Strategic Research Agenda

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Note

The Wheat Initiative wishes to thank the many people who have contributed to this document and in particular, those who responded to the stakeholder consultation as well as the members of the consolidation task-force who included representatives from the Scientific Board, the Research Committee and the Institutions' Coordination Committee of the Wheat Initiative. We also would like to thank the Expert Working Groups and the Research Committee who provided their input in the Strategic Research Agenda. Finally, we thank all the Wheat Initiative Members who are contributing to the progress of the Wheat Initiative.

This Strategic Research Agenda builds on the "International Vision for Wheat Improvement" Document elaborated in May 2013. It is an evolving agenda that will be updated to reflect the developing challenges and demands as needed.

Contents

Executive Summary

To meet the expected 60% increase in demand for wheat by 2050 in a sustainable and resilient way, more research is needed through significant investment and collaboration between public and private partners.

The Wheat Initiative was established in 2011 under the aegis of the G20 Ministries of Agriculture to address this challenge by coordinating international research efforts on wheat and by providing opportunities for an increased and more efficient utilisation of resources through the alignment of national and regional activities and pooling of resources.

This Strategic Research Agenda builds on the Wheat Initiative Vision Document launched in May 2013. It has been designed to set out clear policy-relevant wheat research priorities for the short (1-5 years), medium (5-10 years) and long term (>10 years), and to list the strategic actions needed to address these priorities.

The **key challenges and priorities** for wheat research are organised around four thematic core themes:

(1) Increase wheat yield potential,
(2) Protect yield potential,
(3) Protect the environment and increase the sustainability of wheat production systems,
(4) Ensure the supply of high quality, safe wheat,

and two cross-cutting themes:

(5) Enabling technologies and shared resources,
(6) Knowledge exchange and education.

The Strategic Research Agenda identifies **game-changers** that will allow the efficient delivery of improved wheat cultivars adapted to target environments, including:

- A fully assembled and aligned wheat genome sequence - to access and understand the richness of wheat genetic diversity;
- The availability of all wheat data via an open information exchange framework, supporting the understanding of the interaction of genotype, environment and crop management on the phenotype - to allow for prescriptive wheat breeding;
- The ability to build new combinations of alleles - to increase the deployment of natural and engineered genetic variability in inbred or hybrid wheat cultivars.

In addition, the Strategic Research Agenda recognises the importance of other **underlying priorities**:

- Continued support for existing activities aimed at yield improvement through conventional breeding methods, using existing germplasm and molecular technologies;
- Understanding the genetic, molecular and physiological basis of traits of agronomic and nutritional importance, as well as the identification of gene networks involved in their expression;
- Integrating genetics and agronomy to allow the development of sustainable growing systems accommodating ever-improving cultivars with high yield potential;
- Supporting the development of a global public-private community of wheat researchers sharing knowledge and information that self-perpetuates and expands by means of training and education.

The Wheat Initiative Strategic Research Agenda provides a unique opportunity for policy makers, public research organisations and industry to work together to address the challenges identified and contribute to global food security through a sustainable increase of wheat production.

Introduction

A key factor in the stability of human societies is a reliable and affordable food supply. Food security, as defined during the 1996 World Food Summit, "[…] exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Wheat occupies a central place in human nutrition in numerous regions of the world. Farmers cultivating millions of hectares in developed and developing countries often have no alternative to wheat as the most economically efficient and nutritious cereal in those regions. In a world of rising population and changing diets an important research effort is needed to increase wheat productivity per land area, to avoid production losses due to pathogens and a changing climate, as well as to increase the quality and safety of wheat products, while participating in the global efforts to minimise the impact of agriculture on the environment.

The Wheat Initiative identifies priorities and coordinates the international research efforts on wheat by providing opportunities for an increased and more efficient utilisation of resources than is currently achievable, through the alignment of national activities and pooling of resources to avoid duplication, fill gaps and create critical mass.

THE CHALLENGE: IMPROVING WHEAT PRODUCTIVITY, QUALITY AND SUSTAINABILITY

Wheat is the most widely grown crop in the world and provides 20% of the daily protein and food calories. It is the second most important food crop in the developing world after rice. In recent years, wheat production levels have not satisfied demand, triggering price instability, hunger riots, and government instability. With a predicted world population of over 9 billion by 2050 (UN Population Division), the demand for wheat will increase by 60% compared with 2010. To meet this demand, global annual yield increases must rise from the current level of 1% per year (2001-2010) to 1.6% per year (2011-2050).

All wheat producing countries share an urgent need to increase the rate of genetic gains for yield, tolerance to abiotic stresses, resistance to pathogens and pests, as well as to improve input use efficiency for sustainable wheat production, while ensuring high quality, safe and nutritious food products. To take full advantage of wheat genetic potential, improved agronomic practises and the development of innovative cropping systems are paramount. These challenges can be met through an unprecedented effort from the wheat research community to increase and coordinate funding at the international level.

COORDINATING WHEAT RESEARCH AND CONTRIBUTING TO FOOD SECURITY

Created in 2011 following endorsement from the G20 Agriculture Ministries, the Wheat Initiative provides a framework to establish strategic research and organisation priorities for wheat research at the international level in developed and developing countries alike. The Wheat Initiative fosters communication among the research community, funders and global policy makers, and aims to secure efficient and long-term investments to meet the global wheat research and development goals.

The success of the Wheat Initiative depends on the engagement of the global wheat community in its fullest sense. All countries, companies, stakeholders and NGOs interested in wheat improvement are welcome to participate and contribute to the development of this global research coordination platform, to improve food security and resolve the urgent challenge of sustainably providing enough safe, nutritious and affordable food for a growing world population.

WHEAT INITIATIVE VISION AND MISSION

The Wheat Initiative aims to encourage and support the development of a vibrant global public-private research community by sharing resources, capabilities, data and game changing ideas and technologies to improve wheat productivity, quality and sustainable production around the world.

To answer the challenges of wheat research internationally, the Wheat Initiative:

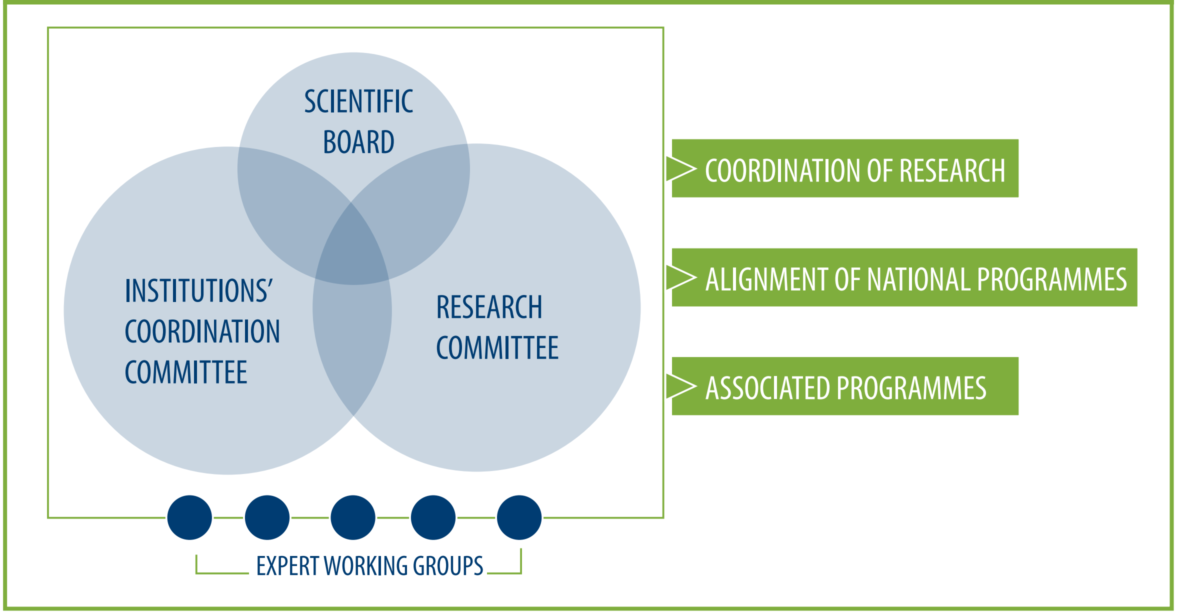
- Has developed a dynamic global Strategic Research Agenda for wheat research through the identification of priorities and challenges beyond the capacity of single research groups and countries, which can be best addressed by international coordination and communication between researchers, research institutions and funding organisations;
- Encourages efficient investment in wheat research based on the capabilities and synergies of national and international programmes;
- Stimulates the development of new collaborative programmes and coordinated actions across developing and developed countries;
- Develops, communicates and coordinates knowledge sharing amongst the international wheat research community;
- Improves access for all to knowledge, resources, services and facilities;
- Supports education of students and life-long learning of wheat researchers and informs stakeholders and consumers;
- Stimulates public-public, public-private and private-private collaborations.

DEVELOPMENT OF THE WHEAT INITIATIVE STRATEGIC RESEARCH AGENDA (SRA)

The Wheat Initiative SRA builds on the Wheat Initiative International Vision for Wheat Improvement[1]. It provides a framework for public and private research organisations, funding agencies and policy makers to coordinate efforts through shared implementation plans.

