

- Shortage of water is a major limiting factor for wheat production in China, particularly in the northern part of Yellow and Huai Valley, i.e., the provinces of Hebei and Shandong. Another important constraint is heavy water pollution. Irrigation has been reduced from 4-5 times to 2-3 times during wheat season, therefore, combination of new varieties with outstanding performance under reduced irrigated conditions and water saving technology such as bed planting will be crucial for increasing productivity in China
- Sharp eye spot and take-all have become the major diseases and no significant progress has been made in developing resistant varieties. Integration of pathology and breeding, or development of GM wheat will eventually provide great opportunity for improving resistance. Head scab has been moved to northern China due to the expansion of conservation technology under wheat-maize rotation system. Toxicity caused by head scab is a big concern for food safety reason. Multiple durable resistance offered by *Yr*18 and *Yr*29 could reduce the risk of resistance breakdown for stripe rust and powdery mildew.
- Maize/wheat competition, with drastic spring wheat acreage reduction which is replaced by maize; hybrid rice/wheat competition in the South
- Small farm size (0.65 ha), strong competition between grain and cash crops, as well as farmer's interest shifting to non-farming activities
- Urbanization and differences of revenues between urban and rural areas having for consequence a significant input increase, especially human costs

## Other Emerging Trends in Production

There are several other emerging trends in production which are as follows:

- Seedling rate increase due to promotion of zero-tillage, with lodging becoming a problem
- Irrigations reduced from 4-5 times to 2-3 times
- Investment needs for accelerating the mechanization, as lots of farmers move to urban areas
- More concerns about food safety/ security, quit flour bleaching with flour colour becoming a critical breeding goal

Global warming advanced the heading date by 7-10 days in northern China, but maturity period remains basically unchanged. Wheat type has changed in response to rising temperature, facultative type replaced winter type and spring type has replaced facultative type. Therefore, a positive effect on yield was observed due to the extended grain filling period. Winter wheat also replaced spring wheat in Gansu and Ningxia and it shows 20 per cent yield advantage and benefits for the following crops. However, significant temperature and rainfall fluctuations observed during the last few years may have negative effect on wheat production, i.e. the drought of last years in Yunnan. Improvement of tolerance to high temperature and drought, and multi-location testing will benefit the development of widely adapted varieties under changing environment.

Combination of elite cultivars, good quality seeds and improved crop management are the main approaches for meeting the productivity challenge. In breeding, yield potential has always been the top priority. It remains the top priority in China. The significant genetic improvement in grain yield in China were primarily attributed to increased kernel weight per spike, reduced plant height, and increased harvest index, and partly attributed to the combination of Chinese and foreign germplasm. Large kernel size is generally preferred in China and it is associated with fast grain filling under high temperatures, which are very common in northern China after anthesis. Therefore, thousand kernel weight (TKW) is an important selection criterion in Chinese wheat breeding programs. Considering the limited potential to further increase of TKW in Chinese environments, and the trends of reducing spike number per unit area, it is generally believed that further increase of kernels per spike (even 2-3 kernels) could offer an opportunity for increasing grain yield potential. Experience in developing new cultivars such as Zhoumai 18 and Zhongmai 175 supports this approach. The significant increase in grain yield in China mainly occurred in the early 1980s, largely due to the successful utilization of dwarfing genes and the incorporation of the 1B1R translocation. However, it is very unlikely that further reduction in plant height will benefit yield progress. Most current leading cultivars have plant heights around 75-85 centimeters, suggesting that combinations of *Rht-B1b* or *Rht-D1b* with *Rht*8 confer optimal plant height for those regions. Combination of *Rht-B1b* with *Rht*8 is suggested in Zone III. The GA-insensitivity genes *Rht-B1b* and *Rht-D1b* have pleiotropic effects on plant growth, causing reduction in coleoptile length and seedling leaf area. Other dwarfing genes such as *Rht* 8 and *Rht* 9 that do not confer GA insensitivity may, therefore, be more suitable in reducing final plant height without compromising early plant growth. Other innovative approaches such as derived synthetic lines have sometimes been used with a great success, i.e. in Sichuan. Until today, hybrid approaches in wheat have been less successful in commercialization than in rice or maize.

The use of new seed ranges from 10-80 per cent in different provinces. In crop management, delayed sowing and early wheat harvest allows the possibility to increase the maize yield in mid-North China, with an excellent productivity of wheat/maize rotation system, 13-15 tons per hectare per year. Crop management enhancement includes promotion of conservation agriculture and water saving technology such as bed planting.

Quality breeding has been very successful in the last 10-15 years. Initially, Chinese wheat was not suitable for mechanized production, but now it has become possible. Improvement of quality still remains a great challenge in China. Pan bread and noodles are the targeted products for northern China and soft wheat is targeted for southern China. In addition to gluten quality, improvement of colour and starch property is crucial for high noodle quality wheat. It is expected that demand for good quality wheat will increase with the rapidly increasing consumption of fast foods, such as instant and frozen noodles, and western products, such as bread and cookies. It is estimated that market demand is already for more than 20 million tons of good quality wheat, suitable for noodles, dumplings, western breads, cookies and cakes. This represents around 20 per cent of the national production and over 50 per cent of the commercial wheat. In addition to good quality cultivars, the industry will require appropriate production systems, improved quality testing, and adequate grain segregation and storage capacity. Experience has shown that a combination of high grain yield and excellent industrial quality is possible, as exemplified by Jimai 20 and Yumai 34, leading cultivars in Shandong and Henan, respectively. But, small farmers (around 0.7 ha) face great challenges in producing stable commercial wheat varieties.

Molecular markers have great potential in improving breeding efficiency if they can be integrated with conventional breeding programs. In addition to validating molecular markers from other programs around the world, the CAAS-CIMMYT (International Maize and Wheat Improvement Center in Mexico) joint wheat program takes a leading role in molecular marker development and application, through close collaboration with the Shandong AAS in Jinan, the Sichuan Academy of Agricultural Science in Chengdu, and the Gansu Academy of Agricultural Science in Lanzhou. Around 100 available markers, including those developed by other programs around the world, targeting traits including quality, disease resistance, plant height, and adaptation. Currently, molecular markers are used to characterize cross the parents, improve selection efficiency in segregating populations of backcrosses, and confirm the presence of targeted genes in advanced lines.

Chinese scientists started to work on GM wheat in the early 1990s, and a national wheat GM project was initiated in 2008 with involvement of major breeding programs. This project with excellent funding support is designed for 15 years. The targeted traits include resistance to biotic and abiotic stresses such as drought and pre-harvesting sprouting, processing quality for improving gluten strength and starch parameters, and yield potential. Significant progress has been made in improving drought tolerance and resistance to pre-harvesting sprouting. Field trials are being conducted in several institutes and it is expected that rapid progress will be achieved in the near future. China is also part of the world wheat genome sequencing project.

In addition, it is emphasized that governmental policy supports have also been constant from 2003 on following aspects:

- End of agricultural quota system
- Support for crop production at the rate of $ 200 per hectare
- Subsidized elite seeds and mechanization

- Constant wheat price increase $ 320 per ton in 2012
- Support to public and private partnerships
- Increased funding for research and extension, including a large investment on GM crops, wheat included, despite a relative decline of urban consumer's acceptance.

## Future Strategy

Food self-security remains the P.R. of China's basic policy in cereals/wheat and a strong perennial governmental support for research and production its main tool. Higher and more stable wheat yield must be achieved under less inputs and unpredictable climate conditions, with simultaneous multiple disease/insect resistance. Collaboration between CIMMYT and other institutes will continue to be determinant for integrating new varieties and improved management systems, resulting in a better profitability. Under the growing pressure of the new Chinese urban middle class-220 millions in 2012, 500 millions projected in 2020, market demand for better quality wheat will increase and allow more bread and noodle industrialization. Food safety becomes a new top priority, with a particular concern about the impact of head scab toxins and chemical residues on human/ animal health.

The area of Chinese wheat was maintained at 24 million hectares for the last four years and it is very unlikely that further expansion in planting area will occur. With the continuing increase by population and improvement of living standards, production of 120-130 million tons is expected in 2030. In the meantime, Chinese wheat production is facing great challenges in several aspects, notwithstanding reduction of soil fertility, water scarcity, environmental contamination, and increased frequencies of high temperatures and droughts caused by global climate change, combined with increasing worker shortages and land-use shifts from grain production to cash crops. Breeding for high yield potential remains the first priority. The future challenge of wheat breeding in China is to raise grain yield, or to both maintain genetic gains in grain yield and improve processing quality, without increasing inputs for the wheat-based double cropping system in the main wheat growing regions. Continuous support for technology improvement, increasing farmer size and further promotion of mechanization, and supporting policy for cereal production, particularly adjusting price under the inflation condition, will be the key factors to meet the increasing demand of cereal consumption in the future. The minimum purchasing price for wheat and rice has been established since 2004 as an effective measure to promote grain production. At present, contracted management rights shares 17.9 per cent of the total farmer land contracted by rural households, this will permit to increase farm size and increase profitability, but will not change the ownership of the land.

Chinese government has released new measures to promote breeding and seed industry, and to encourage private sector's investment in seed business. At present, 30-40 per cent lines in regional trials and 20 per cent varieties in the major wheat regions are from private companies or developed through public-private partnership. Seed subsidy is also employed to promote new varieties. Increased investments in seed industry both from public and private sections and private-public partnership will make significant contributions to increase the productivity.

For decades, repeated attempts have been made to develop non-GM hybrid wheat systems, and China remains a major, if not the main world player in this sector. Several breeding teams had been working with various types of cytoplasmic male sterility systems based on alien cytoplasm, genic male sterility, and gametocides. Following the success of hybrid rice, hybrid wheat breeders are trying to develop two-line hybrid wheat systems that exploit differential plant responses to different thermo-and photo-period environments. Even with further progress in the science, commercial hybrid wheat will be delayed as we will need to bridge the gap between the breeding nursery and the farmer's field. However, if successfully developed, hybrid wheat would undoubtedly contribute a significant production increase.

With a significant investment in wheat biotechnology, it is expected that both molecular marker assisted selection and genetic transformation will play increasingly important roles in the future. In 2008, the Chinese government decided to fund a GM wheat project for 15 years. It is crucial to integrate the advances in biotechnology into leading conventional breeding programs. Biotechnology also offers new tools for breeding programs and international cooperation may accelerate their use. More training is needed for breeders to take advantage of available markers in practical breeding programs.

## Conclusion

During the last decades, China achieved significant progress in wheat production and in wheat quality through its public research and cooperation with CIMMYT. Further yield increase at stable or slightly decreasing acreage must be achieved in the future under less input conditions whatever the evolution of the global warming. In this perspective, conventional breeding and selection assisted by markers will continue to play a crucial role, as well as the improvement field management systems through the country. After 40 years of hybrid wheat research, there is no significant commercial progress. However, this goal is achievable as in maize and rice without complementary use of gene engineering. The question remains open in China as in other countries. Potentially, Chinese GM wheat tolerant to drought would tremendously secure the China's wheat production and a GM hybrid would offer higher yield regularity.

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# 8. Wheat Improvement in India

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## Introduction

India is the second largest producer of wheat in the world next only to China, contributing about 35 per cent of the total cereals produced in the country. The systematic breeding work was initiated by resorting to hybridization among the Indian genotypes and the exotic wheats, which resulted in the development of disease resistant varieties against the rust virulences prevailing in different parts of the country. Although the wheat improvement program has made significant progress, an important milestone in this process was created with the establishment of the All India Coordinated Wheat Improvement Project (AICWIP) in 1965 by the ICAR with its headquarters at IARI, New Delhi. The initiation of AICWIP resulted in the real breakthrough in productivity, occurred from introduction of semi-dwarf Mexican wheat which led to usher the green revolution in the country. Nevertheless, the system so created in the form of AICW&BIP provided a strong platform for working in close collaboration and this led to develop better wheat varieties to suit to varying production conditions of different wheat growing zones of the country. The wheat production progressively scaled new heights year after year. The phenomenal increase in area, production and productivity established new records.

## Area, Production and Productivity of Wheat in India

The country is now producing 85.93 million tons of wheat from 29.5 million hectares of area during 2010-11 (Fig. 1). India, the second largest wheat producers in the world since 1997 and has not only been able to meet the domestic demands and maintain a sizeable buffer stock of around 20 million tons of wheat in the country, but now is in a position to export wheat to other countries.

The diverse environmental conditions and food habits support the cultivation of three species of wheat, viz., *T. aestivum*, *T. durum* and *T. dicoccum*. Among these, *T aestivum*

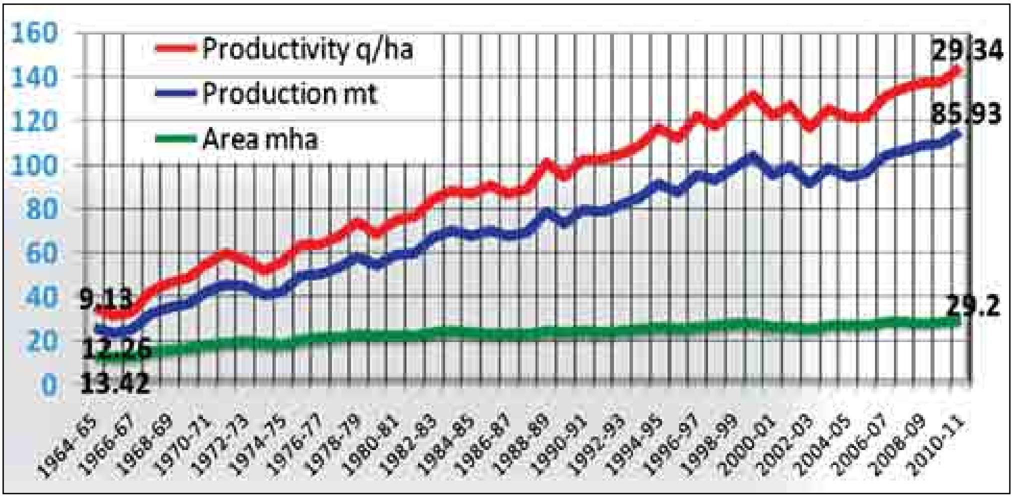


**Fig. 1.** Trend in area, production and productivity of wheat in India

(bread wheat) is contributing approximately 95 per cent to total production while another 4 per cent comes from durum wheat and one per cent from *Dicoccum*. The organized wheat research in India started more than hundred years ago after the joining of Sir Howards as the Imperial Botanist at Pusa (Bihar) in 1905.

The main strength of AICW&BIP had been its multidisciplinary and multilocational approach adopted in carrying out comprehensive research in the field of wheat improvement. The multi-disciplines are Crop Improvement (Breeding, Genetics & Physiology); Crop Protection (Pathology, Entomology & Nematology); Resource Management (Agronomy & Soil Science), Quality (Cereal Chemistry) and Social Science (Statistics, Extension & Economics). There are 32 funded centers primarily located at different State Agricultural Universities (SAUs). In all, there are 107 wheat scientists in position at these centers. Besides, nearly 250 more scientists are associated with field testing program across the country. There are around 155 field testing sites which are located in six wheat growing zones of the country. Wheat crop in India is grown under six diverse agro-climatic zones (Fig. 2), wherein Indo-Gangetic Plains (IGPs) comprising the North Western Plains Zone (NWPZ) and the North Eastern Plains Zone (NEPZ) form the major wheat tract followed by the Central Zone (CZ) and the Peninsular Zone (PZ). This classification of zones has been based on climatic conditions, soil types and growing duration of wheat. During wheat growing season, the expected changes in climatic factors, viz., precipitation/winter rains, minimum and maximum temperature, wind velocity and its direction, sun shine hours, etc. need to be determined before making a drastic change in the future breeding strategies. However, realizing the vast variation in the climate in different regions of India, the ongoing programs are tuned to address even the micro-niche as well as the region specific needs. Similarly, modern varieties and matching production and protection technologies are being developed across the country to mitigate the possible anticipated effects.

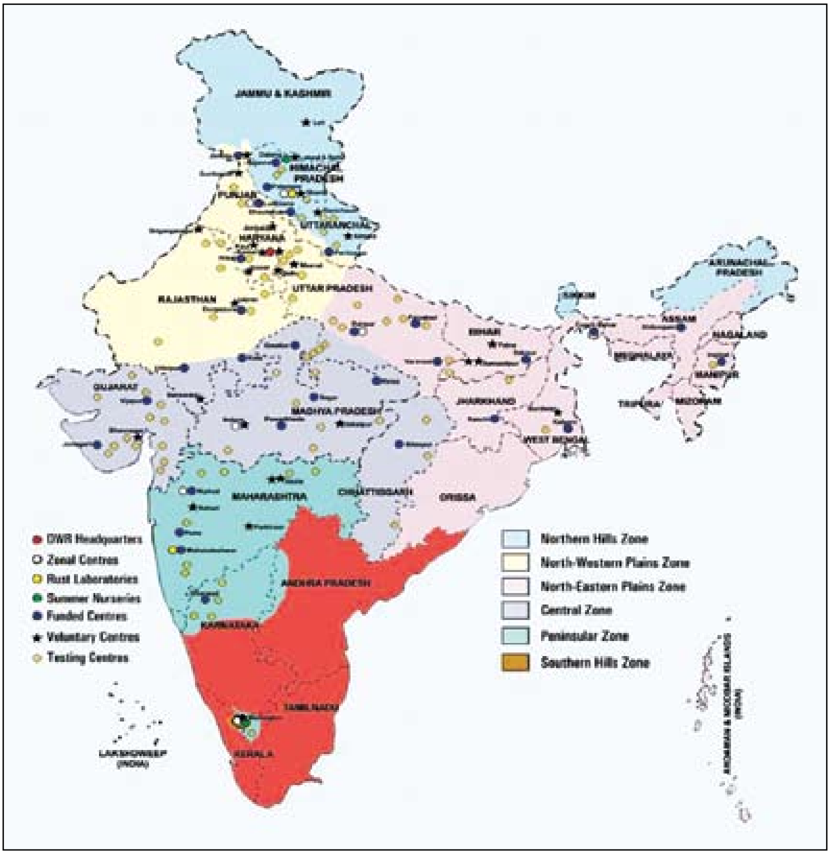


**Fig. 2.** Wheat growing zones and coordinated centers of AICW&BIP

At present, India is in comfortable position as far as wheat production is concerned. India is endowed with unique wheat germplasm capable of growing and yielding satisfactorily under sub-optimally higher temperatures. Especially the wheat varieties grown in the central and southern parts of the country carry genetic potential for tolerating usually higher temperatures prevalent in these areas during wheat growing season. Therefore, these materials offer scope for improving varieties with respect to heat tolerance for cultivation in northern plains of the country. Also, the new science of biotechnology can be properly utilized in targeting heat tolerance traits and transferring them in the background of high yielding varieties. Moreover, the main challenge before the farm scientist will remain to sustain the higher wheat production under comparatively rising temperature in time to come.

## Major Achievements in Increasing Wheat Production and Productivity

The Indian wheat program since inception of AICWIP till 2011 has developed and released 382 improved varieties of wheat and *Triticale* for commercial cultivation under different production conditions (Table 1).

**Table 1.** Wheat and triticale varieties released in India during 1965-2011

| Species | Released by | | Total |
|---|---|---|---|
| | CVRC | SVRC | |
| Bread wheat | 211 | 112 | 323 |
| Durum wheat | 25 | 24 | 49 |
| Dicoccum wheat | 05 | - | 05 |
| Triticale | 04 | 01 | 05 |
| **Total** | **245** | **137** | **382** |

*CVRC - Central Variety Release Committee, SVRC – State Variety Release Committee*

Among these, the landmark varieties like Kalyansona, Sonalika, C 306, WL 711, UP 262, WH 147, HD 2189, HD 2009, Lok 1, HUW 234, HD 2329, VL 616, HD 2285, GW 496, HI 8498, GW 322, WH 542, PBW 343, UP 2338, HD 2733, DBW 17, etc. dominated and occupied larger area due to wider adaptability, high yield potential, disease resistance, better grain quality, etc. It is also worthwhile to mention here that a total of 34 four varieties developed in Indian wheat program benefited other countries of the world by their adoption, adaptation and multiplication leading to commercial production (Table 2). Many of these varieties and other genetic stocks shared under collaborative research projects have been utilized as one of the parents in developing high yielding wheats by these countries (Table 2).

The strength of Indian wheat program can also be visualized by the suitability of Indian germplasm in Asian, African and Mediterranean regions of the world. It is fascinating to note that some of the landmark varieties (NP 4, Kalyansona and Sonalika etc.) became popular in more than one country. At present, good choice of improved varieties is available to farmers for growing under different production conditions (Table 3).

Besides, 136 trait-specific genetic stocks of wheat and triticale have also been identified and registered (Table 4) for utilization in hybridization program. These include donors for resistance/ tolerance to major biotic and abiotic stresses, primary yield component, grain quality attributes, CMS lines, etc. Seeds of all these genetic stocks have been maintained in the National

**Table 2.** Indian wheat varieties released in other countries

| S.No. | Variety | Country | Year of Release |
|---|---|---|---|
| 1. | BAW 28 (UP301/ C306) | Bangladesh | 1983 |
| 2. | CC 464 | S Africa | - |
| 3. | Chhoti Lerma | Nepal, Pakistan | 1968 |
| 4. | CPAN 1796 | Nepal | 1988 |

*Contd...*

*Table 2 (Contd.)*

| S.No. | Variety | Country | Year of Release |
|---|---|---|---|
| 5. | DWR 162 | Indonesia | - |
| 6. | HD 1220 | Algeria | |
| 7. | HD 1931 SIB | Lebanon, Saudi Arabia, Pakistan, Algeria | 1974 |
| 8. | HD 1999 | Oman | 1978 |
| 9. | HD 2009 | Pakistan | 1978 |
| 10. | HD 2172 | Syria, Sudan | 1981, 1983 |
| 11. | HD 2189 | Nepal | 1982 |
| 12. | HD 2204 | Nepal | 1983 |
| 13. | HD 2320 | Nepal | 1985 |
| 14. | HD 2322 | Afghanistan | 1987 |
| 15. | HD 2380 | Bhutan | 1992 |
| 16. | HP 1209 | Nepal | 1981 |
| 17. | HUW 251 | Nepal | 1988 |
| 18. | Janak | Nepal | 1975 |
| 19. | Kalyansona | Myanmar, Nepal, Ethiopia, Yemen, Mongolia, Oman | 1968, 1968, 1970, 1973, 1974, 1977 |
| 20. | Kanchan (UP301/ C306) | Bangladesh | 1983 |
| 21. | K 816 | S Africa | - |
| 22. | K 852 | Pakistan | - |
| 23. | Mukta | Sudan | 1978 |
| 24. | NP 4 | Australia, Brazil, South Africa, Myanmar | 1916 |
| 25. | NP 12 | Argentina | 1916 |
| 26. | NP 111 | Australia | 1930 |
| 27. | NP 798 | China | 1964 |
| 28. | Pratap | Bangladesh | 1981 |
| 29. | RR 21 (Sonalika) | Nepal | 1968 |
| 30. | Safed Lerma | Oman | 1978 |
| 31. | Sharbati Sonora | Myanmar | 1968 |
| 32. | Sonalika | Bangladesh, Bhutan, Ethiopia, Pakistan, North Vietnam, Yemen PDR, Yemen AR | 1968, 1968, 1970, 1971, 1972, 1973,1976 |
| 33. | UP 262 | Nepal, Thailand, Myanmar | 1978, 1987 |
| 34. | WL 711 | Pakistan, Afghanistan | 1989 |

**Table 3.** Improved varieties of wheat for different zones and production conditions

| Zone | Production condition | Varieties |
|---|---|---|
| Northern Hill Zone | TS-IR-high fertility | HS 507, VL 804, VL 738, HS 240 |
| | TS-RF-low fertility | HS 507, VL 804, VL 738, HS 240, TL 2942(trit) |
| | ES-RF-low fertility | VL 829, HPW 251, VL 616 |
| | LS-RI-medium fertility | HS 490, VL 892, HS 420, HS 295 |
| | High altitude areas | HS 365, VL 832, SKW 196 |
| North Western Plains Zone | TS-IR-high fertility | DPW 621-50, HD 2967, DBW 17, PBW 550, PBW 502, PBW 343, WH 542, UP 2338, HD 2687, PDW 291(d), PDW 233 (d), WH 896(d), WHD 943(d) |
| | LS-IR-medium fertility | PBW 590, WH 1021, DBW 16, PBW 373, RAJ 3765, UP 2425 |
| | TS-RF-low fertility | WH 1080, PBW 396, PBW 175, Kundan |
| North Eastern Plains Zone | TS-IR-high fertility | DBW 39, CBW 38, Raj 4120, K 307, HD 2824, PBW 443, PBW 343, HD 2733, HUW 468, K 9107, HP 1761 |
| | LS-IR-medium fertility | HI 1563, HD 2985, HW 2045, DBW 14, NW 2036, HD 2643, NW 1014, HP 1744, Halna |
| | TS-RF-low fertility | HD 2888, MACS 6145, K 8027 |
| | LS-RF-low fertility | K 9465, K 8962 |
| Central Zone | TS-IR-high fertility | HI 1544, GW 366, GW 322, GW 273, DL 803-3, HI 8498(d) |
| | LS-IR-medium fertility | MP 1203, HD 2864, HD 2932, MP 4010, DL788-2 |
| | TS-RF-low fertility | HI 1531*, HI 1500, HW 2004, Sujata, HI 8627(d)*, HD 4672(d) |
| Peninsular Zone | TS-IR-high fertility | Raj 4037, GW 322, HUW 510, DWR 162, HD 2189, MACS 2971(dic), HI 8663(d), DDK 1025(dic) |
| | LS-IR-medium fertility | PBW 533, HD 2932, HD 2833, Raj 4083, NIAW 34 |
| | TS-RF-low fertility | NI 1415*, HD 2987*, PBW 596*, K 9644, HD 2781, NI 5439, AKDW 2997-16(d) |
| Southern Hill Zone | TS-RI-medium fertility | HW 2044, HW 1085, COW (W) -1 |
| Marginal areas | Salinity-alkalinity condition | KRL 210, KRL 213, KRL 19, KRL 1-4 |
| Very late sowing | IR-Medium fertility | Raj 3765, PBW 373, Halna |
| Summer sowing | | HS 375 |

**Also suitable for restricted irrigation, (d) = durum wheat, (Dic) = dicoccum wheat, TS = Timely Sown, LS = Late Sown, ES = Early Sown, IR = Irrigated, RF = Rainfed, RI = Restricted irrigation, Trit : Triticale*

**Table 4.** Identification and registration of trait-specific genetic stocks

| Trait(s) | No. of genetic stocks |
|---|---|
| Biotic stresses (rust, loose smut, powdery mildew, Karnal bunt, hill bunt and foliar blight) | 75 |
| Abiotic stresses (drought, heat and salt tolerance) | 12 |
| Primary yield components (grain size, grain number per spike and fertile tillers per unit area) | 6 |
| Grain quality (protein, lysine, beta carotene, sedimentation value, bread quality score, *chapati* quality score, spread factor. loaf volume and HMW sub-units of glutenins) | 22 |
| CMS lines with maintainers and fertility restorers | 8 |
| Others | 13 |
| **Total** | **136** |

Gene Bank at NBPGR, New Delhi and in the germplasm repository of DWR, Karnal. The DWR, Karnal has also been assigned the responsibility of multiplying and supplying seeds of important donors to wheat breeding centers in the country for using in hybridization program.

In addition, at the Directorate of Wheat Research, Karnal, two lines were developed from the progeny of the cross NIAW 34/ *Lr19* (RL 6010) //CMH81A-575 which involved a short duration variety of bread wheat and a buitre type line for agronomic traits and a source of leaf rust *Lr19*. These two lines are dwarf with average height of 54 cm and 58 cm, respectively and hence never lodge in the field. These showed high tillering with comparable spike length and protein content with best check PBW 343. Being very promising, these can be used as the donors for dwarfing trait in improving tall genotypes as lodging is very serious problem now a days due to erratic weather conditions at dough stage.

## Constraints in Productivity Enhancement and Emerging Challenges

**Narrow genetic base:** The wheat program is one of the important programs in the country and has been very vibrant during the last four decades, as indicated by the production, productivity and other achievements. But, there is no room for complacency and the program needs to be more responsive to the new emerging needs under the present scenario. It is well known that country's wheat production has been continuously increasing for the past five years, but at the same time the productivity has been stagnating at 2.7-2.9 tons per hectare. The intensive and massive cross breeding efforts made by wheat breeders at national and international level during the last 50 years in the development of high yielding wheat varieties seem to have exhausted the available useful variability in germplasm holdings. This opinion can be verified in Indian context from the apparent yield plateau being witnessed due to slowing down the pace of yield improvement in the form of new varieties developed during last one decade. The increase in productivity which is treated as real indicator of yield potential of varieties also showed the same trend. In the first instance, the increase in productivity jumped from 100 to 139 per cent during 1975-84 and it remained unchanged during the next decade of 1985-94, but later on came down to 122 per cent (1995-04) and 104 per cent (2005-09). Therefore, from research point of view, the level of gain in the genetic potential of grain yield of futuristic wheat varieties has to be pushed up for achieving the vertical increase in wheat production because there is little scope for further horizontal expansion of area under wheat.

**Adverse effects of climate change:** It is obvious that any significant change in climate will have impact on agriculture or in food production as these two are interrelated. Increase in ambient temperature may lead to shorten crop duration, increase crop respiration rates, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer use efficiencies and increase evapo-transpiration. It is anticipated that the adverse effects on wheat productivity and total production may be felt in the long run.

**Heat stress:** Heat stress is a major abiotic stress limiting yield. Wheat is sensitive to high temperature (both early and late heat) but magnitude of damage will depend on background ambient temperature, stage of development and variety. Extremes of temperature at sensitive developmental stages are especially detrimental as temperatures above $30^0$C around anthesis can damage pollen formation and reduce yield. Effects of increased $CO_2$ on wheat yields will normally be positive but benefits will vary with the prevailing temperature regime and availability of other inputs (water and nutrients). Whether such benefits will offset negative effects of warming is, therefore, a critical issue for any assessment of wheat production under changed climate. It is established that many physiological traits / parameters, viz., grain filling duration (GFD), canopy temperature (CT) have strong correlation with terminal heat tolerance (THT). It is assumed that reduced GFD will avoid the damage done due to terminal heat stress, while a low CT will help the plant withstand terminal heat stress. In view of this, both GFD and CT have been used while selecting for higher wheat yields under high temperature at the time of maturity and thus can be effectively utilized for QTL analysis as parameters for terminal heat tolerance.

**Water scarcity and drought tolerance for yield enhancement in drier areas:** Water is becoming a limiting factor in production all over the country. In wheat, irrigation scheduling is followed depending on the availability of water. Excess utilization of ground water in dry areas has led to depletion of underground water and farmers are expecting to get reasonable grain yield with sub-optimal irrigation. Through restricted irrigation experiments, it has been found that a single post sown irrigation under rainfed condition can double the grain yield of many of the wheat genotypes. Drought or moisture stress is another important factor determining area under wheat cultivation vis-à-vis total wheat production in the country. Considerable area (86%) sown under wheat has an access to irrigation, however, crop sown in about 14-15 per cent of the area, which amounts approximately to 4 million hectares, depends on rain. Hence, failure of monsoon followed by absence of winter rains largely reduces area as well as productivity particularly in the central and peninsular parts of the country as well as in northern hills. In fact, drought stress is a major constraint in rainfed agriculture particularly in the semi-arid regions of the tropics. As a matter of fact, besides developing a few varieties through empirical approach, no breakthrough could be made in increasing the productivity in drought prone areas of the country. Although, number of physiological parameters have been put forward for identifying drought tolerant genotypes of wheat, but none of these parameters could become practically feasible for selecting individual plants from the segregating generations. Hence, the breeders had no option other than to select individual segregants based on their phenotypic performance under natural conditions of drought which may or may not yield to desired type of genotype. Nevertheless, on limited scale, the segregating material can be exposed to artificial moisture stress under controlled conditions to select drought tolerant and drought susceptible plants based on seeding survival. Recently, the carbon isotope discrimination (CID) technique has been successfully utilized in identification of drought tolerant genotypes.

**Technology for tackling abiotic stresses:** Now, with the availability of biotechnological techniques, the mapping populations in the form of recombinant inbred lines (RILs) have been utilized for identifying the QTLs / major genes governing heat tolerance in wheat. The RILs developed by crossing WH 730 (heat tolerant) and Raj 4014 (heat susceptible) have been used for carrying out intensive studies on phenotyping and genotyping leading to identification of genes for heat tolerance. Similarly, experiments are in place to identify wheat varieties which give good response to limited irrigations. It has been seen that certain wheat genotypes primarily developed for rainfed condition do yield double if provided two irrigations i.e. one for sowing and another at CRI stage. In case, there is no need of pre-sown irrigation due to availability of residual moisture, the first irrigation is applied at CRI stage, and second irrigation can be provided at flowering stage for achieving desired results. Some of the promising wheat varieties, namely, HI 1500, HI 1531, HI 8627, PBW 596, etc. have given around 3.5 quintals per hectare as compared to 1.5-2.0 quintals under rainfed conditions. Hence, all possible efforts have to be made to develop water use efficient (WUE) wheat genotypes and WUE wheat cultivation technology to face the shortage of water for irrigation.

**High cropping intensity and shorter crop duration:** In addition, wheat is sown late on considerable area in north-western and north-eastern plains of India due to high cropping intensity and delayed harvest of previous crop. As a result, the crop gets exposed to higher ambient temperatures at the time of grain filling, which cause significant reduction in productivity. The Indian wheat improvement program has been instrumental in developing improved varieties suitable for cultivation under varying environmental conditions. Performance of different varieties is assessed based on their grain yield per unit of land. This is an important indicator but with climate change and emerging scarcity of water and energy, other indicators like stability and efficiency are also acquiring importance. Therefore, due consideration is being given to varietal attributes like (a) resilience to withstand climatic aberrations, and (b) input use efficiency. Thus, assessment of performance of different varieties should be based on a composite index which incorporates all important attributes by assigning suitable weights to them. Studies involving advanced wheat genotypes have helped in characterizing the environments in terms of weather parameters and also in terms of plant responses.

It has been conclusively shown that biomass production is a key factor in high grain yield performance under late sown high temperature environments. Reports have indicated that various morpho-physiological parameters are related to heat stress which adversely affect wheat yields. The probable approaches for further increasing the yield potential of wheat varieties include pre-breeding for parent building vis-à-vis transferring novel traits of economic importance from wild or alien species in the usable genetic background of hexaploid genotypes, exploitation of heterosis for the production of hybrid wheat and resorting to winter × spring wheat hybridization for generating variability and developing facultative high yielding varieties suitable for early sowing.

## Current Efforts for Improving Wheat Productivity

**Developing hybrid wheat:** Developing hybrid wheat is a good option for productivity increase. Exploitation of heterosis is a workable approach for increasing the yield potential of wheat genotypes. The availability of cytoplasmic male sterile lines (CMS), their maintainers and fertility restorers has increased the possibility of developing hybrid wheat. This activity has been taken up in a network project mode involving DWR, Karnal; IARI, New Delhi and PAU, Ludhiana. At present, efforts have been made to convert commercial varieties into male sterile lines, studying the floral biology and identifying suitable maintainers and restorers besides developing heterotic gene pools.

**Developing new plant types:** Efforts have been made to genetically architecture a new plant type (NPT) that has high harvest index and biomass. In crops like wheat, number of grains per plant serves as the sink and helps in identifying the potential high yielders. The research efforts particularly at IARI, New Delhi are going on to increase the harvest index through enhanced grain yield along with the higher biomass. To increase the biomass for higher yield potential, the following characteristics are being introgressed:

- Desired canopy structure
- Rapid leaf area development
- Rapid nutrient uptake
- Increasing lodging resistance (robust stem)

Physiological parameters like greater radiation use efficiency, increased rate of grain filling, increased number of grains per spike, efficient nutrient uptake efficiency and better stem reserve mobilization, are being taken into account for making a new plant type (NPT). Two high yielding varieties, namely, Vaishali and Vidisha were released which were developed using local germplasm-SFW through NPT approach. Several other genotypes based on NPT have been developed which possess high 1000-grain weight, higher grains per spike, higher biomass, dark green and broader leaves, thick stem and efficient root system.

**Sustaining wheat yields through enhanced disease resistance:** The host resistance is the cheapest, effective and environmental friendly means of controlling the menace of three rust diseases. In fact, there had not been any serious rust epidemic in India during the last four decades due to deployment of rust resistance genes in the form of improved wheat varieties released for commercial cultivation. So far, quite a few resistant genes against rust diseases have been utilized by wheat breeders in the country. However, emergence of a new stem rust race Ug99 (TTKS) in Uganda (Africa) has posed a serious threat to wheat cultivation across the globe. Luckily, Ug99 race has not been detected so far in Indian wheat fields, but there is every likelihood of its arrival sooner or later in our country. To pre-empt the threat posed by Ug99, the anticipatory resistance breeding work was initiated in collaboration with CIMMYT and BGRI by screening Indian wheat materials against Ug99 at Njoro (Kenya) where this race is existing in natural condition. So far, little over 700 Indian wheat genotypes have been screened at Njoro (Kenya) against Ug99 and 78 genotypes have shown resistance to this race. Of these 78 genotypes, 25 are the commercial varieties of wheat and triticale. Besides, there are known *Sr* genes like *Sr*25, *Sr*26, *Sr*27, *Sr*29, *Sr*32, *Sr*35, *Sr*36, *Sr*39, *Sr*40, *Sr*44 and *Temp* which can be utilized in breeding program for developing resistant varieties of wheat against Ug99. To counter the menace of important races of stem rust of Indian origin, there is also need for immediate attention. The useful *Sr* genes like *Sr*2, *Sr*5, *Sr*25, *Sr*26, *Sr*27, *Sr*32, *Sr*35, *Sr*39, *Sr*40 and *Sr*43 need to be utilized on priority basis for keeping the menace of stem rust under control in the stem rust vulnerable areas of central and peninsular India. A new race of stripe rust known as 78S84 has come to stay in Indian wheat fields and it has knocked down the most popular variety of wheat PBW 343 which is covering more than 7 million hectares of area in Indo- Gangetic plains. The stripe rust disease is prevalent in northern and southern hills, north western and north eastern plains of the country. However, the central and peninsular parts remain free from this disease due to unfavorable weather conditions. For keeping stripe rust under control, new *Yr* genes like *Yr*5, *Yr*10, *Yr*15, Cappelle Desprez and China 84-40022 should be utilized in the breeding program. Among other diseases which need immediate attention in breeding for resistance are Karnal bunt, foliar blight, powdery mildew and loose smut. Although, the incidence of Karnal bunt disease is presently not so severe as it used to be during eighties and nineties, however, due to its cosmetic nature and ban for trading in international market, breeding efforts need to be continued for the development of resistant varieties. The resistance donors for Karnal bunt disease are now available in both bread wheat (HD 29, HD 30, W 485, W 1786, KBRL 10, KBRL 13, KBRL 22, ML 1194, WL 3093, WL 3203, WL 3526, WL 3534, HP 1531, ISD 227-5) and durum wheat (D 482, D 873, D 879, D 895) for breeding purpose. Resistance has been incorporated in high yielding wheat varieties like PBW 343 and WH 542 by back crossing. Chromosome region (4B, 6B and 5A) linked to KB resistance has been identified.

