Chapter 26
Translational Research Networks

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Abstract Without higher yielding and more climate resilient crop varieties, better agronomy and sustainable inputs, the world is on a course for catastrophes in food and nutritional security with all the associated social and political implications. Achieving food and nutritional security is one of the most important Grand Challenges of this century. These circumstances demand new systems for improving wheat to sustain current needs and future demands. This chapter presents some of the networks that have been developed over the years to help address these challenges. Networks help to: identify the most urgent problems based on consensus; identify and bridge knowledge silos; increase research efficacy and efficiency by studying state of the art germplasm and sharing common research environments/platforms so multiple strands of research can be cross-referenced; and creating communities of practice where the *modus operandi* becomes cooperation towards common goals rather than competition. Networks can also provide identity and visibility to research programs and their stakeholders, thereby lending credibility, increasing investment opportunities and accelerating outputs and dissemination of valuable new technologies.

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26.1 Learning Objectives

- Understanding the added value associated with translational and collaborative research networks.

26.2 The Research Continuum from Pure Science to Application

No one laboratory or organization can realistically encompass the full continuum of science from discovery research to delivery and adequate testing of new crop cultivars. There are many reasons for this including historical precedents of research organizations, the means by which science funding is allocated and the different specializations, research facilities and even locations required to achieve specific classes of research outputs. Nonetheless, for crop improvement to be dynamic enough to ultimately have impact in farm fields and meet societal demands, there needs to be a flow of knowledge from academia to applied crop science and breeding. Each area has its own specialization and demands, so rather than seeking conformity, linking them as a stepwise pipeline is a more likely approach to achieve synergy.

Plant scientists in academia are funded to work at the frontiers of understanding of genetics, physiology, cell biology etc., disciplines which even among themselves may not necessarily be interconnected or built upon. The use of model species and controlled environments -from petri dishes to growth rooms- maximize control and repeatability of treatments, as well as throughput since the cutting-edge of science is a highly expensive space. This approach furthers the understanding of specific processes but by definition is considered reductionist, since the different directions at the frontiers of science are not necessarily contiguous. Furthermore, much effort is invested in developing tools to further the research scope, a recent example is the use of tomography to study root growth and architecture, which while clearly of great potential in crop improvement is not tailored for application *per se*.

Crop scientists are typically trained in the academic approach and seek to apply discovery research in a real world context by applying treatments to understand specific growth and adaptive processes. If that understanding is intended to be used for genetic improvement, it can still take some time to move this from academic to applied research. For example, a textbook may explain what makes a cactus more stress tolerant than cabbage but to understand how two wheat genotypes, individuals of the same species, differ in their adaptive capacity is likely more challenging, requiring research approaches that may be quite different compared to academic precedents [1, 2]. A crop scientists may conduct experiments under more realistic growing environments, preferably under field conditions, posing additional challenges in obtaining controlled and accurate data (Table 26.1). Nonetheless, such approaches more likely lead to genetic improvement, being representative of growing conditions [3, 4]. However, the step from crop science to breeding is also significant.

Demand-driven breeding must establish priority traits that are better defined by high-throughput and application of well-established methods, than science *per se.* Examples are maintenance breeding to assure a crop does not become susceptible to new strains of diseases and pests [5] (see Chaps. 8 and 9) the need for diverse

Table 26.1 Main differences between field crop growing environments and controlled growth facilities

