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Review

Meeting the Challenges Facing Wheat Production: The Strategic Research Agenda of the Global Wheat Initiative

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Abstract: Wheat occupies a special role in global food security since, in addition to providing 20% of our carbohydrates and protein, almost 25% of the global production is traded internationally. The importance of wheat for food security was recognised by the Chief Agricultural Scientists of the G20 group of countries when they endorsed the establishment of the Wheat Initiative in 2011. The Wheat Initiative was tasked with supporting the wheat research community by facilitating collaboration, information and resource sharing and helping to build the capacity to address challenges facing production in an increasingly variable environment. Many countries invest in wheat research. Innovations in wheat breeding and agronomy have delivered enormous gains over the past few decades, with the average global yield increasing from just over 1 tonne per hectare in the early 1960s to around 3.5 tonnes in the past decade. These gains are threatened by climate change, the rapidly rising financial and environmental costs of fertilizer, and pesticides, combined with declines in water availability for irrigation in many regions. The international wheat research community has worked to identify major opportunities to help ensure that global wheat production can meet demand. The outcomes of these discussions are presented in this paper.

Keywords: wheat; climate change; strategy; coordination; yield; germplasm; agronomy

1. Introduction

Multiple challenges face wheat productivity around the world, particularly the impact of climate change and the need to reduce inputs in many regions. Addressing these challenges requires continued innovation and collaboration across the international wheat research and breeding network. The network is global and diverse and covers all continents. The Strategic Research Agenda (SRA) highlights the research challenges that are relevant across the globe and indicates where combined and coordinated action across the research community offers our best options for success.

2. Background

The broad adaptation of wheat has made it suitable for many production environments around the world. Its success has made it both critical for the world's food supply and a major component of the agricultural environment. A strong research and breeding network has underpinned the improvements in wheat production efficiency over the past hundred years, and this network will be essential to ensure sustainable wheat production in an increasingly unstable climate. The wheat network operates in the public and private sectors and across the full wheat value chain, from growers to handlers and marketers, processors and other end-users. Mobilising this network and directing focus onto activities that address the major challenges is the key role of the Wheat Initiative.

A few years after the Wheat Initiative was established, a series of meetings were held to develop a strategic research agenda for the global wheat research community. The resultant document, which was published in 2015, included short- (1–5 years), medium- (5–10 years) and long-term (over 10 years) objectives across the full gamut of wheat research, but with a major focus on genetics and breeding. Significant progress has been made against the objectives (see Section 3). In re-visiting the research agenda, we have sought to address major changes in the challenges facing wheat producers and gaps in the international research programs.

2.1. Why Wheat?

It is estimated that agriculture occupies about five billion hectares, which is almost 40% of the land surface [1]. Of this, about one-third is cropped, with the remainder used for grazing livestock. Most of the cropland, about 90%, is under annual crops, and just over 20% is under irrigation. The growth in the world's population has imposed strains on the use of cropland, and it is estimated that the area of land available per person for cropping has halved between 1961 and 2018 (from 0.36 to 0.18 ha/capita) [2].

Wheat is the most widely grown crop, with the area sown to wheat in 2019 estimated at 216 million hectares, and over 90 countries each produce over 10,000 tonnes annually [3]. The three cereals, maize, rice and wheat, dominate crop production, accounting for almost 90% of the world's cereals, and play a critical role in human nutrition. Although wheat represents 26% of the total world cereal production, it occupies almost 30% of the land used for cereal production (Table 1).

Table 1. Data on cereal production, trade and food supply. Production and trade numbers represent the annual average for the decade 2011 to 2020, and food supply information is the annual average for the decade 2010 to 2019. Maize and wheat imports and exports include grain and flour, and rice imports and exports include broken, husked, milled and paddy rice and rice flour [3].

Annual average for 2011–2020 data		***Maize***	***Rice***	***Wheat***
Area sown	Million hectares	191	162	219
Production	Million tonnes	1057	739	733
Import	Million tonnes	149	42	189
	Value (USD billion)	3.8	2.5	5.3
Export	Million tonnes	153	43	192
	Value (USD billion)	3.4	2.4	4.9
	% Production traded	14	6	26
Annual average for 2010–2019 data				
Food quantity	Million tonnes	139	584	499
	kg/capita/year	19	80	66
Calories	Kcal/capita/day	159	542	540
Protein	g/capita/day	3.8	9.9	16.4

Together, cereals provide 45% of the caloric and almost 40% of the protein intake in the human diet. Although maize exceeds both wheat and rice in total production, only around 12% of maize is used for food, with the remainder used as animal feed or for industrial purposes, such as ethanol production. In contrast, 77% of the rice and 65% of the wheat crop is used for food (Table 1). However, wheat occupies a special and strategic role in global food security, as shown by the social unrest during the Arab Spring a decade ago. Wheat is particularly important, since almost 25% of the global production is traded internationally, while most rice is consumed in the country of production with only about 0.4% traded [3].