Similarly, the breeding for developing resistant cultivars against foliar blight is now feasible due to standardization of disease creation techniques, disease scoring methodology and availability of resistance donors such as Harit 1(M 3), LBRL 1, LBRL 4, LBRL 6, LBRL 11, LBRL 13 and DBW 46. A high level of resistance to spot blotch was achieved by crossing resistant varities of wheat with agronomically superior varieties following rigorous selections for low area under disease progress curve (AUDPC) in segregating generations. Besides, in order to facilitate the molecular mapping for resistance against Bs, three different sets of recombinant inbred lines (RILs) have been developed and are being utilized for identification of major QTL conferring resistance to spot blotch. Fortunately, there is no serious problem of any insect-pest in our country in wheat crop. The incidences of termites and aphids have sometimes been reported from certain parts, which can be controlled by use of recommended insecticides. In the same way, loose smut and powdery mildew diseases of wheat are very well managed through seed treatment and spray of recommended fungicides, respectively. Nevertheless, in view of decreasing water table and increasing temperature, both termites and aphids may become prominent threats to wheat crop in future.

**Use of molecular tools in wheat breeding:** The intended outputs for the marker programs in wheat breeding include genetic understanding, markers for disease resistance, biotic and abiotic stresses. The outputs for the novel gene programs will include increased knowledge, identification of novel genes and marker assisted trait specific targeted breeding. Breeding strategies adopted should not be directed by the technology but rather by the ability to maximize genetic gains, and breeders need to be confident that selection pressure of this nature will shift the populations in the desired direction. The impacts on the breeding programs will be as follow:

- Significant reduction in the time to develop a new variety
- More effective and direct control of the alleles retained and eliminated
- Possibility of improving traits that were not possible using traditional phenotypic screening
- Access to new genes that will provide greater diversity
- Ability to manipulate the expression of existing genes
- Opportunity to adopt more sophisticated, challenging breeding strategies.

## Tailoring Wheat Varieties Suiting to Different Resource Conservation Technologies

The important resource conservation technologies are as follows:

- To cut down the cost of wheat production without compromising on yield, the zero-tillage technology has been perfected for wheat cultivation. The zero-till-drill machine can make slits and place measured quantity of seed and fertilizer in one go in fields vacated from rice or sugarcane. There is no need of field preparation in zero tillage practice which saves up to 96 per cent in diesel consumption. At the same time, grain yields of wheat obtained under zero tillage technology are as high as realized from conventional tillage. In this way, a saving of around Rs. 2,500-3,000 per hectare is achieved on land preparation for wheat sowing. However, the subsequent agronomic practices for raising a zero till wheat crop are no way different from the conventional tillage. As present, more than two million hectares of wheat area in the states of Haryana, Punjab, Uttar Pradesh, Bihar and West Bengal is under zero-tillage practice.

- Other forms of RCTs which are also gaining momentum include rotary-tillage and furrow irrigated raised beds (FIRBs) technology. The rotary tillage is done by rotavator - cum – drill machine capable of doing three operations simultaneously i.e. pulverization of soil, putting seed and fertilizer in furrows and planking the field. This technology can save about 90 per cent diesel and also given higher yields over zero tillage as well as conventional tillage. In case of FIRBs, there is no saving in diesel use but it offers other advantages like saving in seed, fetilizers and water for irrigation. The FIRBs, technology also offers an opportunity of growing the companion crop in furrows along with wheat on beds.
- The experimental results have shown interaction between genotypes and RCTs indicating the need to develop separate wheat varieties suitable for particular RCT. Wheat genotypes exhibiting better seed germinability, seedling vigour and higher root biomass during early as well as later growth stages have been found more suitable for growing under zero-tillage conditions. Similarly, for FIRBs technology, wheat varieties possessing long coleoptile and capable of producing more effective tillers per unit area are preferred.
- Besides, the nitrogen use efficiency was more in zero tilled wheat. Sustainability of rice-wheat system by popularizing available resource conservation technologies, refinement of machines, developing tillage specific varieties, improving water and nutrient use efficiency and tackling weeds and insect-pests under new tillage conditions is being investigated in detail.
- In addition, improving soil health by increasing carbon content, correction of micro-nutrient deficiencies / toxicity and balanced use of fertilizers are some of the very relevant aspects that limit wheat productivity over time.
- Experimentation is being made to explore the use of organic farming, use of agriculturally important micro-organisms, bio-agents and promoting biological control of pests and diseases in the changing scenario.
- To slow down the impact of climate change, adopting resource conservation technologies like zero tillage and bed planting especially with surface residue retention using second-generation seeding machines like Rotary Disc Drill and Happy Seeder can help in avoiding burning which adds to environmental pollution. Moreover, it will help in temperature moderation and offsetting the adverse effect of rising temperature in addition to improving the health of soil.
- Micronutrient efficient breeding strategies need to be devised for stable yields. Synthetic wheat hexaploids have the potential to improve current levels of Zn efficiency in modern

wheat genotypes. These efficient cultivars have lower external B or Zn requirements, and are able to extract the low levels of B or Zn efficiently. At the same time, they are also able to utilize the micronutrients more efficiently for growth. Much needs to be done to meet crop requirements for micronutrients that are relatively small, but their deficiencies greatly limit the effectiveness of macronutrients. Since micronutrient deficiencies are posing a problem in Indian population, all efforts have to be made to evolve efficient wheat varieties having rich contents of micronutrients like, beta carotene, copper, zinc, iron, manganese, etc. To improve nutrient use efficiency, their requirement should be worked out for the entire cropping system. Similarly, bio-fertilizers should be amalgamated in cultivation to enhance the efficiency of inorganic fertilizers. The genetic variation in Fe, Zn and Mn efficiency will allow more efficient genotypes of wheat to be developed in future.

## Improving Grain Quality for Industrial and Domestic Use

Till now, more and more emphasis had been placed on increasing yield *per-se* and improving *chapati/roti* making quality for meeting the requirement of indigenous population. However, under the changing scenario of the domestic market and emerging consciousness for better quality products, it has now become imperative to breed wheat varieties for fulfilling the quality standards of industrial products. In time to come, the foremost need will be to further improve the genetic potential of wheat varieties for accumulating higher content of protein in grain. Grain hardness is another important parameter required for making good quality *chapatis*, bread and biscuits. Now, the genetics of grain hardness is better understood and role of puroindoline genes in imparting varying degrees of grain hardness in wheat has been elucidated. By utilizing the wild and mutant alleles of puroindolines A (Pin A) and B (Pin B), the desired level of grain hardness or completely soft grains can be produced with the help of simple genetic manipulation and laboratory tests. Soft grains accompanied with weak gluten strength are considered quite suitable for manufacturing good quality of biscuits. In this context, mention can be made of an Indian landrace of wheat known as Nap Hal which contains a unique combination of double null trait at Glu-D1 locus responsible for weak gluten. This trait of Nap Hal can be exploited and desirable plants can be selected from the segregating generations with the help of simple laboratory tests. There are now useful donors available for improving the sedimentation value, yellow pigment, hectolitre weight, semolina recovery and cooking quality of pasta products made out of *Durum* and *Dicoccum* wheats. Similarly, the accumulation of essential micro-nutrients in the grains can be improved through combined use of conventional and molecular breeding approaches.

## Strategies for Meeting the Future Challenges

Among the future priorities for wheat improvement, two pronged strategies are in place in the national program: i) short-term, ii) long-term. The short-term strategy is primarily to bridge yield gaps through available technology. For short-term approaches that have a very good scope to increase yield with available technologies, efforts are needed for transferring the technologies at the grass-root level and bringing in remedial measures that impede wheat production growth in certain parts of the country. The second one is long-term strategy that needs immediate attention. The opinion can further be verified in Indian context from the apparent yield plateau being witnessed due to slowing down the pace of yield improvement in the form of new varieties developed during last one decade. Information generated by coordinated efforts indicates that Punjab has a potential of harvesting 7.5 tons per hectare. The potential NWPZ is around 7 tons per hectare. At present, average wheat yield in this zone is around 4.0 tons per hectare, which indicates that there is a big gap between the theoretical and attainable yield. It has been noticed that there is a yield gap of at least 1.0 ton per hectare in the NWPZ and nearly 1.5 tons per hectare in the NEPZ between the farmers' practice and the technology demonstrated in frontline demonstrations. If the wheat yields of frontline could be realized by all the farmers of these two zones, that have nearly 18 million hectares, the present yield can be increased by another 20 million tons. This indicates the magnitude of un-harvested yield that is still there in the northern states. This can be accomplished only by making the farmers conversant with the latest varieties and crop management procedures. The above yield gaps are only in relation to the available best genotypes that in general yield up to 6.0 tons per hectare and in the event of further yield advancement due to technological progress, then the magnitude of yield gap will widen further. Quality seed constitutes an important component of technology for bridging the gap in yield. Production of quality seeds and replacement of old varieties with new released varieties is an important approach in minimizing the yield gap. New varieties that have been developed for various cultural conditions in different zones have got the capacity to bridge the gap in yield to a great extent.

## Reaching Out to Farmers

Technology promotional activities can go a long way in helping the farmers and the Directorate has been successful in organizing demonstrations, series of farmers days, exhibitions, press conferences, TV talks, training programs, meetings, workshops and organizing visits of farmers/students/policy makers to create awareness as well as in-depth discussion on various issues of concern. Hundreds of front line demonstrations (FLDs) are conducted at the farmers' fields in close collaboration with line departments on resource conservation technologies such as zero tillage, furrow irrigated raised bed planting integrated pest management, improved varieties and packages of practices. Through these FLDs, large yield gap have been observed in every state, thereby indicating that if these yield gaps are taken care of by the extension agencies, the country could harvest additional about 25 million tons of wheat.

## Seed Dynamics

In addition to the progress made in technology development, breeder seed production program has been successfully meeting the demand of quality seed to farmers and seed industry in the country. As a result, today about 150 improved varieties including PBW 502, PBW 550, UP 2338, Raj 3765, HI 8498, K 9107, HS 295, VL 804, GW 322, PBW 373, PBW 343, HUW 468, HW 2045, HD 2733, DBW 14, DBW 16, DBW 17, DBW 39, NW 2036, etc. are in the seed production chain. This change in deployment of large number of varieties has not only increased the number significantly but also provided choice to farmers thereby diversifying the genetic base to avoid large area under a few varieties. Presently, India is producing more than 35,000 quintals breeder seed of wheat varieties and is capable of fulfilling the national requirement of 32,000 quintals breeder seed which are indented annually through Department of Agriculture and Cooperation (DAC) in the country. However, there is a strong need for faster replacement of old varieties to ensure the national food security.

## Conclusion

Since the onset of the Green Revolution in 1960's, India has had spectacular increase in production, productivity and quality of wheat. The total production increased in the magnitude of about seven folds from roughly 12 million tons in 1965 to 85.93 million tons in 2011. This was achieved due to strong research by ICAR/SAU's which permeated into a set of improved varieties of wheat and barley resistant to diseases and high yields with stable performance. Critical assessment of the anticipated climatic changes and their probable impact on wheat crop have been visualized. Both, the long-term and short term strategies are being executed for sustaining the productivity of wheat in India. In order to meet the projected demand for wheat, new technological advances under changing climatic conditions becomes one of the vital components of wheat research in the country. In the area of crop improvement, emphasis is being placed on developing new genotypes that are responsive to high input management and capable of yielding beyond 7 tons per hectare. In this pursuit, the selection in segregating generations under varying climatic conditions will help to breed wheat genotypes tolerant to harsh conditions. The future genotypes of wheat must be nutrient and water use efficient, possess desired level of disease resistance and quality traits. However, in view of the global climatic changes, we need to highlight the importance of heat and drought tolerance to further improve yield and quality status of wheat varieties. At the same time, agronomic interventions or approaches to increase soil carbon content through organic manures, wide scale adoption of reduced tillage practices and proper residue management are essential to cut down overall gaseous emission to a great extent. In view of changing food habits and requirements of domestic as well as international market, future priorities are now inclined towards improving wheat quality for industrial uses, besides increasing yield and resistance to various biotic and abiotic stresses. The synergy between research, developmental and extension workers, can lead India to achieve the projected demand of wheat in the time to come. Any of these components in isolation will not be successful in further increasing and sustaining the yield levels in case of wheat. The Indian wheat program has required infrastructure, manpower and new tools and is capable of meeting the future challenges. It can be concluded here that to counter the possible effects of global climatic variations, integration of approaches including conventional breeding, modern biotechnological tools, resource management techniques of agronomy and regular survey and surveillance for monitoring the incidence of pests and diseases will be the key issue in shielding against climatic vagaries and thereby ensuring food security for the ever increasing population of the country.

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# 9. Wheat Productivity in Islamic Republic of Iran: Constraints and opportunities

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## Introduction

Iran is one of the largest countries in the Central and West Asia and North Africa (CWANA) region with total area of 165 million hectares lying between latitudes 24° and 40° N, and longitudes 44° and 64° E. The total population is 75 million with growth rate of 1.3 per cent. The topography is marked by mountains in western and northern Iran, plateau in central parts and desert lowlands in southern and eastern Iran. Mean altitude is more than 1,200 m above the sea level.

The country is generally known for arid and semi-arid climate except for Caspian Sea regions. On the basis of the three criteria in the UNESCO approach: moisture regime, winter type and summer type, Twenty eight agro-climatic zones have been differentiated, of which only six (arid-cool winter-warm summer, arid-cool winter-very warm summer, arid-mild winter-very warm summer, semi arid-cold winter-warm summer, semi arid-cool winter-warm summer, and semi arid-cold winter-mild summer) occupy nearly 90 per cent of Iran. Water shortages are compounded by the unequal distribution of rainfall.

The country's average annual rainfall is about 250 mm, which is less than 30 per cent of the global average of 860 mm, with erratic distribution; early drought and terminal drought are predominant. Moreover, the annual distribution of precipitation is diverse in terms of timing and location. Near the Caspian Sea, rainfall averages about 1,280 mm per year, but the Central Plateau and the lowlands to the south it seldom exceeds 100-200 mm, far below the minimum required for dryland farming. The temperature is the second major constraint that affects the rainfed agricultural production. It varies from -35°C (abs. min) in high altitudes to 54°C (abs. max) in littoral zone. The rate of evaporation per annum ranges from 700 to 4,200 mm.

Iran lies within the West Asia diversity center where crops of global importance have originated and includes the diversity of farming systems prevailing in CWANA region and in the non- tropical drylands. The diversity of climate in Iran provides an opportunity for producing diversified horticultural and field crops. Agriculture is an important sector, employing about 21.1 per cent of the labour force in the country, but contributing only 13 per cent to the national GDP. Of the total agricultural land (19 mha), 10 million hectares are rainfed and the rest are irrigated. Major crops include wheat, barley, rice, chickpea, cotton, sugar beet, vegetables, fruits and nuts. Table 1 shows the area, production and yield of some major irrigated and dryland crops.

Livestock includes large number of sheep and goats (about 80 million), mostly raised in an extensive management system. The dry areas account for a major part (30 per cent) of the agricultural land in Iran. In the 1970s and the early 1980s, productivity in those areas was particularly low, and the country imported about 30 per cent of needed agricultural commodities to meet the domestic demand of a rapidly growing population. Its further development is tightly linked to strategies to overcome specific and global challenges (global warming, land degradation, water scarcity, loss of biodiversity, etc.). Self- sufficiency has been achieved for wheat in 2004 due to government's intensified efforts and supports. The current policy of the Ministry of Jihad-e-Agriculture is to achieve self-reliance for major agricultural commodities within the coming 5-10 years to contribute

**Table 1.** Area, production and productivity of major crops in Iran

| Crop | Cultivated area (ha) | | | Production (t) | | | Productivity (kg/ha) | |
|---|---|---|---|---|---|---|---|---|
| | **Irrigated** | **Rainfed** | **Total** | **Irrigated** | **Rainfed** | **Total** | **Irrigated** | **Rainfed** |
| Wheat | 2,706,996 | 4,171,923 | 6,878,919 | 10,137,770 | 4,525,975 | 14,663,745 | 3,745 | 1,085 |
| Barley | 624,491 | 942,963 | 1,567,454 | 1,972,399 | 983633 | 2956032 | 3,158 | 1,043 |
| Rice | 630,562 | 0 | 630,562 | 2,612,174 | 0 | 2,612,174 | 4,143 | 0 |
| Maize | 291,763 | 85 | 291,848 | 2,165,879 | 251 | 2,166,130 | 7,423 | 2,973 |
| Chickpea | 13,743 | 588,814 | 602,557 | 16,159 | 308,627 | 324,786 | 1,176 | 524 |
| Beans | 92,981 | 4,329 | 97,310 | 202,377 | 5,908 | 208,286 | 2,177 | 1,365 |
| Lentil | 13,378 | 195,690 | 209,067 | 16,663 | 84,121 | 100,784 | 1,246 | 430 |

*Contd...*

*Table 1 (Contd.)*

| Crop | Cultivated area (ha) | | | Production (t) | | | Productivity (kg/ha) | |
|---|---|---|---|---|---|---|---|---|
| | Irrigated | Rainfed | Total | Irrigated | Rainfed | Total | Irrigated | Rainfed |
| Other pulses | 26,405 | 5,474 | 31,879 | 39,294 | 4,708 | 44,002 | 1,488 | 860 |
| Cotton | 113,345 | 3,215 | 116,560 | 279,338 | 4,336 | 283,673 | 2,464 | 1,349 |
| Tobacco | 6,945 | 4,929 | 11,874 | 11,691 | 3,788 | 15,479 | 1,684 | 768 |
| Sugar beet | 185,888 | 0 | 185,888 | 6,709,112 | 0 | 6,709,112 | 36,092 | 0 |
| Cane | 66,549 | 29 | 66,578 | 4,958,867 | 524 | 4,959,391 | 74,515 | 18,083 |
| Soybean | 61,100 | 20,675 | 81,774 | 149,664 | 35,304 | 184,967 | 2,449 | 1,708 |
| Rapeseed | 74,010 | 87,035 | 161,045 | 149,925 | 165,165 | 315,090 | 2,026 | 1,898 |
| Other oilseeds | 65,832 | 22,662 | 88,494 | 88,867 | 26,118 | 114,986 | 1,350 | 1,153 |
| Potato | 159,875 | 3,969 | 163,844 | 4,188,207 | 30,315 | 4,218,522 | 26,197 | 7,639 |
| Onion | 55,367 | 3,880 | 59,247 | 1,993,028 | 45,335 | 2,038,363 | 35,997 | 11,683 |
| Tomato | 146,837 | 625 | 147,462 | 5,054,830 | 9,741 | 5,064,571 | 34,425 | 15,588 |
| Other vegetables | 93,843 | 18,499 | 112,342 | 2,242,824 | 225,541 | 2,468,365 | 23,900 | 12,192 |
| Melon | 75,899 | 2,299 | 78,198 | 1,356,452 | 10,898 | 1,367,349 | 17,872 | 4,740 |
| Watermelon | 95,718 | 23,379 | 119,096 | 2,719,320 | 147,003 | 2,866,324 | 28,410 | 6,288 |
| Cucumber | 81,562 | 789 | 82,350 | 1,933,975 | 4,516 | 1,938,491 | 23,712 | 5,731 |
| Other ground crops | 39,321 | 2,578 | 41,899 | 643,139 | 9,394 | 652,533 | 16,356 | 3,644 |
| Alfalfa | 583,263 | 55,208 | 638,471 | 5,063,195 | 110,166 | 5,173,361 | 8,681 | 1,995 |
| Clover | 54,006 | 17,696 | 71,701 | 630,269 | 462,301 | 1,092,570 | 11,670 | 26,124 |
| Other forage crops | 265,298 | 48,193 | 313,491 | 8,450,754 | 97,218 | 8,547,972 | 31,854 | 2,017 |
| Other crops | 82,827 | 28,429 | 111,256 | 172,228 | 5,422 | 177,650 | 2,079 | 191 |

inclusive economic growth, food, nutrition, environment and livelihood security.

## Status of Wheat Production

The total harvested wheat area in 2010-11 cropping cycle was 6.7 million hectares from which about 2.7 million hectares (40%) were irrigated and about 4.0 million hectares (60%) rainfed (Fig. 1). The total wheat harvested area in Iran has not changed significantly during the period of 2006-11. However, it dropped to its lowest level of about 5.3 million hectares in 2007-08 cropping cycle due mainly to severe drought conditions, and consequently a decrease in the harvested area of wheat (Fig. 1). The wheat crop experienced a very severe drought in the autumn 2010 (Fig. 2).

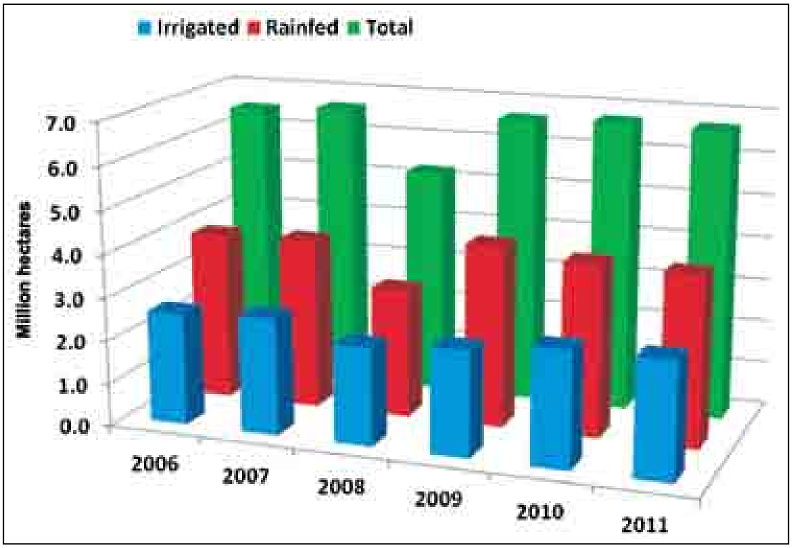


**Fig. 1.** Harvested wheat area in Iran (2006-11)

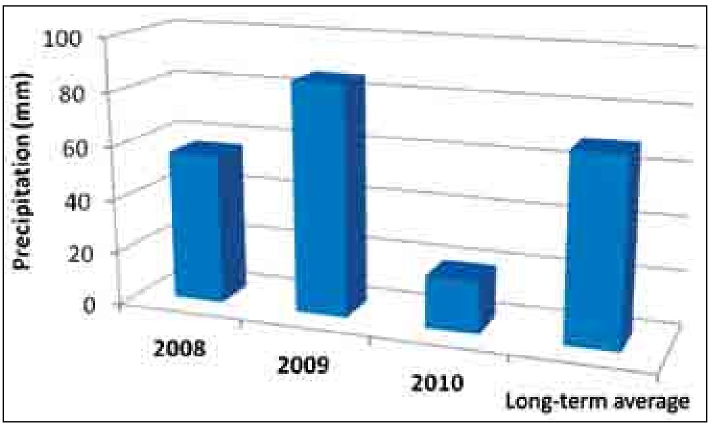


**Fig. 2.** Precipitation in autumn (21 September -21 December) in 2008-10.

The average wheat grain yield of irrigated wheat in 2006-2011 period was the highest in 2007 (3,800 kg/ha) but significantly decreased to 2,856 kg per hectare in 2008 due to drought conditions (Fig. 3). The average grain yield for rainfed wheat was the highest (1,287 kg/ha) in 2010 and the lowest (490 Kg/ha) in 2008 due to severe drought in 2007-08 cropping cycle (Fig. 3). Clearly, the average grain yields in the country are more influenced by the average grain yield of the irrigated wheat (Fig. 3). The average grain yield (806 kg/ha) of rainfed wheat in 2011 was also less than the average of grain yield of rainfed wheat for the period of 2006-11 reflecting severe drought in autumn 2010.

In normal years, about 70 per cent of wheat production is harvested from irrigated wheat areas. The total wheat production reached to about 15.0 million tons in 2007 and 2010 (Fig. 4). This was because of more favourable growing conditions. The 2008 harvest was the

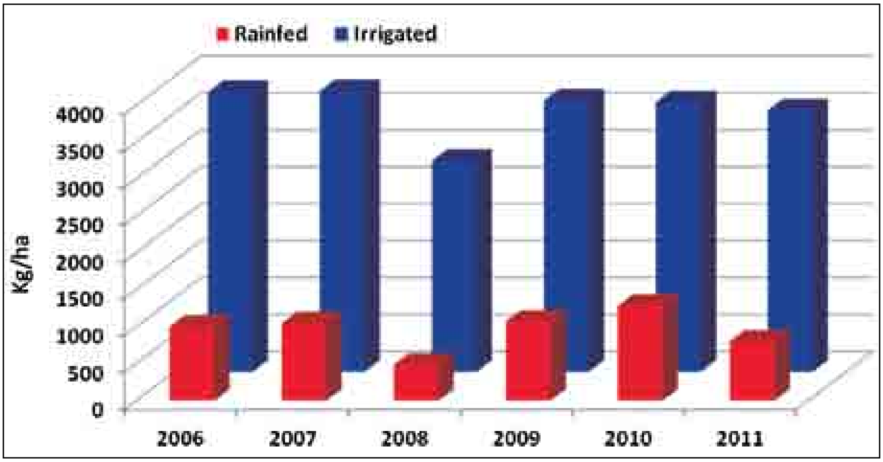


**Fig. 3.** Wheat grain productivity in Iran (2006-11)

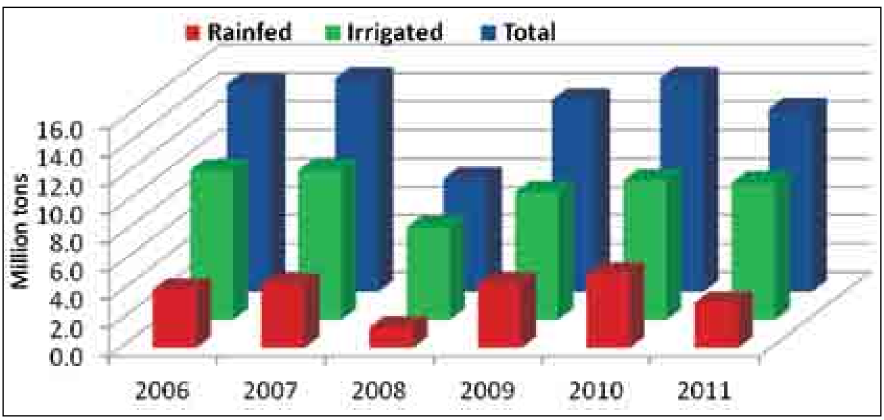


**Fig. 4.** Wheat production in Iran (2006-2011)

lowest (less than 8.0 mt) recorded for the period 2006-2011 (Fig. 4). Reductions were also evident for 2011, with production of 9.65 tons for irrigated wheat and 3.2 tons for rainfed wheat and total production of 12.85 million tons, again reflecting the effect of drought in autumn 2010 (Fig. 2 & Fig. 4).

All the three wheat types, viz., winter, facultative and spring, are grown in different agro-climatic zones under irrigated and rainfed conditions. The temperate zone is the most favourable area for wheat production; high grain yields have been recorded at Kangavar in Kermanshah province (14 t/ha) and in Daryoun in Fars Province (12 t/ha) which are part of this agro-climatic zone. Biotic (e.g. stripe rust, leaf rust, stem rust, Septorias, *Fusarium* head blight, powdery mildew, Sunn pest) and abiotic (drought, heat, cold, salinity) stresses are major limiting factors for wheat production. Stripe rust, leaf rust and stem rust have been reported from all parts of the country, but stripe rust remains the major disease in more favorable years. In 1993, about 1.5 million tons of wheat was lost due to an epidemic of stripe rust. There was stripe rust incident in some parts of the country in 2011, but the crop loss due to this disease was not significant. *Fusarium* head blight and Septoria are becoming increasingly serious diseases in Caspian Sea region as well as in South-west Iran. Leaf rust and stem rust appear late in the season and there is no recent report on crop losses due to these diseases.

In drought years, the invasion of Sunn pest is devastating and in 2007-08 more than 1.5 million hectares area was sprayed to control it. Other diseases as Septoria and tan spot, which were minor, are emerging as economically significant diseases in the Caspian Sea region. Some insects as leaf beetle (Lema), Russian wheat aphid are becoming growing problems in cold areas, and common cereal aphid (*Schizaphis graminearum*) has become a problem in the temperate and warm areas (Esmaeilzadeh Moghaddam *et al.*, 2009).

More than 60 wheat cultivars are commercially grown in different agro-climatic zones, under irrigated and rainfed conditions in Iran. Most of them have become susceptible to stripe rust virulence for *Yr*27. The major commercial wheat cultivars, based on distributed certified seed, are presented in Table 2. About five million hectares are grown under these susceptible wheat cultivars (unpublished data, Ministry of Jihad-e-Agriculture). Hence, in the stripe rust epidemic years, the rate of crop loss is considerable. Even in the absence of stripe rust epidemic, there are some crop losses due to the susceptibility of these commercial cultivars. Therefore, development and release of resistant/tolerant wheat cultivars to new races of stripe rust is a must, and appropriate strategies are necessary for replacement of the old and susceptible cultivars (Table 2).

## Mechanization

Wheat is predominately produced under dryland conditions although significant areas are also irrigated. So, this crop is vulnerable to variations in seasonal rainfall and subsequently soil moisture conservation is extremely important. However, to date, little work has been undertaken in Iran on conservation agriculture whereby zero-tillage crop production is undertaken on a continuous basis eliminating any

**Table 2.** The major commercial wheat cultivars, based on the distributed certified seed, grown in Iran in 2009-10 cropping cycle

| | Cultivar | Virulence for | | Year of release |
|---|---|---|---|---|
| | | *Yr9* | *Yr27* | |
| Irrigated | Chamran (>25%) | R | S | 1997 |
| | Pishtaz (7%) | R | S | 2001 |
| | Morvarid (6%) | R | R | 2009 |
| | Bahar (5.5%) | R | MS | 2007 |
| | Alvand (4.5%) | R | S | 1996 |
| | Zarrin (3.1%) | R | S | 1996 |
| | Shiroodi (3.0%) | R | S | 1997 |
| | Falat (Seri82) (1.7%) | S | S | 1991 |
| | Roshan (0.6%) | S | S | 1960 |
| | Vee/Nac | S | S | 1997 |
| Rainfed | Sardari (>46%) | S | S | 1960 |
| | Koohdasht (>20%) | R | MRMS | 2000 |
| | Azar 2 (16%) | MS | MS | 2002 |
| | Zagros (>8%) | R | S | 1995 |
| | Chenab 70 | S | S | 1976 |

conventional cultivation process. The objectives of this technique are to reduce mechanization costs, increase soil moisture conservation, reduce erosion, and improve soil structure and biological activity. Zero-till machines have recently been procured in Iran but to date, availability of this equipment is very limited in number. It has been primarily utilized as a minimum tillage option to reduce mechanization costs. Weed control is an essential component of conservation agriculture practice and, therefore, particular attention must be paid to agronomy and chemical control since the weed species change over time.

## Production and Climate Change

Evidence shows that climate change is occurring in Iran as in the other parts of the world. Winter temperatures are becoming milder and this is more pronounced in colder areas (Fig. 5).

Rainfall in autumn has reduced and delayed, and hence, planting and establishment of rainfed wheat suffers (Fig. 2). Changes in climatic conditions have significant impact on wheat production through changes in precipitations and temperatures which in turn would influence the frequency of drought years, epidemic of diseases, invasion of insect-pests, emerging of new insect-pests, diseases and weeds which were minor in the past. For example, mild temperature in winter 2010 favoured the overwintering of stripe rust and consequently epidemic of disease in north western to south western parts of Iran. Due to changing climate and reduction

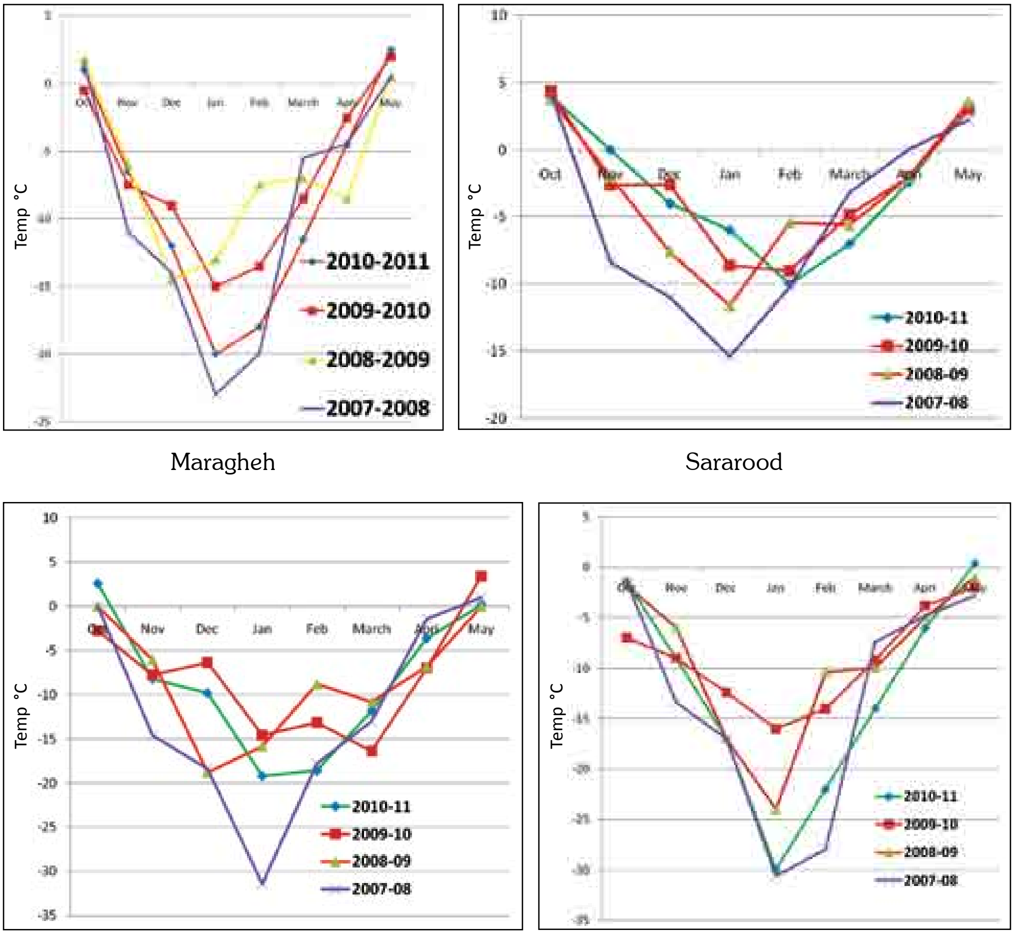


**Fig. 5.** Winter temperatures in four selected rainfed research stations (2007-11)

in precipitation and irregularity in its distribution, the underground water table, main source of irrigation water in irrigated cropping systems, has fallen by one meter per year in many areas, e.g. Mashhad and Neishabour (Mohammadi and Karimpour Reihan, 2008). This has intensified the shortage of irrigation water and hence the drought impact on field crops production. Due to changing climate, it has been estimated that precipitation will decline by 9 per cent and temperature will increase by 0.5-1.5°C in Iran (Sharifi and Bani-Hashemi, 2010). Consequently, rainfed wheat growing areas would decline by 24 per cent by 2025 and 33.5 per cent by 2050. Rainfed wheat grain yield would also decline by 24 per cent and 32 per cent in 2025 and 2050, respectively. Irrigated wheat grain yield will also reduce by 12 per cent and 28 per cent in 2025 and 2050, respectively (Koocheki and Khorramdel, 2010). Koocheki and Khorramdel (2010) have projected two scenarios:

**Without effect of climate change:** It has been estimated that the population in Iran in 2025 will exceed 96 million people, and hence, wheat production and consumption would be: i) wheat consumption per capita: 210 kg, ii) wheat production: 17 million tons, iii) wheat demand: 20 million tons, and iv) deficit: 3 million tons

**With effect of climate change:** It has been estimated that the population in Iran in 2025 will exceed 96 million people, and hence, wheat production and consumption would be: i) wheat consumption per capita: 210 kg, ii) wheat production: 13.7 million tons, iii) wheat demand: 20 million tons and iv) Deficit: 6.3 million tons

In both the scenarios, the rate of wheat production in Iran would not be meet the demand for wheat in the country. Therefore, challenges for wheat improvement for adaptation to changing climate are to be identified, their importance critically assessed and appropriate strategies to be developed.

## Constraints in Wheat Production

Biotic (e.g. *Yr, Lr, Sr, Septoria, FHB*) and abiotic (drought, heat, cold, salinity) stresses are among the major factors limiting wheat production in Iran. Stripe rust, leaf rust and stem rust occur in different parts of the country. However, stripe rust remains the major wheat disease in more favourable years. In 1993, about 1.5 million tons of wheat was lost due to an epidemic of stripe rust. However, this wheat loss was lower (~5-10%) in 2010, mainly due to diversification of commercial wheat cultivars, with different levels of resistance/tolerance in stripe rust prone areas. *Fusarium* head blight and *Septoria* are becoming increasingly serious diseases in Caspian Sea region as well as in South-west Iran. Leaf rust and stem rust appear late in the season and there is no recent report on crop losses due to these diseases. Field evaluations of the responses of Iranian wheat germplasm to Ug99 in Kenya from 2006 till 2010 showed that the frequency of resistance/tolerance of wheat breeding lines in wheat breeding programs significantly increased. Commercial cultivars, such as Kavir, Bam and the durum wheat cultivar, Arya, and some landraces, such as Sorkhtokhom also showed variable levels of resistance. To reconfirm the reported resistances in Kenya, the resistant lines were re-examined in 2008 and 2009 in the glasshouse at Cereal Research Department, Seed and Plant Improvement Institute, using the Ug99 isolate from Broujerd. The resistance was reconfirmed. Since 2006, significant efforts have been made in breeding and identification of Ug99 resistance/tolerant wheat cultivars. This has led to release of Ug99 cultivars, Parsi, Sivand, Morvarid, Arg, and identification of Bam, Akbari, Kavir, Sistan, Shiraz, Roshan and Sorkhtokhm, commercially grown cultivars also Dehdasht, Karim and Rijaw have been released for warm and semi-warm and moderate dryland areas (Table 3).