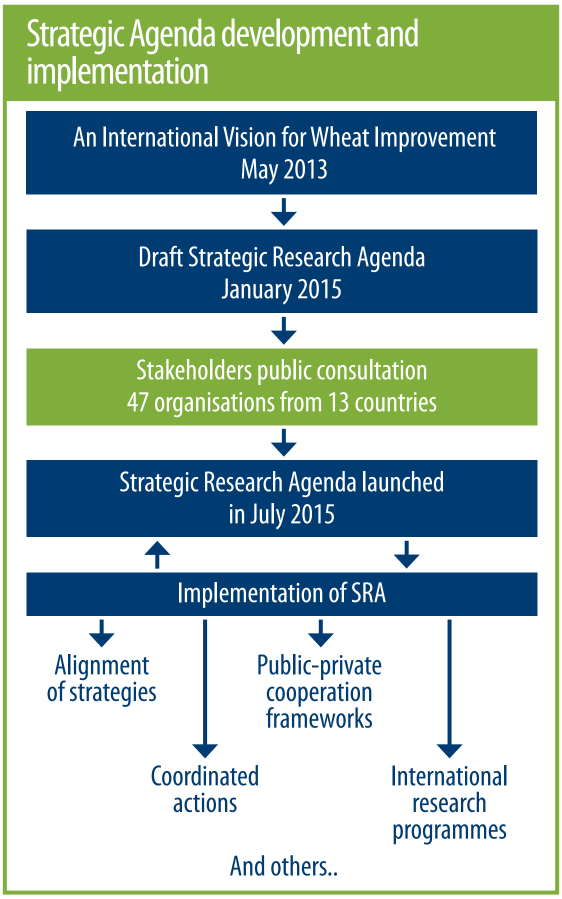
The Wheat Initiative SRA was developed through an iterative process involving the Wheat Initiative Scientific Board and Research Committee, which both contributed to the definition of its core themes and their content. Expert Working Groups of the Wheat Initiative, also open to non-members of the Wheat Initiative, were consulted on the research priorities. Given this broad consultation, the SRA reflects the priorities of the global public and private wheat research community.

Organisation and impact pathway of the Wheat Initiative



The Wheat Initiative fosters communication between the international wheat research community, funders and global policy makers through interactions between its Research Committee, Institutions' Coordination Committee and Scientific Board, in which sit representatives from its members (see Annex 1). The Expert Working Groups of the Wheat Initiative provide members with expert knowledge and strategic advice on specific research areas.

[1] Available at: http://www.wheatinitiative.org/sites/default/files/attached_file/wheatinitiative_visiondocument.pdf



The Wheat Initiative Institutions' Coordination Committee provided input to the SRA and organised an open consultation of Stakeholders. The 47 responding organisations broadly endorsed the draft SRA, and their views were valuable in shaping the final document and in some cases to define the research priorities more precisely.

The SRA has sought to represent the current views of the wheat community and stakeholders about the key challenges facing wheat research globally and the actions that will be needed to address these challenges. Technology is changing rapidly with new techniques and resources being developed for studying biological systems. Similarly, the issues facing wheat producers and end users are in continuous flux. The role of the Wheat Initiative will also change over time as new partners come on board and new international research programs are developed. The Strategic Research Agenda will need to be adapted to reflect these changes. Therefore, a process of regular review and update of the Strategic Research Agenda will be undertaken by the Expert Working Groups, Associated Programmes and the different committees of the Wheat Initiative.

DELIVERY OF THE STRATEGIC RESEARCH AGENDA PRIORITIES

The Wheat Initiative SRA identifies research priorities that can best be tackled at the international level through integrated or coordinated action.

Countries and companies wishing to contribute to the SRA implementation should develop mechanisms to work together and answer the challenges identified. The Wheat Initiative will create a dialogue among its members to define the initial global priorities.

Individual members will then have the opportunity to identify their strengths and networks to underpin areas identified in the SRA.

For each priority area of the Strategic Research Agenda, implementation plans will be developed, largely through the Expert Working Groups or the Associated Programmes. These groups will also monitor progress of the implementation plans and provide regular updates.

The Institutions' Coordination Committee will develop a portfolio of mechanisms to facilitate the efficient delivery of the SRA. This will include encouragement of active research collaborations, alignment of strategies to the Wheat Initiative research priorities at the national, regional or company level, joint-funding mechanisms such as the EU Horizon2020 ERA-NETs, public-private cooperation frameworks, as well as international calls for coordinated research programs. "A la carte" programmes will also be developed where countries participate voluntarily on the basis of their respective political and financial commitments and strategies.

A global database for wheat research will be developed to provide access to information on and for researchers and policy-makers outlining who is doing what, where and with whom. This will facilitate collaboration and coordination of research.

The overall progress of the Wheat Initiative in implementing and updating the Strategic Research Agenda will be monitored to ensure that it fulfils its objective of coordinating the international research efforts on wheat and providing opportunities for efficient utilisation of available capabilities and resources through alignment of national activities to international priorities.

Wheat Research Key Challenges and Priorities

The strong rise in wheat yields has been associated with genetic improvements in yield potential, resistance to diseases and pests, adaptation to abiotic stresses, and advances in agronomic practises from the green revolution in the 1960's to the early 1990's. However, the rate of increase in wheat productivity has slowed, with large variations of yield between countries. Genetic yield increases of up to 1% per year have been achieved historically, but global 'on-farm' wheat yields are beginning to plateau in many wheat producing areas.

In order to increase wheat production by at least 60% by 2050, several targets were identified in the Wheat Initiative Vision Document:

- Increasing the yield potential of wheat cultivars;
- Closing the yield gap on under-performing land and increasing the sustainability of cropping systems;
- Monitoring wheat diseases and developing wheat cultivars with durable resistance;
- Increasing resource use efficiency and tolerance to abiotic stress;
- Improving the nutritional and processing quality and safety of wheat cultivars;
- Tailoring wheat cultivars and types to diverse agro-ecosystems and production systems;
- Supporting implementation of modern breeding methods by all breeders;
- Ensuring access to shared platforms and standards;
- Benefiting from a Wheat Information System to provide easy access to data and information.

STRATEGIC RESEARCH AGENDA THEMES

The Wheat Initiative Strategic Research Agenda (SRA) was developed with the aim of achieving these targets in 2030 and beyond through partnerships between private and public organisations.

The SRA is organised into four thematic core themes and two cross-cutting themes.

The SRA has been designed to set out clear policy-relevant research priorities for the short (1-5 years), medium (5-10 years) and long term (>10 years), and to list the strategic actions needed to address these priorities.

Wheat Initiative SRA themes

1 - INCREASE WHEAT YIELD POTENTIAL

2 - PROTECT YIELD
- Controlling wheat diseases and pests
- Improving wheat tolerance to abiotic stress

3 - PROTECT THE ENVIRONMENT AND INCREASE THE SUSTAINABILITY OF WHEAT PRODUCTION SYSTEMS
- Nutrient use efficiency
- Agronomy and crop management

4 - ENSURING THE SUPPLY OF HIGH QUALITY, SAFE WHEAT PRODUCTS

5 - ENABLING TECHNOLOGIES AND SHARED RESOURCES

6 - KNOWLEDGE EXCHANGE AND EDUCATION

OUTSTANDING GAME-CHANGERS

It is foreseen that wheat production will be revolutionised in the future by a few game-changing breakthroughs allowing for more efficient delivery of improved wheat cultivars adapted to their environment, in combination with achievements in several areas of research as described elsewhere in the Strategic Research Agenda.

- The richness of wheat genetic diversity will be accessible and understood by comparison with a fully assembled wheat reference genome sequence; full annotation of the wheat genome will provide access to its functionalities.
- Wheat data and analysis tools will be available to all via an open information exchange framework supporting the understanding of the interaction of genotype, environment and crop management on the phenotype to allow for prescriptive wheat breeding.
- New combinations of desirable alleles in inbred or hybrid wheat cultivars will be created through increased deployment of natural and engineered genetic variability, via the characterisation of the existing wheat and related species germplasm as well as by the generation of new genetic resources by all available and emerging methods (including genome editing, control of meiotic recombination, use of wheat relatives, transgenesis).

Game-changers

Fully assembled and annotated wheat genome reference sequence

Wheat scientific data and analysis tools available to all via a dedicated global information system

Increased deployment of natural and engineered genetic variability allowing new combinations of desirable alleles in wheat varieties

UNDERLYING KEY PRIORITIES

In addition, it will be of utmost importance to maintain a continued support for existing activities aimed at yield improvement through conventional breeding methods, using existing germplasm and molecular technologies.

Major improvements will be achieved for traits of agronomic, processing and nutritional importance (yield potential, interaction with pathogens and pests as well as with beneficial microorganisms, tolerance to abiotic stress, nutrient use efficiency, technological and nutritional quality) through the understanding of their genetic, molecular and ecophysiological basis as well as the identification of the gene networks involved in their expression and their interaction with the environment.

The integration of genetics and agronomy will allow the development of sustainable growing systems that will use appropriate germplasm and will be dynamic enough to accommodate ever-improving cultivars with higher yield potential.

The deployment of new breeding technologies and improved crop management will make it possible to increase wheat yield potential and close the on-farm yield gap in different wheat growing areas, while minimising the impact of agriculture on the environment and addressing global change challenges.

Outstanding partnerships between private and public organisations will need to be established to deliver an increase in yield of greater than 1% per annum. New ways of broadly sharing knowledge and germplasm, free from the limitations and hindrances of restricted intellectual property (IP) use, but allowing value capture mechanisms to support private investment will be essential.