Wheat also plays an important nutritional role. As noted above, cereals account for about 45% of carbohydrate and 40% of the protein in the human diet. Wheat and rice contribute equally to our carbohydrate consumption (19% and 18%, respectively), but wheat accounts for 20% of our protein consumption compared to 12% for rice and only 5% for maize (Table 1) [3].

2.2. Impact of Climate Change

Water availability is the single biggest factor influencing wheat yield. Both breeding and agronomic practices can be used to match maturity to the growing season, and this trait is generally well managed in existing programs. While the adjustment of maturity to the environment has been critical to building wheat yields, problems arise during abnormal seasons when the developmental path of elite varieties no longer matches the rainfall and temperature patterns. Increasing climate variability is exacerbating this problem. Farmers accept that some years will be bad and they may lose money, if this can be offset by good years. An increasing frequency of bad years is a serious problem, and farmers seek varieties and management practices that can take advantage of the good years but minimise the losses in the bad years.

Drought and heat stress are becoming increasingly prevalent. Around half of all wheat globally experiences periods of heat stress, and 20 million hectares or more routinely experience water deficits [4–6]. Models highlight the risks of simultaneous crop failures due to heat and/or drought in global "breadbaskets" [7–9], and extremes in temperature and precipitation are already attributed to 40% of inter-annual wheat production variability [10]. Severe water-scarcity events are expected for up to 60% of the world's wheat-growing areas by the end of this century [11], and each 1 °C increase in temperature is predicted to decrease yield by 7% on average [12,13]. Although some research and modelling studies indicate that rising levels of atmospheric CO_2 will at least partially offset the harmful effects of heat and drought stress, the data are far from consistent [14,15]. Furthermore, the models neglect the harmful effects of rising night temperatures [16], heat shocks, unstable rainfall patterns and

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nutritional factors, for which there is no evidence of amelioration by elevated CO_2 [14], and these factors are likely to further negatively impact wheat yields.

2.3. The Wheat Initiative

The Wheat Initiative was established following endorsement by the G20 Group of Countries in 2011 to provide a global coordination mechanism for wheat research. It formed part of a broad strategy to enhance global food security in the face of major and rising challenges to current food production systems. The Vision of the Wheat Initiative is "to encourage and support the development of a vibrant global wheat public-private research community sharing resources, capabilities, data, knowledge and ideas to improve wheat productivity, quality and sustainable production around the world." The Wheat Initiative comprises public and private researchers, and educators working on wheat to develop strong and dynamic national and trans-national collaborative programs.

Figure 1 shows the structure and organisation of the Wheat Initiative. The most important vehicles for achieving the objectives of the Wheat Initiative are the Expert Working Groups (EWGs). They provide the coordination and operational framework, link researchers with related interests, develop coordinated international projects, enhance the capacity-building of young scientists and set the research priorities.

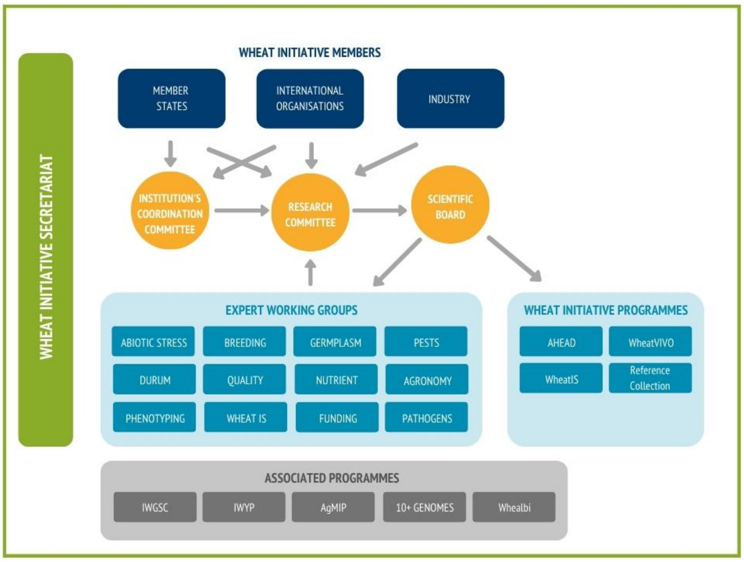


Figure 1. Wheat Initiative organisational structure.

2.4. *Global Wheat Research*

The importance of wheat research is also apparent through the strong public investment; for example, a survey in 2020 identified 771 funded research projects on different aspects of wheat improvement and agronomy in just five countries (Australia, Canada, China, Spain and the USA) [17]. An international survey in 2018 of wheat research projects involving work aimed at enhancing the heat and/or drought tolerance found 162 projects in 21 countries (unpublished data).

The funding of wheat research has followed a similar pattern of change with agricultural research. A strong divide has remained in research support between the world's richest (OECD) versus poorest countries. In 1980, there was a 7.7-fold difference in agricultural research and development funding, with the wealthiest countries investing USD 13.25 per person compared to only USD 1.73 in poor countries. The discrepancy in private sector funding was even more extreme: "in 2011, for every dollar of private AgR&D spent in high-income countries, a meagre 0.8¢ was spent in low-income countries" [18].