Stem rust was reported for the first time in Iran by Esfandiari (1947). An epidemic of the stem rust in the Caspian Sea region in the northern and southern regions of Iran in 1975 and 1976 was reported by Bamdadian and Torabi (1978). In 1976 epidemic of stem rust in southern part of Iran, 100 per cent crop losses occurred in landraces (Bamdadian and Torabi, 1978). The first stem rust race analysis in Iran was reported by Sharif *et al.*,1970. Race

**Table 3.** Commercial wheat cultivars resistant to Ug99 released/identified in Iran during 2006-2011

| **Cultivar/Line** | ***Sr* (Ug99)** | ***Yr* (*Yr*27)** | ***Lr*** |
|---|---|---|---|
| Morvarid | 10RMR | R-MR | MR |
| Bam | 20RMR | MS | MR |
| Parsi | 20RMR | R | MR |
| Akbari | 30RMR | MR | MS |
| Kavir | 30MR | MS | R |
| Arg | 40M | MR-MS | MR |
| Sistan | 20RMR | MR | MS |
| Shiraz | 50MR | MSS | MS |
| Sivand | 50MSS | R | - |
| Babax/LR42//Babax*2/3/Vivitsi | R | R | R |
| Roshan (landrace) | 40RMR | S | S |
| Sorkhtokhm (landrace) | MR | S | MR-MS |

analyses and responses of cultivars and advanced breeding lines were carried out in 1994 and 1995 by Nasrollahi *et al.* (2001). Stem rust was controlled since 1976 by growing CIMMYT germplasm.

In 2007, the presence of race Ug99 was officially reported from Broujerd and Hamadan. These are facultative and winter wheat growing areas. Analysis of samples of Ug99 collected from Borujerd, Hamedan, Poldokhtar and Kelardasht in 2007 and a race collected from Borujerd in 1997 was conducted using differentials carrying stem rust (*Sr*) resistance genes plus several additional wheat genotypes (Nazari *et al.*, 2008 a and b). The results were later confirmed using differential lines. The race has not spread ever since.

## Major Achievements

Two wheat breeding programs at Seed and Plant Improvement Institute and Dryland Agricultural Research Institute have successfully developed and released 29 bread wheat and 6 durum wheat cultivars over the period 2001-12, and these cultivars are commercially grown in different regions of Iran (Table 4).

Since 1999-2000 to 2010-11 crop seasons, the recommended advanced technologies were adopted in different agro-ecological climates in dryland areas of Iran. Results of application of new technologies in the large scale at farmers' fields showed significant differences in wheat productivity during 2000-11 (Ghaffari and Roustaei, 2010). Application of recommended advanced technologies increased wheat grain yield by 30 per cent under drylands in Iran (Table 5).

The reform in the agricultural price policy for inputs and outputs during the last 10 years, has encouraged farmers to adopt new agricultural technologies for strategic field crops. Therefore, policy makers and planners have achieved their goal of encouraging farmers to adopt modern technologies in

**Table 4.** Bread wheat and durum wheat cultivars released in Iran during 2001-12

| S.No. | Cultivar | Year of release | Institute | Origin | Growth habit |
|---|---|---|---|---|---|
| **Bread Wheat** | | | | | |
| 1. | Shahryar | 2001 | SPII | Iran | W |
| 2. | Azar2 | 2001 | DARI | Iran | W |
| 3. | Koohdasht | 2002 | DARI | CIMMYT | S |
| 4. | Pishtaz | 2002 | SPII | Iran | S |
| 5. | Shiraz | 2002 | SPII | Iran | S |
| 6. | Tous | 2002 | SPII | IWWIP | F |
| 7. | Bam | 2006 | SPII | Iran | S |
| 8. | Neishabour | 2006 | SPII | Iran | S |
| 9. | Sistan | 2006 | SPII | Iran | S |
| 10. | Arta | 2006 | SPII | Iran | S |
| 11. | Moghan3 | 2006 | SPII | Iran | S |
| 12. | Drya | 2006 | SPII | Iran | S |
| 13. | Bahar | 2007 | SPII | ICARDA | S |
| 14. | Pishgam | 2008 | SPII | Iran | F |
| 15. | Sivand | 2009 | SPII | Iran | S |
| 16. | Parsi | 2009 | SPII | Iran | S |
| 17. | Uroum | 2009 | SPII | Iran | W |
| 18. | Arg | 2009 | SPII | Iran | F |
| 19. | Rasad | 2009 | DARI | Iran | W |
| 20. | Morvarids | 2009 | SPII | CIMMYT | S |
| 21. | Zare | 2010 | SPII | IWWIP | F |
| 22. | Mihan | 2010 | SPII | Iran | W |
| 23. | Aflak | 2010 | SPII | CIMMYT | S |
| 24. | Ohadi | 2010 | DARI | Iran | W |
| 25. | Rijaw | 2011 | DARI | IWWIP | F |
| 26. | Karim | 2011 | DARI | ICARDA | S |
| 27. | Gonbad | 2012 | SPII | Iran | S |
| 28. | Sirvan | 2012 | SPII | CIMMYT | S |
| **Durum Wheat** | | | | | |
| 1. | Arya | 2003 | SPII | CIMMYT | S |

*Contd...*

*Table 4 (Contd.)*

| S.No. | Cultivar | Year of release | Institute | Origin | Growth habit |
|---|---|---|---|---|---|
| 2. | Karkheh | 2005 | SPII | ICARDA | S |
| 3. | Dena | 2007 | SPII | CIMMYT | S |
| 4. | Behrang | 2009 | SPII | CIMMYT | S |
| 5. | Dehdasht | 2009 | DARI | Italy | S |
| 6. | Saji | 2010 | DARI | ICARDA | S |

**Table 5.** Effects of improved technology on wheat grain yield in drylands in Iran.

| Province | Grain productivity (kg/ha) | |
|---|---|---|
| | Advance technology (kg/ha) | Farmers' practice (kg/ha) |
| East Azarbijan | 1980 | 1538 |
| West Azarbijan | 1630 | 1246 |
| Kordestan | 1645 | 1233 |
| Zanjan | 1450 | 1192 |
| Hamadan | 1790 | 1390 |
| Kermanshah | 1625 | 1102 |
| Mean | 1687 | 1283 |

production of wheat and other strategic crops. Using high-yielding varieties, chemical fertilizers, control of weeds, insect-pests, and diseases, good management practices and enough rain during crop season resulted in higher wheat production in Iran to exceed demand in 2004 for the first time since 1960. Not only wheat production increased from 9.46 million tons in 2001 to more than 14 million tons (48% increase), productivity of other strategic field crops also increased during this period.

## Future Strategies

The following strategies need to be given thrust in future:

- Areas need to be identified for cultivation in future taking in view the climate change into consideration
- Crop management/conservation agriculture
- Application of physiology in wheat breeding programs for cold, drought and heat tolerance and earliness.
- Durable resistance for wheat rusts, particularly stripe rust
- Development of varieties resistant to insect-pests, e.g. Sunn pest
- Application of biotechnology particularly marker assisted selection (MAS) in wheat breeding programs

for diseases/pests resistance as well as heat and drought tolerance

- Enhancement of the rate of adoption of new cultivars
- Socio-economic studies on the adoption of new cultivars and recommendation packages
- More investment in research

## Conclusion

In addition to biotic and abiotic stresses, lack of good agronomy is a major limiting factor in the achievement of genetic potential of improved cultivars in Iran. Tillage practices, rotation, and crop residue management are necessary agronomic practices that need to be researched and improved at the farm level. Drought is always a limiting factor. In the 2007-08 cropping cycle, about 80 per cent of wheat and 20-50 per cent of irrigated wheat were lost mainly due to the severe prevailing drought. Cold is also an environmental constraint to productivity of the wheat in the winter and facultative wheat areas, and sometimes late frosts cause head frosting in temperate areas. Sun pest is now a major problem in all wheat growing areas, having spread to areas where it was previously absent (more than 1.5 million hectares are sprayed). Russian wheat aphid is becoming a growing problem in cold areas, and common cereal aphid (*Schizaphis graminearum*) has become a problem in the temperate and warm areas.

To overcome these constraints and also mitigate climate change effects on wheat productivity in Iran, the major constraints to wheat productivity are to be revisited and identified and critically assessed. Appropriate strategies should be developed and implemented in national wheat improvement program to improve the adaptation of new wheat germplasm to changing climate. Agronomic research is of high priority. Application of physiology and biotechnology in breeding programs to enhance their efficiency in development of germplasm adapted to biotic and abiotic stresses are among other important strategies. However, accelerating the process of releasing of new cultivars is another important strategy to be considered.

The dryland areas are playing important role in Iran's economy and hold tremendous potential for increasing wheat production. Appropriate technologies will help in sustainable agricultural production and restrict environmental degradation. Drought effect should be mitigated for the future through appropriate forecasting methods and management measures. Optimal use of rainfed areas and expansion of supplementary irrigation techniques help to increase yield in many areas where supplementary irrigation water is available.

## Acknowledgement

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# 10. Wheat Research and Development in Nepal

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## Introduction

Agriculture is the mainstay of Nepalese economy, providing livelihoods for two-third (65.6%) of the population and accounting for about one-third of GDP (34.9%). However, agriculture is still a subsistence type. Despite abundant agricultural land, water and biological resources as well as the climatic variation which offer a great potential for agricultural development, current trend in agriculture production and productivity does not match with the population growth for meeting food and other livelihood needs of the people. Slow pace in irrigation development (30% irrigated), farmers' limited access to chemical fertilizers (26 kg N/ha) and improved seeds (SRR 9.46%) are the major factors affecting the poor growth in crop production and productivity.

Rice, maize, wheat, millet and barley are the major cereal crops in Nepal. However, rice, maize and wheat are considered the most important cereals in terms of food security. Wheat is the third largest crop in Nepal after rice and maize. Before 1960's, wheat cultivation was limited to mid and far-western hills of Nepal and it was considered as a minor cereal. After the introduction of semi-dwarf varieties from Mexico, the area and production of wheat in Nepal has been increased dramatically. Since then, wheat cultivation started gaining popularity in the country and now it has become one of the most important crops for national food security. Wheat is the third important cereal after rice and maize in Nepal in terms of area and production but ranks second in terms of food security. Wheat is consumed in the form of chapatti, bread, noodles, biscuits, cookies, etc. Per capita wheat consumption has been increased from 17.4 kilogram in 1972 (when National Wheat Research Program was established) to 65.5 kilogram in 2011.

Wheat consumption rate is increasing at 2 per cent per annum.

In the past, major thrust for wheat research and developments was given to varietal development for different agro-ecological zones and providing package of practices to grow successfully by farming communities. Sufficient source seed production and supply to the client groups was always a priority area in transferring wheat technology (Tripathi, 2008). Continuous research efforts enabled to recommend technologies in different aspects of wheat production like agronomic, soil, entomological, pathological and post-harvest technologies for the farmers and other stakeholders with regular updating. As a result, wheat crop become a major food commodity and continue to grow its area, production and productivity, through time.

Use of high yielding and disease resistant varieties, increased availability of improved seed and efficient supply system, changes in crop management technologies, use of chemical fertilizers, herbicides, awareness on planting time and plant stand management, support from CIMMYT, ICARDA and other international organizations, increased linkages with different stakeholders (NGOs, DADOs, CBOs, etc.) to update the research efforts are major factors contributing to increased area, production and productivity of wheat in Nepal (Tripathi, 2011). However, different micro-climatic environments possess new challenges of biotic and abiotic stress in wheat production. Therefore, National Wheat Research Program (NWRP) has set up new priority areas and reoriented the research efforts to tackle the upcoming problems. Once an exporter of rice, Nepal now is a food deficit country. There is an increasing trend of wheat based industries like flour mills (19 high capacity flour mills in operation), bakeries, biscuits and noodle factories in the country.

In Nepal, National Wheat Research Program (NWRP) was established in 1972. NWRP coordinates the national wheat research system through its ten research stations in terai/ valley (Doti, Sundarpur, Surkhet, Nepalgunj, Bhairahawa, Rampur, Parwanipur, Hardinath, Tarahara and Itahari); six stations in hills (Jumla, Dailekh, Lumle, Kabre, Pakhribas, Agriculture Botany Division) and other disciplinary divisions. Marpha horticulture farm is utilized for shuttling wheat segregating populations during the summer season. It works with Department of Agriculture for dissemination of technologies, and with National Seed Company (NSC) for multiplication and supply of quality seeds.

Till date, NWRP followed the conventional breeding approach for varietal improvement for higher yields with better quality and resistance to abiotic and biotic stresses, wide adaptability and efficient cropping system. Participatory varietal selection approach is being used to identify and select farmer preferred varieties and faster dissemination of selected technologies. Similarly, participatory plant breeding approach is also used to identify and select problem and niche-specific genotypes from the early stage of selection. Outreach research activities such as PVS, farmer's acceptance test, and minikits are being conducted at need-based farmer's fields. Research problems are identified through village level workshops, regional and national technical working group meetings.

NWRP produces nucleus/breeder seed of released and pre-released varieties as per the demand. Besides the varieties and seeds, technologies on crop protection, soil fertility management and industrial quality are also being generated. Several technologies related to resource management have been generated after the establishment of Rice-Wheat Consortium in 1994 such as understanding rice-wheat system productivity trends, diagnostic surveys, tillage and direct sowing (surface seeding, zero-tillage, bed planting, etc.), integrated crop management and integrated plant nutrient management (balanced, efficient nutrient use, soil organic matter dynamics, micronutrients, crop residue management, etc.). The proven RCTs need to be scaled-up and integrated into the concept of conservation agriculture to make long-term benefit. Eastern Gangetic Collaborative Breeding activity between Nepal, Bangladesh and India was launched during 1997-2006. During this period, activities such as Eastern Gangetic Plains Screening Nursery (EGPSN) - 150 entries in 15 locations; and Eastern Gangetic Plains Yield Trials (EGPYT) - 25 entries in 12 locations were conducted. Besides this, NWRP had collaboration with different regional and global institutions such as CIMMYT, ICARDA, IRRI, DWR-India, WRC-Bangladesh, PARC-Pakistan, RWC/CSISA, USAID-Famine Seed Project, DRRW, BGRI/Cornell University, etc. for exchange of germplasm, technologies and information sharing and human resource development. In addition, participation in regional visits and conferences, travelling seminars, etc. were also organized.

## Area, Production and Productivity of Food Crops

In Nepal, rice occupies 43 per cent cereal area and contributes nearly 52 per cent in total cereal production. Maize occupies 26 per cent and wheat 22 per cent area, and contributes 24 and 20 per cent, respectively to the total cereal production. Millet and barley jointly occupy 9 per cent area and contribute 4 per cent of total cereal production. Rice is by far the largest cereal contributing 20 per cent in GDP and wheat contributes 7.14 per cent to AGDP (MOAC, 2010).

Nepal has 3.1 million hectares cultivated agricultural land. Rice is number one crop and grown in 1.5 million hectares and produced 4.46 million tons in 2011. Maize is second crop which is cultivated in 0.9 million hectares with production of 2.07 million tons Total wheat area and production in Nepal for the year 2010-11 was estimated 0.77 million hectare and 1.7 million tons, respectively, with an estimated yield of 2.27 tons per hectare (MOAC 2011) (Table 1), which has increased 6 fold in area and 13 fold in production during the last 50 years.

Similarly, pulses are also important crops in Nepal which occupy 0.33 million hectares and produce 0.32 million ton. Potato has covered 0.18 million hectares and produced 2.51 million tons which plays vital role in food security and economy of the country (Table 1).

Wheat occupies 22.1 per cent of national cereal coverage (3,478,813 ha) with 20.3 per cent contribution in the country's cereal production (8,615,383 tons). It covers 0.77 million hectare with the production of 1.75 million tons and the productivity of 22.75 q/ha (MOAC, 2011). Irrigated wheat occupies 62.94 per cent of total wheat area and producing 1.24 million tons with the productivity of 25.66 q/ha but un-irrigated wheat occupied nearly 37.06 per cent producing 0.51 million tons

**Table 1.** Area, production and productivity of food crops (2010-11 MoA)

| Crops | Area (ha) | Production (mt) | Yield (kg/ha) |
|---|---|---|---|
| Paddy | 1,496,476 | 4,460,278 | 29.81 |
| Maize | 906,253 | 2,067,722 | 22.81 |
| **Wheat** | **767,499** | **1,745,811** | **22.75** |
| Barley | 28,461 | 30,240 | 10.63 |
| Millets | 269,820 | 302,691 | 11.22 |
| Buckwheat | 10,304 | 8,841 | 85.80 |
| Pulses | 334,380 | 318,362 | 95.20 |
| Potato | 182,600 | 2,508,044 | 13.73 |

of grain with productivity of 17.80 q/ha. Wheat crop is grown all over the country which covers 58.62 per cent area in terai, 34.58 per cent in mid-hills and 6.79 per cent in mountains with productivity of 25.29 quintals/per hectare, 19.94 quintals/ per hectare, and 15.09 quintals/per hectare, respectively. Improved seed has covered 97.6 per cent of total wheat area in the country with the productivity of 23.01 quintals/per hectare.

## Past Accomplishments in Increasing Wheat Production and Productivity

Fluctuation in wheat production is very common as in other major cereal crops because of changes in rainfall, cold or hot wind wave, frost, diseases and pests. In early period, effect of abiotic and biotic factors has played significant role on wheat production and productivity in the country. Since 1960, altogether 33 varieties of wheat starting from tall variety Lerma 52 to semi-dwarf high input responsive, high yielding varieties were released in the country. Among these, 13 were introduced from Mexico, 13 from India, and 7 varieties were bred in Nepal. Ten varieties have been released for hills and remaining for terai conditions. Wheat production and productivity increased due to the introduction of improved varieties and quality seeds, new cultivation techniques as well as increased cultivated land. Use of high yielding varieties such as Nepal 297, Bhrikuti, BL1473, Gautam, WK1204 resistant/tolerant to Helminthosporium Leaf Blight and leaf and stripe rusts resulted in overall increase in wheat production and yield. Over the last 40 years, wheat area has increased by seven folds, production by fourteen folds and productivity by two folds in the country (Fig. 1 and 2) In Nepal, most popular varieties of wheat are Gautam, Bhrikuti, Nepal 297, WK1204, Vijay and others which significantly contributing on increasing production and productivity in the country.

## Constraints in Wheat Productivity Enhancement and Emerging Challenges

Wheat production in Nepal is critically affected by three major factors: (i) temperature during the grain filling period, (ii) input application (irrigation and

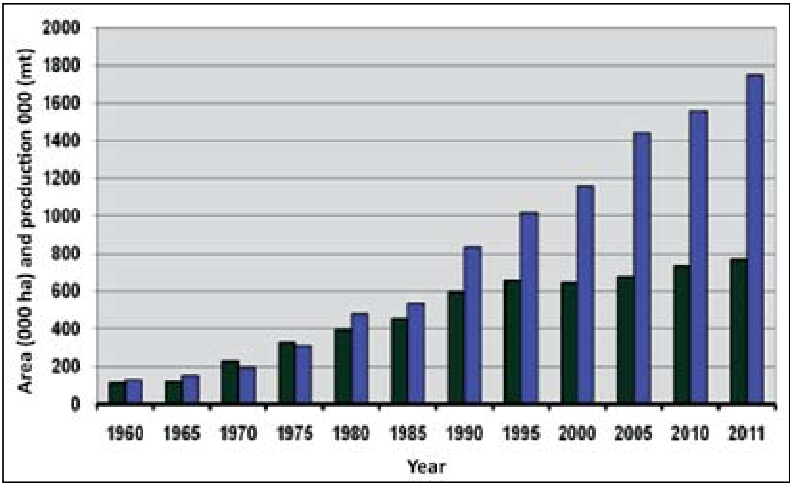


**Fig. 1.** Wheat area and production in Nepal since 1960

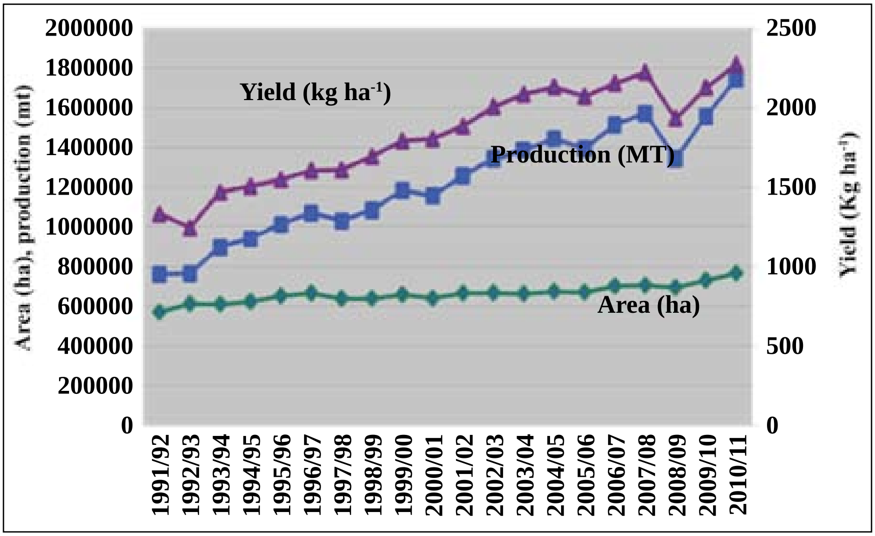


**Fig. 2.** Wheat area, production and productivity over last 20 years

nutrient), and (iii) incidence of diseases. The longer the cool temperatures prevail during the wheat season and lower the incidence of foliar diseases, the higher the production. Various reports show that foliar diseases could reduce yields in South Asia by 23-42 per cent (Saari 1998; Sharma *et al.* 2004; Sharma and Duveiller 2006), low fertilizer dose by 25-46 per cent (Bhandari *et al.*, 2002) and soil pathogens by 8-16 per cent (Dubin and Bimb, 1994; Saari 1998).

Improvement and selection of high and low input and stress responsive wide adaptive wheat genotypes with preferred traits are necessary to increase production and productivity for ensured food security in the country. Existing varieties are not sufficient to increase sustainable production and productivity due to climate change, disease outbreak on wheat by new pathotype especially of stripe and stem rust. Population growth, decreasing land and other resources, soil fertility degradation, climate change are other factors limiting higher production. The following section highlights the major constraints in wheat productivity.

**Increasing temperature regimes, erratic rainfall pattern-climate change:** Crop systems in Nepal are mostly rainfed with crop of different maturity time. Hence, planting longer duration rice varieties also delays the wheat sowing. Late sown wheat varieties are exposed to high heat and hot air at the time of grain filling and anthesis, which results in abortion of grains as well as shriveled grains which reduce the grain yield drastically. Hence, climatic change with increasing temperature regimes and erratic rainfall pattern is the additional challenge to cope up.

**Soil fertility degradation, depletion of soil organic matter and other nutrients:** Continuous cultivation without using proper dose of fertilizer and adding organic manure to soil has resulted insoil degradation and depletion of soil organic matter. Low soil organic matter resulted in low soil flora and fauna and soil health is also deteriorating continuously. Imbalanced application of NPK and other micro-nutrients in soil has also resulted in reduced crop yield. In Nepal, 65.04 per cent of soil is acidic and has low organic matter, nitrogen, phosphorus, potassium and micro-nutrients for wheat crop which always limits the production and productivity. Similarly, 27.3 per cent soil is alkaline which has medium level of nutrient content and only 7.66 per cent is alkaline with high content of nutrients.

**Biotic stresses:** Several wheat diseases such as rust (stripe, leaf and stem), spot blotch, foliar blight, powdery mildews, hill bunt and smut are the major threat to wheat production. Disease incidence changes according to the climatic condition and management practices. New virulent pathotypes of different diseases are emerging that pose new challenges to overcome through new breeding strategy by identifying resistant parents, crossing and selection to develop new resistant varieties. Moreover, time has come to click on biotechnology and molecular breeding. However, rust and spot blotch are considered one of the major breeding objectives to develop resistant wheat varieties. Additionally, aphid (*Aphis spp.*) and *Helicoverpa spp.* incidence in wheat have been reported to result in lower productivity. During 2003-2006, the hill farmers of Nepal faced epidemic of stripe rust that badly affected the wheat crop especially the variety Nepal 297 and RR 21 due to their narrow genetic base to resistance.

**Drought stress:** Most of wheat grown in Nepal is usually irrigated only once at CRI stage and then depend on winter rains. Therefore, winter rain is very important for wheat production in Nepal. Water scarcity due to poor irrigation facilities and windy weather are the two factors restricting wheat from irrigation particularly after anthesis even when irrigation water is available. Rainfall in Nepal is also very erratic and hence, crop suffers from the need of water during different growth stages. Wheat needs moisture for germination and a few irrigations or rain at different stages for growth and development stages.

Hence, limited irrigation facility results the plant to dry and shrivel grain and reduced grain yield which is irreparable loss to the farmers. Therefore, development of drought tolerant varieties for both rainfed and irrigated areas need to be developed on regular basis.

**Depletion of water table:** Underground water table is decreasing as a result of which most of the artisan and shallow wells dried up in summer causing problem for irrigation and drinking water which recharge only after monsoon. This is very alarming situation but people still do not realize its importance and unnecessarily waste ground water.

**Slow improved seed and varietal replacement rate:** Farmers in most part of the country are still planting old varieties with low yield potential. Those varieties are susceptible to different biotic as well as abiotic stresses. Transfer of technology in conventional way takes long time to popularize a variety. It takes 4-6 years for the improved seed to reach the farmers after release of a variety. This process needs to be accelerated in an efficient way. On-farm seed saving is the common practice among farmers and hence, they plant same seed year after year besides replacing with new improved seed. The seed replacement rate (SRR) in cereal crops in Nepal is 9.46 per cent.

**Wheat sterility:** Some eastern terai districts (Morang and Jhapa) and mid-hills (Lamjung, Tanahu, Gorkha) are considered as wheat sterility prone areas. The sterility ranges from 1-100 per cent in extreme cases. There are several factors inducing sterility but major problem was boron deficiency in soil as well as failure of boron uptake by plant. Other factors inducing sterility are hot and dry winds during anthesis, water logging and water deficiency.

**Short sowing season:** Wheat planting season in Nepal is very short which lasts only for 20-25 days. It is estimated that nearly 40 per cent of the farmers generally sow wheat after optimum planting time passes out. This is mainly because most farmers are resource poor and therefore, they cannot manage wheat planting at proper time. This situation becomes inevitable for the farmers because of many reasons such as planting of late maturing rice, overlapping the rice harvesting and wheat sowing, and excess or less soil moisture at planting time. Nevertheless, to address this problem and minimize yield loss NWRP has set up a separate breeding objective to develop varieties for late sown conditions.

**Poor agricultural mechanization:** Non-availability of proper agricultural equipments on time causes higher cost of cultivation and delayed in agricultural operation. Most of the farmers are smaller and are not having capacity to procure improved agricultural implements and machineries. Custom hiring of machineries and equipment could be better option for the farmers but due to policy support from the government and incentives to local traders and manufactures, this is also in transitional phase. In hilly areas, terrain land also limits the use of mechanization.

**High cost of cultivation and low farm gate price:** Increased dependency on inorganic fertilizers, improved seed and labour intensive farming practices have increased the cost of cultivation. Scarcity of labour due to youth migration to urban areas and abroad has increased labour wage and farm cost. Farmers get low prices of their farm produce due to lack of proper government policy on support price. High post-harvest losses and inefficient marketing are other areas of emerging challenges.

**Weed management:** Weeds are problems in wheat production. *Phalaris minor*, wild oats, chenopodium are major weeds of wheat. Impact of these weeds reduce the quality of crop and competes with wheat crop and reduces grain yield.

**Other constraints:** Other constraints in wheat production are lack of timely availability of required quantity and quality inputs such as improved seeds, fertilizers, irrigation water, farm machinery, etc. Similarly, limited infrastructure such as road, storage facilities, and market are also major constraints on production of wheat in Nepal.

New agricultural technologies helped increase food production significantly. However, there is still room for further growth. There are many bottlenecks in using modern technology to achieve good growth. Varietal improvement, conservation agriculture, infrastructure development, human resource development, up-scaling, dissemination of technologies, coordination between stakeholders are the emerging challenges for increasing crop production and productivity in the context of climate change.

## Approaches for Meeting the Challenges

The released varieties of bread wheat in Nepal are not enough to cope up with newly emerging challenges of better nutritional qualities, resistance or tolerance to biotic and abiotic stresses and conservation agriculture. Screening of germplasm to identify genotypes resistant to stripe, leaf and black rust should be continued. Special focus should be given on the screening of genotypes for heat, drought and frost stress tolerance. Nucleus and breeder seed production is one of the activities providing source seed for further multiplication and supply to seed companies and other stakeholders.

Wheat research and development activities, primarily varietal improvement using new sources of genetic base for higher productivity is very important to cope-up with food security in climate change regime. Breeding for abiotic (drought, heat, cold) and biotic stresses (rusts, *Helminthosporium* leaf blight, powdery mildew, hill bunt, loose smut and other wheat diseases) are also equally important. Similarly, research on adoption of conservation agriculture, increased water use efficiency, $CO_2$ and nutrient uptake, improving grain quality and nutritional aspects are other areas of great concern. Good agricultural practices (GAP) can reduce crop production risks to some extent and improve yields even under extreme weather conditions.

Realizing the emerging challenges, the NWRP has focused efforts on enhancing food security, making nation self-sustained through increased wheat productivity and production and reduce poverty. The NWRP has set up the following approaches for meeting the challenges in wheat production in the country:

- Conduct multi-location and multi-disciplinary adaptive research for developing superior varieties resistant/tolerant to biotic and abiotic stresses for different agro-climatic conditions
- Collect, evaluate, identify, maintain, and use suitable donors for different biotic and abiotic stresses

- Develop appropriate wheat production technologies for optimal use of resources in a sustainable manner
- Produce nucleus and breeder seed of popular varieties in required quantity
- Carryout off-season breeding work (shuttle breeding) for rapid generation advancement at suitable hill sites
- Establish good collaboration and partnership with national and international institutions for strengthening wheat improvement research in the country

## Improving Wheat Production for Meeting Future Targets

Sincere efforts from public and private sectors are urgently required to meet the future demand of wheat production for food security. Following section highlights on the envisaged efforts:

**Varietal improvement:** All together 32 wheat varieties have been released since the initiation of organized wheat research in the country. However, only 20 varieties are in cultivation where as 12 varieties have been de-notified since their resistance to major diseases has broken down and are regarded as degenerated (NWRP, 2011). Three varieties have been released in 2009 and 2010 for cultivation all over Terai, viz., NL971 (2009), Aditya (2009) and Vijaya (2010). Variety Vijay (BL 3063) is the first variety of its kind which is resistant against Ug99 race of black stem rust (NWRP 2009/10). The Ug99 is considered major threat to present and future wheat globally (Singh *et al.*, 2011). NWRP has also identified other two Ug99 resistant genotypes, viz., NL 1064 (Danphe) and NL 1073 (Francolin) for hills and terai regions, respectively (Tripathi *et al.*, 2011). Hilly area of Nepal is more prone to stripe rust epidemic and therefore, two genotypes (BL 3235 and BL 3503) have been developed and proposed for release. Some other genotypes like BL 3623, BL 3555 and several others were also evaluated and promoted in pipelines for different ecological zones. These varieties were also evaluated for their earliness to escape terminal heat stress, drought and suitability to late planting.

Other genotypes, namely, Chyakhura, Kiskadee, Becard, Chonte and Chewink are found promising for hills under both irrigated and rainfed conditions. These are also high yielding and stripe as well as stem rust resistant genotypes. These lines are being tested in the farmers' field through participatory varietal selection. In addition to bread wheat improvement, durum and perennial wheat are being explored in western Nepal for crop varietal diversity. Perennial wheat could be good crop for conservation agriculture in high hills of Nepal. Besides, efforts are being made to develop high yielding, abiotic and biotic stress tolerant wheat varieties for current and future cereals and mixed crop-livestock systems under Cereal System Initiatives for South Asia (CSISA) project. Collaboration with regional as well as international institutions is being strengthened on broader perspective for increasing wheat production and productivity.

**Pathological research activities:** Continuous disease monitoring is going on in wheat to update the disease status in Nepal. Monitoring addresses the disease prone area and the potential host of different disease in Nepal. Screening of wheat germplasm against major disease is a continuous process. A total of 300 genotypes of wheat have been screened every year for rust and foliar blight at five different locations. The genotype which showed the inconsistent or low level of resistant against foliar blight and rust are excluded from the stock each year. Besides monitoring and scoring of diseases and their management aspects through nutrients, fungicides and other agronomic means are regularly studied to control the major diseases.

**Crop management research:** Research efforts are continued to explore new agronomic and crop management practices such as tillage and crop establishment, soil fertility and nutrient management, planting time and methods in order to prepare package of practices for the farmers in new changing environments. Planting without pulverization and any land preparation helps to plant crop at right time. Resource conserving technologies (RCTs) are major breakthrough in rice wheat system as they reduce the cost of cultivation and irrigation. Crop establishment is also quicker and timely. Fallow lands were brought under cultivation which increased land utilization. RCTs reduce the requirement of farm labour with increased yield and income. Different resource conserving technologies such as zero tillage, residue management, bed planting and surface seeding are being fine tuned to the local circumstances and adopted by farmers (Tripathi *et al.*, 2008). These technologies are also popularized for mitigation and adaptation purposes to cope up with the impact of climate change. These technologiesare known to reduce emission of glasshouse gasses such as $CO_2$, $N_2O$ and $CH_4$ and increase the carbon sequestration into the soil.

**Outreach and socioeconomic research:** Technological verification and promotional activities are integral part of national wheat research program which has been implemented with national and regional perspective. The major tools used in verification and promotion of different wheat technologies are participatory variety selection (PVS), farmers' field trials (FFTs), farmers' acceptance test (FAT) and front line demonstrations (FLDs) on national basis. Besides national level outreach research in wheat, regional outreach sites are established to bridge the technological gap among the research and development partners with farmers. Farmers' fairs, field days are conducted and publication of technical bulletins for the farmers' and other stakeholders are brought out on regular basis.

## Future Strategies

The research should focus on climate smart agriculture for the development of multiple stress tolerant crop varieties. Hence, varietal improvement for abiotic (heat, drought, cold) and biotic (rusts, HLB, powdery mildew, *Fusarium*, hill bunt) stresses will be continued in close collaboration with regional and global institutions. Molecular marker tools will be used in wheat breeding for identification of genes of different traits and introgression of those genes will be undertaken for developing varieties of different purposes. Breeding for grain quality and biomass will be focused for human and livestock consumption. Priority will also be given to develop suitable crop management and resource conservation technologies in the context of climate change.

Previewing the production trends, food insecurity scenario, constraints in productivity enhancement, meeting existing challenges (including climate change), future targets and lessons learnt will be addressed through the following strategies :

- Strengthening research capacity to develop location specific varieties/ technologies
- Research on physiological aspects to cope-up with the impact of climate change
- Use of modern biotechnological tools in wheat breeding
- Public-private-partnership (PPP) for technology generation and dissemination
- Strong linkages with agricultural universities and research institutions
- Research on key emerging issues (adaptation to climate change, conservation agriculture, agriculture mechanization and post-harvest)

## Conclusion

Wheat research in Nepal has been providing good return as production and productivity of wheat continues to grow. However, there is less scope of increasing area under wheat cultivation and therefore, there is a need for technological advancement to gain higher production to feed the growing population. Although wheat research has approached to paradigm shift from conventional to advance research system, the limited physical facilities and human resource may result in quick reversal. The mitigation and adaptation strategy to cope-up with climate change, agriculture mechanization to save labour force, time and money, conservation agriculture to protect natural resources and environment are some of the major challenging issues along with the modern technological advancement which need a strong institutional commitment to realize the anticipated goal. These are the areas where CGIAR Centers, international donors and other international communities can play a lead role.

Since the establishment of NWRP in 1972, tremendous efforts were made in wheat research and development in Nepal. The major of achievements are summarized as fillows:

- Since 1960, wheat area has increased by seven folds, production by fourteen folds and productivity by two folds.
- A total of 32 wheat varieties were released in the country, out of which 23 are for terai conditions and 10 for hills.
- Wheat production is one of the economic mainstays in Nepal, but the yield gap between farmers' fields and experimental yields is wide across the country. Experimental yield of wheat is 4.8 tons per hectare and national average is 2.2 tons per hectare.
- Most popular wheat varieties are Gautam, Bhrikuti, Nepal 297, WK 1204, Vijay and others which significantly are contributing towards increasing production and productivity.
- Increased varietal diversification in the country helped mitigate the abiotic and biotic stresses. Further varietal improvement is continued to cope-up the future challenges of these problems.
- Varietal improvement by using new sources of genetic base against existing grain yield and biomass, breeding for abiotic and biotic stresses, conservation agriculture, increased efficiency of

water, $CO_2$ and nutrient, grain quality and nutritional aspects are the main approaches for enhancing wheat productivity.

- Collaboration with regional as well as international institutions needs to be strengthened on broader perspective for increasing wheat production and productivity.

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# 11. Wheat Research and Production in Pakistan

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In Pakistan, wheat being the staple diet is the most important crop and cultivated on the largest acreage (8.902 m ha during the growing season 2010-11) in almost every part of the country. It contributes 13.1 per cent to the value added in agriculture and 2.7 per cent to GDP. Over the past three decades, wheat productivity has been increased largely due to high yielding, disease resistant cultivars and increased fertilizer use. Wheat supplies 37 per cent of the daily calorie intake to the people of Pakistan. Its production has been increased in all the major cropping systems representing the diverse and varying agro-ecological conditions. Pakistan is tenth largest global producer of wheat.

Wheat production zones in Pakistan are given in Fig. 1. The zoning is mainly based on cropping pattern, disease prevalence and climatic conditions.