LIGHT	Light quality, intensity, and diurnal pattern are typically different in growth facilities, even in greenhouses where artificial light supplements may be employed for a variety of reasons, such as during dark winter months at high latitudes
AIR TEMPERATURE	Greenhouses are usually warmer than outside, notwithstanding use of costly cooling systems, while many growth-room facilities experience more abrupt changes in temperature than those experienced in the field.
SOIL TEMPERATURE	The impact of soil temperature is almost completely overlooked in growth facilities, where pots typically experience temperatures that are warmer, more uniform down the soil profile and less buffered to ambient air temperature than of field soil profiles
WATER & HUMIDITY	Both irrigation and relative humidity can mimic field conditions, though are costly/labor-intensive to control
SOIL	Soil from target environments can be used in pots, however, it is much harder to simulate the natural variation in bulk density, aeration and most importantly depth of field soil profiles
FERTILITY	Fertilizer is probably the easiest factor to control, notwithstanding the impact of differences in soil factors, including soil volume and temperature that may impact uptake by roots.
BIOTIC FACTORS	One of the advantages of the controlled environment is the relative ease with which pests and diseases can be identified and controlled compared to the field, though strict hygiene is necessary in the former to avoid infestation.
WIND & CO2	Wind patterns are not typically controlled in growth facilities; this has implications for boundary layers that affect transpiration and gas exchange (which in turn affect plant temperature), as well as local depletion of CO2; wind can also modify plant mechanical strength
SCALE & COST	The biggest advantage of using the field as a laboratory is that in most situations field costs per unit area are much lower than in growth facilities, affecting experimental design and scale.
ROOT VOLUME	To maximize number of test pots and minimize costs of growth facilities, plants are typically grown in small pots. Resulting data show little correlation with field data, since roots can't develop normally; for example to depths where subsoil water may be present.

end-use quality requirements [6] (see Chap. 11), and increments in yield and yield stability to maintain a competitive edge in industry, and to ensure food security [7] (see Chap. 7). While many of these priority traits may be appropriate in 'upstream' research (see Part III of this book), a breeding program typically does not have the required resources, facilities or expertise to investigate novel, potentially better approaches, and at the same time develop improved new competitive varieties. To ensure food security and competitivity, a successful breeding program must put most of its resources into 'production line' efforts rather than research *per se*.

In a changing environment, consumer demand and the economic landscape require breeding methods to be continually fine-tuned and the occasional and necessary step-change in how science is applied in cultivar improvement. Hence a well-defined pathway involving networks of experts is needed to translate basic science to crop science, then to breeding and finally to farm level productivity increases.

26.3 Identifying and Prioritizing Opportunities that Represent Current Bottlenecks to Crop Improvement

Whether the threat to achieving adequate productivity is biotic or abiotic in nature, the principles of identifying and prioritizing opportunities for genetic improvement are similar. The literature is obviously a good place to begin, starting with wheat but also considering breakthroughs that may have been achieved in other crop species. It is more likely that a successful approach in another cereal or monocot species would be translatable to wheat [8], at least in the short term, than from a totally unrelated species. Nonetheless, many funding agencies encourage 'blue sky' or high risk-high return research, in which case the scope may be expanded to model species. While such research has pushed back the frontiers of understanding, there are few examples of translational research to crops [9, 10]. The problem should also be tackled from the bottom up. Experienced breeders can provide insights into what needs 'fixing'. The example often cited was the need for lodging resistance in wheat that sparked the Green Revolution. Another example was emphasis placed by breeders on retention of chlorophyll during grain-filling that arguably led to a body of research on the stay-green trait [11] and ways to measure it at high throughput [12]. Somewhere in between, crop physiologists, working with genetic resource experts, identified sources of a shorter, more upright leaf type that was introgressed from *T. timopheevii* (Zhuk.) Zhuk. in the 1970s. This trait is expressed in many modern wheat cultivars [13], improving light penetration into the canopy and inspiring further research for improving radiation use efficiency (RUE) via improved canopy architecture and photosynthesis [14, 15].

Ironically, some of the most important bottlenecks to improve productivity may be underrepresented in the literature and even in people's models of wheat 'ideotypes', for various reasons [16]. Such bottlenecks can become apparent in discussions among colleagues who share common goals. The practice of some funding agencies in issuing competitive calls for so-called disruptive research is a way to identify new opportunities in this space.

26.4 Establishing Collaborative Networks to Complement Skill Sets and Research Infrastructure

In the early 1950s, USDA initiated the first international wheat rust testing network followed by globally-coordinated research into a number of staple crops -including wheat, rice and maize- starting with the Green Revolution in the mid-1960s. This led to several international crop improvement networks linking national programs to the creation of CGIAR centers and beyond; one of the most impactful has been the International Wheat Improvement Network (IWIN). The scope and function of IWIN and other complementary networks are described below.