Only around USD 69.3 billion was spent on agricultural research in 2011, which represented about 5% of the total research funds [19]. However, there has been a shift in the role of middle-income countries (primarily China, India and Brazil), with their share of investment increasing from only 29% in 1980 to around 43% in 2011 [18].

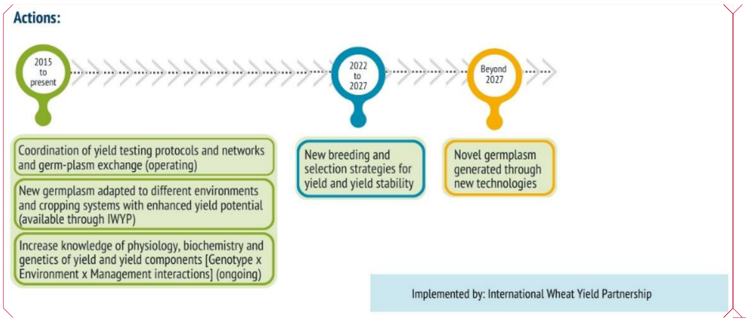
3. **Existing Strategic Research Agenda—Work in Progress**

The Strategic Research Agenda, which was published in 2015, included major changes expected in technology and resources (so-called "Game Changers") and research objectives for the short- (1 to 5 years), medium- (5 to 10 years) and long-term (beyond 10 years). The short-term objectives have been largely achieved and we are now well advanced in addressing the medium-term objectives. The areas addressed are given below:

Game Changers	**Status**	**Next Steps**
A fully assembled and aligned wheat genome sequence	Complete and pan genome also developed	Transcript databases and germplasm collection sequenced
Wheat data availability via an open information exchange framework	WheatIS developed	Expand databases linked to WheatIS and increase functionality
The ability to build new combinations of alleles	Continuing work	Improve access to germplasm with complex allele combinations

3.1. Objective 1: To Increase Yield Potential

Actions related to this objective have been largely covered by the International Wheat Yield Partnership (IWYP), and major progress has been made, with all short-term and several medium-term objectives met. The IWYP is now well advanced in evaluating technological innovations and integrating germplasm and genes into elite germplasm for distribution to breeders. A series of evaluation and breeding hubs have been established for this purpose. The IWYP is now well positioned to complete its mid-term and commence its long-term objectives.



3.2. Objective 2: To Protect 'on Farm' Yield

This objective covered the management of pests and diseases, improving abiotic stress tolerance and nutrient-use efficiency. These are addressed by

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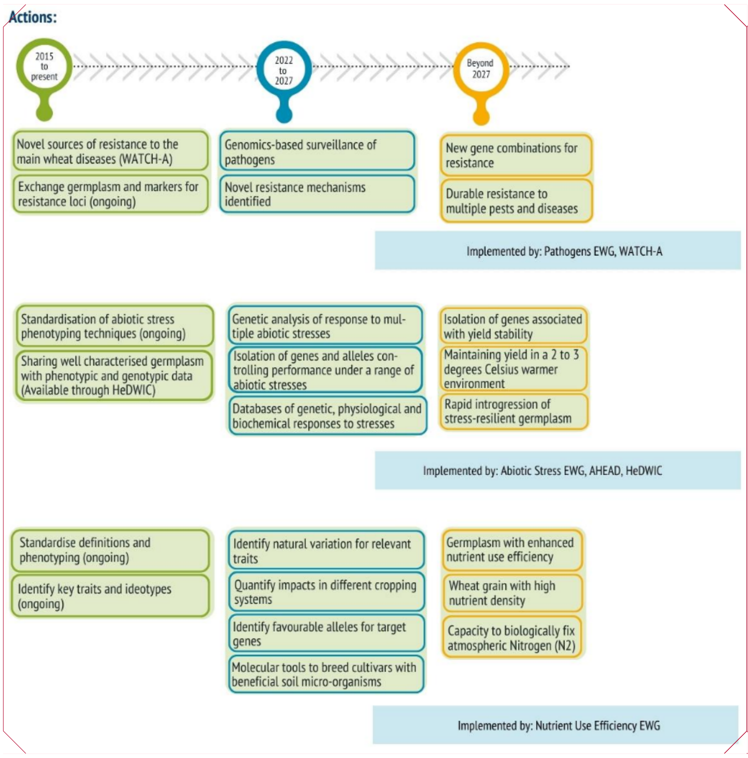
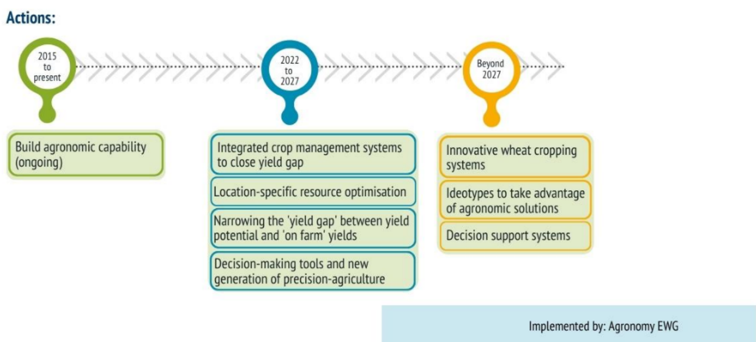
the Abiotic Stress, Pests, Pathogens, Nutrient-Use Efficiency and Agronomy EWGs. Two new international programs have been launched to address the first two issues; the Wheat Initiative Crop Health Alliance (WATCH-A) is currently being established to develop a global disease diagnosis and monitoring system, and the Alliance for Wheat Adaptation to Heat and Drought (AHEAD), which has brought together research programs from several countries to address heat and drought tolerance.