In Pakistan, wheat is grown in different cropping systems such as cotton – wheat, rice–wheat, sugarcane– wheat, maize – wheat, and fallow – wheat. Of these, cotton-wheat and rice-wheat systems together account about 60 per cent of the total wheat area whereas 30 per cent area is under rainfed wheat. Rotations such as maize-sugarcane, pulses and fallow are also important.

Wheat worth rupees 594 billion is produced in the country and one per cent gain or loss in wheat production would be equivalent to rupees 5.94 billion. During the last ten years (2001-2011), national production varied from 18.2-25.0 million tons with an average national yield of 2.26-2.81 tons per hectare. A bumper crop was harvested in 2010-11 because of suitable weather during the growing season (timely rains and prolonged grain filling period) and policies of the government (e.g., adequate supply of inputs, price incentive, etc.). Punjab contributes about 76 per cent of the total wheat production (Table 1).

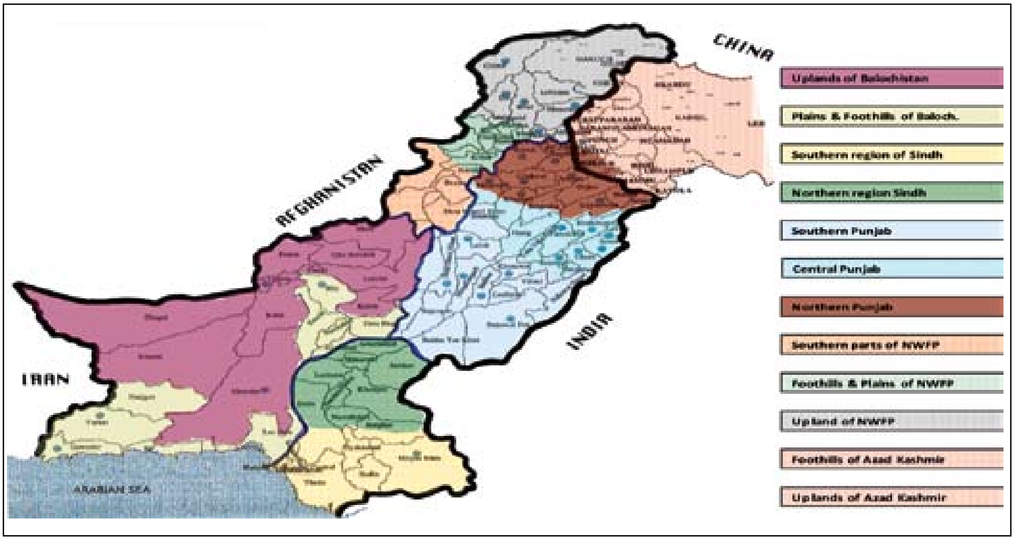


**Fig. 1.** Wheat production zones in Pakistan

**Table 1.** Wheat production in different provinces in Pakistan during 2010-11

| | Punjab | Sindh | Khyber Pakhtunkhwa | Balochistan | Pakistan |
|---|---|---|---|---|---|
| Area (mha) | 6.693 | 1.144 | 0.724 | 0.341 | 8.902 |
| Production (mt) | 19.041 | 4.288 | 1.155 | 0.536 | 25.02 |
| Yield (t/ha) | 2.84 | 3.75 | 1.59 | 1.57 | 2.81 |

Improved semi-dwarf wheat cultivars available in Pakistan have genetic yield potential of 7-8 tons per hectare whereas our national average yields are about 2.8 tons per hectare. Wheat area and production trends in Pakistan are given in Fig. 2. A large number of experiment stations and on-farm demonstrations have repeatedly shown high yield potential of the varieties. The progressive farmers of irrigated area are harvesting 6-7 tons per hectare. Generally, the yield in irrigated area ranges from 2.5-2.8 tons per hectare depending upon the amount of water available and other factors. However, yield in rainfed areas ranges from 0.5-1.3 tons per hectare depending on the amount of rainfall.

Wheat production in Pakistan can be divided into three distinct phases (Fig. 3): 1947-65, prior to the release of semi-dwarf wheats; 1966-76, the "Green Revolution" period when High Yielding Varieties (HYVs) were rapidly adopted on about two thirds of total wheat area and 1976 onward is the post green revolution period when HYVs continued to spread to cover the major wheat area. However, yield plateau have been reached in wheat and production is sustained due to good crop management practices and coordinated efforts.

Wheat production in the country is well below its potential and there is 60

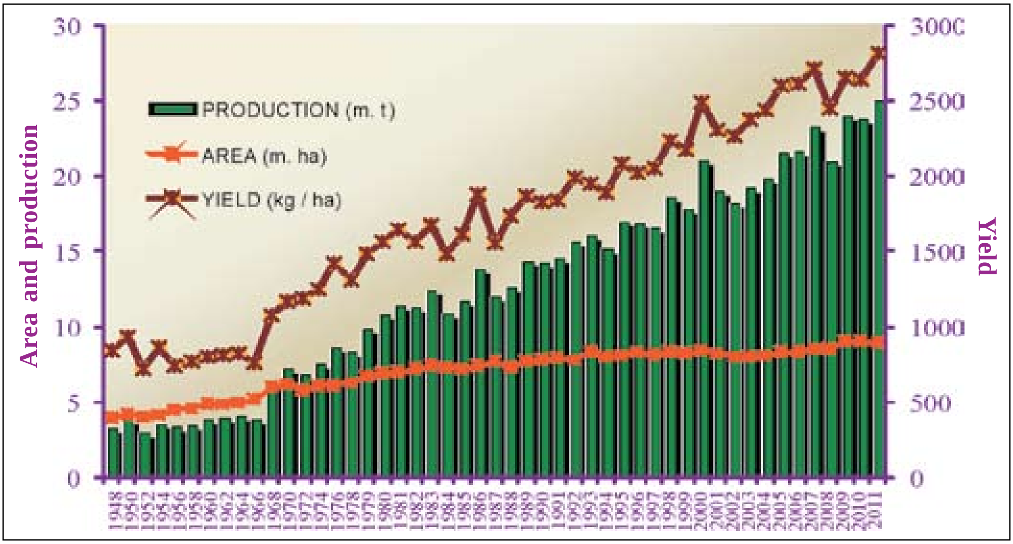


**Fig. 2.** Wheat area and production trend in Pakistan

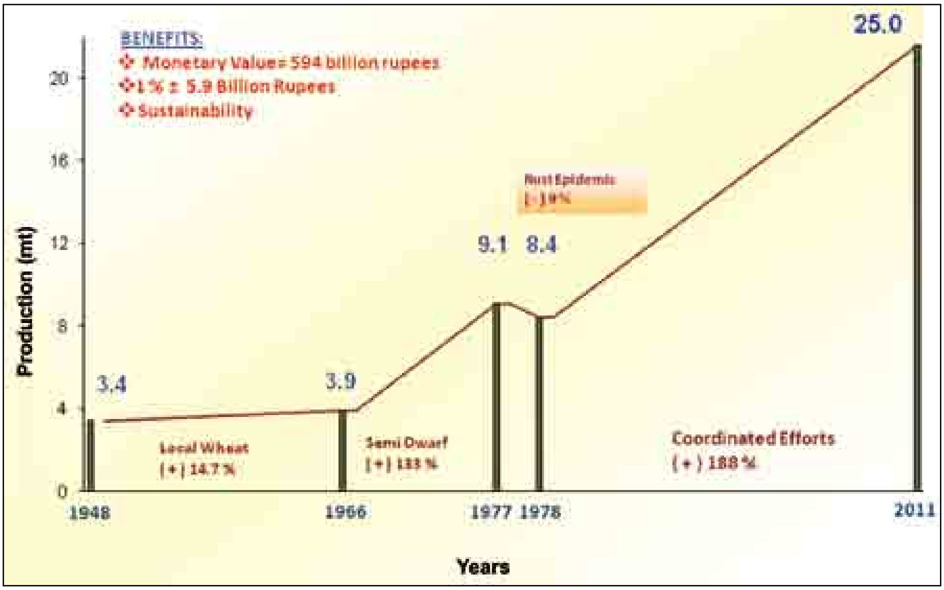


**Fig. 3.** Wheat production phases in Pakistan

per cent yield gap which needs to be narrowed down. The major reasons for low productivity and instability included: delayed harvesting of *kharif* crops like cotton, sugarcane and rice, and consequent late planting of wheat, non availability of quality inputs (e.g. seed, fertilizer), inefficient fertilizer use, weed infestation, shortage of water and weak extension services.

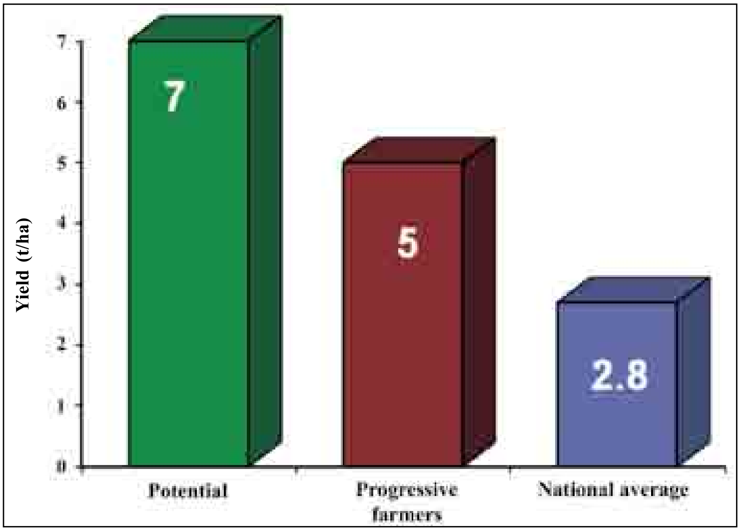


**Fig. 4.** Yield gap in Pakistan

## Wheat Research and Development

In 1977-78, a disease epidemic of stripe rust inflicted heavy losses to the wheat production in the country. As a consequence, it was realized that agricultural research in the country needs to be strengthened. Pakistan Agricultural Research Council (PARC) being an apex body in the country took a number of initiatives and played a vital .role in coordinating the wheat research activities across the country. National Coordinator Wheat was quite instrumental in streamlining all such activities. A multi-disciplinary approach was adopted to evolve stable, high yielding and disease resistant wheat varieties and following major activities were initiated to realize the increased wheat production in the country:

**Establishment of research collaborations/linkages:** Effective research linkages have been established with three international wheat research centers and 26 national and provincial wheat research institutes/programs.

**Germplasm acquisition, evaluation and distribution:** This program has developed an organized system to introduce and distribute wheat germplasm to the breeders of the country belonging to different federal and provincial research organizations, after acquiring it from different international sources. Through this mechanism, high yield potential, disease resistant stress tolerant and good quality traits have been incorporated into new varieties.

**National uniform testing and variety release:** It is a network for evaluating the candidate lines in different agro-ecological zones developed by the breeders of both provincial and national wheat research institutes under the supervision of National Wheat Coordinator. So far, more than 100 varieties have been released in the country through National Uniform Testing Program.

**Annual wheat meeting:** The National Wheat Coordinator plans annual meeting every year. Participants from different research and extension institutions and international centers participate in this meeting where different research and production issues are discussed in detail. Moreover, achievements of different cooperating units are also presented along with next year's plan of work. In the end, future strategies and recommendations are finalized to enhance the wheat production in Pakistan.

**Wheat traveling seminar:** Wheat traveling seminar is another useful activity of the Wheat Coordinated Program of PARC which provides not only an opportunity to the wheat scientists to jointly assess the status of the standing wheat crop but also gives them opportunity to observe and discuss the farmers and extension workers regarding their local problems. The national uniform wheat yield trials (NUWYT) planted in different parts of the country are also evaluated and potential varieties are identified. Above all, the seminar provides an opportunity for the scientists to identify priority research areas. At present, the wheat research programs are giving due emphasis on the drought/heat tolerance, diseases, salinity and crop management.

**Drought and heat tolerance:** In Pakistan, rainfall has been erratic over the years and most of the times the crop faces water shortages and drought conditions aggravated by high temperatures during grain filling period. As a result, wheat production, both in irrigated and rainfed areas, is being hampered. In order to minimize the effects of drought and high temperatures, drought and heat tolerant varieties are being evolved.

**Diseases:** Diseases, especially rusts (stripe, stem and leaf) and emerging disease of powdery mildew are the major biotic stresses of wheat crop which inflict heavy losses when in epidemic form. A simple one year disease epidemic could cause a 2-3 billion rupee loss to the country because of reduction in wheat yield (an example of 1977-78 epidemics) (Fig. 5). Therefore, breeders and pathologists are developing disease resistant and high yielding varieties in order to cope with threats created by ever changing rust races by using approaches like durable resistance.

A new form of stem rust known as Ug99 took several growing seasons to spread from the highlands of Uganda and Kenya in 1999, *via* Ethiopia and Yemen, to reach Iran by 2007. The disease could spread

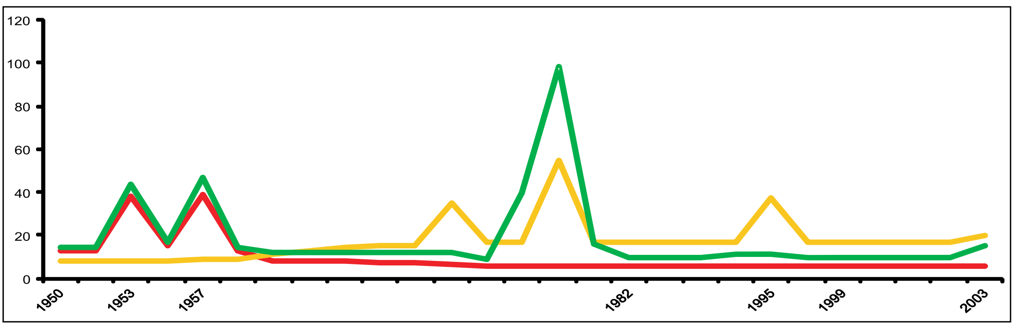


**Fig. 5.** Temporal rust situation in Pakistan

even farther from Iran to the vast wheat fields in Turkey, Afghanistan, Pakistan and India, which are largely planting varieties which are not resistant to Ug99. A local stem rust race RRTTFF has been identified which is a future threat to wheat production. Pakistan is fully aware of this threat and it is a part of the Global Rust Initiative in which resistant varieties are being developed. Pakistan has developed six Ug99 resistant wheat varieties (Lasani 2008, Baras 09, Dharabi 11, NARC 2011, Aas 11 and Punjab 11).

**Salinity:** It is another menace to which wheat is exposed in saline areas of Pakistan. Therefore, there is need to evolve salt tolerant wheat varieties for such ecologies by introducing salt tolerant genes using novel breeding techniques.

**Crop management:** Farmers generally plant wheat late in rice-wheat, sugarcane-wheat, and cotton-wheat areas of Pakistan due to late harvesting of these *kharif* crops which result in drastic low yields because the crop is exposed to heat stress at grain filling period leading to the formation of shriveled grains. Currently, only 20 per cent of wheat is being planted at optimum planting time (15 October to 15 November). To achieve good yield, wheat sowing should be carried out well in time. Any delay in planting would reduce yield drastically. For example, wheat planted after 10 November would reduce the yield as high as 42 kilogram per hectare per day (1% loss per day).

In rice-wheat areas, use of zero-tillage is common whereas relay cropping is good in cotton-wheat zone in which cotton field is irrigated without cutting the cotton crop and then moist wheat seed is broadcasted. Bed sowing is being practiced in cotton zone which results in early planting, water saving and better wheat crop stand.

**Wheat simulation modeling:** Crop simulation models have emerged as valuable tools in enhancing understanding of crop ecology and physiology. PARC takes a leading role in introducing this tool in Pakistan. Scientists at PARC parameterized the Agricultural Production Systems Simulator (APSIM) and Decision Support System for Agro-technology Transfer (DSSAT) in our local conditions (Table 2). These models have also been used by other institutes like Global Change Impact Study Center (GCISC), Islamabad, University of Arid Agriculture, Rawalpindi and University of Agriculture,

**Table 2.** Performance of parameterized APSIM-wheat module under local conditions for grain yield (kg/ha)

| Cultivar/ advance line | Measured | | Simulated | | Bias | *t* | Regression equation | $r^2$ |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | | |
| Wafaq-2001 | 3,245 | 485 | 3,177 | 444 | -68 | -0.36 | S=0.88M+324.3 | 0.92 |
| Chakwal-97 | 3,056 | 542 | 3,017 | 464 | -39 | -0.19 | S=0.83M+473.5 | 0.94 |
| NR-55 | 2,729 | 466 | 2,729 | 483 | 0.2 | 0.001 | S=1.02M-61.73 | 0.98 |
| NR-232 | 3,062 | 524 | 3,067 | 462 | 5 | 0.02 | S=0.83M+528.5 | 0.88 |
| Margalla-99 | 2,938 | 559 | 3,067 | 455 | 129 | 0.54 | S=0.69M+1028 | 0.73 |

Faisalabad. Currently, these are used to simulate the impact of various climate change scenarios (as identified by IPCC) on wheat production in different ecologies of Pakistan.

## Role of International Centers in Wheat Improvement

Wheat Productivity Enhancement Project (WPEP), a three year project at a total cost of US$ 9.0 million is being executed by PARC and 12 partner institutes throughout the country. It is funded by CIMMYT. The major objectives are:

- Surveillance about the nature and distribution (spatial and temporal) of stem rust and stripe rust
- Exploiting the nature and mechanisms of genetic basis of resistance to stem and stripe rust of wheat germplasm available in Pakistan
- Increasing the volume and precision of yield trials and related data at key breeding and testing programs in Pakistan
- Ensuring timely and adequate availability of seed
- Ensuring proper crop and soil management

**Cereal Systems Initiative for South Asia (CSISA) – Wheat Project (CIMMYT):** The Cereal Systems Initiative for South Asia (CSISA) project aims to enhance cereal production in South Asia through deployment of improved varieties / hybrids, crop management technologies and market information.

**HarvestPlus (Improving Zinc in wheat)-IFPRI:** The HarvestPlus project aims to address the issue of malnutrition by improving the Zn quantity in wheat grains through developing biofortified Zn enriched varieties and crop management practices that enhance the Zn concentration in wheat grain

Following are the wheat improvement priorities at present: i) grain yield per hectare, ii) heat and drought tolerance, iii) water use efficiency, iv) earliness, v) resistant to stripe , leaf and stem rust, vi) quality, vii) grain size, and viii) lodging resistance.

# 12. Wheat in Mongolia

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Mongolia's economy was entirely dominated by livestock sector until 1959, when first attempts to develop cropping sector scientifically took roots to address food import dependency, weak domestic production of wheat, potato and vegetables, to satisfy growing national food demand, and to reduce risk of food supply. The country's dependence on livestock sector began to lessen with the emergence of agricultural sector as independent economic sector, greatly contributing to development of light and food industries and starting delicate process of urbanization. Institutes, universities, scientific organizations and technical and vocational education training centers were established in urban and rural centers to train agricultural specialists.

Thanks to the effective government intervention and sizable investment, Mongolia became fully self-sufficient in flour and flour products, and fodder, and annual domestic production of crop reached 680.0-860.0 thousand tons in 1976-90. During this time, Mongolia started to export domestically produced agricultural products to neighbouring countries. Agriculture sector's contribution to national economic development had gradually increased during 1976-1990. Agricultural sector contributed 27-30 per cent to the national GDP during the mean time. The proportion of agriculture production in national GDP significantly declined since 1998. The agriculture sector was hit hard by the disruptive effects of transition process in 1990, such as weakening financial capacity of the agricultural producers, diminishing human resource and amount of agricultural machineries, and the effects of global warming. The self sufficiency rate of flour dropped down to 24.9 per cent, potato 86.0 per cent, vegetables 47.0 per cent as of 2007. Other main factors that still hamper agricultural production, productivity and quality include climatic hazards such as drought, insufficient use of fertilizers, pesticides and herbicides that directly or indirectly cause soil degradation, and plant disease, pest and weed outbreaks.

In order to revive cropping sub-sector and to increase the self sufficiency in flour and flour products, the Mongolian Government launched Crop III Program to be implemented during 2008-10. As a result of this program, 80 per cent of tractors, 65 per cent of harvesting machines, 50 per cent of farming equipments and implements which were to be renewed have been replaced with new ones under technology renovation effort. Mongolia lies in Central Asia, where harsh arid, semi-arid continental climate dominates. Average precipitation rate stays between 240-280 mm. The total size of cropland is estimated at 1.2 million hectares, found at relative elevation of 800-1,300 meter above sea level, of which 664.3 thousand hectares is used as agricultural land, while 561 thousand hectares is abandoned.

A total of 410-430 thousand tons of wheat is required every year to satisfy the growing demand of the nation. A total 448 thousand tons of wheat was harvested from 301 thousand hectares in 2011, fully satisfying domestic demand for wheat. Land productivity reached 1.53 tons per hectare. Abundant wheat harvest in 2011 allowed the country to export 100 thousand tons of wheat in 2012. The cropping sub-sector produced 20 per cent of total agricultural production as of 2011. It also employed 60 thousand farmer households with more than 240 thousand members.

A total of 1,385 crop producing entities and farmers with 663.4 thousand hectares cropland are registered in Mongolia. There are 940 entities and farmers that possess up to 500 hectares cropland, 230 entities with 500-1,000 hectares land, 150 entities with 1,000-2,000 hectares land, 40 entities with 2,000-3,000 hectares land, and 25 big entities that possess more than 3,000 hectares land.

Crop production sub-sector is fully privatized now. Land productivity has been increased by 0.5 ton per hectare against 2007, reaching 1.54 tons per hectare as of 2011. The Government of Mongolia has been taking extensive measures and policy to select and introduce promising varieties with high yield potential that can be adapted in arid continental climate. In order to multiply elite seeds of locally adapted and promising varieties, specialized seed multiplication centers and organizations were established. All crop producers began to be supplied with high quality seeds that conform to national standards from 1982. Following the privatization of cropping sub-sector in 1994, the large state owned collective farms disintegrated into many smaller economic entities with meager equipments and machinery capacity, causing decline in the production of high quality seeds.

In order to revive cropping sub-sector, the Government of Mongolia focuses its activities to improve the quality and availability of high quality seeds. Today, 25-27 varieties of early, medium, and late maturing wheat, 4-5 varieties of other crops are planted in Mongolia. Among these, Altaisky 50 variety is planted in 17.1 per cent of total cropland followed by Buryatsky 79 (16.7%), Selenge (15.9%), Altaisky 100 (8.5%), Altaisky 530 (7.2%), and Buryatsky 34 (6.8%).

These six varieties are planted in 72.2 per cent of total cropland. Varieties such as Altaisky 99, Skala, Albidum 43, Darkhan 74 are grown in 1.6-2.8 per cent of total cropland, while Jorny, Buryatskaya ostistaya, and Tsagaan deglii varieties are grown in 1.4-5.0 per cent of total cropland under irrigation.

The priority under the government policy is to intensify crop production and irrigated farming, and to improve land efficiency by improving legal and economic enabling environment, supplying crop producers with high quality seeds, continuing technology renovation, and introducing innovative technologies.

The major challenges in crop production in Mongolia are listed below:

- Climatic hazards, such as climate change, global warming, excessive heat, low precipitation cause severe harvest loss. Comparing to other countries, the average land productivity of 1.5 tons per hectare is very low in Mongolia.
- Insufficient financial resource for the introduction of innovative technologies, preserving soil fertility, expanding irrigated farming area, and taking measures to influence the weather, also pose big challenges.
- As a landlocked country, the cost of introduction of innovative technologies, and transportation cost of food and agricultural products, fodder to other countries is very high. In general, transporting products to other countries is a big challenge for Mongolia.
- In order to strengthen the achievements in cropping sub-sector, to introduce innovative technology, to improve land productivity and crop quality, and to intensify crop production, the Government of Mongolia plans following complex measures:
  - (i) To draft the law on "Crop insurance" to mitigate the risks in cropping sub-sector and establish legal environment of the cropping sector and to have this law adopted by the parliament
  - (ii) To reflect the issues of cropland possession by crop producers in respective laws and legal acts to improve land use
  - (iii) To legalize allocation of certain percentage of mining income to agricultural cropping sector development as investment, and
  - (iv) To promote rotation of cash crops, to preserve soil fertility, to plant shelterbelts and build fences, and to improve seed quality and supply
- Construction of new irrigation schemes and restoration of old schemes also need priority attention.

The crop production and productivity will be improved by realizing all above mentioned activities. The assessment of soil erosion, large scale agrochemical analysis of soil will be carried out with government fund in 561 thousand hectares land that have been abandoned since 1998. By increasing the amount of investment to cropping sub-sector, the country will be able to fully utilize 1.2 million hectare cropland by 2020, with estimated annual production of 0.70-0.98 million tons of crops, of which 030-0.45 million tons will be available for export.

To achieve expected results in near future, the Government of Mongolia is taking following policy measures:

- The import of tractors, harvesters, agricultural equipments and implements, irrigation equipments, fertilizers, agricultural chemicals is exempted from VAT and import tax, in order to promote renovation of agricultural cropping sector.
- The resources from international programs-projects, and state budget

are directed to restore old irrigation schemes, expand irrigated farming area, introduce innovative irrigation technologies and construct rain water collection systems.

- Efforts are being made to create favourable tax conditions and enable access to financial support for crop producers to bring in innovative technological renovation and to import medium and small scale machineries and equipment.
- Reliable seed multiplication and supply of drought-resistant grain crops and fodders will be ensured by promoting investment in seed industries and improving collaboration with science institutes.
- Appropriate policies will be in place in order to increase food production and create access to foreign markets by promoting production of locally adapted varieties and rotations of crops, fodders and cash crops that have higher domestic and international market value and demand.
- Enhancing domestic production, import and utilization of both chemical and biofertilizers, will be used as one of the tools to ensure sustainable productivity.

# 13. Improvement, Production and Multiplication of Wheat in Afghanistan

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## Introduction

Wheat is one of the strategic crops of Afghanistan as it covers a vast area of agricultural land and is required in huge quantities for food purposes. The agricultural area in Afghanistan is 39.8 million hectares out of which 7.9 million hectares is arable and less than 4 million hectares is cultivated annually.

Out of 4 million hectares, 1.8 million hectares of irrigated and 1.7 million hectares of rainfed land is used for cultivation of wheat. About 85 per cent of Afghanistan's population is involved directly or indirectly in Agriculture. Our country was almost self-sufficient in food production in 1970s, but unfortunately conflicts erupted and disorganized the entire process. The level of production decreased, infrastructures and service institutions in agriculture, particularly the irrigated land, were destroyed. On the other hand, the Agricultural Research Institute of Afghanistan (ARIA) and other entities involved in agricultural research which were successfully involved in production and multiplication of wheat were badly affected and many experts left the country. The population of the country is now over 27 million. Therefore, wheat as the main food is an important crop for food security and generation of employment, and thus, the government has accorded a high priority to this aspect.

## Key Issues

**Factors contributing to yield increase in wheat:** The following factors are important for increasing the wheat yield:

- Provision of agricultural inputs like fertilizers, improved seeds, agricultural machinery and protection against plant diseases and pests
- Improvement of irrigation systems
- Establishment of credit sources for farmers

- Implementation of strategic reservoirs system
- Rehabilitation and strengthening the Agricultural Extension Department
- Rehabilitation and strengthening the Agricultural Research Institute
- Increasing the yield per unit of land
- Development of agricultural land
- Scientific and technical management

**Factors contributing to increased production of wheat:** Afghanistan is suffering from conflicts and insecurity for over 30 years. The economy of the country is related to agriculture in particular to wheat which is a crop that contributes towards elimination of hunger and ensures food security. The farmers of our country are now empty handed and need agricultural services. The following factors are important for increasing wheat production:

- The farmers need efficient agricultural equipments like tractors and other technical machinery but currently most of the farmers carry out their practices using cows and mechanical equipments like shovels.
- Annually, the farmers need 0.4 million ton of urea and 0.2 million ton of DAP fertilizers to cultivate their irrigated and rain-fed land.
- Farmers need agro-chemicals that can destroy the weeds and that eradicate the infestation of locust. They require chemicals to control the diseases and pests.
- The other support for the farmers is the establishment of loan and credit system. Years before, the system existed and the farmers were able to work out their problems as there was an Agricultural Development Bank, but now the bank does not exist and should be rehabilitated.
- The other important issue is provision of improved seed for farmers. In 1970s, supply of improved seed was taken over by Government. Modern farms for production and multiplication of wheat were established for farmers, but unfortunately, all the infrastructures were destroyed. The farmers require 55-65,000 metric tons certified wheat seed of different varieties for irrigated and rain-fed lands annually. Currently, only local varieties are used in rain-fed areas.
- Fortunately, during the last decade the system for provision of improved seed was established with the support of FAO, CIMMYT, ICARDA, EU and MAIL.
- During this period, production of different classes of seed, viz., breeder, foundation, registered and certified seed are produced. The responsibility for production of breeder seed is given to ARIA, foundation and registered seed are being produced by ISE which is a public enterprise and a huge volume of certified seed is produced by private seed enterprises. There are 105 registered private seed enterprises in Afghanistan.
- If these obstacles are removed, not only Afghanistan would become self-sufficient in food production, but would also be able to export wheat to other countries.

Althrough the activities in this field were started from scratch but a significant progress has been made. The major achievements are as follows:

- A total of 105 private enterprises have been established in the country.

- Seed Enterprises Association under the name ANSOR was established in 2008 and now ANSOR has the membership of ECOSA.
- National Seed Policy was adopted in 2005.
- For the first time, the Seed Law was enacted in 2009.
- The volume of production has increased and the average yield of seed enterprises became 7-8 tons per hectare of different improved wheat varieties. The grain yield at farmers fields increased from 1.5 to 2.5 tons per hectare and the plan is to increase the average yield of farmers to 4.0 tons per hectare.
- The most important achievement is that the Government is working with the private sector under the same umbrella which can be considered as a good example of rehabilitation in the country.
- Tables 1,2 and 3 show the variation in wheat production in the country. Fig. 1 shows the production of cereal crops (2002-11).

**Table 1.** Production of cereals in 2011 ('000 t)

| Crop | May forecast | September estimate | Difference (Sep-May) |
|---|---|---|---|
| **Wheat** | | | |
| Irrigated | 2,917 | 3,067 | 150 |
| Rainfed | 339 | 321 | -18 |
| **Total** | **3,256** | **3,388** | **132** |
| Rice | 450 | 450 | – |
| Maize | 301 | 301 | – |
| Barley | 305 | 305 | – |
| **Grand total** | **4,312** | **4,444** | **132** |

**Table 2.** Cereal balance sheet, May 2011-12 ('000 t)

| Crop | Requirement | | | | | Domestic production | Deficit |
|---|---|---|---|---|---|---|---|
| | Food | Seed | Feed | Loss | Total | | |
| **Wheat** | | | | | | | |
| Rainfed | – | 119 | – | 48 | – | 321 | – |
| Irrigated | – | 209 | – | 460 | – | 3,067 | – |
| **Total** | **4,346** | **328** | **–** | **508** | **5,182** | **3,388** | **1,794** |
| Rice | 462 | 22 | – | 32 | 516 | 450 | 66 |
| Maize | 54 | 11 | 191 | 45 | 301 | 301 | – |
| Barley | 27 | 30 | 202 | 46 | 305 | 305 | – |
| **Grand total** | **4,889** | **391** | **393** | **631** | **6,304** | **4,444** | **1,860** |

**Table 3.** Area and production of different cereals in 2011 (September, 2011 estimates)

| Crop | Area ('000 ha) | Yield (t/ha) | Production ('000 mt) |
|---|---|---|---|
| **Wheat** | | | |
| Irrigated | 1,156 | 2.65 | 3,067 |
| Rain fed | 1,076 | 0.30 | 321 |
| **Total** | **2,232** | **1.52** | **3,388** |
| Rice | 210 | 3.20 | 450 |
| Maize | 183 | 1.64 | 301 |
| Barley | 190 | 1.61 | 305 |
| **Grand total** | **2,815** | | **4,444** |

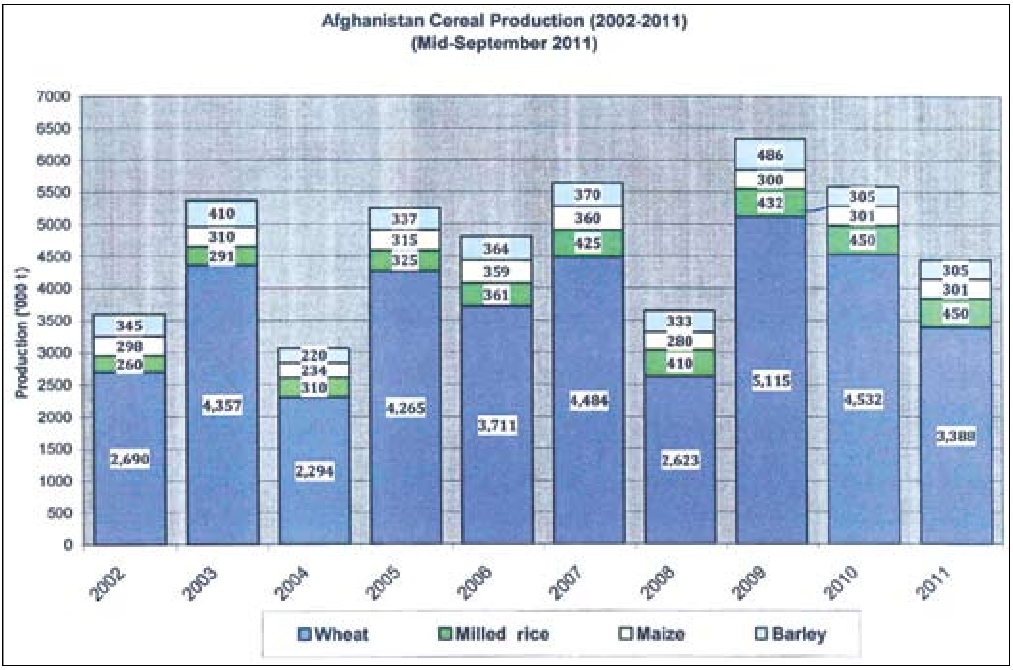


**Fig. 1.** Production of cereal crops in Afghanistan (2002-11)

## Improvement of Irrigation Systems

During the last decades, the climate change has resulted in droughts not only in Afghanistan but many other countries. However, if the irrigation systems are improved in our country, there is enough water to avoid any disturbance in agriculture. During 1970s, Afghanistan constructed dams and modernized canalization for irrigation which suffered damages and require urgent rehabilitation and development. Currently, the old systems of canals are being used for irrigation and require rehabilitation. Due to lack of modern irrigation systems and dams, almost 75 per cent of Afghanistan's irrigation sources are directed outside the country. Afghanistan's Ministry of Agriculture has put enormous efforts to improve the irrigation systems, yet it has not improved due to numerous problems.

The implementation of National Program for Development and Utilization of Water Sources and Irrigation is already planned by MAIL as follows:

- Construction of 30 medium and large dams for irrigation
- Construction of 2,000 small scale water reservoirs
- Plan to increase the area under wheat cultivation and avoid water wastage

Water is an extremely important factor in agriculture and sincere efforts are being made in this regard. The other issue which has a high importance is the strategic food reserves. MAIL has put numerous efforts in this regard. The farmers have surplus production at the time of harvesting and they need storage or purchasing sources to avail economic benefit. They sell their surplus products at low price and they suffer economic loss. The government has decided to buy a certain amount of surplus product at a reasonable price from farmers. This process has the following benefits:

- Farmers will benefit from this process and will be able to invest in cultivation of wheat in future.
- The Government will also benefit from this system as it will be able to use these reserves during critical moments, disasters and high prices.
- The wheat market will be balanced
- This system will strengthen the investment in wheat cultivation
- This system will provide good support to WFP Food-For-Work schemes

There are several other benefits of this system. It is hoped that MAIL would purchase 0.2 million ton of surplus wheat from farmers this year. There are challenges in this regard too. The six silos and stores that belonged to Fertilizer Company require urgent rehabilitation.

## Agricultural Research Institute and Production & Multiplication of Breeder Seed of Different Varieties of Wheat

- Agricultural Research Institute has a long background history in the country
- ARIA has 7 central and 10 field research stations
- ARIA has 12 Departments and the Department of Crop Improvement is the most important which has working relation with international organizations like CIMMYT, ICARDA and FAO. It acquires research materials from international sources with the support of CIMMYT.
- Currently, the research activity for wheat is centered around the introduction of varieties from exotic sources.
- ARIA not only works on cereal crops, but also on industrial crops, vegetables and horticultural crops.
- As per law, ARIA has the responsibility to produce breeder seed of different varieties of wheat. In this year, ARIA produced more than 100 tons of breeder seed.

- ARIA has been able to develop 31 wheat varieties that are registered in National Variety Catalogue with the support of FAO and ICARDA. Out of these varieties, 11 are spring varieties and 4 are winter varieties.

These services were accomplished during these harsh conditions faced by the country. Afghanistan has a rich germplasm collection of over 950 different local varieties of wheat. ARIA has suffered huge loss during the past 3 decades of war and conflicts; in particular ARIA experts fled the country due to insecurity.

## Support to ARIA

Adequate support needs to be provided to ARIA in the following areas:

- Rehabilitation of irrigated and rainfed research stations should be done.
- Supply of modern scientific technical equipments should be ensured.
- The national genebank for germplasm conservation needs to be established.
- Academic institutions need to be strengthened/established to provide trainings and also the master and doctorate degrees.
- Programs for crop improvement need to be implemented considering the modern approaches.
- The capacity of production and multiplication of breeder seed should be strengthened.
- Strong working relationship with international organizations like FAO, ICARDA and CIMMYT should be developed.
- As and when required, the need based research materials should be provided to ARIA.

## Challenges

The following challenges need to be addressed on priority:

- Lack of credit systems for farmers
- Lack of agriculture development bank in the country
- Non-availability of market for the private seed enterprises due to lack of purchasing power by farmers due to war and conflicts
- Lack of interest by national and international investors in agriculture
- Lack of machinery and agricultural equipments for farmers
- Shortage of budget for rehabilitation of ARIA
- Shortage of experienced and skilled personnel in different areas of agricultural research
- Rehabilitation and construction of strategic grain reserves

## Conclusion and Recommendation

Afghanistan's Ministry of Agriculture should appeal to all the international institutions and friendly countries for both financial and scientific support.