Coordinated public and private investment and development of global partnerships in the key priority areas identified in the Wheat Initiative Strategic Agenda will ensure the stable and sustainable delivery of research outputs. Translation of research achievements into innovations by a new generation of breeders throughout the world and their adoption by farmers and consumers will allow a 60% increase in wheat production in 2050 thereby contributing to global food security and safety.

CORE THEME 1
Increase wheat yield potential

CHALLENGE
Increasing wheat yield potential

ASPIRATION
Wheat cultivars with yield potential enhanced by up to 50% in 2040

CHALLENGE

Increasing wheat yield potential

Yield increases of up to 1% per year have historically been achieved in some regions of the world, but not all. This global increase was obtained by a combination of increased genetic yield potentials and improved crop management practices. Yield potential is defined as the yield of a cultivar when grown in environments to which it is adapted, with non-limiting nutrients and water and with pests, diseases, weeds, lodging, and other stresses effectively controlled. Wheat yield potential differs according to the environment in which it is grown. The challenge will be to further increase the yield potential in wheat cultivars adapted to diverse environments and cropping systems by improving the efficiency of light interception and conversion into biomass by photosynthesis and of partitioning into grain.

ASPIRATION

Wheat cultivars with yield potential enhanced by up to 50% in 2040

AIMS AND OBJECTIVES

The current ceiling of genetic yield potential is likely to be the result of constraints in many processes in the scheme of carbon capture, biomass accumulation and redistribution into grain. The biology of yield is very complex and therefore needs to be tackled by a diversity of approaches including:

- Increasing our understanding of the genetic and physiological basis of yield potential;
- Modelling yield potential in different regional areas/conditions and defining adapted ideotypes;
- Improving light interception in the canopy by modifying plant and ear architecture;
- Enhancing solar energy conversion efficiency in wheat by optimisation of photosynthesis;
- Optimising plant phenology, development and partitioning to maximise grain yield;
- Transferring discoveries and technology breakthroughs obtained in other species into wheat.

Most of these aims are in the scope of the International Wheat Yield Partnership (IWYP). In addition, increasing the resilience of yield to climate change through improvements in yield stability should allow consistently high yields over multiple years and environments.

RESEARCH NEEDS

Breeders can deliver new cultivars with higher yield potential if provided with the germplasm, resources and the tools to do it, as shown by the success that has been achieved to date by private and public breeders in the developed and developing world. However, the current rate of gain is insufficient and significant investment to develop more robust programmes and large international and public-private partnerships are needed. Fundamental and applied research will contribute to enhancing genetic gain for yield potential and is required to translate it to final products (cultivars) and information on how to grow them. These requirements can be translated into four key research activity areas that cover the topics identified above:

- Increasing the knowledge base for improving yield potential, including the genetic control of yield components, physiological and biochemical processes that can increase biomass and harvest index, the optimisation of phenology and plant architecture, the identification or generation of variation in the efficiency of photosynthesis in wheat germplasm;
- Utilising game-changing breeding methods and the latest technologies to improve the effectiveness of breeding for yield potential, such as the use of hybrids, application of 'omics', bioinformatics, and genomic selection;
- Developing new genetic resources for breeders with tools such as interspecific crosses, targeted mutation and genetic engineering.
- Exploiting research results from other genera to improve yield in wheat.

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PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Coordination of yield testing protocols and networks and germplasm exchange
Medium-term (5-10 years)	• Develop new germplasm adapted to different environments and cropping systems with enhanced yield potential for distribution to breeders • Increase knowledge of the underlying physiology, biochemistry and genetics of yield and yield components together with Genotype x Environment x Management (G x E x M) interactions • Apply new breeding and selection strategies to yield and yield stability, such as hybrids and genomic selection
Long-term (>10 years)	• Novel germplasm generated through new technologies, such as genome editing and genetic engineering

ON-GOING INTERNATIONAL ACTIONS

- International Wheat Yield Partnership (IWYP)
- CGIAR Research Program on Wheat (WHEAT CRP), Flagship Projects (FP) 2 and 3

WHEAT INITIATIVE ACTIONS

- Support IWYP through promotion and provision of support where requested
- Monitor global activities and identify any unfulfilled research needs
- Promote and support new international actions where requested

Associated Programme
International Wheat Yield Partnership

CORE THEME 2
Protect yield potential

CHALLENGES

Protecting wheat from yield losses due to pests and diseases

Maintaining yield under highly variable environmental conditions

ASPIRATIONS

Wheat cultivars with durable resistance to most major pests and diseases

Wheat cultivars better adapted to diverse environmental conditions in terms of yield and yield stability under stress

SUBTOPIC 2.1 CONTROLLING WHEAT DISEASES AND PESTS

CHALLENGE

Protecting wheat from yield losses due to pests and diseases

Up to 20% of the global wheat production is estimated to be lost each year due to diseases and pests. This amounts to 140 million tonnes ($35 billion dollars at $250/ton) of estimated wheat crop loss in 2012 (FAOSTAT 2014). Globally, current wheat yields would not be achievable without the application of chemical protectants, in particular in developed countries. However, concerns about health and environment call for reduction of chemicals when possible, and for their replacement by cultivars resistant to diseases and pests, which are the prerequisite for environmentally and consumer friendly wheat production. Many farmers in developing countries depend on resistant cultivars. However, most resistance genes, as well as chemical strategies, can be overcome by rapidly evolving pathogens. The occurrence of the new stem rust race Ug99, virulent on 90% of all cultivars grown world-wide when it was detected, yellow rust races adapted to higher temperatures than previous races, potential emerging diseases like wheat blast or the rapidly increasing importance of *Fusarium* species causing head scab but also crown and root rot call for more investments in developing wheat cultivars with durable resistance and/or in managing available resistances.

Major wheat pathogens include rusts (yellow, brown and stem rust), powdery mildew, *Fusarium* species producing mycotoxins in the grain leading to its unsuitability for human or animal consumption, and necrotrophic pathogens developing upon dead tissues such as some *Septoria* and *Pyrenophora* species.

ASPIRATION

Wheat cultivars with durable resistance to most major pests and diseases

AIMS AND OBJECTIVES

While sustained increases in wheat yields are needed to meet future demands, the remarkable ability of pests and pathogens to mutate, produce novel toxins, or otherwise adapt to overcome resistance makes breeding for durable resistance a considerable challenge. Many diseases and pests impact wide international wheat growing zones while others cause local or regional epidemics.

Deployment of host resistance to diseases and pests is the most effective and environmentally sound way of plant protection, as has been demonstrated recently by the Borlaug Global Rust Initiative (BGRI) in the case of resistance against the stem rust race Ug99 which is threatening wheat production in Africa and Asia. Indeed global coordination of efforts are needed to develop management and gene stewardship deployment strategies with the ultimate aim of achieving broad spectrum and durable disease resistance in wheat crops. This will involve:

- Continued identification of novel sources of disease and pest resistance including the newest technologies of phenotyping to broaden the genetic base of resistance against primary wheat pathogens and pests;
- Development of diagnostic genetic markers to assist breeding programmes in the development of disease resistant cultivars;
- Deep knowledge on wheat-pathogen interactions, in relation with the environment and management systems, and use of this knowledge for the development of new resistance strategies;
- Monitoring of pathogen populations for their ability to overcome resistance genes;
- Understanding the impact of climate change on pathogens in order to assess potential new epidemics;
- Deployment of cis/transgenes to augment strategies towards durable disease resistance;
- Coordinated efforts in pre-breeding and breeding programmes to optimise strategies for the efficient use of resistance genes in wheat and to ensure their sustainable deployment by developing resistance management systems.

RESEARCH NEEDS

To improve resistance of wheat to pests and diseases, an efficient collaboration between phytopathologists, geneticists, molecular biologists and breeders is needed to cover the whole chain from the identification of new races of pathogens, the development of new resistant cultivars to integrated pest management.

There are two key factors for improving resistance of wheat to diseases and pests: pathogen surveillance and the identification of new sources of resistances in the wheat gene pool. Completed in parallel, it will be possible to develop novel wheat management regimes that resist the most economically important wheat pathogens and pests.

Identified resistance sources will be analysed in terms of the genetics of the respective resistances followed by the development of molecular markers and the development of efficient (pre-breeding) strategies for marker-based introgression ideally as multiple gene combinations into adapted cultivars.

Genomic tools currently available in wheat and developments in the near future will pave the way for resistance breeding at the allele level. To achieve this, special emphasis has to be given to the isolation of resistance genes from wheat and wild relatives on a large scale, especially for those proven to confer durable resistance.

Knowledge of the sequence of resistance genes will facilitate the detection of the natural allelic diversity and the estimation of the effectiveness of different alleles and provide an opportunity for the creation of new, functional alleles by site directed mutagenesis. With the development of genome editing techniques it will also be possible to perform targeted editing of genes conferring susceptibility with the goal of generating novel resistant phenotypes. Furthermore, isolated genes will facilitate a better understanding of genetic networks leading to resistance in order to improve resistance and to create durable resistances.

Besides research on the host's natural resistance, a deeper understanding of the biology of wheat pathogens and their evolution is needed with respect to wheat-pathogen interactions, effector diversity and the epidemiology of diseases. This also holds true for knowledge concerning the effect of the wheat microbiome on resistance.