3.3. Objective 3: Ensuring the Supply of High-Quality Safe Wheat

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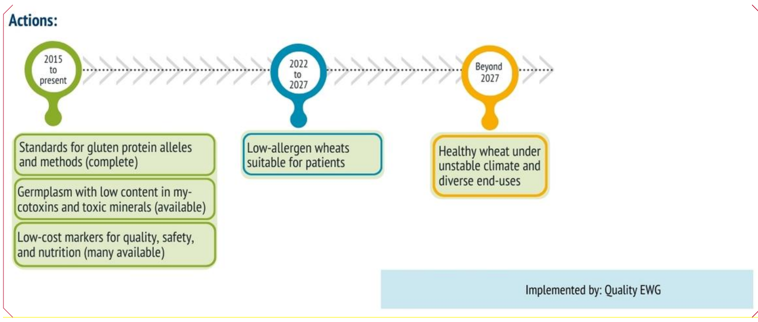
The Quality EWG has developed protocols and reference germplasm collections to support the wheat research and end-use communities. The development of additional reference collections and improvements to the reliability and consistency of quality assessments remain priorities. Technological changes have offered new opportunities for determining wheat quality and safety, but these need to be linked to established assessment procedures.



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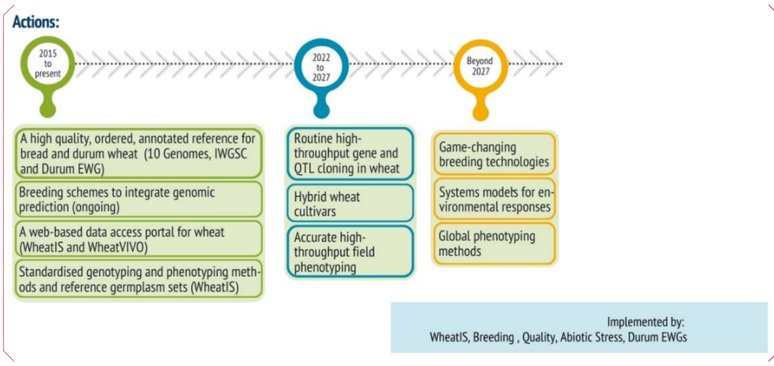
3.4. Objective 4: Enabling Technologies and the Sharing of Resources

The completion of a high-quality wheat genome sequence was expected to be a "game changer", and this has proved to be the case. Since the completion of the first reference quality sequence led by the International Wheat Genome Sequencing Consortium (IWGSC), a wheat pan-genome has been completed, and sequences of durum wheat and several wild tetraploid and diploid wheat progenitors have become available (for example, [20]). Access to wheat data and information is now provided through the Wheat Information System (WheatIS) and WheatVIVO. These databases and data access tools are being continually updated to provide information on diverse genomics resources, wheat researchers, research organisations, projects and publications. The rapid expansion of information makes these systems essential for the research community.



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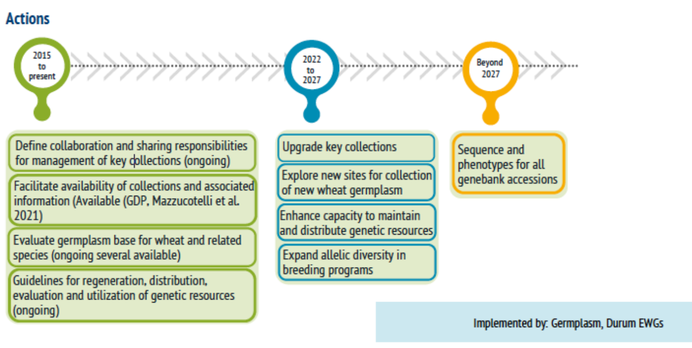
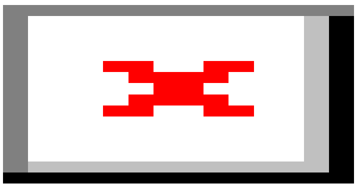
3.5. *Objective 5: Germplasm Accessibility*