# 14. Status of Wheat Improvement in Central Asia

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## Introduction

The Central Asia region encompasses Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Agriculture is the mainstay and major source of employment for rural population across the region. The region covers an area of almost 400 million hectares of which two-thirds are drylands. Food security in the region is closely linked to production and productivity of major cereal crops such as wheat, barley, rice, and maize. Food legumes are minor crops but constitute an important component of rural diets in some parts of the region. Vegetables and fruits are important both as source of nutritional security and as cash crops. Cotton is an important strategic economic crop in the region.

Wheat is the most important food crop in Central Asia and daily per capita calorie drawn from wheat in the region is the second highest in the world after Middle-East and North Africa. Wheat is the most dominant crop covering about 83 per cent of the area planted to cereals. It is grown over 16 million hectares with annual production of more than 21 million tons. Average wheat yield of 1.3 tons per hectare in Central Asia is lower than neighbouring South East Asia (1.90 t/ha), West Asia (2.34 t/ha), South Asia (2.61 t/ha) and East Asia (4.69 t/ha). There are wide yield gaps (approx. 30 - 55%) for wheat in the Central Asian countries. Wheat production occurs both under irrigated and rainfed conditions. Even though wheat produced in the region is more than the requirement, only Kazakhstan and Uzbekistan are self-sufficient in wheat. However, all countries strive to become self-sufficient in wheat production. All countries in the region place high priority to wheat production which also reflects in policy related to agricultural research and development.

## Area, Production and Productivity of Food Crops in Central Asia

The major food crops in Central Asia are wheat, barley, rice and maize. The minor food crops are millets, buckwheat and potato. Kazakhstan has the largest area under wheat production followed by Uzbekistan. The cultivated area, production and yield of various food crops in Central Asia are given in Table 1.

### Wheat statistics

In the year 2010, wheat occupied 16.1 million hectares with the total production of 21.0 million tons at the yield level of 1.30 tons per hectare (FAO, 2011). Kazakhstan has the highest area under wheat cultivation followed by Uzbekistan and Turkmenistan (Fig. 1). Wheat yields are the highest in Uzbekistan (about 5 t/ha). The average wheat yield of the Central Asia region is lower than the average yield in the other regions of Asia (Fig. 2). All countries in Central Asia, except Kazakhstan, primarily grow winter wheat. The average yield of winter wheat is higher than spring wheat in Central Asia, which is also higher compared to wheat yields obtained in other regions of Asia, except East Asia (Fig. 2).

## Past Accomplishments in Increasing Wheat Production and Productivity

During Soviet Union period, wheat was a major crop primarily in Kazakhstan among the Central Asian countries. After independence in 1991, wheat production became priority in all countries due to its importance to food security. Consequently, the countries other than Kazakhstan also made wheat as a strategic crop along with cotton. A part of the traditionally cotton grown area was brought under wheat production. Wheat research became a national priority. However, there was a lack of locally developed improved varieties of wheat and infrastructures needed for wheat research. Initially, wheat varieties developed in Russia and Ukraine were introduced, tested and released in Central Asian Countries other than Kazakhstan. The winter wheat varieties developed at Krasnodar were widely grown in these countries, and still occupy considerable acreage.

Even though the history of wheat improvement in Central Asia is old (Morgounov *et al.*, 2005), most of the development on varietal improvement occurred since 1991 in all countries except

**Table 1.** Area, production and yield of major food crops in Central Asia (2010)

| Crop | Area (mha) | Production (mt) | Productivity (t/ha) |
|---|---|---|---|
| Barley | 1.683 | 1.904 | 1.131 |
| Maize | 0.232 | 1.303 | 5.609 |
| Rice | 0.241 | 0.823 | 3.411 |
| Wheat | 16.126 | 21.040 | 1.305 |
| All cereals | 18.717 | 25.484 | 1.361 |

*Source: FAO (2011)*

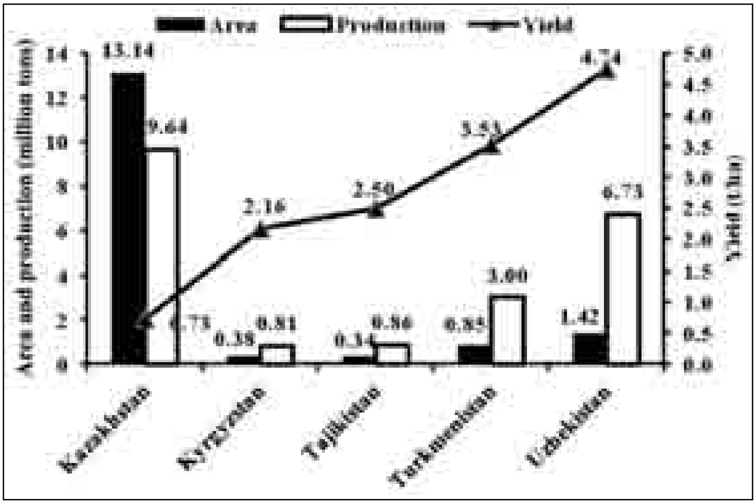


**Fig. 1.** Area, production and yield of wheat in Central Asian countries in 2010
(*Source: FAO, 2011, except for segregated yield estimate of winter wheat in Central Asia*)

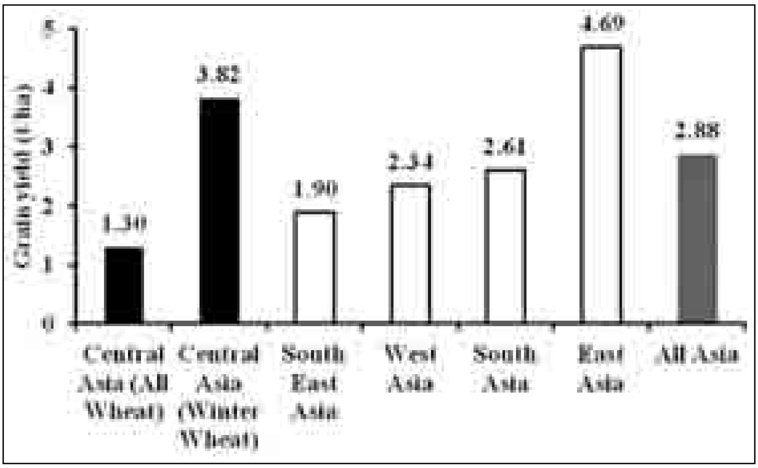


**Fig. 2.** Wheat yield in Central Asia compared to other regions in Asia
(*Source: FAO, 2011, except for segregated yield estimate of winter wheat in Central Asia*)

Kazakhstan. Averaged across the region, wheat yields are stagnant in the past 10 years (Fig. 3). However, the levels of progress in wheat productivity differ among individual countries with some countries showing remarkable progress. In the past 10 years, Uzbekistan achieved about 5 per cent annual gain in yield (Fig. 4). Yield gains were also realized in Tajikistan and Turkmenistan. At present, Uzbekistan has the highest (about 5 t/ha) yield of wheat.

Besides growing varieties developed in other countries, each Central Asian country has now a number of wheat varieties developed within the country. The commercial varieties

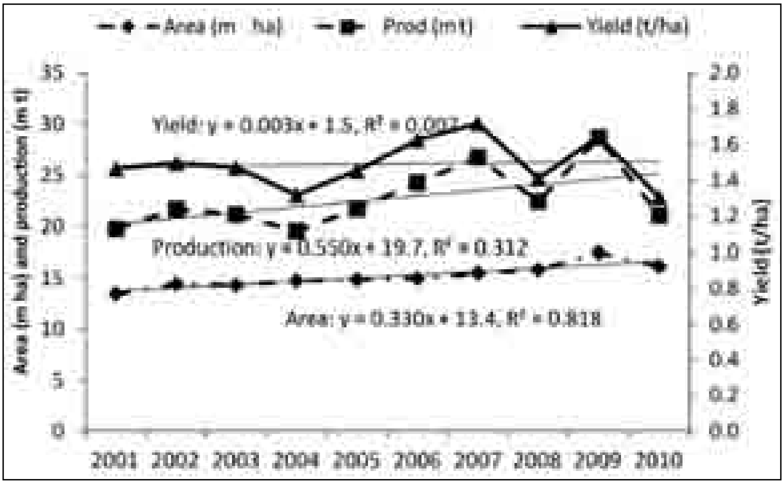


**Fig. 3.** Trend in area, production and productivity of wheat in Central Asia during 2001-2010

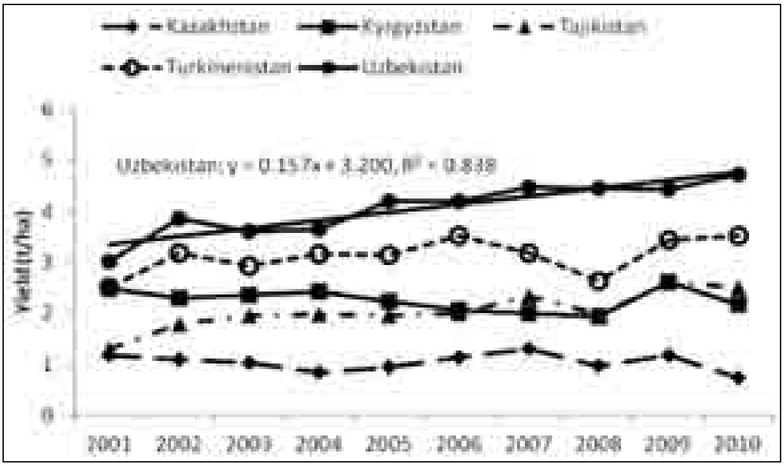


**Fig. 4.** Trend in wheat yield in Central Asian countries during 2001-2010

grown in each country meet the yield goal and locally required end-use quality parameters. There is an array of variability among the varieties grown in Central Asian countries. For example, Uzbekistan grows more than 20 varieties of winter wheat over approximately one million hectares of irrigated wheat land. There are similar examples in other countries. Each country has well developed wheat production packages to achieve high yield. Kazakhstan has well developed practices for conservation agriculture and resource conservation practices. These achievements have been possible due to national commitment towards improving wheat production and productivity. Besides, strong presence of two international centers (ICARDA and CIMMYT) in the region has played an important role in wheat improvement in each country through international collaboration.

## International Collaboration

International collaboration in wheat research in Central Asia started around mid - nineties initially with introduction of improved germplasm from ICARDA and CIMMYT. In the past 17 years, more than 64,000 accessions of wheat have been introduced in Central Asian countries (Fig. 5). International collaboration was also expanded in the area of development of human resource and research infrastructure, and working on joint research projects. The national research institutions immensely benefited from the technical support provided by ICARDA, CIMMYT and many other institutions in advanced countries towards strengthening wheat improvement activities. Through such collaboration, many improved varieties of wheat have been released in different countries in Central Asia, which are grown over large area in the region and play important role in improving food security.

## Constraints in Productivity Enhancement and Emerging Challenges

There are several abiotic, biotic, and socioeconomic constraints to wheat improvement in the region. The major abiotic stresses are drought, heat, salinity and frost. Among biotic stresses, wheat stripe rust is the most important followed by leaf rust. Tan spot, Sunn pest, cereal leaf beetle, and Russian wheat aphid are important constraints in some parts of the region. The socioeconomic constraints include inadequacy of funding, research facilities, number and training of manpower, and policy guided varietal development, adoption and replacement, and seed multiplication. There are fewer experienced wheat breeders than needed in most of the countries. There are inadequate research facilities and use of modern wheat improvement methods and tools. Majority of the wheat varieties occupying

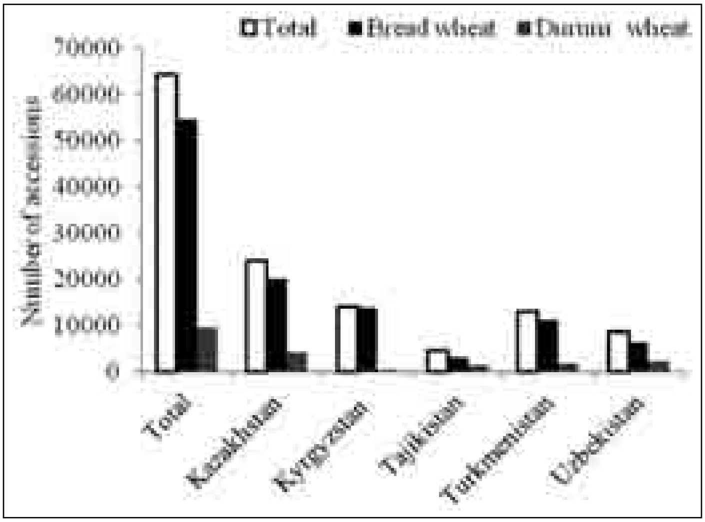


**Fig. 5.** Number of wheat accessions received in different countries in Central Asia during 1995-2011

substantial area in the region lack adequate resistance to important diseases and pests. Wheat improvement programs are not well developed and facilitated in majority of the Central Asian countries to effectively address the deficiency in the commercial varieties. Varietal release and seed multiplication systems are not streamlined to allow swift replacement of deficient varieties with improved ones. There is inadequate funding of wheat improvement related activities. There is a lack of financial incentives and career advancement opportunities for young wheat researchers. A large mass of wheat researchers are ageing with little opportunity to replace them with competent young manpower. There is weak networking for germplasm and scientific exchange among the countries within the region.

Stripe rust has been the most important disease constraint to winter wheat production across the region over the last 12 years and five epidemics occurred during that period (Ziyaev *et al.*, 2011). Since cultivation of the resistant varieties is limited, stripe rust is primarily managed through fungicides, which not only adds to the cost of production but is also harmful to the environment. Recent studies in Uzbekistan and Tajikistan have shown that grain yield reduction due to stripe rust could go up to 40 per cent (unpublished data). Leaf rust is an important disease across the region and its epidemics are experienced on an average once in five years. There has not been any report of Ug99 stem rust in the region. However, it was reported in the neighbouring Iran. Since the commercial wheat varieties have been found susceptible to Ug99 in the evaluation conducted in Kenya, there is a need for preparedness by identifying resistant varieties.

Sunn pest is also a perennial threat to winter wheat cultivation in many parts of Central Asia. Since none of the commercially grown varieties is resistant to Sunn pest, chemical control is widely adopted. There is also a lack of winter wheat varieties resistant to cereal leaf beetle and Russian wheat aphid. Drought caused by the failure of expected precipitations and heat due to sudden rise in temperatures during grain filling are serious constraints to winter wheat production in some years. Drought is a perennial constraint to rainfed grown wheat across the region. Soil salinity has been traditionally managed through leaching in order to grow wheat. Due to decreasing trend in water available for leaching salt, the problem of soil salinity is increasing on wheat lands.

There is a lack of focused effort of replacing old varieties by new ones through accelerated seed multiplication and varietal dissemination plan. There is insufficient participation of farmers and private sector in development and out-scaling of new varieties in most countries.

The widely grown cotton-wheat and wheat-other cereal cropping patterns are detrimental to soil health. Land degradation is a huge problem in Central Asia. There is little inclusion of legumes in the cropping system. There is little application of integrated crop management practices.

There is a lack of young researchers in sufficient number to manage wheat research activities and substitute for the retiring wheat breeders. A survey of plant breeding and related biotechnology capacity was conducted by FAO in Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan (*http://gipb.fao.org/Web-FAO-PBBC/index.cfm*). The constraints identified for wheat breeding research in both public and private institutions were the lack of trained young scientists, poor infrastructure, and lack of modern equipments and machinery and were considered as the main challenges for effective variety development.

## Approaches for Meeting the Challenges including Climate Change

Each country in Central Asia recognizes the wheat production constraints outlined earlier in this paper. There is a team of wheat researchers and decision makers in each country that outlines annual, short-term and long-term strategies to address those challenges. There is also consultation with International Agricultural Research Centers (IARCs) present in the region in developing wheat strategies. Each country prioritizes the areas to be strengthened in order to improve food security. From time to time, there is also regional level wheat strategy meeting often organized jointly by the IARCs and national wheat improvement programs where regional problems are discussed and prioritized and strategies are developed. Each country develops plans and funds research to solve problems related to individual countries. Improved wheat germplasm are introduced from CIMMYT, ICARDA, International Winter Wheat Improvement Program (IWWIP) and other sources.

The national wheat improvement programs in each country regularly evaluate wheat germplasm made available through international collaboration. Besides, each country has its own wheat hybridization program where locally available genetic resources are used in crossing with the improved exotic germplasm to develop new varieties with traits required for local wheat production systems. Each country has developed wheat varieties utilizing this approach.

In order to address disease and pest problem and the abiotic stresses, each country tests international nurseries developed with germplasm for specific problem traits. A recent study has reported that stripe rust resistant germplasm of winter wheat are increasingly becoming available through international nurseries provided by IWWIP (Sharma *et al.*, 2012a). In order to exploit the genetic potential of high yielding varieties and locally available production systems, different management practices are used for rainfed and irrigated systems. Two recent studies have identified high yielding, stable varieties of winter wheat in the international nurseries evaluated in Central Asia along with neighbouring regions (Sharma *et al.*, 2010, 2012b). Anticipatory breeding strategy is being adopted to address the problems likely to emerge or increase in future due to climate change (heat, drought and salinity) and change in pathogen such as new races of wheat rusts including Ug99.

Each country develops and executes annual plan for input supply to the farmers in terms of quality seed of improved varieties, fertilizers, pesticides, irrigation and marketing to maximize production and profitability from wheat cultivation. Often, wheat related policy interventions are made based on needs in individual countries.

## Efforts in Improving Wheat Production for Meeting the Future Targets

Since wheat is the most important food crop, a great deal of national efforts is placed on wheat improvement in order to meet the current demands and future needs for the growing population in the countries in Central Asia. This is done through recognizing the factors that could adversely affect wheat productivity. Development of new varieties resistant to the prevalent biotic and abiotic stresses is at the core of national planning on wheat improvement in all countries in Central Asia. There is a strong awareness towards the use of improved crop management technologies to reduce yield gaps between experimental plots and farmers' fields. Use of resource conservation practices is becoming increasingly popular in the region. Adoption of conservation agriculture is increasing. Since heat is becoming a major threat to wheat production, efforts are being made to identify and use tolerant varieties. Early planting of wheat is being practiced as much as possible to escape terminal heat stress. Applying irrigation during grain development is another strategy being used to reduce the effect of heat under irrigated management.

Since many leading commercial cultivars are susceptible to stripe rust, a planned schedule of fungicide application is adopted to control the disease on irrigated wheat. Given that no commercial wheat varieties are resistant to Sunn pest, pesticide applications are regularly used to control this pest. There is a growing awareness in Central Asia about the potential threat of Ug99 strain of wheat stem rust. Resistant germplasm distributed as international nurseries are regularly evaluated to identify resistant varieties. Advanced breeding lines and commercial cultivars of wheat are sent to Kenya for evaluation against Ug99. Since there is insufficient number of young researchers working in wheat improvement, national efforts are being made to recruit talented young researchers and provide them training and better career opportunities. Also, training opportunities at the international centers and through donor agencies are being widely used to improve human resource capacity in wheat improvement. University curricula are being upgraded to include recent scientific developments which can better equip the graduate students who might chose to join national wheat research teams.

## Future Strategy

Wheat is going to remain the main food crop in Central Asia for there is little evidence of any systematic change in the dietary pattern in the region. Therefore, wheat improvement will continue to take central stage in agricultural research policy to ensure food security for the growing population. While international collaboration is considered vital for addressing the future challenges to wheat improvement, there is an increasing awareness among countries in Central Asia to invest more in wheat research. Additional investment is being considered to strengthen infrastructures and human resource development. Each country is considering application of modern tools in wheat improvement. Conservation agriculture is expanding in order to make efficient use of resources and improve sustainability of production. Upgrading wheat research facilities, recruiting more scientific personnel and improving policies guiding wheat production are top priorities in each country. There is increasing support from the Government in each country to encourage researchers to develop projects with the goal to develop new technologies to solve problems related to agriculture in general and wheat in particular. Each Central Asian country gives high priority to strengthen collaboration with IARCs and research institutions in advanced country in order to benefit from their scientific developments. Research institutions proactively seek partnership in developing joint research projects with IARCs and advanced institutions in different countries.

The region of Central Asia is rich in wheat related genetic resources and each country has a national genebank, The national wheat strategies aim at utilizing these genetic resources in wheat improvement. In order to develop new wheat varieties with high yield, improved quality, resistance to major diseases, tolerant to heat, drought, frost and salinity and acceptable agronomic traits, utilization of local genetic resources are considered important. This is particularly important for incorporating stress tolerant genes into improved varieties. Each country is considering wider adoption of integrated pest management (IPM) practices in order to manage diseases and pests in a sustainable way and reduce the use of chemicals. Even though the IPM system is well developed for cotton, much is needed to be done for wheat. There is little use of modern tools, such as biotechnology, in wheat improvement in Central Asia. However, each country is considering application of biotechnological tools important in order to improve efficiency of wheat varietal development. Depending upon availability, application of biotechnology, especially marker assisted selection, is an important future strategy in wheat improvement in Central Asia.

## Conclusion

Food security in the Central Asia region is strongly linked to wheat productivity. Therefore, improving wheat productivity remains at the core of agricultural policy in the region. The status of area, production and productivity of wheat differ among the five countries in Central Asia. There is a huge scope of improving wheat productivity across the region. There are a number of constraints to wheat production which need to be addressed in order to improve wheat productivity and food security. Wheat stripe rust, Sunn pest, cereal leaf beetle and Russian wheat aphid are important biotic stresses. Drought, heat, frost and salinity are key abiotic stresses. The emerging threats of heat during terminal growth stage, erratic pattern of rainfall and dwindling supply of irrigation water are going to be major challenges for wheat research in order to sustain wheat production. In order to address the above constraints, multilevel approaches are being adopted in Central Asian countries. New improved germplasm are being introduced and evaluated in the region to address the problem of wheat stripe rust and leaf rust and potential threat of Ug99. New varieties are being released, and accelerated seed multiplication is done for efficient out-scaling of new varieties. There are changes taking place in policy related to wheat improvement which will have long-term positive impact on wheat production and productivity. There is renewed consciousness among the national policy makers in Central Asian countries towards wheat improvement due to emerging threats of Ug99 strain of stem rust and climate change. A great deal of effort is being made on capacity development. Overall, intensive wheat improvement efforts in the region are being made, and there are good signs of future progress in wheat productivity in the Central Asia region.

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# 15. The Borlaug Global Rust Initiative: A Global Initiative for Managing Wheat Rusts

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## Introduction

The Borlaug Global Rust Initiative (BGRI), established by CIMMYT, ICARDA, FAO, ICAR, and Cornell University and fostered by the Durable Rust Resistance in Wheat (DRRW) project, is now a global community of 1,400 wheat and rust scientists and other stakeholders. Since the BGRI's inception in 2008, and largely due to its inter-disciplinary and collaborative nature, stem rust research has advanced significantly and the global rust community has continued to realize Norman Borlaug's vision of a more secure wheat crop worldwide.

The DRRW project, a key component of the BGRI, is a global effort to mitigate the threat of Ug99 and other newly emerging races of wheat stem rust, *Puccinia graminis* f. sp. *tritici*. Funded by the Bill & Melinda Gates Foundation and the UK Department for International Development (DFID), the DRRW project is based at Cornell University and is a consortium of scientists from over 20 collaborating institutions. The multifaceted approach of the DRRW project includes an international surveillance effort, an increased understanding of the pathogen at the molecular level, resistance gene discovery, reducing linkage effects of alien introgressions, the development and optimization of molecular markers, resistance gene stewardship, the development of stem rust resistant bread and durum wheat varieties, seed multiplication and delivery, training and capacity building, gender equity, and understanding non-host resistance to rust in rice.

Twenty at-risk countries are contributing surveillance data to a global cereal rust monitoring system created by DRRW collaborators. Nineteen new resistance genes with breeder-friendly molecular markers have been identified. Over seventeen Ug99 resistant lines with a 5 per cent yield advantage have been released to eight national programs in the immediate at-risk zone. Nearly 5,000 tons of Ug99 resistant seed is now being planted across 23,000 hectares in six priority countries. Approximately 50,000 bread and durum wheat lines are being screened in international screening nurseries in Kenya and Ethiopia. Several successful training initiatives have been taken at international centers, and North American, European, Asian, and Australian universities and other institutions. Gender disparity within the wheat breeding community is being addressed in several ways: through annual "Women in *Triticum*" awards that recognize early-career women wheat scientists and their mentors; and through a gender responsive variety selection project that better serves the needs of women wheat farmers.

A core value of the DRRW project is durable rust resistance. The project activities reinforce the need to invest in multi-faceted long-term solutions. In the development of new rust resistance varieties, the DRRW project supports multiple approaches based on both minor small effect genes that permit some small amount of retarded rust development and large effect major genes that elicit the hyper sensitive defence response. Although the stem rust resistance gene *Sr31* was deployed globally and remained effective for over 30 years, the DRRW no longer develops or promotes varieties carrying single stem rust resistance genes knowing that new aggressive and rapidly evolving race groups, such as the Ug99 race group, are overcoming singly-deployed resistance genes within a couple of years after their deployment in some recent cases.

The International Maize and Wheat Improvement Center (CIMMYT) is carrying out many of the breeding activities in partnership with the Kenya Agriculture Research Institute (KARI) and the Ethiopian Institute for Agricultural Research (EIAR) as well as many other national programs in wheat producing countries. CIMMYT's rust resistance breeding activities are largely focused on breeding for adult plant/minor gene resistance in order to protect wheat globally from the boom and bust cycles that result from the deployment of single major hypersensitive response resistance genes.

In addition, the project has a large gene discovery effort in order to generate new wheat varieties with major resistance gene combinations that minimize the likelihood of progressive mutation of stem rust races. Major genes have the desirable characteristic of eliminating the rust inoculum production during parts of the seasonal cycle and they are less temperature sensitive than minor genes. Thus, major genes continue to serve as important genetic resources in the DRRW project but only when used in combinations of three or more genes closely associated in linkage blocks that are unlikely to segregate subsequent to a line's release.

As new sources of rust resistance are obtained in breeder-ready form with optimized molecular markers, it is critical to the DRRW's quest for durable resistance that these genes be deployed responsibly. The use of both APR genes as well as tightly linked combinations of $\geq 3$ major genes both contribute to the goal of the DRRW project and the BGRI to limit the vulnerability of wheat to virulent mutations of stem rust. The project no longer invests in tshe shortsighted deployment of single major resistance genes and encourages other institutions to modify breeder recognition and promotion criteria to reward for responsible gene stewardship.

## South Asia Regional Activities

South Asia regional activities are coordinated by Sathguru Management Consultants. DRRW project's focus in South Asia has been on rust surveillance, capacity building and breeding of wheat lines that are resistant to Ug99. DRRW in association with the Indian Council of Agriculture Research (ICAR), and other constituent organizations, has been instrumental in bringing policy level interventions in the South Asian Association for Regional Cooperation (SAARC) nations to recognize Ug99 as a devastating disease threatening the wheat crop in the region. The efforts began in 2008 with the convening of the South Asia regional participants in developing effective strategy to combat Ug99 in the region.

Since then, with the help of global rust research experts from Africa, USA and Australia, DRRW has been exposing wheat scientists from the SAARC region to rust surveillance activities that include collecting rust samples, dispatching these samples to wheat rust labs, race analysis, purification of the rust race, etc. These initiatives have been conducted in different geographical zones of India, Nepal and Bangladesh and included participants from India, Bangladesh, Nepal, Bhutan, Afghanistan and Pakistan. So far, more than 42 rust workers have been exposed through these activities. As an initiative to make the surveillance activities more precise and the data made available in real time, DRRW has developed and is deploying a SAARC Tool Box, for SAARC nations to upload surveillance data into a central server making use of the Internet as an effective tool. This technology is now being adapted for use in smart phones and tablet computers so that scientists can upload directly surveillance information from the field. These data will contribute to the resources being developed by the International Focal Point and made available on Rust Spore.

In order to expedite the breeding efforts and facilitate the release of Ug99 resistant wheat varieties, national programs in wheat-producing countries have been sending wheat germplasm to the international stem rust screening nurseries in Kenya and Ethiopia for testing the bread wheat lines in the context of these Ug99 hotspots. DRRW has supported the efforts of the South Asian countries to gain exposure to "Standardization of stem rust field notes and germplasm evaluation with discussion on stripe and brown rust" with senior and young scientists deputation to the region and their participation in such training programs. Through these efforts, stem rust resistant varieties have been released in India, Bangladesh and Nepal.

To augment the breeding activities as well as expedite the time to market of rust resistant wheat varieties, DRRW is promoting upstream technologies such as the use of molecular markers to identify the rust resistance genes and their immediate deployment in the wheat germplasm. Scientists from South Asia have been provided exposure and access to biomaterials to work on molecular aspects of wheat improvement with reference to stem rust resistance for development of disease resistant and high yielding genotypes using molecular approaches of wheat research in a global perspective.

Maintaining gender balance has always been a major focus of DRRW through gender-influenced variety selection and through professional development programs, DRRW-South Asia has been actively involved in all aspects of the project's gender initiative. DRRW has also supported wheat scientists from the SAARC region to participate in the BGRI technical workshops held annually and to interact with the global wheat scientist community in order to share knowledge and pledge their scientific collaboration in combating the deadly disease Ug99.

In accordance with the goals of the DRRW and the BGRI as a whole, it is important for SAARC countries to follow responsible gene deployment and replace stem rust susceptible varieties grown in the SAARC region with durably resistant varieties based on multi-genic and APR basis of resistance in order to maximize the impact that the DRRW project activities and accomplishments have in the region in the long-term.

# 16. Climate Change: *Puccinia striiformis* and other Pathogens Affecting Wheat Yield in Asia

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## Introduction

Since 1987 coinciding with the fall of the South Union, there has been several cropping system changes in Central Asian Republics, Middle East and even in South Asia. The new independent nations drove for self-sufficiency in wheat, the major winter cereal which is the backbone of the national food security system. In that process, several crops had to shrink to give space for wheat. The 2007 food crisis only deepened the food self-sufficiency drive leading to the creation of pan-genetic vulnerability due to the wide-spread cultivation of a few varieties with similar resistance genes. Here, the new pan-genetic vulnerability of wheat to *Puccinia striiformis* (*Pst*) and other diseases in Asia is in the context of the global climate change.

## Factors that Influence Plant Disease Severity

For the disease symptom to appear, three elements must converge, namely, favourable environment, vulnerable host and virulent pathogen. Then the disease symptom appears with shortest incubation time and when the favourable situations continue for a protracted period, then the spores produced by the first crop of lesions initiate the second, third infection cycle and so on. Completion of at least seven cycles on the same host can result in disease severity of more than than 80 per cent. Hence, epidemic is a product of polycyclic process and pandemic involving space, time and several disease cycles (Zadoks and Schein 1979; Vanderplank, 1963). In the last decade, several wheat disease pandemics have ravaged the Asia region due to anthropocentric activities and climate change.

## About Climate Change

The millennium global climate has been changing and that has been the driver of evolution and creation of new variation. Industrialization of Europe and the post-second world war globalization due to human activity has accelerated the climate change. The first signal of such a change is the erratic short-term weather. And when it is frequent and equalized over time, it gives an impression that the global mean maximum temperature has increased. Such information is deceptive as seldom due to climate change, there will be continuous raise of temperature by half °C, and in that case all living organisms would have developed adaptive mechanisms against such changes. It is the wide range of fluctuation, duration and frequency of such change that poses a limitation in developing an appropriate technology.

Ludhiana, India is located in the heart of the productive wheat growing plains of North-West India. Analysis of thirty five years (1970-2004) of minimum air temperature, the maximum temperature and rainfall data (Prabuyot Kaur *et al.*, 2006) showed that there was no annual trend of variation for any of the three parameters. But, when the information was divided on the basis of the two main crop seasons as *kharif* (monsoon season crop) and *rabi* (mild winter seasons crop) weather, then the climatic change was clearly evident. There was a small, but insignificant increase of 0.08°C per year in the minimum temperature and a decrease of 0.02°C per year in the maximum temperature. In general, the *kharif* season, rainfall increased by 9.5 millimeter per year. In the *rabi* season, there was no significant trend in the rainfall, but the minimum temperature increased by 0.07°C per year while there was no difference in the maximum temperature. During both the seasons, the minimum temperature increased and it is not clear if the rapid expansion in irrigation and large scale adoption of the rice-wheat farming system contributed to this rise in the minimum temperature. Climate change in a small way happened in the North-West Plains of India and the reason for that has not been authenticated.

The winter precipitation over north western India that favours Pst is governed by mid-altitude level macro weather patterns (Nagarajan *et al.*, 1982) called the "western disturbance" (Pisharoty and Desai, 1954). These are periodically formed low pressure systems originating around Black Sea area during the non-monsoon months and slowly move towards the Indian Himalaya. In this process, they bring-in rain, snow and cold spell over Middle East, southern Central Asia and northern parts of South Asia. This weather system has been correlated with the stripe rust epidemic of South Asia. Any deviation in the western disturbance frequency / strength will affect the rainfed wheat crop and if it brings more rain, the crop may become prone to *Pst* and *Fusarium* head scab.

## Adaptation of the Pathogen

The globally dominant new *Pst* virulence has been shown to have greater fitness and adaptation to a wide range of conditions enabling it to dominate the pathogen flora and cause severe epidemic. The new *Pst* virulence at low temperature of 10-18°C sporulated sooner, expressed symptoms faster, produced more spores per $mm^2$ of lesion in comparison to old isolates, and tests conducted at high temperature regimes of 12-28°C (Milus *et al.*, 2009). Therefore, due to climate change, if parts of Asia tend to become cool and cooler, then such adapted *Pst* may dominate and make the crop prone to epidemics. Such virulences may sporulate even during early fall on volunteer plants / the green bridge and infect the main crop early resulting in severe epidemic.

## Cropping System Induced Changes

Prior to 1987, the Soviet part of Central Asia was a major cotton growing area. Subsequently, the emerging new nations focused on food security and greater water use efficiency. The USDA data shows that Uzbekistan had 2.1 million hectares under cotton and by 2011, it got reduced to 1.4 million hectares and rice from 0.15 million hectares in 1987 to 0.03 million hectare. In Central Asia, rice area got reduced by 0.11 million hectares, and cotton area reduced by a million hectares. All that area was diverted to wheat creating a huge vulnerable varietal continuum and the resultant removal of spatial barriers changed the farm level microclimate favorably tilting the balance in favor of the stripe rust.

## Temperature Dependent Host-Pathogen Gene Expression

Infection types in *Sr*15-bearing seedlings to *P. graminis tritici* (*Pgt*) were low at 18°C and below, mesothetic at 22°C and high at 26°C and above. Infection types in *Sr*9b-bearing seedlings differed between the two strains of *Pgt*; with one strain, infection types decreased with increasing temperature from 18°C; with the other strain, infection types decreased slightly at 30°C (Gousseau *et al.*, 1985). Genes *Lr*18, *Lr*14a, *Lr*30, *Lr*15, and *Lr*11 had lower infection types at low temperature and higher infection types at the higher temperatures. However, genes *Lr*16, *Lr*17, and *Lr*23 had lower infection types at high temperatures, and had high infection types to various isolates at the low temperatures. Genes *Lr*2a, *Lr*3ka, and *Lr*3 had less resistance at low temperatures to isolates that had intermediate infection types to the genes. Dyck and Johnson (1983) and Kholmer (1996) opined that the temperature responses of the leaf rust resistance genes were isolate dependent. Therefore, identifying such useful genes for the predominant virulences and positioning them to accord resistance against inter and intra crop season climate variation will simulate durable resistance to *P. triticina* (*Ptr*).

## Scope for Gene Deployment

In Central Asia, winter wheat is grown from September to July, facultative wheat from September to May and spring wheat from May to August. Durum collateral hosts provide live host for the wheat diseases to survive round the year. While in Iran, all types of wheat are gown depending on the altitude. During the hot summer when temperature exceeds 40°C and there is no wheat around, *Puccinia* moves up to cooler slopes where host is available. In NW India, by late April wheat is harvested and the pathogen moves up in the Himalaya to the interior valleys where wheat is grown during May to October. In the lower Himalaya, only facultative wheat is grown and no winter wheat is grown since it gets trapped in monsoon rain. Taking advantage of the elevation dependent wheat maturity, a strategic gene deployment plan can be designed to cut down the inoculum load, delay the epidemic and thus save the crop loss.

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# 17. Managing Wheat Rusts by Using Minor Genes

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## Introduction

The rust fungi are among the most destructive of plant pathogens, and have caused immense damage in many of the plants cultivated by humans, including field and vegetable crops, trees and ornamental plants. Because of the importance of cereals in sustaining humans, the rust fungi that attack these crops are often regarded as the most important plant diseases of all. Three rust diseases occur in wheat: stem or black rust (caused by *Puccinia graminis* f. sp. *tritici*), stripe rust (caused by *P. striiformis* f. sp. *tritici*), and leaf or brown rust (caused by *P. triticina*). While stem rust has caused complete cop failure, severe infection by the stripe and leaf rust pathogens have caused grain yield losses up to 70 per cent. All three pathogens remain serious threats to global wheat production.

## Genetic Control of Rust in Wheat

The global importance of wheat and wheat rust pathogens have driven world-wide efforts to develop, deploy and manage wheat cultivars with genetic rust resistance. This work had its genesis over 100 years ago when it was demonstrated that resistance to stripe rust in wheat was a heritable Mendelian trait. At the time of these studies, Biffin was unaware of pathogenic variability in *P. striiformis* f. sp. *tritici*. The discovery of physiologic races in *P. graminis* f. sp. *tritici* was crucial in advancing resistance breeding efforts, demonstrating the importance of monitoring rust pathogen virulence and using the most relevant rust isolates in rust resistance pre-breeding and breeding efforts.

## Major Gene and Minor Gene Resistance to Rusts in Wheat

Resistance to rust in wheat is often referred to as being conferred by major genes or minor genes, depending on the phenotype conferred by the resistance locus in question. While these terms are useful, it is important to note:

- They are not mutually exclusive and are, in essence, a division of convenience. Some rust resistance loci that display all of the features typical of minor genes can also be detected as genes of major effect in seedling assays under certain environmental regimes (*eg. Lr34*, Singh *et al.*, 2007; *YrCk*, Park *et al.*, 1992, 2010). Conversely, some loci that can be detected in routine seedlings assays appear to confer minor gene resistance at adult plant growth stages in the field (*eg. Sr12*).
- Major gene resistance is often equated with seedling resistance (resistance effective at all growth stages), and minor gene resistance with adult plant resistance (APR) – this is not always the case.
- Also strictly not true, minor gene or APR is often equated with durable resistance.
- Some (but not all) major genes and minor genes display additivity - combining two or more genes to give levels of resistance beyond those observed for the genes individually.
- While many reports exist of additive minor gene resistance to leaf rust and stripe rust in wheat, a few sources of additive minor gene resistance are known to stem rust.