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PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Identification and characterisation of novel sources of resistance to the main wheat diseases • Exchange germplasm and markers associated with resistance loci
Medium-term (5-10 years)	• Genomics-based surveillance of pathogen populations and epidemiology in routine use • Novel resistance mechanisms identified • Durable resistance to several diseases present in many cultivars
Long-term (>10 years)	• Comprehensive understanding of genetic networks of resistance against primary pathogens • Deployment of durable resistance to multiple pests and diseases

ON-GOING INTERNATIONAL ACTIONS

- Borlaug Global Rust Initiative – Wheat Rusts
- WHEAT CRP, FP 3
- National programs (public and private) targeting regionally important diseases and pests
- ENDURE EU network (Fusarium)
- International Fusarium and Fusarium Genomics Workshops

WHEAT INITIATIVE ACTIONS

- Coordinate research in the area by:
  - Developing the EWG – Control of wheat pathogens and pests
  - Linking with the EWG – Wheat Germplasm Conservation and Use Community
- Facilitate access to technologies
- Support the BGRI
- Support the development of an international program on necrotrophic pathogens

SUBTOPIC 2.2 IMPROVING TOLERANCE OF WHEAT TO ABIOTIC STRESS

CHALLENGE

Maintaining yield under highly variable environmental conditions

Environmental stresses, particularly heat and drought but also salinity, soil acidity, frost and many other factors severely limit wheat production globally. Wheat yield models indicate that a 1°C temperature increase has the potential to restrict wheat yields by 10% in some parts of the world and that the wheat producers in South Asia and North Africa will be hit hardest by climate change. Wheat yield in 2050 could decline by 27% compared with 2000 in some regions under the predicted climate change scenarios.

ASPIRATION

Wheat cultivars better adapted to diverse environmental conditions in terms of yield and yield stability under stress

AIMS AND OBJECTIVES

In most production environments, multiple abiotic stresses challenge wheat plants simultaneously. While tolerance to some stresses is under simple genetic control, others are regulated by multiple interacting genetic mechanisms. Managing tolerance to abiotic stresses will require:

- Characterisation of the environmental and abiotic stresses that limit wheat production in different regions of the world, including assessing the impact of climate change, and development of conceptual models of adaptation to different mega-environments;
- Development of techniques for assessing stress adaptive characteristics of germplasm under field conditions as well as under controlled conditions where appropriate;
- Identification of sources of tolerance to individual stresses and combinations of stress from a broad base of genetic resources;
- Genetic, physiological and biochemical analysis of stress response pathways and processes in wheat;
- Refinement of genetic and physiological models for enhanced stress tolerance;
- Building resilience into cultivars so that they can cope with variable environmental conditions;
- Isolation of genes and alleles underlying stress tolerance loci.

RESEARCH NEEDS

Research needs to address the complexity of stresses faced by wheat producers across highly diverse production environments. Higher plants have evolved multiple, interconnected strategies that enable them to survive unpredictable environmental fluctuations. However, these strategies are not always well developed in the cultivars grown by wheat producers and most of the strategies used in model non-crop species are focused on plant survival at the expense of yield.

The Intergovernmental Panel on Climate Change has predicted that rising temperatures, drought, floods, desertification and weather extremes will severely affect agriculture. For wheat, the genetic control of traits determining yield in water limited and low yielding environments are generally expected to be of low heritability, polygenic and many of the key loci will show epistatic rather than additive effects. Breeding and genetic techniques need to detect and select for these types of loci while also accounting for factors such as maturity, height, resistance or tolerance to soil borne diseases. Tolerance to related stresses such as boron, acidity, salinity and nutrient deficiencies must also be taken into account.

While breeders have been successful in improving performance through direct selection for lines under a range of environmental condition, the opportunity now exists to integrate other approaches. Areas where greater research activity will offer significant advances include:

- Climate modelling and monitoring, including the characterisation of the stresses and probability of stress in different wheat production environments;
- Statistical tools for the analysis of field and controlled environment trials;
- Comprehensive models of physiological and biochemical responses to stresses and stress combinations;
- Field phenotyping methods and well-characterised field sites that have been validated in breeding and gene discovery work;
- A wide range of genomics technologies;
- Studies of the impact of abiotic stress on grain quality;
- Information from other plant systems both crop and non-crop;
- Impact of cropping systems on managing stressful environments.

PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Standardisation of abiotic stress phenotyping techniques • Sharing well characterised germplasm with phenotypic and genotypic data to add value to existing studies
Medium-term (5-10 years)	• Genetic analysis of response to multiple abiotic stresses • Isolation of genes and alleles controlling performance under a range of abiotic stresses • Rapid introgression of stress resilient germplasm into breeding programs • Comprehensive databases of genetic, physiological and biochemical responses of wheat lines to abiotic stresses
Long-term (>10 years)	• Isolation of genes associated with yield stability – high yield under diverse environmental conditions • Maintaining yield in a 2 to 3°C warmer environment and improved adaptation to dry conditions

ON-GOING INTERNATIONAL ACTIONS

- WHEAT CRP, FP 2 and 3
- HeDWIC (Heat and Drought Wheat Improvement Consortium)
- DROPS, EURoot, WHEALBI – EU 7th Framework Program for Research

WHEAT INITIATIVE ACTIONS

- Support the development of HeDWIC
- Coordinate research in the area through development of the EWG – Adaptation of Wheat to Abiotic Stress
- Link with the EWGs:
  - Wheat Phenotyping to Support Wheat Improvement
  - Wheat Germplasm Conservation and Use Community
- Facilitate access to technologies
- Facilitate the development of a network of well-characterised sites for germplasm evaluation

Expert Working Group
Adaptation of Wheat to Abiotic Stress

CORE THEME 3
Protect the environment and increase the sustainability of wheat production systems

CHALLENGES

Improving nutrient use efficiency, defined as the quantity of grain that can be produced from a given amount of nutrient available in soil or applied as fertiliser

Close on farm yield gap and adapt to new production systems and regulations

ASPIRATIONS

Increase the efficiency of nutrient use so that the applied fertiliser is used by the crop, for example increase N use of over 60% of the applied amount

Develop highly stable wheat production systems that integrate novel genetic traits, deliver attainable yield goals and quality targets, enhance environmental sustainability, and mitigate production threats

SUBTOPIC 3.1 NUTRIENT USE EFFICIENCY

CHALLENGE

Improving nutrient use efficiency, defined as the quantity of grain that can be produced from a given amount of nutrient available in soil or applied as fertiliser

Adequate nutrition, and particularly nitrogen availability, is essential for optimal yield and quality of wheat crops. However, given economic and environmental costs, efficient use is essential. More than 25 Mt fertilisers are used annually on wheat with a global nitrogen (N) use efficiency as low as 30% and high discrepancies between regions. It is, for instance, estimated that N use efficiency is twice as high in Western Europe compared with India and China, and 50% more efficient than in the USA.

Micronutrients, particularly iron (Fe) and zinc (Zn), are important for both plant health and the nutritional value of the grain for humans. Rising CO_2 levels is expected to decrease levels of these nutrients in grain and higher yields are frequently associated with decreases in nutrient density.

ASPIRATION

Increase the efficiency of nutrient use so that the applied fertiliser is used by the crop, for example increase N use of over 60% of the applied amount

AIMS AND OBJECTIVES

There is a major opportunity for improvement in both the genetic and the agronomic components of wheat nutrient use efficiency, including:

- Enhancing use efficiency for all the macro- and micro-nutrients important for optimal crop production. Special focus should be given to nutrients that are either costly to produce and supplied in excess of plant requirements in some agro-ecosystems (e.g. N), derived from finite rock mineral resources (e.g. phosphorus), have negative environmental impacts if inappropriately used (e.g. N), and are essential elements of human and animal diets (e.g. Zn, Fe);
- Combining cultivars adapted to optimal agricultural practices (Subtopic 3.2) and optimising nutrient uptake by the roots, nutrient utilisation to produce biomass and nutrient translocation to the grain to ensure quality;
- Integration of genetics, ecophysiology, rhizosphere microbiology and symbiotic interactions to identify traits and chromosomal regions relevant for nutrient use efficiency improvement;
- Taking into account global change impacts on nutrient use for production and quality.

RESEARCH NEEDS

Research is needed to maximise capture, partitioning, and remobilisation of nutrients in the canopy to the grain through genetic improvement. Research will be targeted primarily to:

- Improve the capacity to phenotype nutrient use efficiency in a standardised way in terms of definitions and practical aspects such as controlling the environment to create defined nutrient availability and measurement technologies to evaluate the responses of the plant/crop at different physiological levels;
- Develop pre-breeding programmes to facilitate the use of genetic resources (landraces, synthetics, wild relatives) for traits that will enhance nutrient use efficiency. This may include further research on increasing leaf/canopy photosynthesis per unit of N using the existing genetic variability;
- Favour beneficial interactions with soil microorganisms and enhance the capability to capture N and other nutrients (root architecture, mycorrhizal/diazotroph associations, chemical and biological nitrification inhibitors, root exudation of organic acids);
- Identify loci and alleles involved in enhanced nutrient use efficiency. This approach may be combined with the development of crop simulation modelling, sensitivity analysis for nutrient use efficiency traits as well as the identification of chromosomal regions associated to model parameters.

PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Standardise definitions and phenotyping • Identify key traits and ideotypes
Medium-term (5-10 years)	• Identify natural variation for relevant traits • Quantify potential impacts in different environments and cropping systems • Identify favourable alleles for target genes • Develop molecular tools to breed cultivars which interact favourably with beneficial soil micro-organisms
Long-term (>10 years)	• Deploy germplasm with enhanced nutrient use efficiency • Develop wheats with high nutrient density in grain • Introduce the capacity to biologically fix atmospheric nitrogen

ON-GOING INTERNATIONAL ACTIONS

- WHEAT CRP, FP 2, 3 and 4
- CGIAR Research Program on Agriculture for Nutrition & Health: HarvestPlus
- International Geosphere Biosphere Program (IGBP) project «The International Nitrogen Initiative»
- COST action on Endophytes in Biotechnology and Agriculture (EU)
- B&MGF programmes on N-fixing cereals

WHEAT INITIATIVE ACTIONS

- Coordinate research in the area through the development of the EWG - Nutrient Use Efficiency in Wheat
- Support the identification of favourable alleles for target genes linking with research in rice, barley and maize
- Link to projects aiming at introducing the capacity to fix atmospheric N_2

SUBTOPIC 3.2
AGRONOMY AND CROP MANAGEMENT

CHALLENGE

Close on farm yield gap and adapt to new production systems and regulations

The yield gap, as defined by the difference between the yield potential and the average farmers' yield in a given environment and time, varies enormously between regions of the world with different climate and cropping systems.

Crop management plays an important part in the expression of the genetic potential and in the sustainability of crop production systems.

- Roughly one-half of yield potential is realised through agronomic factors; thus, attainable wheat yield and improved system stability can only be achieved or possibly exceeded when genetics are coupled with innovative integrated crop management strategies, including those based on principles of conservation agriculture;
- If wheat used more of the annual rainfall (not just that from the growing season) grain yield could be increased. Enhanced water efficiency combined with emerging water use technologies and precision tools provide opportunities to reduce the gap;
- In addition to water, Nitrogen is the major limiting factor in wheat. Management strategies, including placement and foliar feeding should aim to enhance use efficiency and/or limit losses to groundwater or atmosphere;
- Agronomics must include components to minimise losses from diseases, weeds, or insect pests.

The best combinations of agronomic practices and genotypes will therefore improve the soil characteristics (pH, organic matter, water infiltration rate, water holding capacity), irrigation efficiency, drought tolerance, and reduce the chemical load brought in by fertilisers, pesticides and herbicides.

ASPIRATION

Develop highly stable wheat production systems that integrate novel genetic traits, deliver attainable yield goals and quality targets, enhance environmental sustainability, and mitigate production threats

AIMS AND OBJECTIVES

Bringing together experts from a broad range of disciplines will contribute to the refinement of wheat production systems to meet the global challenges facing wheat growers and end-users today and well into the future through:

- Site-specific technologies tailored to the needs of different production systems. An understanding of the trade-offs as agronomics are manipulated is needed so that the proposition of solutions is meaningful;
- Integration of new cultivars adapted to innovative and diversified management systems;
- Advancements in farming equipment (e.g. seeding equipment) and precision agriculture tools as key components of agronomic solutions and decision support systems.

These knowledge-based tools and next generation precision agriculture approaches will be key to enabling farmers to reach optimal wheat yield and quality with minimum resources irrespective of agro-ecological production areas.

RESEARCH NEEDS

Research is needed to develop highly productive and stable cropping systems with enhanced environmental sustainability. This will include:

- Development of holistic and integrated agronomic strategies to mitigate the negative impacts of climate change and to enhance environmental sustainability;
- Optimal crop residue management, no-till and cover crops;
- Development of site-specific resource optimisation, integrated nutrient management and wheat rotational strategies for the long-term sustainability and stability of wheat production systems;
- Integration of novel genetic traits and precision agriculture tools into innovative cropping systems;
- Intensified manipulation of agronomic factors to fully exploit wheat yield potential and technological quality to meet end-use requirements;
- Development of decision support systems to mitigate insect, weed and disease related threats to wheat production;
- Agronomics to improve both crop water use and efficiencies in rain-fed and irrigated moisture regimes;
- A knowledge transfer strategy to ensure uptake of new knowledge and innovations at the farm gate and to update scientists on changing field realities.

PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Build agronomic capability (highly qualified personnel and modernised equipment) in developing countries
Medium-term (5-10 years)	• Develop integrated crop management systems that provide agronomic solutions to close on farm yield gap • Develop location-specific resource optimisation (water, soil) technologies for the long-term sustainability of crop production • Further develop knowledge-based decision-making tools (incl. simulation models) and new generation of precision-agriculture approaches • Development of decision support systems
Long-term (>10 years)	• Further development of innovative wheat cropping systems • Develop new plant and crop ideotypes to take advantage of agronomic solutions and vice versa

ON-GOING INTERNATIONAL ACTIONS

- Global Yield Gap Atlas (http://www.yieldgap.org)
- WHEAT CRP FP 4
- Cereal Systems Initiative for South Asia (CSISA)

WHEAT INITIATIVE ACTIONS

- Establishment of an EWG bringing together agronomists, crop physiologists, soil scientists, breeders, entomologists, agricultural engineers, economists, extension experts to transfer knowledge, particularly from large national and international programmes with global outreach
- Facilitate discussions with complementary EWGs to develop future directions
- Support programs to build agronomic human capability in developing countries
- Further develop interactions between agronomists, plant breeders and pathologists to develop integrated pest management systems, to reduce the chemical load on the environment and to develop pest resistance gene stewardship

CORE THEME 4
Ensuring the supply of high quality, safe wheat

CHALLENGE

Producing safe and nutritious wheat with adequate end-use quality in an unstable climate

ASPIRATION

Production of nutritious and healthy wheat grains with adequate end-use quality to meet the demand from subsistence users to industry and produce the great variety of food products made from wheat

CHALLENGE

Producing safe and nutritious wheat with adequate end-use quality in an unstable climate

Wheat produces 20% of our daily protein and food calories. Wheat grain proteins are an important determinant of the quality of end-products such as bread and pasta but may also cause allergenic reactions. Grain carbohydrates affect food processing conditions, as well as the texture, shelf life, and digestibility of end products. Non-starch carbohydrates are of interest in reducing obesity and the incidence of cardiovascular diseases, type 2 diabetes and some cancers. Wheat is also an important source of dietary fiber, minerals and vitamins (notably B vitamins) in the human diet and also contains a wide range of bioactive phytochemicals, many of which have been proposed to have health benefits. Understanding variation in the grain content and composition is necessary to enhance their beneficial health effects and to reduce negative effects. In addition, grain processing plays an important role in determining the availability, functionality and physiological effects of the grain components.

ASPIRATION

Production of nutritious and healthy wheat grains with adequate end-use quality to meet the demand from subsistence users to industry and produce the great variety of food products made from wheat

AIMS AND OBJECTIVES

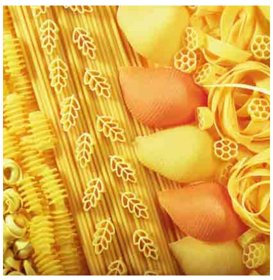
Improvement of quality and safety necessitates the integration of knowledge from multiple disciplines like cereal chemistry, microbiology, human nutrition, toxicology, agronomy and genetics. This complex task will involve studies considering:

- Gluten and starch composition and grain hardness;
- Human nutrition and biofortification;
- Food safety;
- Food technology and chemistry;
- Local breeding and environmental stability, combined with the extremely diverse end-uses of bread and durum wheat;
- Developing genomic resources for breeding for end-use quality;
- Tuning protein composition to maintain end-use properties while reducing the protein content, resulting in improved nitrogen use efficiency;
- Specific traits for specific end-uses, including engagement with processors and nutritionists.

RESEARCH NEEDS

Future research on wheat quality and safety should aim at:

- Standardising methods to examine gluten proteins and improve understanding of the role of gluten proteins on different dough processing conditions and end-product properties, including unifying the nomenclature of gluten alleles;
- Germplasm screening for the identification of sources of variation for various quality component traits;
- A deep understanding of the inheritance of grain bioactive compounds, and the genetics of the bioavailability of micronutrients and high dietary fibre to improve the nutritional value of wheat and increase healthy cereal-based food consumption;
- A deep understanding of the nature and content of proteins of wheat showing allergen and toxic reactions and developing low-allergen wheat suitable for patients suffering in wheat related food disorders;
- Understanding the effects of food manufacturing processes on the digestibility of wheat proteins, bio-availability of nutrients, and the interaction with gut micro-organisms;
- Fine tuning gluten, starch properties and grain hardness according to specific (and diverse) end-uses by understanding Genotype x Environment x Management interaction;
- Reducing mycotoxins (see core theme 2, subtopic 2.1) and toxic minerals in wheat and wheat products;
- Development of low cost biomarkers for the above determinants of wheat quality and safety.