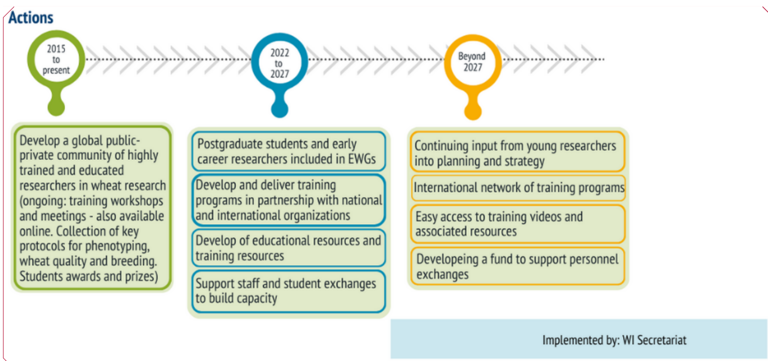
Genetic diversity is critical to wheat improvement. The Germplasm EWG has taken the lead in enhancing access and information on germplasm that is available in public gene banks. Through the Durum EWG, two reference collections have been established covering about 80% of the tetraploid genetic diversity. The Quality EWG has established reference collections for several quality traits and the Heat and Drought Wheat Improvement Consortium (HeDWIC) have collections for abiotic stress tolerance. The Germplasm EWG is working to expand the collections, improve access and update the Global Wheat Conservation Strategy.





3.6. Objective 6: Knowledge Exchange, Education and Training

There has been relatively little progress under this objective, but it remains a major target over the next period.



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4. **Major Issues and Challenges Facing Wheat Production and Research**

Over the coming years, wheat production will be challenged by an increasingly variable climate, with multiple studies indicating a 7% decline in yield for each degree increase in temperature. In irrigated regions, reduced water availability is already having a major impact, and this is predicted to become more extreme with dropping water tables and declining rainfall in water catchments. We can also expect to see increased pressure to reduce inputs in the form of fertilizers (accounting for about 70% of the CO_2 emissions for wheat production), and disease and pest control agents as a means to reduce environmental contamination.

The large gains in wheat yields over the past century have occurred through the adoption of new technologies, new cultivars and innovations in breeding and agronomy. These have tended to focus on the wheat in isolation, rather than considering wheat as part of a broad cropping system or as a major component of the agro-ecological environment. By considering wheat within the agro-environment rather than in isolation, we add complexity to the research agenda, but also provide an opportunity to deploy advances in rotational crops and cropping systems.

Our reliance on scientific advances from the wheat breeding and agronomy community is changing rapidly. The innovations relevant to wheat production are becoming more diverse as science advances. Genomics, phenotyping, crop and climate modelling, bioinformatics, computing and data analysis, yield mapping and global positioning systems are amongst a range of developments from other scientific disciplines that have become routine in wheat research.

Rapid technological advances provide many additional opportunities and options for improving sustainable wheat production, but there are several constraints that may limit our ability to grasp and leverage these opportunities. The major constraints can be summarised under four categories:

4.1. *Inconsistencies in Regulatory Environment*

Certain technologies are subject to complex regulation in some jurisdictions (such as the use of genetic engineering and gene editing), which limits both research capability and the ability of researchers to deliver outcomes to industry. Similarly, some countries enforce limitations on germplasm exchange and flow, and this can inhibit access to research developments, new diversity, and prevent the effective comparison of progress against international targets. Finally, the increased importance of data availability and its application to a wide range of scientific developments would benefit from a clear framework for the sharing and validation of digital information.

Wheat Initiative role:

As a G20-endorsed initiative, the Wheat Initiative has both an opportunity and a responsibility to advocate the importance and relevance of consistent regulation to member countries. The Wheat Initiative can also act as a credible source of information on new technologies and their associated risks and benefits.

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4.2. *Access to Staff with the Necessary Skills in Both New and Old Technologies*

Skilled staff are critical to the delivery of innovation in all aspects of wheat production and processing. The rapid technological advances have meant that modern research programs require access to staff with diverse skills and, in many cases, skills not previously associated with crop improvement and management. Examples include scientists skilled in analysing data from sophisticated phenotyping platforms and biometricians versed in crop and climate modelling. In addition, there is a continuing need for people trained in the more traditional methods required by wheat research groups, such as grain and flour quality assessment.

Wheat Initiative role:

Through the membership of the EWGs, the Wheat Initiative has access to a broad pool of expertise in both traditional and new technologies relevant to wheat improvement. Engaging postgraduate students and early career researchers in Wheat Initiative activities through mentoring programs, supporting staff and student exchanges, developing training resources and running workshops are all valuable options that will be developed.

4.3. *Data access and Standards*

As with many areas of modern biological research, problems around the utilisation of large and complex datasets abound. This encompasses concerns about data standards, access and reliability. Consistency in data collection and processes for ensuring reliability are fundamental ~~in supporting~~to support the exchange of information and allowing researchers to collaborate effectively. The complexity of many datasets and issues around the management and utilisation of "big data" permeate many research areas. The scale and complexity are likely to increase as new tools for data generation and analysis become available. The pool of data and interest in mining these datasets are expected to extend from research and breeding operations through to farmers and processors.