## Durable Resistance

For practical purposes, the most important features of disease resistance are the level of protection from economic damage afforded, and durability. Durable resistance was defined by Johnson (1978) as "resistance that remains effective when a cultivar is grown widely in environments favoring disease development".

The concept of durable resistance makes no assumptions concerning the mechanisms or genetic control of resistance. It has proven to be a very useful concept in disease resistance breeding. While there are many examples of non-durable major resistance genes (*eg.* seedling resistance gene *Lr26*, APR gene *Lr22b*), there are also examples of genes that "remained effective when present in a cultivar that was grown widely in environments favouring disease development", and yet eventually succumbed. Stem rust resistance genes *Rpg1* in barley and *Sr31* in wheat were regarded as durable; however, in both cases pathotypes with matching virulence were eventually detected (races QCC and Ug99, respectively). These examples serve as a warning that there can be no guarantee of durability for any resistance source.

## Are Minor Genes *Per Se* Inherently Durable?

The durability of polygenic resistance, whether major or minor gene based, is often attributed to the increasingly lower probability of a plant pathogen simultaneously acquiring the virulences matching increasing numbers of pyramided resistance genes. There are, however, examples of single genes that appear to be "inherently" durable. Of the five rust resistance genes that have been cloned from wheat to date, only *Lr34*/*Yr18*/*Sr57* can be considered as a durable minor gene.

The basis for the durability of this gene is still not understood, but could relate to the molecular basis of the resistance it mediates, which differs from those of the non-durable "NBS-LRR" type major resistance genes *Lr1*, *Lr10* and *Lr21* (Table 1).

The question of whether or not individual minor genes *per se* are inherently durable is not insignificant. If, individually, these genes are no more durable than major genes, then the durability that is often attributed to them likely stems from their use in combinations. Deploying them singly would lead to loss of effectiveness, as has been seen for many major resistance genes. Qi *et al.*, (1999) obtained evidence of race specificity for partial resistance to leaf rust in barley, and Rouse *et al.*, (1980) provided evidence for the erosion of slow-mildewing in wheat. The latter authors stated that "the interaction between components of slow-mildewing resistance and parasitic fitness indicate that the resistance could at least to some extent erode over time". The recent introduction of an exotic pathotype of *P. striiformis* f. sp. *tritici* into Australia resulted in a rapid and major shift in the Australian stripe rust flora (Wellings, 2007). This pathotype is very similar to, or the same as, one occurring in North America and now regarded as being more aggressive (Milus *et al.*, 2006). It has had a significant effect on Australian wheat germplasm that is not related to major gene resistance – and so the question is raised, "has there been an erosion of minor gene resistance to stripe rust?" Complicating this issue, virulence for a minor stripe rust resistance gene in the triticale cultivar Tobruk, most likely acquired *via* simple mutation, was detected in 2009 (C.R. Wellings, unpubl.).

Clearly, the factors that determine the durability of a given resistance, whether major or minor, single gene or polygenic, are complex. There is evidence that genetic "background" can influence resistance durability (*eg.* the *pvr2*$^{3}$ gene in pepper, Palloix *et al.*, 2009; *Lr24* in wheat in Australia, Park *et al.*, 2000), lending credence to the strategy of using reputedly durable sources of rust resistance as "background" resistance, to which other resistance genes are added (McIntosh, 1988).

## What Have We Learnt, and What About The Future?

Experiences with the development and deployment of rust resistant wheat since

**Table 1.** Rust resistance genes that have been cloned from wheat

| Gene | Putative gene product | Gene action | Durable? | Reference |
|---|---|---|---|---|
| *Lr*1 | CC-NBS-LRR | Major | No | Cloutier *et al.* (2007) |
| *Lr*10 | NBS-LRR | Major | No | Feuillet *et al.* (2003) |
| *Lr*21 | NBS-LRR | Major | No | Huang *et al.* (2003) |
| *Lr*34/*Yr*18/*Pm*38/*Sr*57 | ABC transporter | Minor | Yes | Krattinger *et al.* (2010) |
| *Yr*36 | Kinase-START | Minor | ? | Fu *et al.* (2009) |

Biffin's pioneering studies published in 1905 have shown:

- Some rust resistance genes are more durable than others.
- Past durability, while informative, does not guarantee effectiveness forever.
- Pyramids of resistance genes are preferable.
- Diversity in deployed resistance genes is vital to insure against future pathogen changes.

All of these points reinforce the need to deploy combinations of, preferably, three or more resistance genes, and the importance of ensuring that any genes used are not deployed singly so as to avoid putting in place the stepping stones for rust pathogens to sequentially acquire matching virulence.

Whilst there has been a trend towards increased use of minor gene resistance in controlling stripe rust and leaf rust over the past 30 years, control of stem rust continues to be primarily through the use of major resistance genes in conjunction with either one or both of the minor genes *Sr*2 and *Sr*57/*Lr*34/*Yr*18. The importance of these two loci in protecting wheat from rust globally cannot be understated.

Because very few wheat genotypes lack major genes for resistance, increasing emphasis on minor gene resistance must include careful monitoring major genes in breeding populations to ensure that combinations of minor genes are selected and the major genes are avoided. Our efforts to discover and characterize more rust resistance genes of minor effect need to be redoubled to ensure we can assemble diverse combinations of these genes to insure against potential adaptation to these genes by rust pathogens. In the absence of perfect (diagnostic) markers, understanding rust pathogen variability will remain important if minor gene resistance is to be targeted increasingly in breeding programs.

Equally important is the development of high throughput markers to aid in their selection. Of the markers developed to date, the only csLv34 for *Sr*57/*Lr*34/*Yr*18 (Lagudah *et al.*, 2006) is considered truly "breeder friendly". Although this marker is being used in high throughput assays in breeding programs to assist selection, it is however, not 100 per cent diagnostic despite the gene itself having been cloned. Clearly, challenges remain in developing robust high throughput markers for minor resistance genes.

## Post-release Management of Rust Resistance

The control of rust diseases by resistance is only sustainable if progress achieved through resistance breeding is managed responsibly. Rust pathogens can spread rapidly and consequently international coordination, not only in the development and deployment of genes for resistance but also in rust pathogen surveillance, is essential to ensure sustained control through resistance. There are many examples from the past 60 years of resistance gene breakdowns occurring where a cultivar with a single resistance gene was deployed in a region with moderate to high rust inoculum levels. Releasing and growing rust resistant cultivars not only reduces the threat of disease to individual growers, but of equal importance, ensures that the resistance in current and future cultivars is safeguarded by minimizing the size of rust populations and thereby reducing the chance of developing new mutant pathotype.

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# 18. Management of Wheat Diseases in Asia

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## Introduction

Increasing wheat yield potential and productivity in Asia, like in other parts of the world, will not occur in a vacuum: pests and diseases are ready to take advantage of the situation. Knowing pests and diseases that may cause injuries and are likely to affect the plant health and quality is critical to minimize the gap between attainable yield and actual yield. We highlight concepts and strategies towards controlling major biotic constraints affecting wheat and present emerging challenges with a special attention to Asia. Overall, the approach to manage wheat diseases is similar worldwide excepting that chemical crop protection may be minimal in regions where smallholding prevails compared to more intensive systems.

Knowing the pathogens, their ecology, distribution, virulence patterns and variability is an important step to better control diseases and minimize the gap between actual and attainable yields. In environments characterized by dense stands and high density of tillers, foliar diseases caused by obligate or hemibiotrophic pathogens with a high evolutionary rate are the most important constraints because some of these airborne parasites can migrate over long distances. Pathogen populations with a high evolutionary potential such as rusts and powdery mildew are more likely to overcome genetic resistance than pathogen populations with a low evolutionary potential such as cereal nematodes and soil borne fungi.

Disease epidemics always result from the combination of inoculum, favourable environment (climate, soil and cropping system) and host susceptibility. Changes in cropping systems as a result of adoption of conservation agriculture may have serious implications in some areas such as Central Asia: necrotrophic pathogens such as causing tan spot or Septorias are likely to emerge. *Fusarium* head scab already a major wheat disease in the Caspian Sea region and in large areas in China may increase in regions where maize production grows. In South Asia, the effect of spot blotch, a devastating foliar disease caused by *Cochliobolus sativus* in warmer growing areas can be minimized by reducing physiological stress through timely sowing and adequate use of fertilizers which shows the complex relationship between crop physiology, disease resistance and yield. Resistance breeding combined with rotations, timely sowing and irrigation or even fungicide utilization if affordable, are part of integrated crop management practices minimizing the losses.

Various wheat diseases are commonly found both in advanced and less advanced agricultural systems. Although soil-borne pathogens are more frequently found in rainfed systems, these limitations are not ignored since irrigation water availability may not always be satisfactory and is even becoming a problem in some optimum areas. In a long-term perspective, new challenges will emerge from environmental and climate change. Climate change is likely to modify the wheat disease spectrum in some regions and pathogens or pests considered unimportant today may turn out to be potential new threats in future.

Spot blotch caused by *C. sativus* is reported to prevail on about 9 million hectares of wheat grown after rice in the Indo-Gangetic plains. However, only 40 per cent of this surface is probably actually suffering losses in the range of 5-15 per cent every year, depending on the level and duration of dew, and on heat stress. FHB has been a major concern in China where the disease is endemic in the Yangtze River Basin. In China, the estimate is that scab may affect up to 7 million hectares, and 2.5 million tons of grain may be lost in epidemic years. In South Asia, since wheat flowering time coincides with low relative humidity, although the pathogen is present, FHB is only found sporadically in the Himalayan foothills and in Bangladesh but news challenges may occur with changing rainfall patterns. Root rots inducing premature death of tillers are increasingly important. The dryland crown root rot (*Fusarium* spp. and *C. sativus*), and the cereal nematode (*Heterodera* spp. and *Pratylenchus* spp.) should not be ignored. These are all known to be much more damaging under sub-optimal moisture (rainfed or supplementary irrigation), particularly where plant growth is stressed. In some areas, the yield losses due to various cereal viruses, some of them transmitted by insect pests can occasionally be important. More reports of aphids are emerging including in the North-West plain zones of the Indo Gangetic plains.

The rust diseases of wheat have historically been one of the major biotic production constraints worldwide. Stem (or black) rust caused by *Puccinia graminis* has been under control since the semi-dwarf spring wheats of the green revolution occupied most of the area in South and West Asia in the 1960s. Leaf (or brown) rust caused by *Puccinia triticina* and stripe rust caused by *Puccinia striiformis* continue to pose a major threat to wheat production over a large area particularly in Asia. Leaf rust and stripe rust could affect production on approximately 60 (63%) and 43 (46%) million hectares, respectively, in Asia, if susceptible cultivars were grown there. Movement of *Yr9* virulent race of *P. striiformis* from the East African highlands to the Indian sub-continent over a period of time between 1985 and 1997 when it eventually reached Nepal is a classical example. Earlier, virulence for *Yr2* gene first recorded in Turkey had been traced over time from Turkey to Pakistan. These examples suggest that the entire wheat area in Asia except China may comprise a single epidemiologic zone, a reality even more of a concern when 'megacultivars' cover most of the surface grown to wheat in a single country or when genotypes with the same genetic background are released under different names in several countries. Growing fewer cultivars that carry race-specific resistance genes leads to greater genetic uniformity and, consequently, greater disease vulnerability. Therefore, if a new race arises anywhere in this area, given time it could spread throughout the epidemiologic region.

The strategies to limit damages caused by wheat rusts especially in the last decades followed the principles of a coordinated anticipatory breeding approach. The methodology has been particularly successful against leaf and stripe rusts. The combination of minor genes with additive effect has been particularly effective in reducing disease severity for leaf and stripe rust in the last three decades and the methodology has been shown to be very cost effective for leaf rust. Incorporation of high levels of durable (slow rusting) resistance to stripe and leaf rusts in PBW 343 and Inqualab-91 through a 'single backcross-selected bulk' breeding approach has been very economic to incorporate additional resistance while keeping the high yield potential of broadly adapted commercial cultivars popular with farmers. As a rule, only rust-resistant cultivars should be anyway recommended in more rust-prone areas. Although stem rust was almost ignored for several decades since the green revolution, the significant threat represented by Ug99 showed that rapid action was needed to avoid major losses in large wheat growing areas. The BGRI illustrated the importance of international cooperation and investing in wheat research. It allowed massive testing of advanced lines in East Africa accompanied by an emergency crossing program to combine effective genes.

Spot blotch caused by *C. sativus* is the most serious foliar disease on wheat in warmer areas, particularly in the Eastern Gangetic plains of the Indian sub-continent where high average minimum temperature during winter, combined with fog or heavy dew stimulate the fungus proliferation. The disease induces more losses annually in the sub-continent than leaf rust. Genetic resistance has been incorporated with some success in locally adapted genotypes with high yield potential, and on-farm and on-station trials under warm growing conditions confirm the progress in breeding for spot blotch resistant wheat. However, understanding these relations and genetic differences controlling resilience to stress are needed to further improve resistance and disease control. Crop management, timely sowing and good soil fertility are important components of an integrate crop management for spot blotch. In Nepal, it has been shown that $K_2O$ application had a similar effect than one fungicide application.

Compared to rusts, powdery mildew conidia do not spread over very long distances but the fungus' evolutionary rate is high. Powdery mildew is important in China where at least 12 million hectares can be affected but it may also cause concerns in Pakistan and western India if susceptible varieties are grown and the weather is suitable. Utilization of resistant cultivars is the most economical and environmentally safe means of controlling powdery mildew.

Changes in cropping systems, as a result of the introduction of a new rotation or tillage practice, influence the survival and prevalence of residue borne pathogens leading to a shift in the disease spectrum if new agronomic methods are not accompanied by adoption of cultivars with adequate resistance. Tan spot is common in Central Asia where long winter does not allow fast stubble decomposition and mono-cropping is common. Damages result mainly from destruction of the flag leaf as a result of which the plant is robbed from assimilates or photosynthesis products otherwise destined to fill the grain.

With the exception of an accidental introduction of a new race or parasite, the occurrence of a new disease in a determined geographic area or cropping system is rare. Nonetheless, if a minor pathogen is present and remains marginal due to unsuitable environmental conditions but suddenly the situation becomes favourable for its development, a green bridge between two crops may become possible and the establishment of a disease previously considered as an oddity may become a significant constraint. Blast due to *M. oryzae* is an example of adaptation of a grass pathogen to wheat as a new host in Bolivia and Brazil. In a context of climate and global change, there is a concern about the risk that this disease represents because of the lack of resistance in wheat, the significant losses that can occur and the ineffectiveness of fungicide treatments.

Climate change may also have a major long-term effect on wheat grown areas inducing possibly a shift in the geographical area grown to wheat and its associated biotic constraints to higher latitudes. Thus, the present pathogen and pest spectrum may evolve in a given wheat area. Global warming may lead to important modifications in Asia. For example, by 2050, as a result of possible climate shifts in the Indo-Gangetic plains – currently part of the favourable, high potential, irrigated, low rainfall mega-environment, which accounts for 15 per cent of global wheat production – as much as 51 per cent of its area might be reclassified as a heat stressed, irrigated, short-season production mega-environment. If this scenario proves to be correct, an increase in spot blotch severity and incidence will be expected in future in optimum wheat growing areas where the disease does not cause significant losses today. Furthermore, irrigation water is expected to become more restrictive in many parts of the world due to competition for industrial use. This will make many wheat growing regions sub optimal for production, and potentially increase the importance of some of the diseases such as soil borne pathogens.

Knowing the enemy is the first important step to better control diseases and minimize the gap between actual and attainable yields. This requires understanding ecological conditions favouring a disease, and pathogen and pest variability across geographical areas including their evolution over time. Resistance breeding remains essential and the corner stone of economical and ecological friendly approaches to limit diseases outbreaks. This supposes identification, characterization of source of resistance and making sure that broad and different sources of resistance are effectively used. Genetic resistance is the main method of controlling obligate parasites. However, effective disease control requires that durable race non specific type of resistance be incorporated in high yielding genotypes be incorporated. In addition to identifying and incorporating genetic resistance, crop management will be an additional and necessary way to control non-obligate parasites. The importance of crop rotation to minimize pathogen population size is underscored.

# 19. Integrated Management of Wheat Rust Diseases: Approach of FAO

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## Introduction

Wheat is one of the most important agricultural commodities for the global food security. It is a major staple crop for living of small scale farmers in many developing countries as well as being a commercial asset for many large scale producers. Therefore, wheat productivity is very important for food security in general and for the livelihoods of smallholder farmers in particular. In this context, wheat rust diseases, namely, stripe rust (*Puccinia striiformis*), leaf rust (*Puccinia triticina*) and stem rust (*Puccinia graminis* f.sp. *tritici*) reduce wheat yields and quality directly affecting the livelihoods of wheat producers as well as food security in general.

Many scientific findings have verified the importance of trans-boundary nature of the wheat rust diseases and their movement within and between the wheat growing regions. Formation and movement of stripe rust and stem rust races in the last two decades have caused serious concerns at the global level, indicating that the rust diseases can have serious consequences for food security especially in developing countries. Thus, national and international efforts must take into account the needs for empowering national capacities to tackle with this important challenge. For this, strengths and weaknesses of the national institutions and their approaches must be studied and strengthened accordingly.

## Current Settings and Challenges

Large scale producers in developed countries have better capacity to access the knowledge resources and inputs for management of wheat rust diseases. Their coordination frameworks and public and private institutional settings facilitate evaluation of the situation and implementation of the necessary actions effectively. However, still these frameworks might need to be improved in some cases and international cooperation would be necessary to monitor global and regional movement of new rust races to develop long-term management strategies at regional and global level.

In developing countries, small holder farmers mostly rely on official resources and assistance for monitoring and control of wheat rust diseases. Due to inadequate resources, wheat crops of small scale producers are affected most. In many cases, rust diseases are ignored or not noticed and when climatic conditions become conducive, especially in humid seasons, farmers are caught unprepared and they encounter significant yield and quality losses. National coordination mechanisms, linkages and institutions play a very important role in management of the wheat rusts, because of their airborne and complex nature. Thus, it is important to evaluate the functions of the stakeholders and related institutions including their roles, responsibilities and working relationships for management of the rust diseases.

## Overall Coordination and International Collaboration

Wheat rust management strategies must be based on integrated approaches taking into account the importance of surveillance and monitoring approaches, cultivar development, registration and recommendation, seed production, technology transfer and farmer participation. In many countries, Ministries responsible for agriculture have departments dealing with crop protection issues at various scales and under a variety of names. In general, these departments are responsible for developing and implementing strategies for the management of crop diseases. Overall management of wheat rust diseases is usually part of the mandate of such departments. These departments are expected to cooperate with other public offices and stakeholders where necessary for this task. However, in many cases such coordination mechanisms are either not present or ineffective. Even without much investment, such coordination actions could improve effectiveness of management efforts. Therefore, improvement of communication and coordination among the relevant institutions must be considered as the key element of the efforts directed to improving national rust management capacities.

Since the rust diseases are air borne and trans-boundary, only national actions can not be adequate for the management of wheat rust diseases. It is essential for the national systems to follow up the developments in surrounding countries and regions. Thus, regional cooperation mechanisms and networks are essential in view of taking immediate actions where necessary and developing medium and long term management strategies. In this regard, cooperation with international organizations and programs would be essential. This is extremely important especially for monitoring pathogenic diversity, resistance breeding, sharing of experiences and capacity development.

## Tasks and Institutional Arrangements for the Integrated Management of Wheat Rust Diseases

For the management of wheat rust diseases, a prerequisite is an effective surveillance and monitoring approach. In many countries, various institutions are involved in this task. Surveys are conducted either by crop protection department, extension agencies or research institutions. In some cases, parallel surveys are done by more than one department or institution without an effective collaboration. For an efficient national surveillance system, an effective cooperation among the relevant institutions is essential for a wider and effective coverage.

In many cases, survey activities are combined with the research activities for race analysis by the research institutions which are set up in various structural arrangements. These research institutions may be concentrating on either crop protection or breeding or even be a University entity. In any case, cooperation with other local institutions and offices would be necessary to enhance efficiency of the integrated management efforts.

## Research, Breeding and Seed Production

Resistance breeding activities are mandated to research institutes working on crops. These research institutions may be either concentrating on breeding or in some cases may also be covering partly or fully wheat rust related research including breeding, surveillance, race analysis and fungicide use. An important challenge for research is to establish an effective collaboration network among the national and local research institutions and stations as well as other offices involved in integrated management of wheat rusts.

Challenges in the area of plant breeding also include long duration of variety development and inadequate human resources and physical capacities. In order to facilitate provision of sustainable inputs from the research sector, their capacities and linkages with the extension system would need to be strengthened. Breeding programs must also consider rust resistance as one of the key breeding objectives. Participation of the farmers and industry in breeding and selection of the cultivars would also help to better identify the genotypes that would be easily accepted by farmers.

Variety registration systems must have elements and incentives to encourage development and use of cultivars that are resistant to wheat rust diseases. In many cases, such elements are either not present or inefficient. Producers must be made aware of the resistance level of the cultivars either through a recommendation list approach or other means of communication.

Seed production is generally done by public enterprises but emphasis given to rust resistance of cultivars is not adequate in cultivar preference for seed production. Also speed of deployment of improved cultivars is low and seed multiplication volume is short of demands in most cases. Support to development of private sector and non-governmental organizations in this area could help extending the volume of seed production of improved cultivars.

## Technology Transfer, Training and Farmer Participation

Unless knowledge and seeds reach the farmer, no effort would be successful for the management of wheat rust diseases. Therefore, an effective technology transfer approach would be essential for effective implementation of rust management strategies. In most cases, extension service is the most widely present agricultural public offices network. In order to utilize this structure effectively for management of rusts, the extension officers would need to be equipped with the necessary knowledge and tools. Usually, connection between the central government structure, extension offices and farmers is not strong enough and this needs to be strengthened through improved communication, farmer participation and coordination mechanisms. Farmer organizations should not function only as administrative or political platforms but also they should contribute to the work of the public offices in designing and implementing strategies and activities for management of wheat rust diseases. Areas of joint actions could include participatory breeding, training programs and in some cases even in seed production and surveillance.

## Conclusion

Management of wheat rust diseases is a complex challenge for the farmers to achieve themselves due to trans-boundary nature and frequent occurrence of new races. Moreover, no single measure would be adequate for their management economically in the long-term. A holistic approach would be necessary for planning and implementing management actions. Therefore, all relevant stakeholders and institutions should play their role and bring together their capacities in this effort in an integrated manner. For an effective rust management, in the first place policy makers and institutions must be made aware of the importance of the wheat rust diseases and their impact on wheat productivity. This would be necessary to convince relevant authorities for their commitments for contingency plans and management actions. This is very important since it is evident that one of the major problems regarding the management of wheat rust diseases is lack of sufficient policy level awareness, physical capacities and human resources.

In this regard, a comprehensive plan of action is necessary to establish a national coordination mechanism and contingency plans with the aim of identifying the tasks and actions necessary for the management of the wheat rusts. Responsible institutions must be identified for these tasks and their duties and working arrangements must be outlined through an integrated and participatory approach. Representatives of the relevant institutions and stakeholders including those responsible for research, surveillance, protection, seeds and extension must meet regularly before or during the wheat growing season to monitor the developments and identify actions to be taken. In this context, strengthening of national capacities to improve interaction, communication and coordination among the relevant institutions would facilitate a more effective joint effort through participation of all the relevant institutions. This would help to manage wheat rust diseases more efficiently and as a result minimizing the losses encountered due to wheat rust diseases and improving wheat productivity.

# 20. WHEAT: Global Alliance for Improving Food Security and the Livelihoods of the Resource-poor in the Developing World

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Recurrent food crises combined with the global financial meltdown, volatile energy prices, natural resource depletion, and climate change undercut and threaten the livelihoods of millions of poor people. Accounting for a fifth of humanity's food, wheat is second only to rice as a source of calories in the diets of developing country consumers, and it is the first as a source of protein. Wheat is an especially critical "stuff of life" for the approximately 1.2 billion "wheat dependent" to 2.5 billion "wheat consuming" poor-men, women and children who live on less than US$ 2 per day and approximately 30 million poor wheat producers and their families. Demand for wheat in the developing world is projected to increase 60 per cent by 2050. At the same time, climate-change-induced temperature increases are likely to reduce wheat production in developing countries by 20-30 per cent. As a result, prices will be more than double in real terms, eroding the purchasing power of poor consumers and creating conditions for widespread social unrest. This scenario is worsened by stagnating yields, soil degradation, increasing irrigation and fertilizer costs, and virulent new disease and pest strains.

These challenges are the grand purpose for a revised strategy for the CGIAR Centers engaged in wheat research. The strategy is designed to ensure that public-funded international agricultural research helps most effectively to dramatically boost farm-level wheat productivity and stabilize wheat prices, while renewing and fortifying the crop's resistance to globally important diseases and pests, enhancing its adaptation to warmer climates, and reducing its water, fertilizer, labor and fuel requirements. The strategy aims to enable, support, and greatly strengthen the efforts of national governments, the private sector, farming communities, and international, regional and local organizations-creating or capitalizing on synergies.

Building on the input, strength, and collaboration of over 200 partners from the public and private sector, wheat will be the catalyst and apex of an emergent, highly-distributed, virtual global wheat innovation network. It will couple discovery science in advanced research institutes with national research and extension programs in service of the poor in developing countries. The CRP on Wheat will pursue 10 "Strategic Initiatives" (SIs) that are build on each other to prioritize, design, validate and disseminate wheat technologies.

**SI 1.** **Technology targeting for greater impact:** Work will increase the effectiveness and impact of wheat research on food security, poverty reduction, gender equity, and the environment, through better targeting of new technologies. This will be reinforced by improved policies, strategic analysis, and institutional innovations that strengthen linkages among stakeholders along the wheat input-output value chain. This initiative will interact with and support all other wheat initiatives in priority setting, targeting, impact assessment, and monitoring, and with CRP 2, 4 and 7.

**SI 2.** **Sustainable wheat-based systems:** Innovation systems that encompass farmers and multiple institutions will enable 10-15 million farmers to adapt and implement sustainable, productive, and profitable techniques. Total farm productivity and incomes from irrigated and rainfed wheat systems will thereby increase by 15–25 per cent, contributing to climate change mitigation and adaptation while reducing soil erosion and degradation, labor, and fuel use. This SI will interact with SI 1, 3, 4, 5, 8, and 10, and with CRP 1.1, 1.2, 2, 3, 5 and 7.

**SI 3.** **Nutrient and water-use efficiency:** Novel methods and decision guides will allow 15 million small holders in irrigated areas to produce wheat with less fertilizer and water and help smallholder wheat producers in rainfed areas to increase crop yields and reduce their risk of economic losses and hardship. This SI will interact with SI 2, 4, 6, 9, and 10, and with CRP 1.2 and 5.

**SI 4.** **Productive wheat varieties:** Robust, farmer-preferred wheat varieties will bring 1.0 per cent annual growth rate in wheat productivity to be maintained solely by breeding, beyond agronomic interventions, and despite climate change effects that would otherwise increasingly reduce wheat production. This SI will have close linkage with SI 1, 2, 3, 5, 6, 7, 8, 9 and 10, and also with CRP 1, 4 and 7, and GIBS.

**SI 5.** **Durable resistance and management of diseases and insect pests:** Enhanced genetic resistance and management options for diseases, insect pests, and viruses that cause significant economic losses on millions of hectares of wheat lands will safeguard US$

1.0–2.5 billion worth of wheat production, as well as the livelihoods of millions of farmers affected by virulent new disease strains in developing countries. This SI will interact with SI 2, 4, 8, 9, and 10. Linkages with other CRPs will be *via* SI 4 product delivery.

**SI 6. Enhanced heat and drought tolerance:** New genetic and physiological technologies will restore wheat productivity in developing world areas vulnerable to climate-change-induced heat and drought stress and escalating food prices, thereby reducing these threats for over 900 million people, one-seventh of the world's population, particularly in South and Central Asia. This SI will interact with SI 3, 4, 9, and 10, with strong interactions with CRP 7.

**SI 7. Breaking the yield barrier:** Cutting-edge interventions will raise the wheat's genetic yield potential by as much as 50 per cent, tapping into complementary expertise and the innovation capacity of the public and private wheat communities worldwide, thereby ensuring long-term food security for humankind. This SI will interact with SI 4, and 9.

**SI 8. More and better seed:** More diverse wheat seed systems will offer developing country farmers quicker access to improved varieties, encouraging broader public and private participation, as well as alternative and innovative seed production and marketing by farmer groups and communities. This SI will interact with SI 1, 2, 3, 4, and 5, with CRP 2.

**SI 9. Seeds of discovery:** A researcher/breeder-oriented data platform will foster and support comprehensive use of the native diversity of wheat and its wild relatives, thereby accelerating breeding gains and counteracting climate change effects and water, land, and nutrient scarcities. This SI will interact with SI 1, 3, 4, 5, 6, 7, 10 and maize SI 8, and GIBS.

**SI 10. Strengthening capacities:** This initiative will train a new generation of wheat professionals, with a strong focus on women and young professionals, enabling national wheat improvement programs, in partnership with CGIAR institutions and other stakeholders, to improve the efficiency, impact, and sustainable intensification of wheat-based cropping systems. This initiative will interact with and support all other wheat initiatives and, with maize, capacity development and information management and dissemination.

During the recent decades, investments in international commodity research have fallen and yield productivity gains have slowed down; even more so in wheat, a crop for which there has been little private sector involvement. Inelastic demand, depleted physical stocks, focus on production in a few breadbaskets, and the overreaction of governments and financial markets have brought the world to a situation where relatively small, weather-related production shortfalls, in a single breadbasket, leads to large price fluctuations, affecting up to 2.5 billion poor consumers and impacting social stability. It is time for decisive action to close the wheat yield gap in low- and middle-income countries. These countries account for two-thirds of the world's wheat production. New technologies and an international alliance of concerted investments are required to meet wheat demand from expanding populations, both rich and poor.

Activities under wheat focus on the developing world and have been prioritized with developing country stakeholders, but wheat integrates a global wheat community through active participation in initiatives such as the International Wheat Sequencing Consortium, the Borlaug Global Rust Initiative, the International Triticeae Mapping Initiative, the Wheat Yield Consortium, the International Research Initiative for Wheat Improvement, and the Hybrid Consortium, to name a few. As a result, wheat partners are uniquely placed to exploit and contribute to international efforts, as well as to apply results for the benefit of developing world agriculture.

In line with specific requests from the global wheat research and development community, leadership from wheat will come in exploiting the wild relatives of wheat through new synthetic wheats, in cytogenetic manipulations for alien gene transfer from wild and cultivated relatives, in finding new sources of pest and disease resistance (particularly rust resistance), in new physiological tools for selecting heat and drought tolerant lines, as well as applying systems-based approaches and precision agriculture technology to improve the productivity, sustainability, and resource-use efficiency of the developing world's wheat production systems. Through its linkages with international efforts, wheat will benefit from developments in advanced economies in crop genomics, genetics, pathology, physiology, and agronomy; it will direct emerging technologies from that work into varieties and production systems adapted for lower-income wheat growing countries.

With a targeted annual budget rising to US$ 93.4 million – to which the CGIAR currently contributes approximately 18 per cent of the funding through unrestricted support, and bilateral CGIAR and non-CGIAR donors contribute approximately 32 per cent of the funding through over 100 individually designed projects, wheat technologies and outcomes will lead to 21 per cent increase in productivity in the target domain by 2030, adding an annual value of US$ 1.3 billion by 2020 and US$ 8.1 billion by 2030. This will reach up to 40 million farm households and provide enough wheat to meet the annual food demand for many wheat consumers—an additional 56 million in 2020 and up to 397 million in 2030.

Wheat research program will be implemented in partnership with new and existing partners from: i) CIMMYT, ICARDA, Bioversity, ICRISAT, IFPRI, ILRI, IRRI and IWMI, ii) The Genomics and Integrated Breeding Service (GIBS), and the Generation Challenge Program, iii) 86 national agricultural research institutes, iv) 13 regional and international organizations, v) 71 universities and advanced research institutes, vi) 15 private sector organizations, vii) 14 non-governmental organizations and farmer cooperatives, and viii) 20 host countries.

Humanity faces tremendous challenges to food security and also must confront environmental degradation that will worsen if no measures are taken. Given the time needed to create the improvements described, we must act now so that poverty and hunger can be reduced, human health and nutrition improved, and resources used sparingly in order that they may support future generations.

# 21. Conservation Agriculture in Wheat Systems of Indo-Gangetic Plains: Marching Towards Evergreen Revolution

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The Indo-Gangetic Plains (IGP) of South Asia inhabited by 900 million people (one seventh of the world population), is agriculturally most important regions of the world. The IGP, the heartland of the Green Revolution (GR) currently accounts for 15 per cent of global wheat production and serves as breadbasket of the region. Though the IGP is highly productive and optimal eco-region for wheat farming systems but, keeping in view the compounding impact of deteriorating natural resources, escalating cost of production inputs, and energy, growing labour shortages, (Jat *et al.*, 2009, 2012; Saharawat *et al.*, 2010), receding ground water table coupled with increasing irrigation costs (Rodell *et al.*, 2009) and loss of biodiversity, future gains in wheat productivity and production with greater or even current resource use efficiency will be challenging. Recognized as second generation problems of the GR, these are leading to un-sustainability and food insecurity. The recent trends and future forecasts for climatic variability further exacerbates the problems by projecting a decrease in favourable wheat growing areas to the magnitude of 51 per cent by 2050 (Reeves, 2009). Moreover, keeping pace with wheat demand for the ever increasing population while keeping food prices lower, the annual gains in wheat productivity would have to increase from 1.1 to 1.7 per cent essentially from the same land area, with less water, nutrients, fossil fuel and labour. In this regard, the important question that comes to fore is that where will the future productivity gains come from and will germplasm improvement research repeat the productivity gains achieved in the last 4 decades? It seems that much of these gains in wheat production in the region will have to come increasingly from adoption of 'Best-Bet' natural resource management practices. For example, deploying location-specific 'Best-Bet' practices alone can increase the productivity by nearly 47 per cent through bridging management yield gaps in Eastern Gangetic Plains while sustaining the yields of high productivity intensive wheat systems of western Indo-Gangetic Plains. Even targeting bridging at least half of the management yield gaps using CA based technologies in cotton-wheat, rice-wheat, rainfed mixed farming systems, sustainable intensification of rice-fallow, and intensification in sugarcane pigeon pea systems can increase the wheat production to the tune of 1.0; 5.0; 5.4, 6.4; 2.0 million tons (total ~20.0 mt), respectively by 2020.

Critical analysis of situation suggests that the principal indicators of non-sustainability of agricultural systems include soil erosion, soil organic matter decline and salinization which are primarily caused by (i) intensive tillage induced soil organic matter decline, soil structural degradation, water and wind erosion, reduced water infiltration rates, surface sealing and crusting, soil compaction, (ii) insufficient return of organic material, and (iii) mono cropping, in addition to other factors indicated above. Therefore, the region needs a paradigm shift in crop management, technology adaptation and scaling-out strategies to address the growing challenges of natural resource degradation, reversal of declining factor productivity, bridging management yield gaps through resource use efficient and climate resilient wheat farming practices relevant to the need of resource poor farmers. This brings to the fore infusion of new tools, techniques and approaches including innovation systems enabling food, nutritional and livelihood security for the teeming millions on a long-term sustainable basis while conserving natural resource base and help in adaptation and mitigation to climate variability. In this respect, conservation agriculture coupled with innovative scaling-out strategies including networks, partnerships, knowledge sharing and capacity building mechanism has been suggested/accepted as a vehicle for change and marching towards ever green revolution in the region.

Conservation agriculture (CA) has demonstrated incredible potential for optimizing crop yields, economic and environmental benefits in different production systems and diverse agro-ecologies and thus CA is recognized as agriculture of the future, the future of agriculture. Though, like any other tillage and crop establishment technology, it may not be a panacea for all present day ills, but has proven to bring out south American Agriculture out of its stagnant state almost 20 years ago, skyrocketing the cereals and oilseed production system. Several studies across the production systems and ecologies globally suggest that CA systems with location-specific adaptation have resulted in tangible outputs under almost all kind of environments/ecologies. The CA based management solutions and strategies in wheat systems of IGP has proved to produce more at less water, energy, costs and labour, facilitate rational use of residues to avoid burning, improve soil health and promote timely planting of wheat to address issues of terminal heat stress and help adapt and mitigate climate change effects. Experiences from the strategic research as well as farmers participatory field trials across the eastern Gangetic plains (EGP) reveals that zero-tillage in wheat systems help in timely planting that reduced the yield loss due to terminal heat effects from 77 kilogram per hectare per day under conventional tillage to 65 kilogram per hectare per day even under late planting (after 21 November till 20 December; most wheat in EGP planted during this window). Further, direct drilling of wheat (no-till) in residues (surface mulching) keeps canopy temperature lower by 1.0 to 1.5°C during grain filling stage (cooling effect due to transpiration) owing to sustained soil moisture availability to the plants and results in significant yield advantages (up to 0.5 t/ha). In cotton-wheat systems of western IGP, the innovative CA based technologies facilitates advancing wheat planting in standing cotton (relay seeding) with yield gains of 0.5 to 1.0 ton per hectare (Buttar *et al.*, 2012) in addition to other associated virtues and can potentially benefit 4.5 million hectares wheat acreage in South Asia. In other wheat based rotations i.e. maize-wheat and legume-wheat, permanent beds have shown monetary benefits to the tune of US$ 200-300 per hectare compared to conventional practices in addition of other benefits of savings on water, labour, improving soil health and environmental benefits. Layering laser assisted precision land levelling over CA based crop establishment techniques has additive effects (Jat *et al.*, 2011). However, defining appropriate component technologies suited to local needs and align them with CA principles needs immediate and focussed attention for potential benefits and large scale uptake of CA. For example, significant tillage × genotype × cropping system interactions were observed in wheat systems suggesting tailoring genotypes for target management scenario and thus redefining recommendations for cultivar choices (Yadav *et al.*, 2011). Therefore, the way crop management is being practised in different production systems, ecologies (e.g. plains and sloppy lands) and farmer circumstances may vary the importance of the 'unvarying objectives' according to local situations, resource endowments of the farmers and farming systems. The CA is an innovation process for iterative guidance and location specific adaptations that suggests that CA systems are 'divisible' in nature and 'flexible' in operation allowing farmers to benefit from them under diverse situations. Also, the CA based crop management technologies are an "open" approach, easier to mainstream and be able to immediately respond present day critical needs that address concerns of emerging challenges of resource degradation, water, labour and energy shortages, declining farm profitability and changing climates.