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PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Standards for gluten protein alleles and methods • Germplasm with low content in mycotoxins and toxic minerals • Low-cost molecular (and non-molecular) markers for quality, safety and nutritional determinants
Medium-term (5-10 years)	• Low-allergen wheats suitable for patients suffering from wheat related food disorders
Long-term (>10 years)	• Deployment of healthy wheat considering unstable climate and diverse end-uses

ON-GOING INTERNATIONAL ACTIONS

- Gluten group/workshop
- International Cereal Chemistry (ICC)

WHEAT INITIATIVE ACTIONS

- Coordinate research in the area through the development of the EWG - Improving Wheat Quality for Processing and Health
- Coordination with EWGs:
  - Durum Wheat Genomics and Breeding
  - Wheat Germplasm Conservation and Use Community
- Coordinating activities
- Facilitating access to technologies

CROSS-CUTTING THEME 5
Enabling technologies and shared resources

CHALLENGE

Building the resources and capabilities to support cutting-edge wheat research, breeding and agronomy

ASPIRATION

Wheat to become a preferred research target for scientists as a result of freely available technology, germplasm and resource base

CHALLENGE

Building the resources and capabilities to support cutting-edge wheat research, breeding and agronomy

Wheat has a large and complex genome, is grown in diverse production environments, and has broad germplasm resources. The very best tool-kit of cross-cutting technologies and methodologies, together with increased characterisation, use, and sharing of available genetic diversity of wheat, is needed to support the challenges faced by wheat researchers and breeders.

ASPIRATION

Wheat to become a preferred research target for scientists as a result of freely available technology, germplasm and resource base

AIMS AND OBJECTIVES

There have been rapid advances on techniques supporting biological research, many coming out of medical research or studies in model crops. Supporting the rapid transfer of these technologies to wheat and developing new methods and resources based on wheat represents a key aim of the Wheat Initiative. The main aims of this core theme are:

- Development of cross-cutting enabling technologies in support of core themes 1-4 to address shared platforms and methodologies for breeding, genotyping and phenotyping;
- Completion of a high quality reference sequence and full annotation of the wheat genome to serve as a resource for marker development and gene discovery in wheat;
- Completion of a "Wheat Information System" (WheatIS) to provide the international wheat community a single, comprehensive access point for wheat data and informatics tools;
- Development, characterisation and deployment of genetic resources, and technologies to enhance the rate of genetic gain in wheat breeding programs.

SUBTOPIC 5.1 ENABLING TECHNOLOGIES AND METHODS

RESEARCH NEEDS

A Reference Sequence of the Wheat Genome

The availability of a reference sequence of the wheat genome will build a foundation to enable gene isolation, functional analyses, new allele discovery for pre-breeding, polymorphism discovery for marker-assisted selection, and an increased understanding of the impact of epigenetic modifications and transposable elements on gene regulation. Generation of a reference sequence anchored to genetic and phenotypic maps is the focus of the International Wheat Genome Sequencing Consortium (IWGSC). IWGSC is coordinating research to complete the bread wheat genome sequence by focussing on:

- Completion of genetically anchored physical maps for all 21 wheat chromosomes;
- Sequencing of the minimum tiling-path of BAC clones derived from the physical maps;
- Assembly and annotation of pseudo-molecules for each of the 21 wheat chromosomes;
- Integration of the sequence data into the WheatIS.

Parallel research activities to integrate whole genome shotgun sequencing and improve the definition of the wheat gene space as well as support for the annotation of the reference genome sequence are also a priority. Sequencing of the durum wheat genome, using the hexaploid wheat genome reference sequence as a foundation, is a high priority for the durum wheat genetics and breeding community. In addition to the genome sequence, large RNAseq data sets are being produced for wheat as well as proteomic and metabolomics data. These will be related to the genome sequence and phenotypic traits, and integrated into the WheatIS. Additional genomic resources, necessary to answer post-genomic challenges such as diversity, population genetics, regulation and epigenetics, also need to be integrated into the WheatIS.

Revolutionised Breeding Systems

Research into novel methods, tools and technologies will facilitate the development of widely-adapted elite genotypes and accelerate selection cycles to reduce time from discovery to the target market.

Predictive science has the potential to improve the efficiency and sophistication of breeding by phenotyping only those genotypes with the greatest potential for cultivar release. Research to develop new algorithms and predictive models for genome wide-association mapping studies and implementation of genomic selection in applied breeding programmes is needed.

Recombination underpins the generation of new genetic combinations through crossing and provides the raw material for selective breeding. Recombination is mostly limited to distal regions of wheat chromosomes, restricting new combinations of alleles to these regions in breeding populations. Modulation of recombination along the chromosomes should allow new genotypes to emerge as well as facilitate the introgression of useful genes from wheat related species.

Deployment of hybrid wheat will likely contribute to wheat productivity and yield stability in the future. Research focusing on defining heterotic pools to maximise hybrid vigour and yield, and to develop effective pollination control systems for cost-effective hybrid seed production systems are needed.

Genetic engineering through mutation, genome editing and transformation is a critical tool for the identification and characterisation of wheat genes and has the potential to generate new genetic variation that will be valuable in breeding new cultivars. International coordination of well-characterised TILLING (Targeted Induced Local Lesions In Genomes) populations, and research programs to allow full implementation of gene and genome editing technologies is needed.

Although the techniques for producing and evaluating transgenic wheat lines are now well established, the technology is closely regulated and the regulations vary across jurisdictions. In many regions, field evaluation of transgenic wheat is not permitted or is complex and expensive. Currently, no transgenic wheat is under commercial production. Other technologies, such as genome editing, are now being applied to wheat but it is still unclear how this technology will be viewed by different regulatory agencies.

The Wheat Initiative supports the use of genetic engineering to advance wheat research and looks forward to its responsible application to wheat improvement. Given the importance of genetic engineering to wheat research and the variation in regulatory requirements, the Wheat Initiative encourages partnerships and collaborations that assist in the development and evaluation of genetically engineered wheat breeding lines and genotypes, while respecting jurisdictional requirements and sensitivities.

The Wheat Initiative will act as a source of credible, unbiased information on current activities and opportunities for wheat transgenic research and cultivar development.

Crop and Plant Modelling – Systems Biology

As the global climate is changing, the interactive effects of plant traits, environment and management must be understood under region-specific climate change scenarios. The ability of process-based crop models to simulate the interactive effects of plant traits, environment and management makes such models attractive tools for plant breeding. However, research is needed to improve model responses to disease and pests, climate and soil factors, including high temperature, elevated atmospheric CO_2 and variable water and nutrient supply as well as their interaction with specific crop traits, and to develop a framework to handle crop model uncertainties and enable model applications to:

- Characterise and define target environments including climate change "hotspots";
- Test the potential impact of specific morpho-physiological traits on yield, quality and resource use for key environments and climate change hotspots;
- Explore possible ecophysiological mechanisms affecting traits;
- Assist in understanding interactions of traits, environment and management;
- Improve the characterisation of traits in genetic studies and breeding nurseries.

In recent years, several international projects have led to an explosion of phenotypic data and detailed characterisation of wheat molecular variation, differential transcriptome profiles, metabolite profiling and proteomic characterisation. Research focusing on a systems biology approach is a high priority, where integrating multiple -omics platforms and sophisticated bioinformatics systems can be used to unravel the underlying mechanisms of plant growth and development, adaptation to harsh environments, and resistance to biotic stresses. This is a growing area in model plant research and it is important that it is also captured for addressing the needs of wheat improvement. Incorporation of major adaptation gene information into wheat models is a first step in this process.

PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• A high quality, ordered, annotated reference sequence of bread wheat • Reshape breeding schemes to optimally integrate genomic prediction to enhance genetic progress
Medium-term (5-10 years)	• A reference sequence of the durum wheat genome • Routine high-throughput gene and QTL cloning in wheat • Robust systems-based models for wheat responses to the environment • Hybrid wheat cultivars
Long-term (>10 years)	• Game-changing breeding technologies to accelerate the rate of genetic gain

ON-GOING INTERNATIONAL ACTIONS

- IWGSC
- WHEAT CRP
- CGIAR Research Program on Climate Change, Agriculture and Food Security
- AgMIP Wheat
- Integrated Breeding Platform
- International Triticeae Mapping Initiative (ITMI)

WHEAT INITIATIVE ACTIONS

- Support the activities and funding of the IWGSC
- Coordinate research in the area through the development of EWGs:
  - WheatIS
  - Wheat Breeding Methods and Strategies
  - Wheat Plant and Crop Modeling
  - Durum Wheat Genomics and Breeding
- Facilitate access to game-changing technologies
- Develop a credible information resource on transgenic wheat research and opportunities

Associated Programme

International Wheat Genome Sequencing Consortium (IWGSC)

Expert Working Groups

- **Breeding Methods and Strategies**
- **Wheat Plant and Crop Modelling**
- **Durum Wheat Genomics and Breeding**

SUBTOPIC 5.2 SHARED PLATFORMS AND TECHNOLOGIES

RESEARCH NEEDS

Wheat Information System (WheatIS)

Integrated research approaches require combining data and information from all areas of wheat research. We need to develop an integrated information system that provides access to information that can then be applied to wheat research, practical breeding, crop modelling and wheat management strategies. Currently, wheat data are independently dispersed among several databases around the world which limits their full potential for exploitation by the wheat research and breeding community. The development of a single-access web-based WheatIS (www.wheatis.org) linking existing and new databases will allow sharing and integration of data resources as well as provide a common platform housing available bioinformatics tools. To achieve the full potential of the Wheat Information System, efforts are needed to:

- Define standards, protocols and processes for sharing and integrating wheat data in keeping with other international initiatives;
- Develop a web platform allowing the exchange of standardised data files and associated meta data between different repositories;
- Develop a distributed index search engine to allow dynamic search of different databases through a single entry point;
- Develop a robust and fast distributed infrastructure;
- Provide user-friendly bioinformatics tools to use the data efficiently;
- Establish links with the wheat users' community through outreach, training, and dissemination activities.