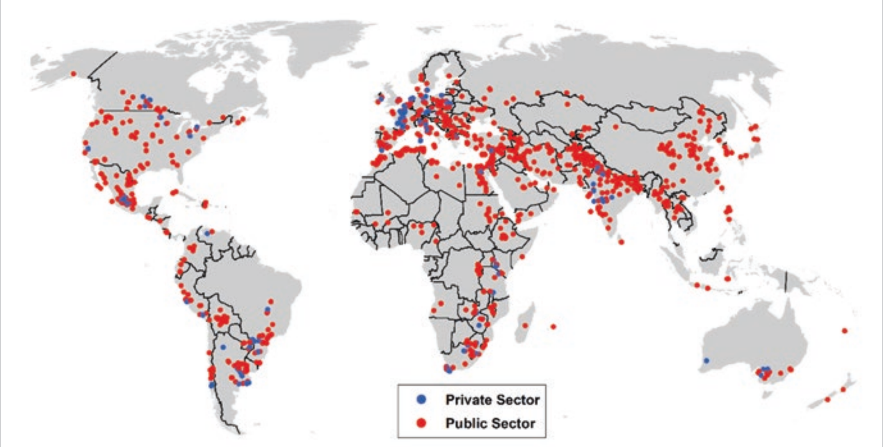
26.4.1 The International Wheat Improvement Network

The IWIN tests new bread and durum wheat and triticale lines at hundreds of sites in over 90 countries (Box 26.1). Breeding for traits of strategic importance, such as diseases that threaten entire regions or may cause pandemics, is conducted at strategic research hubs in order to develop and distribute approximately 1000 high yielding, disease-resistant lines targeted to major agro-ecologies each year, made freely available on request [17].

Box 26.1: Global Trialing Sites of the International Wheat Improvement Network

IWIN embraces a global collaboration of wheat scientists testing approximately 1000 new high yielding, stress adapted, disease resistant wheat lines each year as approximately 1800 sets of nurseries at around 250 locations annually, resulting in massive phenotypic data sets [18, 19].

To date, IWIN has collected over 10 million raw phenotypic data points and delivered germplasm that is estimated to be worth several billion dollars in extra productivity to more than 100 million farmers in less developed countries, annually [20] and by raising yields has saved more than 20 M ha of land from being brought under cultivation [21].



Public and private breeding programs that have received germplasm under the International Wheat Improvement Network (Figure drawn by Kai Sonder, CIMMYT).

National programs use the lines as new breeding material for new sources of traits i.e. parental lines for crossing; as candidates for release of new varieties; and for research. Data on new lines is shared within the network. Economic analysis of IWIN-related cultivars suggests that they are grown on over 50% of spring wheat area in less developed countries (Fig. 26.1), generating additional value (attributable to IWIN research) of US $2–$3 billion annually, spread among resource-poor farmers and consumers. The cost-benefit ratio of investment is estimated at ~100:1 [22].

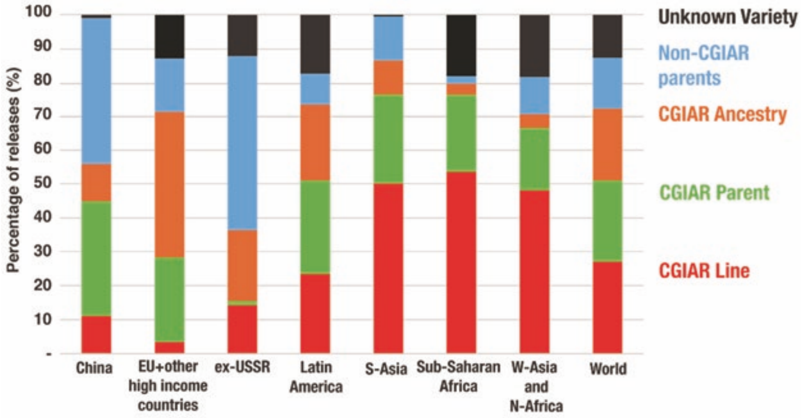


Fig. 26.1 Spring bread wheat released by region/origin through IWIN, 1994–2014. (Reprinted with permission from [22])

This does not even factor in the added value of avoiding rust and other disease epidemics by incorporating genetic disease resistance [5]. Further, IWIN curates a database containing millions of phenotypic and genotypic data points that have value for data mining and modelling (e.g. see Sect. 26.4.2).