Through significant efforts of the regional NARES, CGIAR Centers, ARIs, NGOs, private sector organizations including manufacturers and innovative farmers of the region, the CA based technologies in wheat systems has been extended and adopted by large number of farmers to cover nearly 2.0 million hectare area in South Asia (Erenstein and Laxmi, 2008). But, the growth in accelerated adoption of these technologies during recent past has slowed down due to one or the other factors including dynamics of adaptability and suitability of component technologies and policy issues. Therefore, the CA based management solutions as described above together with putting right policy in perspective to support investments on CA machinery, region-specific seed production, creation of service windows, develop CDM like mechanism, carbon credits and environmental services for farmers, extend reach of farmers through ICTs, develop innovation systems and common regional platforms for knowledge sharing can help accelerated adoption of these technologies to achieve evergreen revolution in wheat production systems of IGP.

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# 22. Enhancing Wheat Production and Productivity through Resource Conservation in Pakistan

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In Pakistan, wheat being the staple food is cultivated on an area of about 8.8 million hectares in almost every part of the country. It contributes 14.4 per cent to the value added in agriculture and 3.2 per cent to GDP. Over the past three decades, increased agricultural productivity occurred largely due to the deployment of high-yielding cultivars and increased fertilizer use. It is grown in different cropping systems such as cotton-wheat, rice-wheat, sugarcane-wheat, maize-wheat, and fallow-wheat. Of these, cotton-wheat and rice-wheat systems together account about 60 per cent of the total wheat area whereas rainfed wheat covers almost 15 per cent area. Rotations with maize-sugarcane, pulses and fallow are also important. Wheat is indispensable source of carbohydrates for the poor. Its production in the system is lagging behind the growth in demand over the years. Amongst the important wheat yield limiting factors are late planting, due to late harvesting of crops and lack of technological innovations. Late planting is a major problem in most rice-wheat areas, except for the Indian Punjab.

Sowing of wheat after mid November causes reduction in grain yield by one per cent per day. Farmers generally plant wheat late in rice-wheat sugarcane-wheat, and cotton-wheat areas of Pakistan due to late harvesting of these *kharif* crops which results in drastic low yields because the crop is exposed to heat stress at grain filling stage leading to the formation of shriveled grains. Any delay in planting would reduce yield drastically. For example, wheat planted after 10th November would reduce the yield as high as 42 kg/ha/day (1% loss per day). Late -planted crop has lower germination, fewer tillers, smaller heads, shriveled grains and lower biomass than the timely planted crop. Therefore, the change in sowing time from present to two weeks earlier could result in addition to 2.0 million tones in national wheat production. The RWC's major recent success has been the development, testing and deployment of resource conserving technologies for growing wheat after rice (Hobbs, 2001). Currently, only 20 per cent of wheat is being planted at optimum planting time (15th October to 15th November). Improved tillage and crop establishment methods present real potential for improving the sustainability and productivity. It is, therefore, imperative to look for new interventions of resource conservation technologies and to exploit the all-possible available resouces to enhance the crop productivity for the enhancement of farmer's income and livelihood.

There is around 60 per cent yield gap in wheat (Fig. 1), which needs to be narrowed down. Wheat production in the country, however, has been well below potential and variable. The major reasons for low productivity and instability include delayed harvesting of *kharif* crops like cotton, sugarcane and rice, and subsequently late planting of wheat, non availability of improved inputs like seed, inefficient fertilizer use, weed infestation, shortage of irrigation water, drought in rainfed and terminal heat stress, soil degradation, and inefficient extension services. Moreover, farmers are not aware of modern technologies because of weak extension services system.

## Production Constraints

To improve system productivity, wheat crop must be planted at the optimal time. Late planting not only reduces yield but also reduces the efficiency of the inputs applied to the wheat crop. The reasons for late planting of wheat in the rice-wheat system are many. Farmers generally plant wheat late in rice-wheat, sugarcane-wheat, and cotton systems in Pakistan due to late harvesting of these crops which results in drastic low yields because the crop is exposed to heat stress at grain filling period leading to the formation of shriveled grains.

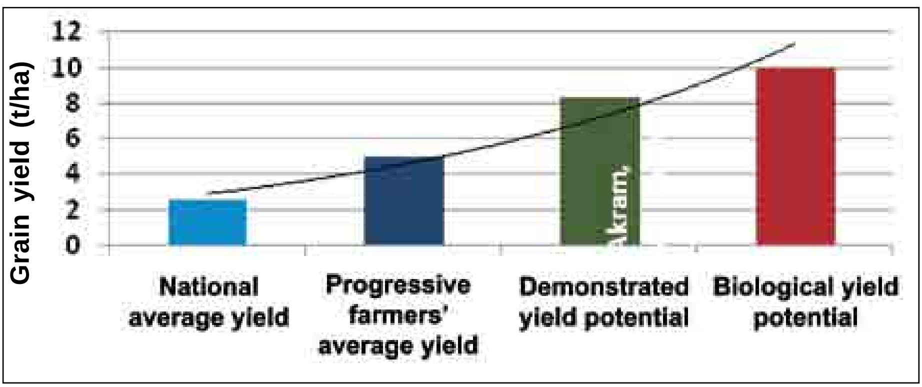


**Fig. 1.** Comparison of progressive farmers, demonstrated potential and biological potential yield with national average yield

Any delay in planting would reduce yield drastically. For example, wheat planted after November 20 would reduce the yield as high as 42 kg/ha/day (1% loss per day). Late-planted crop has lower germination, fewer tillers, smaller heads, shriveled grains and lower biomass than the timely planted crop (Fig. 2).

Therefore, the change in sowing time from present to two weeks earlier could result in additional yield of 2.0 million tons in national wheat production.

The other major cause of late wheat planting is the long turnaround time between rice harvest and wheat planting. Long turnaround can be caused by many factors, including excessive tillage, soil moisture problems (too wet or too dry), lack of animal or mechanical power for ploughing, and the priority farmers place on threshing and handling the rice crop before preparing land for wheat (Fig. 3).

Coupled with the problems of late planting of wheat is the problem of poor germination and crop stand. Most farmers in Pakistan sow wheat by broadcasting the seed into ploughed land and incorporating it by another ploughing. Part of the reason for this is residue management problems in fields following rice. The loose straw and stubbles are raked and clog the seed drills. Broadcast seed results in seed placement at many different depths and into different soil moistures, variable germination. land preparation resulting in loose stubble and a problem of drill clogging.

## Production Strategy

Rice-wheat cropping system is the major

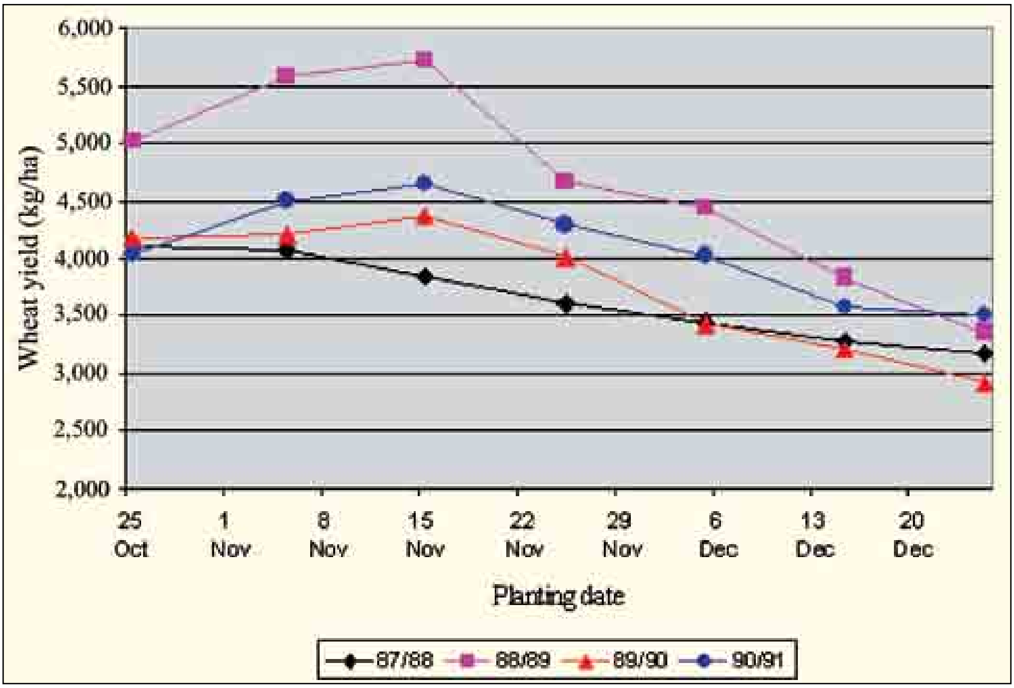


**Fig. 2.** The effect of planting date on wheat yield

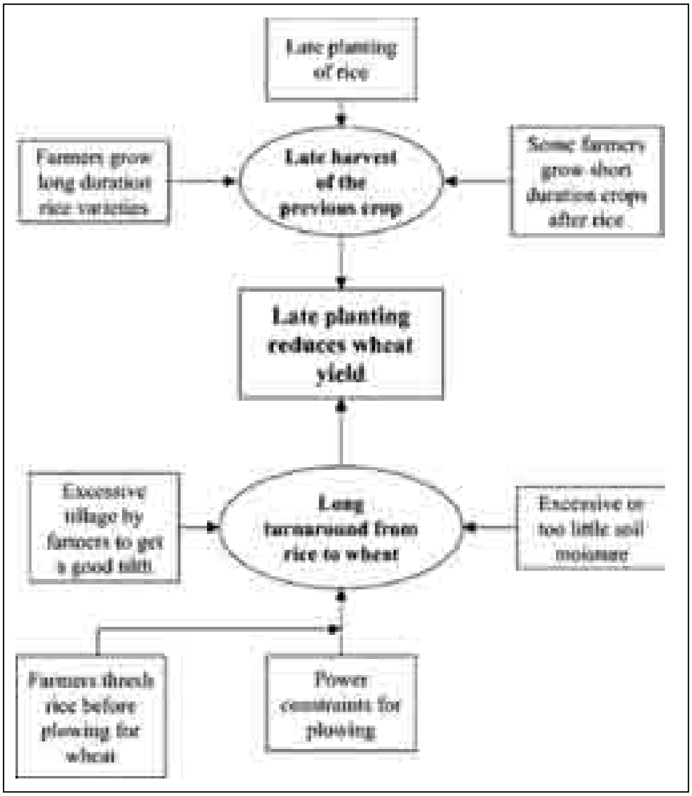


**Fig. 3.** The most common causes of late wheat planting following rice harvest

cereal production system in Pakistan occupying approximately 70 per cent of the total cultivated land. The system meets the food security of the people of Pakistan but its sustainability and stability is threatened due to various unknown factors. The improved package of resource conservation technologies indicates the rapid potential for improving the sustainability and productivity of the system. In the recent past, major success in the wheat production and productivity enhancement in South Asia region has been the development, testing and deployment of resource conserving technologies. Conservation Agriculture particularly the reduced tillage and crop establishment methods presents the real potential for improving the sustainability and productivity. It is, therefore imperative to look for new interventions of resource conservation technologies (Table 1) and to exploit all possible available resources to enhance the crop productivity for the enhancement of farmers' income and livelihood.

The proposed strategy for maximizing wheat productivity in Pakistan is based on wide scale adoption of following CA technologies.

## Laser Land Leveling

Conventional methods of land leveling are time consuming, laborious, inefficient and expensive. The farmers accordingly

**Table 1.** Conservation agriculture adoption in Pakistan

| Technologies | Total units | Total area (ha) |
|---|---|---|
| Laser land leveling | 8,124 | 898,944 |
| Zero tillage | 6,047 | 507,050 |
| Bed planting | 2,509 | 276,450 |

prefer to level their fields with laser technology. Laser land leveling is a process of smoothing the land surface (± 2 cm) from its average elevation using laser-equipped drag buckets. This practice uses large horsepower tractors and soil movers that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved either by cutting or filling to create the desired slope/level. This technique is well known for achieving higher levels of accuracy in land leveling and offers great potential for water savings and higher grain yield.

### *Major benefits*

The laser land levelling has the following major benefits: i) uniform moisture environment for crops, ii) more level and smooth soil surface, iii) reduction in seeds, fertilizer, chemicals and fuel used in cultural operations, iv) improved field traffic ability, v) uniform distribution of water in the field, vi) uniform germination and growth of crop and vii) reduction in time and water required to irrigate the field.

## Zero Tillage

Rice-wheat cropping system is the major cereal production system in Pakistan occupying approximately 70 per cent total cultivated land. The system meets the food security of the people of Pakistan but its sustainability and stability is threatened due to various unknown factors. The improved package of resource conservation technologies have great potential for improving the sustainability and productivity of the system. To improve system productivity, the wheat crop must be planted at the optimal time, Late planting not only reduces yield but also reduces the efficiency of the inputs applied to the wheat crop. The reasons for late planting of the wheat in the rice-wheat system are many. Zero tillage method of the planting can address the issue of late planting in rice-wheat cropping system.

It is a method of sowing a crop without prior cultivation and with very little soil disturbance at seeding. In rice-wheat systems, use of a tractor-drawn seed drill with 6 to 11 inverted - T tines to seed wheat directly into unploughed fields with a single pass of the tractor. This increases the amount of water and organic matter (nutrients) in the soil and decreases erosion.

In the late 1980s, 34 zero-tillage trials were conducted on farmers' fields over three years in the rice-growing belt of the Pakistan Punjab (Aslam *et al.*, 1993). Some farmers grow long-duration, photosensitive, high-quality basmati rice that matures late. Farmers prefer to grow basmati rice despite its lower yields because of its high market value, good straw quality (used for livestock feed), and lower fertilizer requirements.

The other major cause of late wheat planting is the long turnaround time between rice harvest and wheat planting. Long turnaround can be caused by many factors, including excessive tillage, soil moisture problems (too wet or too dry), lack of animal or mechanical power for ploughing and the priority farmers place on threshing and handling the rice crop before preparing land for wheat. Coupled with the problems of late planting of wheat is the problem of poor germination and plant stands. Most farmers in the IGP sow wheat by broadcasting the seed into ploughed land and incorporating it by another ploughing. Part of the reason for this is residue management problems in fields following rice. The loose straw and stubbles clog the seed drills. Broadcast seed results in seed placement at many different depths and into different soil moistures, resulting in variable germination. Land preparation resulted in loose stubble and a problem of drill clogging.

Significantly fewer weeds were found under zero-tillage than conventional tillage (Verma and Srivastava 1994), contrary to the experience in developed countries (Kuipers, 1991; Christian and Bacon, 1990). This observation has been confirmed at many other locations. In 336 on-farm trials in Haryana state, India, significantly lower weed counts were found in fields with zero-tillage either before or after herbicide applications .This difference can be explained by the fact that, in the rice-wheat cropping system, most weeds in the wheat crop germinate only in wheat season. Because the soil is disturbed less under zero-tillage, fewer weeds are exposed and germinate. Weed problems are typically more severe under conventional tillage. Longer-term research is needed to anticipate future consequences of tillage changes on weed populations. Early planting is the main reason for the additional yields obtained under zero-tillage. Zero-tillage plots were planted as close as possible to 20 November, the optimum date for planting wheat in Pakistan. Crop cuts have shown that zero-tillage produces 400-500 kg per hectare more grain than traditional systems. This is attributed to earlier, timely planting, fewer weeds, better plant stands and improved fertilizer efficiency because of placement with the seed drill. Some farmers are now in their 15th year of using zero-tillage and find no deleterious effects that would make them revert back to the traditional system.

## Bed Planting

In bed planting system, wheat or other crops are planted on raised beds. This practice has increased dramatically in the last decade or so in the high yielding, irrigated wheat-growing area of northwestern bed and furrow system of irrigation consists of alternate furrows and flat beds. Most of the crops grown in the IBIS are sown on the flat in basins using flood irrigation method. With application losses of around 25-40 per cent. Better irrigation efficiency can be achieved by adopting Bed and Furrow irrigation technique. This system of irrigation has been introduced in Pakistan very recently. Causes of low application efficiencies include over-irrigation, improper irrigation methods and timing, non-specific irrigation scheduling and non levelled fields (Gill, 1994). The bed-and-furrow system of irrigation for wheat and other row crops have many benefits over the conventional basin irrigation methods. Heavy monsoon rains cause temporary water logging, especially on sodic soils with low permeability, and about 35 per cent of the Indus basin is affected by either water logging or salinity or both (Anon. 1997b).Crust created as a result of unwanted rains on newly grown cotton in flat fields does not let the cotton seed germinate, during the early stages of crop, cotton has to be replanted if it rains after the seed is broadcasted or drilled in basin irrigation system. The early rains are very damaging for crop. The farmers who have not shifted to this technology had to broadcast or drill the seed for even three to four times. On the contrary, cotton grown along bed and furrows save the farmer from major damages under many such catastrophes.

### *Major benefits*

- Water saving of about 50 per cent as half of the water diverted to the flat fields is sufficient to irrigate two acres of cotton fields where bed and furrow system of irrigation is adopted.
- In spite of short interval between the irrigations, the over all water requirement for raising the cotton crop on beds is only 60 per cent of the water used in flat sowing fields.
- The crop growing operations are quicker and require less labour.
- Less incidence of disease occurrence and better survival against the virus attacks.
- The crop becomes ready for harvesting two weeks earlier if grown on beds.
- Bed planter can plant on 10-15 acres in a day.
- On raised beds, border effects allows the canopy to intercepts more solar radiation, it strengthens the straws, and the soil around the base of the plant and remains drier to prevent crop from lodging.
- In hand harvested rice fields, wheat crop can be planted in just one pass.
- The bed planter reshapes the beds and furrows, plants the crop and places fertilizer at appropriate depth into the soils along seed or between seed rows in the center of the bed at 5-10 cm depth.
- In combine harvested rice fields, crop straws can be incorporated into the beds using a shovel type furrow openers fixed on the front bar of the bed planter frame.
- First irrigation may be followed by second irrigation with an interval of 5-7 days depending upon the climatic condition.

## Crop Residue Management

Presently, crop residues in combine-harvested rice fields are being burnt for cleaning fields before planting of wheat causing a serious atmospheric pollution and this also results in loss of nitrogen by up to 80 per cent. Rice straw / chaff left after harvest help keep the soil healthy and productive. Organic matter from these residues binds soil particles and improves the soil structure. Leaving the straw as surface mulch has not received much thought in Asian agriculture. However, results from rainfed systems and some preliminary results in Asia suggest that this practice may benefit crop establishment and vigour under zero-tillage (Sayre, 2000).Well-structured soils possess potential to drain faster, make better seedbeds, and improve soil ability to deliver water and nutrients to crops. Burning crop residues lower the soil ability to produce high yields as over 60 per cent of the nutrients stored in crop residue are lost through burning. Besides, burnt soils require increasing amounts of fertilizer to be productive. Chopped rice straw is also a valuable commodity as it can be sold to the local companies / industries making products like straw board and paper. Supplementary income through selling of rice chaff in the market in addition to improving soil structure is its additional importance. The continuous developments have resulted in the "Combo Happy seeder/Turbo seeder", a compact, light weight, tractor mounted machine with the capability of managing the total loose straw and anchored rice residue in strips just in front of each furrow opener. It consists of two separate units a straw management unit and a sowing unit. The Turbo Seeder cuts, lifts and throws the standing stubble and loose straw and sows in one operational pass of the field while retaining the rice residue as surface mulch. To reduce the straw load over the seed row, the straw managing rotor was modified to cut standing stubbles for 7.5 cm width (just in front of the furrow openers) and leaving the standing stubbles in other 12.5 cm strip between the two furrow openers. It was observed that with the above modification nearly 30 per cent of the total straw load was reduced. This power tiller operated driven machine can be operated with 40-60 HP tractors and can cover one acre in 1-2 hours.

### *Benefits*

The major benefits of crop residue management are: i) planting of wheat without land preparation in rice standing stubbles and heavy rice residue just after rice harvesting, ii) uniform drilling of seed, iii) sowing wheat in the residual moisture, iv) saving of irrigation water, v) timely planting of wheat, vi) chopped residue as mulch helps in moisture and temperature conservation, vii) less weed infestation, viii) enhanced soil fertility, ix) decreased pollution, x) saves beneficial insects, xi) enhanced soil microbial activity, xii) protection of the fertile surface soil against wind and water erosion, xiii) increased soil $NO_3$ concentration by 46 per cent, xiv) Increased nitrogen uptake by 29 per cent and xv) Increased yield.

## Wheat Straw Chopper

Wheat harvesting through combine harvester is gaining popularity in Pakistan. The conventional combines are, however, mainly concerned with the grains, which generally leave the straw un-cut and un-chopped in the field for subsequent burning. To manage the straw from combine harvested wheat fields, a tractor operated wheat straw chopper-cum-blower, having the capability to harvest uncut straw and to pickup the combine ejected straw from the combine-harvested fields for subsequent chopping was identified from the region.

One unit of the machine was acquired through the Rice-Wheat Consortium. The chopper was initially tested and demonstrated at National Agricultural Research Center (NARC), Islamabad and subsequently at farmers' fields to assess its suitability for adoption in the local conditions. In view of field performance of the chopper, the farmers showed their keen interest in its use. The machine is capable of converting wheat stubbles on one acre into straws in one hour by consuming just six liters of diesel. The chopper not only converts stubbles in to straw but also collects wheat spike-lets / grains from the field left from being harvested through combined harvester in a specified chamber in the machine after separating it from the stubbles. The straw so collected in the sac or in the trolley fitted behind the chopper also reduces labour requirement to load straw over the trolley. In Pakistan, the technology has gained the popularity and almost 2,000 wheat straw choppers are being used by the farmers and more than 30 manufacturers are making units. The cost of unit is US $ 4,000-5,000.

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# 23. Impact of Climate Change on Wheat Productivity and Adaptation Strategies

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Cereals hold the major share of food grains and wheat is the most important crop world-wide. Among the 12 wheat mega-environments (ME), Indo-Gangetic Plains (ME1) and Central India (ME4C) are the major wheat producing regions in South Asia. Wheat yields need to be increased from current 2.6 to 3.5 tons per hectare in coming 25 years (Ortiz *et al.*, 2008) to meet the projected increase in demand due to increase in population. For India, the projected demand for wheat is anywhere between 93 to 103 million tons by year 2020. However, the wheat production is likely to face challenges from climate change apart from several issues like competition for resources such as land, water and labour, in spite of recent gains in production.

Projected increase in temperatures due to climate change is likely to affect the crop production by 10-40 per cent in Indian region by 2080-2100 (Rosenzweig and Parry, 1994; Fischer *et al.* 2002; Parry *et al.* 2004; IPCC 2007b) under business as usual scenario without considering the future technological developments and adaptation by the farmers and policy interventions. Even though, wheat is irrigated in majority of the regions, about 15 per cent of area, mainly in some parts of central and eastern India, is supported only by the residual soil moisture. Generally, it is sown in the second week of November, after the harvest of monsoon season crop, but in some regions, it is sown late in December exposing it to high terminal heat stress. On the other hand, wheat seedlings in some parts of central India also experience early heat stress.

The crop is sensitive to high temperature which affects photosynthesis, growth and development and number of grains and thus grain yield. Higher temperatures during March in 2004, in the Indo-Gangetic Plains, caused wheat crop to mature earlier by 10-20 days resulting in reduction in wheat production more than 4 million tons in the country (Samra and Singh, 2002) while terminal heat stress in Punjab in 2010 reduced yields by about 5.8 per cent (Gupta *et al.*, 2010). Recent analysis on heat stress on wheat yield in certain pockets of IGP indicated a reduction in yield up to 20 per cent due to a 2°C increase in seasonal temperatures (Lobell *et al.*, 2012). On the other hand, low temperatures can be problematic for seed set. Projected increase in temperatures and increased frequency of heat and cold waves, therefore, can cause significant constraints for wheat production in future climate scenarios. Assessments on the impacts of climate change on wheat indicate the possibility of loss of 4-5 million tons in production with every rise of 1°C temperature throughout the growing period even after considering carbon fertilization but no other adaptation benefits (Aggarwal, 2008). With 3°C increase in temperature, the loss is projected to be 19 million tons and with 5°C increase this will be about 27.5 million tons (Aggarwal and Swaroopa Rani, 2009).

Recently, an analysis on the regional impact of climate change on wheat yield in climate scenarios of 2020 (2010-2040), 2050 (2041-2070) and 2080 (2071-2100) periods for A1b, A2, B1 and B2 emission scenarios was carried out using InfoCrop-wheat model (Kumar *et al.*, 2012).

The study indicated that climate change is projected to reduce the timely sown irrigated wheat production by about 6 per cent in 2020 scenario from existing values (Fig. 1). When late and very late sown wheat also is taken into consideration, the impacts are projected to about 18 per cent in 2020, 23 per cent in 2050 and 25 per cent in 2080 scenarios, if no adaptation measures are followed. However, adaptation to climate change by sowing improved varieties and employing improved input efficiency technologies coupled with application of additional nitrogen can not only offset the negative impacts, but can also improve the net yields by about 10 per cent in 2020. However, in 2050 scenario, such adaptation measures marginally improve yields, while in 2080 scenario, the wheat yields, are projected vulnerable by about 6 per cent in spite of above adaptation strategy.

Apart from the gradual increase in seasonal temperatures, climate change is projected to increase the frequency of heat and cold waves. On all India basis, a 36 year (1969-2005) simulation analysis indicated that coincidence of a 3°C increase in temperature during flowering or initial phase of grain filling could reduce production by about 6 per cent while a similar temperature increase during grain ripening phase could cause about 4 per cent reduction in production (Kumar *et al.*, unpublished).

In order to meet the demand, wheat yield should increase to 3.8-4 tons per hectare by 2020 (Kumar, 1998) and more than 4 tons per hectare by 2050 AD. This target may further increase if area under wheat is reduced in future. In India, past 45 years have seen a gradual improvement in wheat yields and the yield gap reduced by about 0.5 per cent every year. Since a large gap between potential, attainable and actual yields exists, it is important to reduce the yield gap through technology targeting. For instance, introduction of

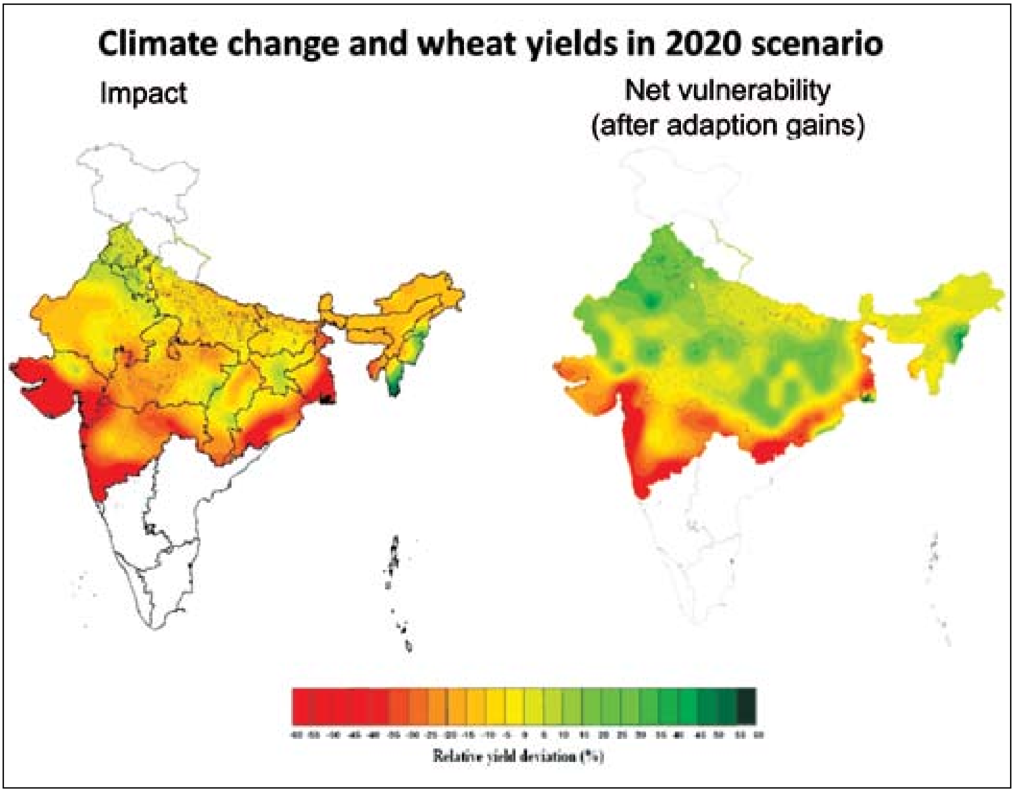


**Fig. 1.** Impact of climate change on timely sown wheat yields in India in 2020 scenario (PRECIS)

terminal heat tolerant variety (WR 544) in the farmers' fields in about 10 villages could improve yield up to 18 per cent even with farmers' management. However, climate change is projected to reduce the potential yield of current wheat cultivars, thus making it necessary to use integrated crop improvement approach (Varshney, *et al.*, 2011) to develop 'input use efficient and region specific adverse-climate tolerant varieties'. A system approach for farm management becomes crucial for promotion of green RCTs. Apart from this, weather based agro-advisory and supportive policies can provide a strong platform for sustainable wheat production.

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# 24. Developing Terminal Heat Tolerant Wheat

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Wheat, the third largest staple food in the world after corn and rice, is largely adapted to low temperature environments. Hence, contribution of wheat to global food security is highly vulnerable to predicted rise in ambient temperatures. With large area sown to wheat in subtropics, South Asian countries rely more on spring wheat, which is better adapted to high temperatures relative to winter wheat. However, even spring wheat is highly prone to rise in temperature during the grain growth phase that often coincides with declining soil moisture level. The grain growth phase is highly sensitive to both gradual and sudden rise in temperatures that often occur during crop season particularly when sowing is delayed. Hence, wheat genotypes tolerant to post-anthesis thermal stresses are crucial for climate resilience of wheat production in the region. Wheat improvement for thermal stress can be accomplished by integrated efforts to characterize both the high temperature environments with high resolution and the response of genotypes with precision high enough to dissect the mechanisms of tolerance to stress. Techniques and screening protocols to differentiate environmental effect from the genetic effect of thermal stress on plants can be of immense use in associating traits with genes. Here, an attempt has been made to highlight the possible strategies for genetic improvement of wheat for post anthesis thermal stress tolerance taking into consideration recent advances in science and technologies.

## The Target for Thermal Tolerance in Wheat Based on Estimated Losses due to Rise in Temperature

The optimum post-anthesis temperature for the maximum kernel weight in wheat is about 15°C (Chowdhury and Wardlaw, 1978), and each 1°C rise in temperature above the optimum can cause a 3-5 per cent reduction in single grain weight under both controlled environments (Wardlaw *et al.*, 1989) and field conditions. This is also evident from one of the recent studies where rise in temperature by 10°C above 20-15°C under controlled environment reduced grain yield by 33 per cent (Morteza *et al.*, 2003). Several experiments conducted under field conditions with staggered sowing to expose late sown plant to higher temperature at the time of grain filling have revealed that delay in sowing by a month can reduce the grain yield of spring wheat genotypes grown across the Indian sub-continent by 25-30 per cent (AICW & BIP Reports).

Observed variations in average growing-season temperatures of ±2°C in the main wheat growing regions of Australia can cause reductions in grain production of up to 50 per cent mainly due to increased leaf senescence as a result of temperatures more than 34°C (Asseng *et al.*, 2011). Analysis of predicted climate change on wheat in Northern India has revealed that each degree rise in temperature can reduce wheat yield by four million tons (Aggarwal *et al.*, 2010). Recent analysis of satellite data on phenology and senescence in wheat grown in Indo-Gangetic Plains have revealed that the loss of grain yield can be as high as 20 per cent with an increase in ambient temperature by 2°C. If extrapolated, grain yield losses can be up to 16 million tons with the present total production of more than 80 million tons per year. Thus, from experiments under controlled environmental condition, field experiments and crop simulation model, One can have a fair idea about magnitude of losses at plant as well as regional scale. Optimistic research efforts to reduce the possible damage due to thermal stress even by 10-20 per cent can significantly contribute to sustainability of wheat production in hot environment. To accomplish the task, we should assess the causes of high temperature induced losses and options available for genetic improvement for thermal tolerance.

## Causes of Reduction in Grain Yield at High Temperature Stress

The reduction in grain growth duration is the major cause of losses in productivity under high temperature environments. Further, in many of our current cultivars, heat stress induces pollen sterility, seed abortion during early development, and an early transition to the dry seed stage, which results in small shriveled kernels. The decline in the rate of grain growth is mostly due to a decrease in the rate of starch accumulation; protein deposition is less temperature sensitive (Bhullar and Jenner, 1985). In addition, vulnerability of key enzymes such as Rubisco Activase, rapid leaf senescence is one of the major causes of reduction as it impedes supply of current photosynthesis for grain development.

## Crop Improvement Options

Persistent efforts are being made to develop wheat genotypes tolerant to high temperatures. However, the tolerance to heat stress is a difficult trait for the wheat breeder to select. In addition, tolerance is genetically and physiologically complex, and its expression is highly influenced by the various environmental factors during growth and development of grains. For decades, researchers have relied on the grain yield as an indicator of heat tolerance and plants that had high yield under temperature environments were considered heat tolerant. However, future success in genetic improvement of thermal stress tolerance could be determined by trait based breeding that requires identification and dissection of the genetic components of tolerance mechanisms. Both the heat avoidance mechanism driven by plant's capacity to keep its canopy cool as well as heat tolerance mechanisms that directly determine heat tolerance needs to be carefully matched with suitable environments to design the future wheat genotypes. Canopy cooling that increases water extraction from the soil could become a liability when water is limited. Insight into molecular mechanisms that determine thermal tolerance can help in associating traits with genes for marker aided selection.

## Traits and Molecular Markers

Several traits have been associated with tolerance to thermal stress in wheat (Reynolds, 1994). Membrane thermo stability (MTS), measured on field-acclimated flag leaves. Flag-leaf photosynthesis measured at booting, anthesis and during grain filling, rate of loss of leaf chlorophyll content during grain filling, stomatal conductance, and canopy temperature depression have been shown to be associated with yield performance of wheat under high temperature environments. Many of these traits are rarely used in breeding program as they are labour intensive and often not found to be as convenient and reliable as grain weight, an important yield component (Mohammadi *et al.*, 2007). Techniques to measure canopy temperature depression (CTD) measured with an infrared thermometer is now popular among wheat scientists. However, appropriate procedures to handle these instruments and the time of measurements are very crucial for ensuring quality of phenotypic data. As alternative, high throughput technologies are being developed to screen large number of genotypes by employing thermal cameras and automation (Rane *et al.*, 2010). These technologies can enable us to enhance frequency of observations to understand the process contributing to grain yield under high temperatures. This can also help in precisely relating the trait with genes and QTLs for a particular environment.

QTLs contributing to grain filling duration (GFD) have been reported by using SSR markers in wheat (2002). The experiments have revealed that three SSR markers, viz., Xgwm132, *Xgwm 577* and *Xgwm 617* were linked to grain filling rate (GFR) by quantitative trait loci (QTL) analysis of the $F_2$ population (Barakat *et al.*, 2011). Genes and gene marker for other traits associated with thermal tolerance have also been reported, however, many of the reported markers for stress tolerance are rarely used in breeding program mainly due to lack of validation in different environmental and genetic background.

## Possible Strategies

**Redefining the target population of environments (TPE):** Understanding the target environments is vital for designing wheat for high temperature environment as adaptation of genotypes is often location specific (Rane *et al.*, 2007). High temperature environments have a wide range of climatic, edaphic, social factors that can influence access to irrigation. It would be difficult to find a common solution across the heat stress environments and hence, the success may be ensured by environment specific approach for genetic improvement. Further, the knowledge of ground realities can help in developing desired plant types to suit high temperature environment. For example, in the North Western Plains of India, substantial area sown to wheat is irrigated. However, farmers hesitate to irrigate the field in the month of March which coincides with grain filling mainly because of heavy winds that can lead to crop lodging. In the absence of sufficient irrigation, even those plants that are highly capable of keeping their canopy cool may not express the tolerance. These situations indicate necessity to redefine the suitable thermo tolerant varieties. Obviously, tolerance to limited moisture and crop lodging should be integral components of the thermal tolerance in wheat genotypes.

**Special emphasis on adaptation to high night temperatures:** Most of the studies assume that the trends in day temperatures are often followed by trends in night temperature. This assumption needs to be revisited, taking into consideration the temperature trends emerging from global warming. Studies have indicated that night temperatures are more crucial and are highly correlated with grain yield reduction relative to day temperatures as indicated by All India Coordinated Wheat and Barley Improvement Project (AICW&BIP) data. Hence, the strategies for screening wheat genotypes for high temperature tolerance needs to be reoriented.

**Breeding for given resource management conditions:** With long history of research and practice in real field conditions, resource management has now sufficiently evolved to get the best out of minimum resources available for the farmers. Previously, agronomic practices were designed to suit new genotypes. However, new genotypes suited to existing resource conservation technologies needs to be designed to avoid technology footprints on the environment while sustaining the productivity under hot environments.

**Escape mechanism in different perspective:** Since, escaping heat stress had been the major strategy to develop high temperature tolerant genotypes, the focus of crop improvement was on developing short duration varieties for high temperature environment. However, inherent escape mechanisms, if any, in wheat genotypes should be explored to avoid high temperature hours for vital processes contributing to grain development in the diurnal cycle. Genotypes that can flower and release pollen in early hours of the day may have advantage over the one which release pollens during late and hot hours that contribute to pollen sterility. In addition, the genotypes, which can quickly recover from heat stress and those which can utilize night hours for synthetic processes, if any, involving translocation of stem reserves and carbohydrate accumulation in grain filling need to be characterized.

**Temperature resilient metabolism:** Rubisco activase (RCA) constrains the photosynthetic potential of plants and endogenous levels of RCA could serve as an important determinant of plant productivity under high temperatures (Ristic *et al.*, 2009). A significant, positive, linear correlation was found between the expression of wheat 45-46 kDa RCA and plant productivity under heat-stress conditions. Results support the hypothesis that endogenous levels of RCA could play an important role in plant productivity under supraoptimal temperature conditions. This important observation needs to be validated under different heat stress environments before employing molecular markers for thermo tolerant wheat. In addition to leaf photosynthesis, spike photosynthesis should be given due consideration under high temperature that enhance leaf senesce. There are ample evidences that stay green features contribute to grain yield of thermo tolerant genotypes, however, other factors such as longer crop duration and poor translocation of stem carbohydrates may disqualify stay green types for high temperature environments.