Phenotyping Platforms

Novel high throughput phenotyping platforms for the field and controlled environment are allowing precise measurement of wheat traits, either for phenotypic selection or for genetic studies designed to dissect complex traits. To reduce the gap between genomics and phenotyping for wheat improvement, it is necessary to characterise existing infrastructure and to strengthen international initiatives aimed at developing new technologies for wheat phenotyping, including protocols for simulating target environments and for trait phenotyping and/or identification. Priorities include:

- Improving the precision of current phenotyping techniques;
- Establishing common protocols and reference germplasm to facilitate data comparison and exchange;
- Developing low cost, high throughput tools for field-level screening and for specific traits;
- Assessing new technologies to study currently inaccessible characteristics, e.g. non-invasive detection of root architecture and function.

High-throughput phenotyping facilities and the use of modern sensor technologies is expected to result in the generation of large volumes of data. Therefore, a concerted effort is needed to develop efficient tools for the analysis, storage and publication of high-resolution phenotyping data. There is also a critical need for research to evaluate and improve the prediction of trait effects measured in controlled conditions relative to performance in the field. Defining global sets of reference cultivars and defining standards for phenotypic and environmental data collection are a priority to allow for comparison and statistical integration of phenotypic datasets between locations and years.

Genotyping Platforms

High throughput genotyping methods are providing an unprecedented supply of molecular markers for anchoring genomic sequences that will allow the genetic dissection of complex wheat traits, for use in wheat breeding programs. The number of Single Nucleotide Polymorphism (SNP) markers in wheat is no longer a limitation for application into breeding and several SNP detection platforms based on different technologies are already available to the community. However, such technologies are not always accessible to breeders with limited resources and it is important that training and access to resources are supported within the wheat community. Further research into common high throughput Genotyping by Sequencing (GbS) and other genotyping/sequencing strategies, as well as association of genetic variation with plant phenotypes is needed to facilitate wheat genetic improvement.

PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• A web-based data access portal for wheat • Standardised genotyping and phenotyping methods and selection of reference germplasm sets
Medium-term (5-10 years)	• Global network of accurate high-throughput field phenotyping
Long-term (>10 years)	• Accelerating the rate of genetic gain through utilisation of global phenotyping networks

ON-GOING INTERNATIONAL ACTIONS

- WHEAT CRP
- International Plant Phenotyping Network (IPPN)
- European Plant Phenotyping Network (EPPN)

WHEAT INITIATIVE ACTIONS

- Coordinate research in the area through the development of EWGs:
  - WheatIS
  - Wheat Phenotyping to support Wheat Improvement
- Act as a source of standardised data management and link to international phenotyping networks
- Facilitate access to technologies

Expert Working Groups

- **Wheat Information System**
- **Wheat Phenotyping to Support Wheat Improvement**

SUBTOPIC 5.3 GENETIC RESOURCES

RESEARCH NEEDS

Utilisation of genetic resources is the basis of wheat breeding and is therefore fundamental to sustaining global wheat production. However, part of the genetic diversity present in landraces of wheat and in ancestral species was not captured or was lost during wheat domestication and subsequent selective breeding. Introgression of novel functional variation found in wheat landraces, old cultivars and related species into adapted backgrounds will be critical to enhancing yield potential of wheat and to provide new sources of resistance and tolerance to biotic and abiotic stresses. Diversity plays also a central role in a hybrid wheat approach. However, the use of genetic resources in breeding is currently limited, largely because there has not been a global assessment and characterisation of the hundred thousands of accessions conserved in genebanks, leading to scarce genotypic and phenotypic information. Additionally, gene transfer from related species has been hampered by linkage to deleterious traits and by biological aspects such as differences in ploidy level or genomes involved. In addition, information is dispersed among genebanks, which makes systematic access from the wheat research community difficult.

Ex-situ collections of wheat and related species held in genebanks need to be managed securely in a cost effective manner and accessed easily and ideally freely by a broad range of users. While great advances have been made in recent years, further support is needed to help genebank managers link and operate individually held collections within a global system and to support the wheat global ex-situ conservation and utilisation strategy through efficient coordination, capacity building, integrated information systems, and by rectifying key gaps in existing collections including genomic and phenotypic data.

Specifically, efforts to update and implement the global wheat conservation strategy should be supported with an emphasis on the use of wheat and related species germplasm in breeding.

Current work on the development of a single-access web-based system enabling cross-searching of multiple gene banks must be supported to facilitate sharing of genetic material. This will be further enhanced by the inclusion of bioinformatics tools linking them with systematic genomic and phenotypic data (for example through the WheatIS).

To facilitate utilisation of genetic resources, new methods for their effective incorporation and uptake into breeding programs are required. This involves developing reliable phenotypic and genotypic data on accessions in gene bank collections as well as pre-breeding efforts. The wheat genetic resources community needs to operate as a global partnership to ensure the cohesion, security, functionality and use of germplasm collections following the recommendations of the International Treaty on Plant Genetic Resources.

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PRIORITY ACTIONS

RESEARCH OBJECTIVES	
Short-term (1-5 years)	• Define collaboration and sharing responsibilities for management of key collections • Assess and facilitate availability of collections and associated information • Evaluate the germplasm base for wheat and related species and broaden it if needed • Define guidelines for regeneration, multiplication, distribution, evaluation and utilisation of genetic resources
Medium-term (5-10 years)	• Upgrade key collections • Explore new sites for collection of new wheat germplasm • Enhance capacity to maintain and distribute genetic resources effectively • Expand allelic diversity deployed in breeding programs via a more efficient and broader use of wheat and related species' genetic variability
Long-term (>10 years)	• Generate sequence and detailed phenotypic information for all genebank accessions

ON-GOING INTERNATIONAL ACTIONS

- National Genebanks
- Genebanks CRP
- WHEAT CRP
- Global Crop Diversity Trust
- DivSeek

WHEAT INITIATIVE ACTIONS

- Support coordination in the area through the development of the EWG – Global Wheat Germplasm Conservation and Use Community
- Facilitate stronger interactions between the gene banks and breeding communities
- Facilitate links with the WheatIS and Wheat Phenotyping to Support Wheat Improvement EWGs
- Support the International Treaty on Plant Genetic Resources for circulation of germplasm and their use in breeding

CROSS-CUTTING THEME 6
Knowledge exchange and education

CHALLENGE

Exchanging knowledge between wheat researchers globally and building capacity

ASPIRATIONS

A well-connected public-private community of wheat researchers sharing knowledge and information throughout the world, self-perpetuating and expanding by means of training, education, networking and mentorship

A broad understanding of wheat, wheat science and of the role of research and technology in addressing the challenges of facing global wheat production

CHALLENGE

Exchanging knowledge between wheat researchers globally and building capacity

The need to exchange knowledge to strengthen wheat research globally and to enhance public-private partnership appeared in all the areas covered by the previous scientific core themes of the SRA. Education in wheat research was pointed out as a necessity by scientists and policy makers. For example, industry has difficulties recruiting wheat breeders because there are not enough being trained. In addition, capacity building in agriculture in developing countries was identified as a means to address more efficiently the needs faced in specific regions of the world. Finally, a major limitation to the use of modern technology is variable community support and understanding of the potential of these technologies to solve food insecurity issues.

Mentoring and networking are critical components for success in all disciplines of science, and even more important in smaller scientific communities, such as wheat improvement, where resources are limited but the need for impact is great. Mentoring is considered so important for the development of scientists that the US National Science Foundation now requires its grantees to provide information on how they will mentor postdoctoral fellows.

The working world of scientists is changing. For the same reasons that the Wheat Initiative must work to strengthen public-private partnerships in research and product development, we also must acknowledge and incorporate all of the roles that researchers must play to be successful in their careers – such as manager, mentor, administrator, and scientist – which also in turn contribute to the successful delivery of Wheat Initiative strategic objectives.

Education, training, networking and mentorship are especially important for engaging and retaining early career researchers, especially from the developing world, as well as female scientists. The Wheat Initiative's strategic goals will only be achieved if a vibrant community of scientists is fostered and supported well into the future. They must be supported to establish and maintain quality standards for research, data collection, and knowledge sharing, but also to develop a collective voice to be able to advocate for needed funds, policy support, or public attention. Such a community will likely further contribute to the Wheat Initiative's strategic goals by engaging with the public on occasion for the purposes of dialogue and learning in areas of interest and importance to them.

ASPIRATIONS

A well-connected public-private community of wheat researchers sharing knowledge and information throughout the world, self-perpetuating and expanding by means of training, education, networking and mentorship

A broad understanding of wheat, wheat science and of the role of research and technology in addressing the challenges of facing global wheat production

AIMS AND OBJECTIVES

Addressing the challenges of communication, training and education will be the responsibility of people involved or connected to wheat research and industry. The Wheat Initiative will aim to support these activities, help develop generic tools and programmes and facilitate the development of training and communication partnerships. This will be achieved through:

- Developing networking activities to build communities around common research objectives;
- Encouraging and facilitating mobility of researchers globally and at all levels to foster transfer of knowledge;
- Organising seminars and conferences to foster creative thinking and cross-disciplinary exchanges;
- Organising training workshops around specific areas of research and technology for the scientific community, wheat growers and end-users;
- Fostering education and training of early career scientists in wheat science, in developed and developing countries;
- Advertising training opportunities and fostering social networks of scientists, both virtually and face-to-face;
- Supporting scientists' efforts to engage with public audiences and the media to contribute to dialogue and learning.