26.4.2 The Heat and Drought Wheat Improvement Consortium (HeDWIC)

HeDWIC was formally established in 2020 to complement the IWIN by connecting translational research on climate resilience to mainstream wheat breeding through pre-breeding. HeDWIC's aims (https://hedwic.org/about/) are intended to add value to developing more climate resilient wheat varieties by:

- Facilitating global coordination of wheat research related to heat and drought stress with a special focus on countries in the Global South.
- Developing research and breeding technologies prioritized by stakeholders (researchers, breeders, farmers, seed companies, national programs, and funding organizations).
- Connecting geographically and agro-climatically diverse sites for rigorous testing of promising concepts.
- Curating data resources for use by the global wheat research community.
- Accelerating the deployment of new knowledge and strategies for developing more climate resilient wheat.
- Preparing a new generation of young scientists from climate-affected regions to tackle crop improvement challenges faced by their own countries.
- Building additional scientific capacity of wheat researchers in a coordinated fashion that enables a faster response to productivity threats associated with climate change.

Funding from the Foundation for Food and Agricultural Research (FFAR https://foundationfar.org/) is enabling HeDWIC to confront several research gaps (Fig. 26.2), in an effort led by CIMMYT in collaboration with many partners worldwide including IWIN and the International Wheat Yield Partnership (IWYP) (see Sect. 26.4.3).

HeDWIC inspired the Wheat Initiative (see Sect. 26.6) to establish the Alliance for Wheat Adaptation to Heat and Drought (AHEAD) program (*https://www.wheat-initiative.org/ahead*) which serves as an umbrella for HeDWIC and related projects, and brings into focus priorities for wheat improvement in the developed world, including partnerships between public and private sectors. The research goals of AHEAD and HeDWIC are broadly aligned and interactive, with the development of climate-resilient wheat as common goal.

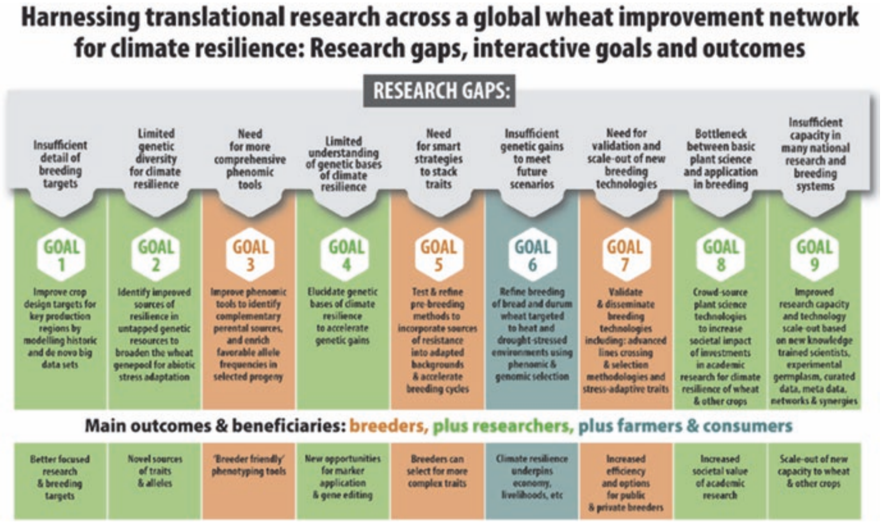


Fig. 26.2 Harnessing research across a global wheat improvement network for climate resilience: Research gaps, interactive goals and outcomes