**Shoot and root architecture:** Each of the traits such as tiller number, leaf position, reflective cooling, stomata distribution, leaf senescence pattern along the canopy profile, stem and spike architecture may contribute partially to the high temperature tolerance in wheat. Further, root depth, angle of growth, proportion of roots in the upper horizon to the lower horizon and root senescence can determine plants potential to absorb water from deeper layers and hence can contribute to cooler canopy. Shoot and root architecture may also help in preserving soil moisture by foliage cover above the soil and also by holding soil particles together respectively particularly in vertisol.

**Employing plant phonemic tools:** Characterizing the genes through genomic tools have become easier now than it was a decade ago. However, we are yet to decipher functions of many of the genes. Recent plant phenomic tools aim to bridging this technology gap by facilitating precise and rapid characterization of responses of plants to environmental stimuli. These noninvasive tools integrate visible and hyper spectral imaging technologies with automation that can enhance our capacity to identify traits and genes contributing to tolerance to abiotic stresses (Tester and Langridge, 2010). However, these tools need to be complemented by techniques to simulate natural environment as well as appropriate experimental design particularly for field phenotyping.

**Thermal stress in combination with other stresses:** While omics approaches are gathering momentum to deliver the farm products, one of the concerns is that the co-occurrence of different stresses is rarely addressed by molecular biologists (Mittler, 2006). The response of plants to a combination of two different abiotic stresses is unique and cannot be directly extrapolated from the response of plants to each of the different stresses applied individually. Tolerance to a combination of different stress conditions, particularly those that mimic the field environment, should be the focus of future research programs aimed at developing thermo tolerant wheat.

Taking into consideration the underlying complexities in mechanisms of tolerance to high temperatures and individual contribution of several traits so far reported, an appropriate strategy should be developed to identify the genes and stack them in suitable genetic background that matches with the target environment and resource management practices. Further, valuable traits from wild relatives of wheat can be utilized to improve thermal tolerance in wheat by employing appropriate molecular tools.

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# 25. Improving Quality Traits in Wheat

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## Introduction

India achieved record production of 85.93 million tons during 2010-11 and is the second largest producer of wheat in the world for the last more than a decade. The production is hovering around 85 million tons inspite of reduced area, severe draught and several other unforeseen reasons. It shows the resilient nature of Indian wheat program and this could be made possible by developing high yielding, disease resistant varieties and matching production technologies. Wheat is a unique gift of nature to mankind as a large number of end-use products such as chapati, bread, biscuit and pasta can be made from it. The increase in domestic demand of baked and pasta products along with economic liberalizations and global trade have offered opportunities for better utilization of wheat. The projected demand for bread by the 11$^{th}$ Five Year Plan is 2.7 million tons, biscuit is about 3.5 million tons and pasta is 0.25 million ton. The annual growth rate of the baking industry is projected to be around 5 per cent. Hence, wheat quality needs utmost attention so as to meet the domestic and export requirements in the time to come.

## Industrial Quality Requirements of Wheat Products

Three species of wheat namely, *T. aestivum*, *T. durum* and *T. dicoccum* are cultivated in the country. Bread wheat is contributing approximately 95 per cent, while around 4 per cent comes from durum wheat and just about 1 per cent is the share of dicoccum wheat to the total wheat production. The quality requirements of wheat for various products like chapati, bread, biscuit and pasta are different. Hard wheat (*T. aestivum*) with strong and extensible gluten and high protein is required for making good bread. For biscuit, the quality requirements are soft wheat, low protein and weak and extensible gluten. For chapati, we need hard wheat, medium to high protein and medium and extensible gluten. For pasta products, hard wheat (*T. durum*) with strong gluten, high protein, low yellow berry incidence and high β-carotene content are required.

Grain hardness (GH) is an important parameter, which is used as grading factor to determine wheat types and also to define end-product quality. The difference in hardness between hard and soft wheat is due to one major gene, designated as Hardness (Ha), located on the short arm of chromosome 5D. A 15kDa protein is shown to be present in the extracts of water washed starch granules from soft wheat and is absent in those of hard grains. Thus, this protein is a marker for grain softness and has been called as "Friabilin" or "Grain softness protein" (GSP). It is primarily composed of two sub-polypeptides, puroindoline-a and puroindoline-b.

Glutenin has the important property of swelling in various non-reducing solvents (dilute acetic acid, lactic acid and SDS) and the swelling volume appears to be directly related to quantity and quality of glutenin. SDS sedimentation volumes also have been highly influenced by environment, crop season, and their interaction with cultivars. Nevertheless, SDS sedimentation volumes are highly heritable and can be used for screening early generation progeny.

Proteins are classified into different solubility groups such as albumins (soluble in water and dilute buffers), globulins (not soluble in water but soluble in saline solutions), prolamins (which are soluble in 70-90 per cent alcohol), and glutenins (which are soluble in dilute acids or alkalis). Two major classes of glutenin subunits have been identified in wheat endosperm: the high molecular weight (HMW) and the low molecular weight (LMW) glutenin sub-units. High molecular weight glutenin subunits (HMW-GS) are components of the glutenin polymer and, therefore, play a major role in the determination of the unique visco-elastic properties of wheat dough. The HMW glutenin subunits *1Dx5+1Dy10* ('d' allele) have been associated with high dough strength and good bread making quality, whereas, allelic sub-units *1Dx2+1Dy12* (containing the 'a' allele) are associated with poor bread making properties. The LMW-GS represent about one third of the total seed storage proteins and about 60 per cent of total glutenins. The low molecular weight glutenin sub-units (LMW-GS) are 30-50KDa in size, comprising approximately 40 per cent of the prolamin fraction of wheat and together with the HMW-GS, form the structural backbone of the glutenin polymer. In general, the LMW-GS are associated with dough resistance and extensibility and some allelic forms of LMW-GS show even greater effects on these properties than HMW-GS. Gliadins are monomeric proteins, which are, in their native state, soluble in 70 per cent aqueous alcohol. In accordance with their mobility in Acid-PAGE, they are divided into four groups: α–(fastest mobility), β-, γ- and ω-gliadins (slowest mobility). The molecular weight ranges from 30 to 75kDa. Specific ω-gliadin bands have been correlated with both dough strength and dough weakness.

The rheological properties of dough are a key determinant of the quality of baked products. The gluten matrix, which encloses the starch granules and fibre fragments, is a major determinant of dough rheology. Each class of wheat is characterized by unique rheological properties that determine its suitability for making specific products. Within the cereal industry, there has been a long history of using descriptive empirical measurements of rheological properties like mixograph, extensiograph, alveograph, etc. These tests are used to predict baking performance and behaviour of dough during processing before baking.

The *1BL/1RS* translocation has been widely used in global wheat breeding, even though it has a significant and negative effect on dough qualities for both bread and Chinese noodle. Selection for or against the presence of rye chromatin may be accomplished using DNA markers to detect the presence of rye repetitive DNA sequences. Using the gene specific primers for ω-secalin, a 1076-bp fragment was generated in genotypes with the *1BL/1RS* translocation, whereas a 636-bp fragment for Glu-B3 locus was amplified in genotypes without *1BL/1RS*.

Diagnostic DNA markers for the prediction of wheat quality are a useful addition to the range of tools available to wheat breeding programs, especially for early generation screening of wheat lines. DNA markers offer the advantages of being applicable to any developmental stage and any tissue of the plant, and of producing results that are independent of environmental conditions.

About ten thousand wheat grain samples belonging to different AICW & BIP trials are analysed every year. All the second year Advanced Varietal Trials entries including checks are evaluated for chapati, bread, biscuit and pasta. Product specific genotypes were identified for chapati (>8.0 score out of 10.0), bread (>575 ml loaf volume), biscuit (>8.0 spread factor) and pasta (>6.5 score out of 9.0). All the first and second year entries including checks are analysed for quality parameters like grain appearance, test weight, protein, grain hardness index, sedimentation value, moisture, phenol test, extraction rate, wet gluten, dry gluten, gluten index and high molecular weight glutenin subunits (HMWGS). Promising genotypes have been identified showing superiority in these quality traits.

## Development of Product Specific and Nutritionally Rich Wheat Varieties

The identified varieties for various wheat products are the result of the spill over of the breeding program for high yield and disease resistance. They have not came out from any systematically adopted quality-breeding program. What is needed is that right from selection of parents and advancement of generation, apart from high yield and disease resistance, the product specific quality requirements are also taken into account so as to develop varieties, which can make various wheat products of international standard. Focused efforts in germplasm evaluation and working out relationship of end products with different yield and quality components are required. Quality wheat breeding program has helped in selecting good progenies for chapati and bread quality. Materials are available in $F_2 – F_5$ generations exhibiting more than 8.5/10.0 chapati quality score and upto 700 ml bread loaf volume. Extensive evaluation of germplasm (both indigenous and exotic) is being done, promising parents are selected and used in the crossing/back crossing block in an attempt to develop product specific wheat varieties.

## Use of Molecular Marker Technology Approach in Wheat Quality Improvement

Basic studies on identification of bio-chemical/molecular markers associated with key nutritional components like protein, β-carotene, iron and zinc are further required to adopt bio-fortification in wheat. Molecular marker technology approaches have been used for the improvement of wheat quality. The recombinant inbred lines (RILs) have been developed for various quality parameters and wheat end products. Several markers (STMS, ISSR etc.) have been identified associated with the quality traits required for making excellent end products. The RILs and released wheat varieties have been extensively studied for HMWGS, LMWGS, Y-gliadin, Ppo loci, pin a, pin b and 1B/1R translocation. Construction of framework map and QTL analysis has been done. The use marker-aided selection (MAS) for the improvement of end product quality is in progress.

## Quality of Indian Wheat

More than six thousand wheat samples, collected from main mandis of 13 major wheat growing states, have been analyzed for grading and non-grading parameters, flour characteristic, HMWGS, rheological properties and baking evaluation of chapati, bread and biscuit. An atlas has been prepared for all the quality parameters, product specific varieties and areas have been identified and classes and grades of Indian wheat have been proposed. This would help in making strategies for procuring wheat from the mandis for domestic and export purposes. The situation is satisfactory with regard to the test weight but the mandi samples need improvement in damaged kernel, foreign matter, shrunken and broken kernel. Through proper cleaning and grading by machines, samples in lower grades can be upgraded to higher grades. The average protein content is relatively low in the northern parts of the country (10-11.5 per cent) and it improves in the central and peninsular region where it remains between 12-13 per cent. The average extraction rate is the maximum in Madhya Pradesh (70.7%). The baking data clearly indicated that the upper part of the country comprising of Himachal Pradesh, Uttranchal and Punjab is comparatively better in biscuit quality. The middle part of the country, particularly Madhya Pradesh, Rajasthan and Gujarat, is good in chapati quality. Likewise, the lower part of the country comprising Gujarat, Maharashtra and Karnataka is comparatively better for bread loaf volume. Based on the quality requirements of various end products and the type of wheat available, Indian wheat cultivars have been divided into 5 classes. Depending upon the extent of physical parameters like hectolitre weight, damaged kernels, foreign matter, broken and shrunken kernels, total defects and other classes, 5 grades have been proposed for Indian wheat.

## Nutritional Quality

Minerals although required in very small amounts are very important part of the metabolism. Most of the mineral requirement of the humans is fulfilled by a balanced diet comprised of cereals, fruits and vegetables. But, for populations which are mainly dependent on cereal based diets or live in the regions where the soils are low in minerals, they often suffer from malnutrition. Nearly 2 billion people around the world are affected by micronutrient deficiency and, according to the World Health Organization, it is the leading cause of death through disease in developing countries. Biofortification has been defined as the process of increasing the bio-available concentrations of essential elements in edible portions of crop plants through agronomic intervention or genetic selection. Biofortifying crops that feed the world's poor (wheat or rice) can significantly improve the amount of these nutrients consumed by these target populations. The Indian bread and durum wheat cultivars possess low levels of grain iron (27-55 ppm)* and zinc (20-50 ppm)* thus emphasizing the necessity for identification and utilization of wild germplasm for wheat biofortification.

Breeding strategies should generate micronutrient enhanced wheat cultivars without compromising tolerance to abiotic/biotic stress, crop productivity, and acceptable end-use quality, thereby increasing the likelihood that farmers will adopt the cultivars and consumers will accept foods made from them. There are three breeding sub-strategies that may be applied individually or in various combinations. These are (i) reducing the level of anti-nutrients such as phytate and tannins in staple food, which inhibit the bio-availability of minerals (ii) increasing the levels of nutrients and compounds such as ascorbic acid, b-carotene and cysteine-containing peptides that promote the bioavailability of minerals, and (iii) increasing the mineral content in the grain.

## Climate Change and Wheat Quality

Predicted elevated levels of $CO_2$ and higher atmospheric temperature are major concerns for improving wheat quality. The quality traits with high heritability are less influenced by the environment. For example, gluten strength as measured by sedimentation is influenced less by the increase in $CO_2$ but protein content for flour decreases significantly with increased $CO_2$ concentration. Generally, there is some increase in protein content at high temperature, but there is change in the glutenin/gliadin ratio and thus, adversely affect the quality. In addition, increased temperature may influence starch biosynthesis which ultimately can affect starch quantity and quality. Adaptation such as breeding for heat tolerant cultivars and changing fertilizer management may be needed to counter changes in wheat quality associated with elevated $CO_2$ and temperature.

Thus, there is a need to develop product specific and nutritionally rich wheat varieties. For this, there is a need to critically evaluate the germplasm (both indigenous and exotic) for important quality parameters alongwith their genetic and molecular basis, develop micro-level test requiring less amount of wheat and time so as to use them in analyzing early generation breeding material, establish relationship of end products with different yield and quality components, study starch and other components and use molecular marker technology approaches. Simultaneously, there is also need for upgradation of quality related facilities at mandis, contract farming, segregated procurement, transportation and storage, market intelligence and pricing policy and adequate linkages between research and industry. To achieve this target of wheat quality improvement in totality, the whole chain of production, procurement, transportation and storage on one side and research and market intelligence on the other hand will have to be properly streamlined. The policy planners, scientists, traders and above all the farmers will have to work together to achieve the desired result.

# 26. Current Status and Future Strategy for Seed Production in Asia

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Wheat is an important staple cereal widely grown in various ecological settings of Asia. Its role in food and nutrition security has been steadily increasing. However, there is a growing concern about stagnation in its production and productivity in the major wheat growing countries of the region. During 2010-11, the global wheat production was about 682 million tons covering 227 million hectares area with an average productivity of 3.0 tons per hectare. Asian countries produced 223 million tons of wheat from an area of 101 million hectares during 2009-10 with the productivity level of 2.23 tons per hectare. The world population by the year 2050 is projected to be 9 billion of which 5 billion will be in Asia. In order to meet the demand of this huge population, food production needs to be doubled by that time and 70 per cent of the increase should come from the productivity and only 20-30 per cent may be achieved through area expansion. According to FAO's estimate, wheat production should increase to 302 million tons by 2050 in Asia to meet the needs for human consumption. Asia is also regarded as a low income region with a large number of small and marginal farmers having agriculture as the primary occupation.

Seed is the most important input of the crop production system and, therefore, deserves special attention as well as investment, which cannot be met through public sector only. The agriculture development, including the seed supply system is shaping up well in most of the Asian countries, barring a few like Afghanistan, Tajikistan, and Uzbekistan. Several measures have been taken by the countries in this region to improve the seed system through policies, legislation, technical support and establishment of necessary infrastructure. India's introduction of New Policy for Seed Development in 1988, Protection of Plant

Varieties and Farmers' Rights Act, 2001 are some such steps which helped the industry to grow, fostering better public-private partnership and attracting more investments in this sector. Formation of APSA in 1994 and launching of a SAARC Seed Forum in 2010 also aim at fostering regional cooperation in building a strong seed system in Asia-Pacific in general and South Asia in particular.

Owing to the low profit margins, the supply of high volume-low value seeds such as wheat remains the primary responsibility of the public seed supply system in most of the countries. Also, in such crops, a large proportion of the seed (>75 per cent) is generally farmer-produced and farm-saved leaving a seed replacement rate of 10-25 per cent in different countries. However, some countries like Bangladesh record more than 75 per cent SRR in wheat primarily because of poor storability of seed at high humidity and warm storage conditions at farm level. A higher rate of seed replacement not only ensures use of quality seed for satisfactory crop establishment under variable field conditions, but also is an effective mechanism to introduce better, improved and new varieties which can perform better under less favourable growing conditions. By using high quality seed, the seed rate which is 100-120 kilogram per hectare in different varieties/conditions, can also be reduced substantially.

Farmers' participation in seed production is an effective mechanism of improving the wheat seed supply system. In the participatory approach, greater stress is given on exchange of information between farmers and scientists. Such work has been undertaken in South Asia through NARS in collaboration with CIMMYT (South Asia), which helped faster dissemination of the wheat technologies like varieties and resource conservation technologies to the farmers' fields. In Bangladesh and Nepal, farmers participatory trial results are embedded in the official procedures to avoid delay in access to new varieties. The Indian Council of Agricultural Research (ICAR) has also implemented participatory seed production as a standard way of accelerating seed availability to farmers. This approach has been tried in different parts of India by encouraging partnership between the research organizations (that develop new varieties for better performance under a wide range of cultivation conditions and produce seed) and small farmers in seed production, cleaning, grading and safe storage. This also helps farmers in trying (and evaluating) newly developed varieties and selecting the best material as per their preference. Farmers, once trained, can either use their skill for the production of seed for their own use or become contract seed producers for commercial seed producing agencies or form their own producer companies for greater economic returns.

Cost of seed constitutes a small fraction (5-10 per cent) of the total cost of crop production in wheat. However, a yield advantage of 20-30 per cent is achievable simply with the use of quality seed. In addition, seed is an efficient carrier of other supplements such as pesticides, nutrients, bio-inoculants etc. Hence, concerted efforts are needed to promote seed enhancement treatments for greater efficacy of pesticides, location-specific and need-based micronutrient management and also apply super absorbent seed coats for more efficient water use. Physical methods of stimulation of seed quality and vigour through electromagnetic treatments have also shown great promise and can be applied if adequate infrastructure and appropriate machinery is set up.

To manage the poor storability of wheat seed in humid and warm conditions, particularly in the South Asian region, several newly developed drying and packaging alternatives, such as super absorbent zeolite drying beads and bags and cocoons made of fused poly ethylene bilayers with gaseous barrier has also been reported to be effective for prolonged storage. The organized seed sector and research institutions have a greater role to play in this regard. Details of seed requirement, production and replacement ratio that are important for increasing wheat production in Asia-Pacific region have been presented.

# Annexures

*Annexure I*

# Inaugural Address

**Hiroyuki Konuma**
Assistant Director General and Regional Representative for
Asia and the Pacific
Bangkok, Thailand

Dear Dr. Thomas Lumpkin, Dr. Raj Paroda, Dr. Masa Iwanaga, distinguished participants, ladies and gentlemen!

It is a great pleasure for me to inaugurate this extremely important regional consultation on "Improving Wheat Productivity in Asia" jointly organized by FAO and APAARI in collaboration with CIMMYT, ICARDA and JIRCAS. I warmly welcome all of you to this consultation. I express my deepest thanks to CIMMYT, ICARDA and JIRCAS to be with FAO and APAARI in organizing this event jointly.

While we are approaching 2015, it is becoming more and more clear that not all the countries in this region will achieve MDG target 1, in spite of their tireless efforts. As you all know, FAO has been assisting member countries for taking appropriate measures on food security in a comprehensive and integrated manner since 1996 when FAO organized World Food Summit (WFS) and the latest follow-up meeting held in 2009 in FAO Headquarters, Rome where FAO reminded all member countries that we have to work harder to achieve MDG target 1. The world population is expected to reach 9.2 billion in 2050. To meet the growing demand, according to new estimates released by FAO recently, the world food production has to be increased by 60 per cent in 2050 from the level of 2005/07 and in case of developing countries, it has to be increased by 77 per cent during the same period.

Food security of this region largely depends on the availability of rice and wheat- two major food security crops of the Asian people. Two major rice and wheat producing countries (China and India) are located in this region. These two countries rank first and second in the world in terms of population too. FAO-IRRI organized a similar regional consultation on "Increasing rice productivity in underexploited areas of South Asian countries" on 10-11 March, 2010. As an outcome of this consultation, a project proposal has been developed which is under consideration of some donors for possible funding. It indicates FAO's focused attention to these two important crops that are vital for food security in Asian countries. It is also worth mentioning that the Asian region is the net importer of wheat and productivity growth of this crop has been slowing down. In this backdrop, we are meeting today here to discuss how to increase productivity of wheat in Asian countries by reversing trends in current productivity growth. The other important purpose of this consultation is to inform member countries about the development status of wheat so that they can take appropriate decision for improvement in time. The challenges ahead of us are enormous. In the past, in this sector we had made considerable success but at the cost of substantial damage to the environment. Future productivity growth should come in an environmentally sustainable manner. In view of that, FAO has been advocating sustainable crop production intensification (SCPI) and diversification with ecosystem approach which has been clearly described in a recently published book "Save and Grow". I am also pleased to inform you that in recently completed APRC held in Vietnam on 12-16 March 2012, this new approach has been highly appreciated and the Director General, FAO mentioned that sustainable food production and consumption will remain FAO's main priority area of intervention.

The bottom line is that we have to increase both productivity and production of wheat in an environmentally sustainable way and make wheat production system more stable and less risky and vulnerable. By increasing productivity and making wheat production system sustainable, we can release land from this crop for the use of other crops. Importance of this crop has been increasing due to less water requirement of wheat compared to rice which is becoming scarcer. Our understanding is that to achieve success in this sector, we have to target improvement both in "breeding" and "agronomy" simultaneously. Past experience showed that emphasis in one sector bypassing other sector and scientific thinking in isolation is one of the main obstacles to increasing productivity of this crop. Availability of plant genetic resources and creation of greater genetic diversity; use of molecular genetics and biotechnological tools and techniques in combination with conventional breeding systems to develop better varieties; and modern crop management technologies will play vital role in achieving productivity gains in wheat.

We are firmly confident that all these issues, among others, will be discussed in this forum in detail in next two days and the consultation will come up with implementable recommendations for further actions in collaboration with development partners with ultimate goal to reduce poverty and hunger in this region. FAO attaches utmost priority to this consultation to know more about the problems of productivity gains in wheat and their possible solutions. Our expectation from this forum is extremely high and that is why we have tried our best to ensure participation of best scientists of the region in this consultation. We have also tried to bring together large number of country representatives, development partners and international institutions so that a lively scientific and development oriented discussion can be held for the betterment of our people.

In view of that FAO and APAARI have put lot of efforts to make this meeting successful. We also hope that we will work together in future too, to implement the recommendations that emerged from this meeting.

I would like to thank all our development partners for accepting our invitation and thanks again to APAARI for its excellent cooperation. We are very grateful to CIMMYT, ICARDA and JIRCAS to agree to our request to support this consultation and also for their participation. We in FAO look forward to the deliberations and outcomes of this important consultation and will be happy to work further with our partner agencies and member countries for improving the food security of the poor people through wheat productivity gain in this region.

I wish you fruitful deliberations and a pleasant stay in Bangkok, Thailand.

*Annexure II*

# Welcome Address

**Raj Paroda**

Executive Secretary, Asian-Pacific Association of Agricultural Research Institutions (APAARI)

Bangkok, Thailand

Dr. Hiroyuki Konuma, Dr. Thomas Lumpkin, Dr. Masa Iwanaga, Dr. Ronnie Coffman, Dr. Subash Dasgupta, distinguished participants, ladies and gentlemen !

At the outset, I would like to extend a very warm welcome to you all to this important "Regional Consultation on Improving wheat productivity in Asia", being jointly organized by Food and Agriculture Organization - Regional Office for Asia and the Pacific (FAO RAP), Asia-Pacific Association of Research Institutions (APAARI), in collaboration with International Maize and Wheat Improvement Center (CIMMYT), International Center for Agricultural Research in the Dry Areas (ICARDA) and Japan International Research Center for Agricultural Sciences (JIRCAS).

As you all know, the growth rate in wheat productivity has come down to less than one per cent in comparison to much higher growth rate of 1.8 per cent in human population. For achieving the projected global demand of 650 million metric tons of wheat by 2030, there is need to accelerate the overall wheat production annually by at least 2.0 per cent. Since, there is little scope for expansion in area under wheat, the only alternative left is the vertical improvement by enhancing the genetic potential of wheat varieties.

Also, the new challenges are emerging on account of the global climatic change, new threats of diseases and pests, new weed flora, herbicide resistance, depleting soil health and stagnating productivity levels. There are number of options available for breaking the yield barriers in wheat which include new breeding initiatives for developing wheat hybrids through CMS approach, widening the genetic base of varieties through the use of winter × spring variety hybridization, synthetic wheat varieties and wild species for increasing resistance/tolerance against various biotic and abiotic stresses that adversely and significantly affect the wheat productivity. Since both winter and spring wheat are grown in different ecological conditions and both the gene pools have evolved in isolation, there is likelihood of introgression of diverse genetic factors. Winter wheat is expected to bring improvement in spring wheat varieties with respect to effective tillers per unit area and grains per spike, besides contributing genes for drought tolerance, bread making quality, powdery mildew resistance and resistance/tolerance to cold/frost. These breeding strategies need to be augmented in ongoing research programs of participating countries to further enhance the yield potential and genetic diversity.

Besides, the narrow genetic base, biotic stresses such as yellow and stem rust diseases need special attention to fulfill the demand of the new varieties and matching production technology for different production conditions. Synergy between conventional and new molecular tools to develop new technologies for enhanced productivity and input use efficiency is extremely important.

The Indian wheat program including the All India Coordinated Wheat Improvement Project has made breakthrough in the wheat production starting from green revolution era to the second highest producer of wheat in the world. This has been possible mainly due to well designed, multi-dimensional, multi-locational and a model program that enabled the country to harvest the record wheat production of 85.97 million tons from 29 million hectares area during 2010-11 and a record production of 90 million tons is expected this year from an area of 29 plus million hectares. Although, the wheat production in India has been continuously increasing from the last five years (75.8 mt in 2007, 78.6 mt in 2008, 80.6 mt in 2009, 80.7 mt in 2010 and 85.97 mt in 2011), the productivity has been stagnating at 2.7-2.8 tons per hectare. This calls for intensified efforts to change the plant ideotype in order to enhance productivity potential, early vigour and faster crop establishment.

This consultation is very timely and provides opportunity to discuss during the next two days the major thematic areas such as breeding strategies, applications of molecular breeding for biotic and abiotic stresses, resource optimization for enhanced productivity, management of new races of rusts and other emerging diseases, enhancing value addition and quality improvement and managing impact of climate change on sustainable production of wheat in Asia. The scientists engaged in wheat research should focus not only on improving productivity but also product quality parameters. It is high time that we pay adequate attention to conservation agriculture, improving soil health, input use efficiency, mechanization and diversification of cropping system.

A new race of yellow rust known as 78 S 84 has come to stay in Indian wheat fields and it has knocked down the most popular variety of wheat PBW 343 which is covering more than 7 million hectares of area in Indo-Gangetic Plains. Also, new stem rust race Ug99 posed a serious threat to wheat cultivation across the globe and starting from Uganda, it has already reached Iran. However, to pre-empt the threat posed by new races, the anticipatory resistance breeding work have been initiated by screening wheat materials from wheat growing countries at hot spot locations where high disease pressure exists under natural filed conditions. Besides, a regional network for survey and surveillance of new races by the participating countries needs to be established and strengthened to keep watch on the disease scenario under changing climate.

Another crucial factor is terminal heat which is becoming the main hindrance in recent times for achieving new heights in wheat production. With each degree rise in ambient temperature beyond 30°C during anthesis, wheat yield is reduced by 3-4 per cent. Similarly, each degree rise in minimum temperature beyond 15°C at the time of grain filling leads to about 290 kg/ha loss in grain yield. More than hundred years ago, Howard made a statement that wheat production in India is a gamble due to temperature and this is true in present times as well. With climate change shrinking in winter spell coupled with rise in temperature in February-March has become a usual phenomenon in the wheat granary of Indo-Gangetic Plains of India. Several heat tolerant genotypes of wheat have been identified using physiological techniques like canopy temperature depression (CTD), cell membrane stability, stem reserve mobilization (SRM), heat sensitive index (HSI), etc.

Besides, there is great need to focus on tagging resistant genes, and use of marker assisted selection for gene pyramiding to breed genotypes with durable resistance. It is necessary to establish maker assisted selection laboratory facilities in each country. Adoption of transgenic approach to improve the quality and to impart resistance to important diseases needs attention. Survey and surveillance activity needs to cover more area so that the monitoring of diseases and insect-pests can be done more effectively and emergence of new races/virulence can be known within a short time through such program at regional level.

In view of changing climatic conditions and introduction of new resource conservation technologies (RCTs), it is imperative to study the effect of climatic change on the spectrum and dynamics of different diseases, insects and pests with respect to wheat crop. There is need to breed varieties suited to zero tillage condition in particular and also to make efficient use of limited supply of water and essential nutrients. The double cropping pattern (rice-wheat) over about 12 million ha in South Asia has adversely affected the soil health and ground water. Rice-wheat system should, therefore, be diversified by incorporating crops like mungbean, urdbean, soybean, pigeonpea, etc. to improve the soil health. The efforts already initiated in this direction should be further strengthened. Furrow irrigated raised bed (FIRB) technology plays an important role in diversification of rice-wheat system by providing alternative for raising crops like pigeonpea, soybean, maize, vegetable peas and wheat for enhancing productivity and profitability. Hence, popularization of this system is needed to gain the maximum profit. Use of laser land levelling which is proving as a precursor for the adoption of new RCTs, needs to be popularized with a view to increase the area under cultivation, economize on the use of water and nutrients. Combined use of inorganic fertilizers with organic manures and biofertilizer, crop residue management, crop diversification, intensification of rice-wheat system by introducing vegetable pea in between rice and wheat and a cultivation of summer mung/ sesbania, etc. also need to be popularized. In addition, efforts are needed for popularizing farm machines like rotary disc drill, happy seeder, rotavator, etc. for cost effective higher productivity.

I would like to emphasize that the grain quality aspects have not been paid adequate attention and hence, there is an urgent need to initiate regional programs for breeding for quality traits and to restructure our research agenda focusing on quality aspects without compromising on the high yield, adaptation and rust resistance. It is essential to create facilities for screening material to identify high molecular weight (HMW) banding pattern, sedimentation value and atomic absorption to estimate levels of micronutrients. More and more emphasis need to be placed on the development of product specific varieties suitable for making good quality noodles, biscuits, pastas, breads, chapattis, etc. The quality improvement work should be based on genetic information and molecular markers available for use in breeding program.

You all will agree that we have to be prepared for new challenges as population in Asia is increasing at a faster rate and a demand for additional production of wheat is estimated to be around 230 million tons by the year 2030. This will call for the integration of classical breeding approach and new cutting edge molecular tools involving different disciplines. The issue of narrow genetic variability, recombinant DNA technology and hybrid wheat are to be addressed in time bound manner for bringing a paradigm shift in varietal development to make desirable progress.

I would like to emphasize that we need to devise and follow innovative ways in developing technologies. We should try to bring about novel changes in wheat plant. Can it be possible to transform $C_3$ wheat plant into a $C_4$ system which is physiologically more efficient system than $C_3$? Such a change may prove to be a boon to wheat plant under changing climatic conditions. Will it be a reality in this age of biotechnology to infuse 'Nif' genes into wheat? Under the present situation when the soil health is largely at stake, the self-sustaining system for nitrogen supply to wheat plant is very much needed.

I am sure that the research managers, researchers and other stakeholders representing various disciplines and programs would deliberate during these two days and come out with the road map to addresses major issues to plan future research strategies so as to overcome the anticipated problems of wheat production in Asia for the years to come.

I wish the regional consultation a great success.

*Annexure III*

# Technical Program

**Thursday, April 26, 2012**

Registration: 08:30 – 09:00

**Inaugural Session**

| | | |
|---|---|---|
| 09:00 - 09:15 | Welcome and Brief on Consultation | Raj Paroda, APAARI |
| 09:15 - 09:25 | Special Remarks | Masa Iwanaga, JIRCAS |
| 09:25 - 09:40 | Chairman's Address | Thomas Lumpkin, CIMMYT |
| 09:40 - 10:00 | Inaugural Address | Hiroyuki Konuma, FAO |
| 10:00 - 10:05 | Vote of Thanks | Subash Dasgupta, FAO |
| 10:05 - 10:30 | *Tea/Coffee Break and Group Photograph* | |

**Technical Session I: Strategy for Increasing Wheat Productivity**

*Chair* : S. Nagarajan, PPVFRA
*Co-Chair* : Mirdad Panjsheri, MAIL
*Rapporteur* : Gyanendra Singh, DWR

| | | |
|---|---|---|
| 10:30 - 11:00 | Strategy for wheat improvement in Asia | Hans J. Braun, CIMMYT |
| 11:00 - 11:20 | Strategy for increasing wheat productivity | S. Rajaram, ICARDA |
| 11:20 - 11:40 | Germplasm conservation through use and role of biotechnology in wheat improvement | K.C. Bansal, NBPGR |
| 11:40 - 12:00 | Hybrid wheat and herbicide tolerance research at MAHYCO | Usha Barwale Zehr, MAHYCO |
| 12:00 - 12:20 | Regional collaboration for wheat in Asia | A.K. Joshi, CIMMYT |
| 12:20 - 13:00 | Discussion | |
| 13:00 - 14:00 | *Lunch* | |

**Technical Session II: National/Regional Wheat Scenario**

*Chair* : Thomas Lumpkin, CIMMYT
*Co-Chair* : Shahid Masood, PARC
*Rapporteur* : S.S. Singh, National Consultant, Govt. of India

| | | |
|---|---|---|
| 14:00 - 14:15 | Country Report : Bangladesh | Jalal Uddin, WRC |
| 14:15 - 14:30 | Country Report : China | Alain Bonjean, LIMAGRAIN |
| 14:30 - 14:45 | Country Report : India | Indu Sharma, DWR |
| 14:45 - 15:00 | Country Report : Iran | Abdolali Ghaffari, IDLARI |
| 15:00 - 15:15 | Country Report : Nepal | Dhurba Bahadur Thapa, NARC |
| 15:15 - 15:30 | *Tea/Coffee Break* | |
| 15:30 - 15:45 | Country Report : Pakistan | Shahid Masood, PARC |
| 15:45 - 16:00 | Country Report : Mongolia | Tuul Dooshin, MFALI |
| 16:00 - 16:15 | Country Report : Afghanistan | Mirdad Panjsheri, MAIL |
| 16:15 - 16:30 | Report on Central Asia | R.C. Sharma, ICARDA |
| 16:30 - 17:00 | Discussion | |
| 17:00 - 18:30 | Working Groups | Moderator |
| | 1. Research Priorities and Need Assessment | H.S. Gupta, IARI |
| | 2. Development Initiatives for Inclusive Growth | Subash Dasgupta, FAO |
| 19:00 | *Reception Dinner* | |

**Friday, April 27, 2012**

**Technical Session III: Managing Wheat Diseases**

*Chair* : Ronnie Coffman, Cornell University
*Co-Chair* : Robert Park, University of Sydeny
*Rapporteur* : Etienne Duveiller, CIMMYT

| | | |
|---|---|---|
| 08:30-08:50 | Global initiative for managing wheat rusts | Ronnie Coffman, Cornell University |
| 08:50 - 09:10 | Wheat diseases and climate change in Asia | S. Nagarajan, PPVFR |
| 09:10 - 09:30 | Managing wheat rusts by using minor genes | Robert Park, University of Sydeny |
| 09:30 - 09:50 | Management of wheat diseases in Asia | Etienne Duveiller, CIMMYT |
| 09:50 - 10:10 | Integrated management of wheat rust diseases : approach of FAO | Fazil Dusunceli, FAO |
| 10:10 - 10:30 | Discussion | |
| 10:30 - 11:00 | *Tea/Coffee Break* | |

**Technical Session IV: Stakeholders Dialogue on CRP 3.1 (Wheat)**

*Chair* : Raj Paroda, APAARI

*Co-Chair* : Hans Braun, CIMMYT

*Rapporteur* : A.K. Joshi, CIMMYT

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|---|---|---|
| 11:00 - 11:30 | Objectives, strategies and stakeholders' involvement in CRP 3.1 (Wheat) | Hans Braun, CIMMYT |
| 11:30 - 13:00 | General Discussion | |
| 1300-1400 | *Lunch Break* | |

**Technical Session V: Addressing Emerging Challenges**

*Chair* : Masa Iwanaga, JIRCAS

*Co-Chair* : R.R. Hanchinal, UAS Dharwad

*Rapporteur* : M.L. Jat, CIMMYT

| | | |
|---|---|---|
| 14:00 - 14:15 | Promoting conservation agriculture in Indo-Gangetic Plains | M.L. Jat, CIMMYT |
| 14:15 - 14:30 | Conservation agriculture for improved wheat production in Pakistan | Mustaq Ahmad Gill, DOA |
| 14:30 - 14:45 | Impact of climate change on wheat productivity | S. Naresh Kumar, CECRA |
| 14:45 - 15:00 | Developing terminal heat tolerant wheats | J. Rane, NIASM |

| | | |
|---|---|---|
| 15:00 - 15:15 | Improving quality traits in wheat | R.K. Gupta, DWR |
| 15:15 - 15:30 | Current status and future strategies for seed production in Asia | H.S. Gupta, IARI |
| 15:30 - 15:50 | *Tea/Coffee Break* | |
| 15:50 - 16:20 | Discussion | |

**Plenary Session**

| | | |
|---|---|---|
| | *Chair* : Hiroyuki Konuma, FAO | |
| | *Co-Chair* : Thomas Lumpkin, CIMMYT | |
| | *Rapporteur* : Bhag Mal, APAARI | |
| 16:30 - 17:00 | Sessions' recommendations | Rapporteurs |
| 17:00 - 17:20 | Remarks by Co-Chairs | Thomas Lumpkin, CIMMYT<br>Raj Paroda, APAARI |
| 17:20 - 17:30 | Concluding remarks by Chair | Hiroyuki Konuma, FAO |
| 17:30 - 17:35 | Vote of thanks | Bhag Mal, APAARI |

*Annexure IV*

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