Wheat Initiative role:

The mechanisms for establishing and maintaining data standards are important to most modern areas of research, and the WI needs active links to other groups addressing these issues. The EWGs provide a resource to develop data standards covering the different research areas relevant to wheat production, and the Wheat Information System (WheatIS) and WheatVIVO resources provide tools to support data access.

4.4. *Support for Multinational Research and Public–Private Partnerships*

Support for research involving industry and public sector partners from multiple countries will play a key role in building capabilities to tackle large global research problems. Most current research funding and investment mechanisms operate at a national level, but many of our major research objectives are multinational and require a diversity of expertise that cannot be addressed by a single country or organisation.

Wheat Initiative role:

Through the membership of the WI, a direct path has been developed between the research community and organisations involved in making funding and investment decisions on wheat research. This provides an opportunity, unique for a major crop, to build international collaboration. The Funding Expert Working Group (FEWG) was established to specifically address the challenge of supporting multinational research programs, and they have provided a model for building the necessary support. Two new coordinated programs have been developed based on the FEWG recommendations (AHEAD and WATCH-A), and this approach can be extended to other critical research areas. The Wheat Initiative also provides a platform ~~for~~ to ~~engaging~~ engage industry ~~in~~ to assess~~ing~~ and ~~driving~~ drive the research agenda and promoting public–private partnerships, as well as information sharing.

5. **Research Priorities**

5.1. *Strengthen Existing Research Activities*

The short-term objectives described in the 2015 Strategic Research Agenda have been largely achieved, with the possible exception of the knowledge sharing and training and education targets. As outlined above, we are now well advanced in the medium-term objectives. These remain high priorities for the next few years.

The EWGs of the WI provide a series of fora for the research community to meet, exchange ideas and plan research collaborations. Although they vary in their activities, they have provided the dynamic centre of the WI activities and their role will continue to be critical in the overall operation of the Wheat Initiative. For several areas where an increased coordinated effort was identified, additional coordinated programs were initiated. The first such programs were the International Wheat Genome Sequencing Consortium (IWGSC) and the International Wheat Yield Partnership (IWYP). These are well established and operate independently of the WI secretariat. Two new programs have been initiated and are still at the early stages of operation; AHEAD started in 2020 and WATCH-A in 2022.

The continued support for the EWGs through the WI and members, the established collaborative programs (IWYP and IWGSC) and particularly for the new programs (AHEAD and WATCH-A), will be essential over the next few years.

New focus areas:

In the planning and discussion meetings, three research areas were identified as requiring attention (agronomy, germplasm, and roots and soil). All three areas were regarded as offering high returns with respect to wheat improvement, albeit at different timeframes, are of significance to wheat production globally, and are likely to benefit from increased coordination and investment. These areas were previously identified as priorities, but technological advances and increasing pressure to address the impacts of climate change have meant that additional resources and coordination would offer significant benefits.

5.2. *Enhance Agronomy in its Broadest Definition (Crop Production and Soil Management)*

Major benefits can be derived from considering wheat production within the broad cropping system, and there are several examples where integration across agronomic, genetic approaches and the cropping system have resulted in significant increases in yield and yield stability [17]. However, there is still a systematic 'yield gap' between research yields and 'on-farm' yields in many countries and environments. The concept of considering the diverse options available through Genotype × Environment × Management is now widely accepted, but not all research programs have access to the full gamut of skills needed and adequate environmental data to support effective modelling. The importance of appropriately linking breeders, physiologists, pathologists and agronomists has been well established, but technological advances offer far broader benefits if they can be integrated into crop improvement and delivery programs. However, groups that are able to cover a broad spectrum of capabilities require strong investment, and this may not be feasible for small or poorly resourced programs or for programs that focus on a specific and relatively small target region or issue. The options provided through the application of new capabilities, in combination with the constraints imposed by an increasingly variable climate and pressure to reduce inputs, will require a redefinition of the major traits and objectives affecting wheat productivity.

Wheat Initiative role:

The broad expertise base available through the EWGs provides an ideal opportunity to support the development and application of new technologies and capabilities to small wheat improvement programs. Through the identification of the capabilities and needs of wheat research and delivery programs, options ~~for~~ to expand~~ing~~ capabilities by linking groups, providing support for staff exchanges and targeted training activities will help build the necessary capacity. In some cases, the support can be provided remotely, for example with crop and climate modellers, but in other cases, staff will need to move between groups. In addition to identifying the needs of individual programs, the Wheat Initiative can develop an expertise database that can be called on to provide specific support.

5.3. *Increase Genetic Diversity*

Genetic diversity underpins crop breeding and improvement, but the germplasm base has been narrowing, and this has been proposed as a key reason why rates of genetic gain have been declining for our major crops, including wheat [21]. It is estimated that less than 10% of the natural diversity has been captured in the elite germplasm of our major crops [22]. However,

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major yield gains have also been introduced: for example, 30% of all wheat varieties produced by CIMMYT are now derived from 'synthetic' wheats obtained by crossing the wild *Aegilops tauschii*, D genome with elite tetraploid AB genomes wheat [23]. In addition to barley, rye and the various cultivated forms of wheat, the Triticeae tribe includes 25 genera, and genetic information from many of the 300 or more species can be transferred to wheat by simple crosses [24]. In the medium term, yield gain will benefit from the recent advances in the isolation of disease resistance genes effective against major pathogens. A wealth of resistance genes has recently been cloned by forward genetics starting from donors identified in the primary and secondary wheat gene pool [25].