26.4.3 *The International Wheat Yield Partnership (IWYP)*

The fact that much more food needs to be grown on essentially the same or less land amounts – to me correct is less of land in the coming decades is well established and accepted. This increase in productivity is compounded by changing diets, changing climates, and pests and diseases that will continue to undermine sustainable high crop production which puts more stress on food supplies and consumer prices. For these reasons, IWYP (https://iwyp.org/) was launched in late 2014 with the goal to increase the genetic yield potential of wheat (by 50% over 20 years was proposed). IWYP is a unique partnership of public and private institutions that deploy a highly efficient model for funding international research and coordinating and integrating the research into a holistic science and development program. IWYP complements the IWIN by linking research on yield potential to wheat breeding through translational research and pre-breeding.

IWYP was launched in late 2014 to increase the genetic yield potential of wheat closer to its biological limits (by 50% over 20 years was proposed) . IWYP is a unique partnership of public and private institutions that deploys a highly efficient model for funding international research, and coordinating and integrating the research into a holistic science and development program. IWYP complements the IWIN by linking research on yield potential to wheat breeding through translational research and pre-breeding.

IWYP operates as a not-for-profit voluntary collaborative partnership. The public sector funds and contributes high-quality research seeking breakthroughs to boost wheat yields around the world, and the private and public sectors across the world exploit the validated discoveries in their breeding pipelines, then test, scale and market better varieties for their respective markets. There is no significant duplication in public and private sectors because the environments and national markets for which their respective products are optimized are significantly different, and therefore all the locations where farmers grow wheat can benefit. IWYP exploits the best relevant science globally, is focused, operates with a sense of urgency, leverages outputs to generate added value and drives research outputs for delivery by both public and private wheat breeding programs worldwide, with the goal of generating significant yield improvements in farmer's fields. IWYP takes many steps to make certain its efforts are aligned with other current relevant research programs and initiatives worldwide (Fig. 26.3). All IWYP products are freely available.

Importantly, IWYP is product driven with focused scope and objectives. The basis of the IWYP strategy is:

- Deploy top quality scientific research from international teams with a united focus on potential yield boosting traits.
- Actively coordinate research projects around the world for greater efficiency.
- Achieve a succession of research breakthroughs in key traits.

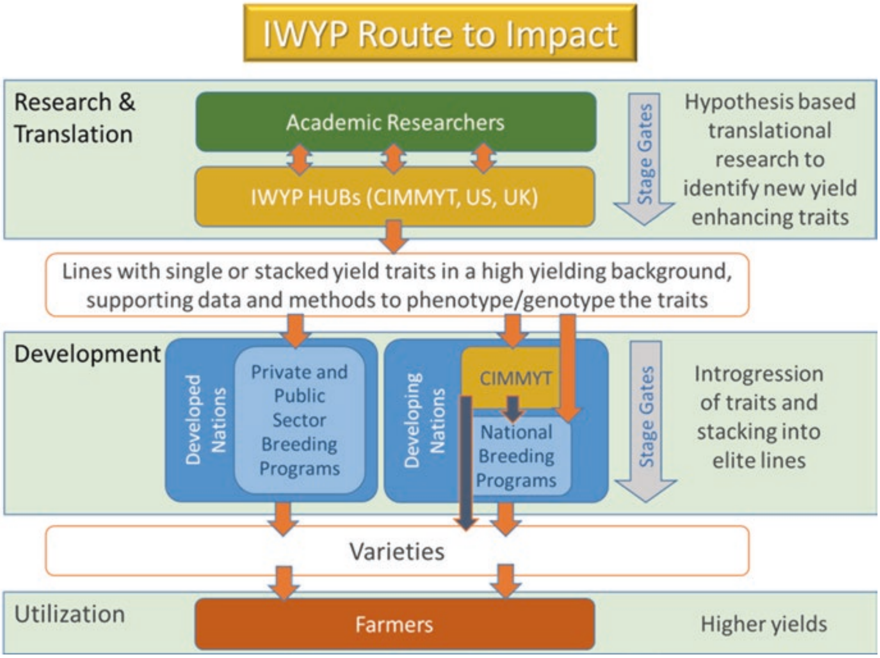


Fig. 26.3 IWYP deploys a model where a consortium of public funding organizations supports collaborative international research that feeds centralized development Hubs that deliver new traits and germplasm to breeding programs worldwide. These product pipelines further develop the IWYP innovations and deliver new higher yielding varieties to farmers worldwide