PRIORITY ACTIONS

OBJECTIVES	
Medium-term (5-10 years)	• Develop a global public-private community of highly trained and educated researchers in wheat research

ON-GOING INTERNATIONAL ACTIONS

- Different International Consortia, Projects and Programs: IWGSC, BGRI, WHEAT CRP SI-5,
- International Plant Phenotyping Network, European Plant Phenotyping Network, AgMIP, MACSUR, HarvestChoice, YieldGap, etc.
- International Wheat Conference
- International Wheat Genetics Symposium
- WHEAT CRP Strategic Initiative 5

WHEAT INITIATIVE ACTIONS

- Facilitate networking activities through the development of a WheatVIVO directory
- Support the organisation of training workshops for all EWGs
- Facilitate the organisation of an International Wheat Congress every two years
- Develop a PhD scholarship programme dedicated to wheat
- Support coordination of e-learning in wheat education
- Advertise education opportunities, fellowships and job offers on the Wheat Initiative website
- Develop mentoring opportunities including drawing on a pool of retired scientists
- Facilitate public/private training opportunities

Annexes

The Wheat Initiative currently brings together 16 countries, 2 international research organisations and 9 private companies, whilst continuously welcoming new public and private members.

ANNEX 1
WHEAT INITIATIVE REPRESENTATIVES

TYPE	NAME	INSTITUTIONS' COORDINATION COMMITTEE (ICC) AND RESEARCH COMMITTEE (RC) REPRESENTATIVES
		MEMBERS
COUNTRIES	Argentina	ICC: Roberto Salvarezza, President, CONICET
		RC: Viviana Echenique, Marcelo Helguera
	Australia	ICC: Brondwen MacLean, Executive Manager Research Programs, GRDC
		RC: Eric Huttner, Mark Peoples
	Canada	ICC: Gilles Saindon, Associate Assistant Deputy Minister, Science and Technology Branch, AAFC
		RC: Brian Beres, George Clayton
	France	ICC: François Houllier, President and Director General, INRA
		RC: Jacques Le Gouis, Pierre Martre
	Germany	ICC: Bettina Pellio, Senior Research Management, BMELV
		RC: **Frank Ordon (Chair)**, Nils Stein
	India	ICC: J.S. Sandhu, Deputy Director General (Crop Science), ICAR
		RC: K.V. Prabhu, Indu Sharma
	Ireland	ICC: John Spink, Head of Crop Science Department, Teagasc
		RC: Fiona Doohan, Ewen Mullins
	Italy	ICC: Marina Montedoro, European and International Policy Department Secretariat, MiPAAF
		RC: Luigi Cattivelli, Roberto Tuberosa
	Japan	ICC: Masaru Iwanaga, President, JIRCAS
		RC: Shunsuke Oda, Hisashi Tsujimoto
	Turkey	ICC: Ali Osman Sari, Deputy Director General, GDAR
		RC: Hikmet Budak, Emin Dönmez
	UK	ICC: **Steve Visscher (Chair)**, Deputy Chief Executive & Chief Operating Officer, BBSRC
		RC: Nick Harberd, Graham Moore
	USA	ICC: José M. Costa, National Program Leader, Grain Crops, USDA-ARS
		RC: Gina Brown-Guedira, Brett Carver

TYPE	NAME	INSTITUTIONS' COORDINATION COMMITTEE (ICC) AND RESEARCH COMMITTEE (RC) REPRESENTATIVES
MEMBERS		
INTERNATIONAL RESEARCH CENTRES	International Maize and Wheat Improvement Center (CIMMYT)	ICC: Martin Kropff, Director General
		RC: Hans Braun, Marianne Bänziger
	International Center for Agricultural Research in Dry Areas (ICARDA)	ICC: Andrew Noble, Deputy Director General, Research
		RC: Michael Baum
PRIVATE COMPANIES	Arvalis - Institut du Végétal	RC: David Gouache, Philippe Gate
	Bayer CropScience	RC: Catherine Feuillet, Frank Schmidt
	Florimond Desprez V&F	RC: Olivier Robert, Pierre Devaux
	KWS	RC: Chris Tapsell, Viktor Korzun
	Limagrain	RC: Valérie Mazza, Sebastien Praud
	Monsanto Company	RC: Claire Cajacob, Michael Grosz
	RAGT 2n	RC: Richard Summers, Olivier Lucas
	Saaten Union Research	RC: Volker Lein, Mario Gils
	Syngenta Crop Protection	RC: **Rollin Sears (Vice-Chair)**, David Nevill
OBSERVERS		
COUNTRIES	Brazil	ICC: Ladislau Martin Neto, Executive Director for Research and Development, EMBRAPA
		RC: Ana C. Albuquerque, Luciano Consoli
	China	ICC: Xueyong Zhang, CAAS
		RC: Zhonghu He, Xueyong Zhang
	Hungary	ICC: Norbert Somogyi, Senior Advisor, NARIC
		RC: Laszlo Lang, Laszlo Cseuz
	Spain	ICC: Paloma Mergarejo, Vice-Director, INIA
		RC: Conceptio Royo Calpe, Josefina Sillero

ANNEX 2
WHEAT INITIATIVE SCIENTIFIC BOARD

NAME	POSITION	ORGANISATION
Hans-Joachim Braun	Director Global Wheat Program	International Maize and Wheat Improvement Center (CIMMYT), Mexico
Hirokazu Handa	Head of Research Planning Section	National Institute of Agrobiological Sciences (NIAS), University of Tsukuba, Japan
Peter Langridge (Chair)	Emeritus Professor	University of Adelaide, Australia
Hélène Lucas[2]	Wheat Initiative International Scientific Coordinator	National Institute for Agronomic Research (INRA), France
Graham Moore	Programme Leader, Crop Genetics	John Innes Centre, UK
Curtis Pozniak (Vice-Chair)	Associate Professor	Crop Development Center, University of Saskatchewan, Canada
Indu Sharma	Project Director	Directorate of Wheat Research, DWR Karnal, India
Chris Tapsell	Global Wheat Breeding Lead	KWS UK LTD, UK
Gabriela Tranquilli	Researcher	National Agricultural and Technology Institute (INTA), Biological Resources Institute Castelar, Argentina

[2] Ex-officio

ANNEX 3
WHEAT INITIATIVE EXPERT WORKING GROUPS AND ASSOCIATED PROGRAMMES

EXPERT WORKING GROUPS[3]

NAME	NUMBER OF MEMBERS/ COUNTRIES	CHAIR(S)/ VICE-CHAIRS/PROPOSERS
Wheat Information System	18 /7	**Chair**: Hadi Quesneville (INRA) **Vice-Chairs**: Mario Caccamo (TGAC), David Edwards (Uni Queensland), Gerard Lazo (USDA-ARS)
Durum Wheat Genomics and Breeding	90/22	**Chairs**: Roberto Tuberosa (Uni Bologna), Luigi Cattivelli (CRA)
Wheat Breeding Methods and Strategies	18/8	**Chairs**: Alison Bentley (NIAB), Gilles Charmet (INRA)
Wheat Phenotyping to Support Wheat Improvement	49/21	**Chair**: Senthold Asseng (Uni Florida) **Vice-Chairs**: Ulrich Schurr (FZJ), José Luis Arraus (Uni Barcelona)
Wheat Plant and Crop Modelling	38/12	**Chair**: Senthold Asseng (Uni Florida) **Vice-Chairs**: Frank Ewert (Uni Bonn), Pierre Martre (INRA), Scott Chapman (CSIRO)
Control of Wheat Pathogens and Pests	44/20	**Chair**: Richard Oliver (Uni Curtin) **Vice-Chairs**: Robert Park (Uni Sydney), Steve Goodwin (USDA-ARS)
Adaptation of Wheat to Abiotic Stress	Developing	**Proposers**: Peter Langridge (Uni Adelaide), Matthew Reynolds (CIMMYT)
Nutrient Use Efficiency in Wheat	Developing	**Proposers**: Malcolm Hawkesford (Rothamsted Research), Jacques Le Gouis (INRA)
Global Wheat Germplasm Conservation and Use Community	Developing	**Proposers**: T. Payne (CIMMYT), P. Bramel (Global Crop Diversity Trust), A. Amri (ICARDA)
Improving Wheat Quality for Processing and Health	Developing	**Proposers**: T. Ikeda (NARO), A. Juhasz (HAS), J. Rogers (Uni Buenos Aires), P. Shewry (Rothamsted Research), V. Lullien-Pellerin (INRA), S. Chulze (UNRC), R. Chibbar (Uni Saskatchewan), C. Guzman (CIMMYT)

ASSOCIATED PROGRAMMES[4]

NAME	WEBSITE
International Wheat Genome Sequencing Consortium (IWGSC)	www.wheatgenome.org
International Wheat Yield Partnership (IWYP)	www.iwyp.org

[3] Detailed information about the Wheat Initiative Expert Working groups can be found at http://www.wheatinitiative.org/activities/expert-working-groups
[4] Detailed information about the Associated Programmes to the Wheat Initiative can be found at http://www.wheatinitiative.org/activities/associated-programmes

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Coordination: Hélène Lucas
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