Despite considerable effort by several genebanks and research programs, much remains to be done to better characterise and facilitate the use of novel germplasm. Similarly, tetraploid collections will play an important role in identifying and selecting novel haplotypes that are not yet exploited in bread wheat.

Wheat Initiative role:

- A broad series of activities can be undertaken to address this research priority:
- Revise and update the Global Wheat Conservation Strategy prepared in 2007 [26].
- Encourage the large-scale genotyping and phenotypic characterisation of germplasm held in the major genebanks.
- Advocate for the free and open exchange of germplasm and associated data.
- Encourage the utilisation of existing specialist germplasm collections collated by EWGs and share the outcomes:
  - Tetraploid collections developed by the Durum EWG
    - Durum elite and landrace collection in conjunction with a tetraploid core collection (GDP: Global Durum wheat Panel) capturing about 80% of the AABB haplotypes [27] of the collection (TGC: Tetraploid wheat Global Collection) described in [28].
  - Heat and drought tolerant germplasm collections developed by HeDWIC.
  - Wheat quality assessment panels developed by the Quality EWG.
- Support research aimed at the enhanced utilisation of unadapted germplasm:
  - Development of introgression populations.
  - Re-domestication.
  - Exploration of novel germplasm evaluation strategies.
  - Development of efficient methods for gene editing.

5.4. Understanding Root and Soil Biology

Clearly, soil and root health are critical for sustainable wheat production. Soil research has had a significant impact on understanding the limitations to production, but direct studies of root development and their interactions with the soil have been difficult due to problems in accessing and phenotyping root systems. There has been considerable investment in devising new strategies for root phenotyping and studying nutrient flow [29]. Root angle has been widely targeted due to its easy phenotyping, high heritability and genetic variability and noticeable effects on yield [28,30,31]. Through advances in genomics platforms, it has also become feasible to study the soil microbiome and structure, which opens new perspectives for studying root-related stress tolerance and nutrient acquisition.

Areas of research where greater capacity and investment is needed include:

- Continuing improvement of root phenotyping techniques, particularly in the field.
- Expand information of soil–microbe–plant interactions.
- Integration of data and information on roots and the microbiome in the analysis of wheat production with the full cropping system. It will also be

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important to emphasise the differences between low and high input systems and organic farming.

Wheat Initiative role:

Support the development of research programs targeting below-ground features by encouraging research collaborations. These should cover the research priorities listed above. The WI could establish a working group to explore options for facilitating research in the area.

6. Wheat Initiative Structure and Organisation

6.1. Develop Educational and Training Programs

Technological advances have opened new opportunities for wheat research but have also increased the complexity of research teams. As noted above, modern programs require quite diverse skills to be effective and access to appropriately trained staff can be difficult. In addition, many traditional skills are becoming harder to source but are still important. This is particularly the case for quality assessment.

Although the WI has offered workshop and training programs in some areas, this has not been a major activity. In 2021, a new plan was approved to encourage the engagement of postgraduate students and early career researchers (ECRs) in the EWGs. This involves establishing two new membership categories and setting up a representative group from young researchers to provide input into the operations and strategy setting of the Wheat Initiative. A budget has been allocated to support these activities.

Wheat Initiative role:

Given the recognised importance of education and training, the WI should explore the possibility of employing a coordinator to develop the many options, liaise with existing related programs and explore funding opportunities.

- Ensure the full and rapid implementation of the postgraduate and ECR plan for involvement in the EWGs.
- Establish an exchange program that provides partial funding for students to work in other laboratories.
- Encourage EWGs to deliver training workshops and courses, and link to existing options offered by other organisations, such as universities, CIMMYT and ICARDA.
- Develop an online Wheat Initiative seminar program.
- Develop mentoring programs to support students and link to industry.

6.2. The Wheat Initiative as an Advocacy and Lobby Organisation

The membership of EWGs represents a wealth of knowledge and expertise around wheat. This provides a trusted resource for information on wheat and wheat research and can be used to complement advocacy groups, such as farmer and processor organisations. The Wheat Initiative also plays a role ~~in ensuring~~to ensure that the needs of the research community are heard in government and international agencies. The diverse and multidisciplinary expertise represented in the WI allows the identification of globally relevant targets and the assessment of the feasibility of different approaches, in order to address challenges to wheat production; in other words, the Wheat Initiative can identify targets and strategies that fit the biological reality.

There is also value in providing information to the general public on the importance and relevance of wheat to global food security and validating the most relevant outcomes.

Wheat Initiative role:

- Produce public explanatory documents and videos covering the Wheat Initiative activities, major topics and issues affecting wheat production, such as the role of germplasm exchange, gene editing, hybrid wheat, and crop protection.
- Participate in relevant G20 workshops and meetings and develop links to government agencies and international organisations.
- Advocate and lobby for the support of transnational research.

- Develop links to the wheat grower and processing industry organisations.
- Promote wheat resources such as WheatIS and WheatVIVO.

6.3. *Expand Engagement*

The current membership of the Wheat Initiative is dominated by developed countries with low representation from industry and from some regions, such as North and sub-Saharan Africa, and Asia. This is also reflected in the membership of the EWGs, even though scientists from 47 countries are members. Broader engagement would expand the reach of the Wheat Initiative and increase access to skilled researchers and important wheat production regions. Therefore, the Wheat Initiative is actively seeking to increase industry participation and encourage the involvement of researchers and government agencies from resource-poor counties that import a large quota of their wheat consumption, such as Indonesia (100%), Egypt (80%), Tunisia (80%), etc., with all the entailed socio-economic and political consequences.

Wheat Initiative role:

- The Institutions' Coordination Committee has established a sub-committee to work through the options to build membership.
- Develop and distribute documentation explaining the value to industry from joining the WI—Industry.

Value Proposition

- Increase industry participation in WI activities, particularly in training and mentorship: a component would be to identify platforms and capabilities that could be used by industry.
- Identify and target government and institutional organisations in major wheat producing and wheat-importing countries to seek greater engagement in the WI.
- Target early career researchers in under-represented countries to encourage the membership of EWGs. In addition, provide support to allow key people from these regions to participate in WI activities.

6.4. *Supporting Multinational Research*

There are relatively few opportunities to directly support multinational research programs. An exception has been the International Wheat Yield Partnership (IWYP), where funding was made available from several countries to support a coordinated research program. However, the creation of a pot of funds to support international research is not regarded as a viable option to support multinational research. Consequently, the Funding EWG was established to specifically consider possible mechanisms to support multinational research activities. The outcome of the FEWG was a three-stage plan:

Stage 1—Coordination across existing research to capture synergies, prevent duplication and identify gaps—low incremental costs but a proactive coordination is instrumental and essential.
Stage 2—Project alignment and leverage of existing investments: initially focus on the twinning of existing projects or building on a call(s) for proposals by one or more national funders joining (e.g., recent AAFC (Canada)/BBSRC (UK) IWYP-aligned call-linked consecutive calls for proposals in each country).
Stage 3—Scaling-up joint investment: under the key areas of interest to all funders, funding can be allocated to a common/centrally managed pot/program or managed nationally by a lead funder, still aligned under a broad umbrella theme.

This model was used to establish two new alliances: AHEAD and WATCH-A.

Wheat Initiative role:

AHEAD and WATCH-A provide the first two examples of implementation of the strategy developed by the Funding EWG. The progress of these initiatives will be closely monitored and used to make decisions on additional multinational programs.

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7. Conclusions

The huge benefits derived from investment in wheat research are clear but cannot be taken for granted. The G20 Ministers of Agriculture recognised the importance of research and collaboration when they endorsed the Wheat Initiative, and a unique structure has been created as a result.

There are practical steps we can take to capture the benefits provided by research and collaboration.

- Boost research and technology delivery capabilities by investing in staff and student training and encourage and support the exchange of personnel between research organisations and building research infrastructure. This can be achieved if national research programmes place priority on activities with strong international linkages. Financial or organisational support from national agencies to research groups seeking participation in international partnerships would be beneficial.
- Provide support, both financial and organisational, to international activities aiming to facilitate the exchange of resources, particularly germplasm, and support the evaluation and delivery of research outcomes.
- Actively participate in Wheat Initiative research alliances that gather the capabilities and resources targeting global research challenges. These include the work of the Expert Working Groups and the three current alliances: The International Wheat Yield Partnership (boosting wheat yield potential), the Alliance for Wheat Adaptation to Heat and Drought (producing heat- and drought-tolerant germplasm) and the Wheat Initiative Crop Health Alliance (diagnosis and monitoring of wheat diseases).

Author Contributions: All authors participated in at least one workshop to develop the overall plan and identify research priorities. All authors were involved in the review of meeting outcomes, action plans and draft versions of the paper. P.L. prepared the initial draft of the paper and revised the document based on feedback from all other authors. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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Abbreviations

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AAFC	Agriculture and Agri-Food Canada
AHEAD	Alliance for Wheat Adaptation to Heat and Drought
BBSRC	Biotechnology and Biological Sciences Research Council
CIMMYT	International Maize and Wheat Improvement Centre
EWG	Expert Working Group(s)
FEWG	Funding Expert Working Group
HeDWIC	Heat and Drought Wheat Improvement Consortium
ICARDA	International Centre for Agricultural Research in the Dry Areas
IWGSC	International Wheat Genome Sequencing Consortium
IWYP	International Wheat Yield Partnership
SRA	Strategic Research Agenda
UK	United Kingdom
WATCH-A	Wheat Initiative Crop Health Alliance
WheatIS	Wheat Information System
WI	Wheat Initiative

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