- Create added value by combining breakthroughs in elite germplasm.
- Utilize centralized downstream development platforms (Hubs) to deliver new higher yielding germplasm with novel traits in elite genetic backgrounds and push them toward deployment.
- Drive the improved germplasm into established breeding pipelines around the world, both public and private, which will deliver new higher yielding varieties to farmers in both the North and the South.

Details on IWYP research can be found in a series of monthly IWYP "Science Briefs" (https://iwyp.org/iwyp-science-briefs/) and are summarized in the IWYP Annual Reports (https://iwyp.org/annual-report/). Section 26.4.3.1 presents some key outputs of translational research.

26.4.3.1 Examples of Translational Research Outputs from Collaborative Platforms: The Case of IWYP

- Wheat lines developed in part by the IWYP Hub at CIMMYT through selection of IWYP target physiological traits have been released as varieties in Pakistan and Afghanistan.
- IWYP developed lines have shown higher yield than CIMMYT elite lines and local checks across multilocation trials. Selection for IWYP target traits such as biomass and radiation use efficiency, in combination with physiological and grain formation traits can lead to increased genetic yield potential.
- Since 2015, the IWYP Hub at CIMMYT has disseminated several hundred wheat lines as Wheat Yield Collaboration Yield Trial (WYCYT) "sets" to wheat researchers and breeders worldwide through the International Wheat Improvement Network (IWIN). From WYCYT data, the annual rate of genetic gain over last 5 years is ~1.3% (Sukumaran et al., Chap. 25). This is close to the 1.7% annual genetic gains required to meet the 50% yield potential increase by 2035.
- A better understanding of the contribution physiological traits such as biomass, radiation use efficiency and harvest index make to enhanced grain yield and combine these traits in new lines.
- Many sources for improvements to these traits come from unimproved/wild material.
- A dedicated IWYP testing network of 30 locations, the "IWYP Yield Potential Trait Experiment" (IYPTE) has been established to augment the field evaluation data received by IWIN.
- Two IWYP Hubs were established for winter wheat in the UK and the US complementing the work undertaken on spring wheat germplasm. These three interconnected validation and pre-breeding Hubs will develop the major categories of wheats grown globally, expanding IWYP's reach into more breeding programs and increasing potential impact.
- Early generation pre-breeding and experimental lines are made widely available.
- Information on genes/molecular genetic markers discovered by the IWYP Research Projects for source and sink traits is routinely collated and promoted for uptake by wheat breeders.

- Information on any novel phenotyping and genomics tools and protocols developed by IWYP are collated and promoted for use by third parties.
- Novel alleles for genes controlling grain size (width and length) and spike traits are routinely crossed into multiple wheat backgrounds, particularly wheat lines with high biomass, to develop germplasm with improved source sink balance and higher yield.
- Novel alleles have been identified for genes controlling wheat phenology along with the knowledge of which combinations of these alleles should be used to maximize yield and harvest index.
- Wheat parent lines transferred to public and private breeding programs with:
  - improved energy capture that leads to improved yield;
  - improved radiation use efficiency at the scale of the canopy;
  - high dry matter partitioning to the grain (increased harvest index) and lodging resistance;
  - rapid return to full photosynthetic efficiency following a short period of shading (sun-shade transition) ensuring optimal conversion of carbon dioxide to sugars;
  - chromosome segments introgressed from wild wheat relatives with increased photosynthetic efficiency relative to the wheat parents or variation in floral morphology;
  - favorable native alleles conferring enhanced shoot growth and biomass production backcrossed into multiple wheat lines.
- Identification of wheat landraces and other genetic resources with increased levels of photosynthetic efficiency compared to selected modern wheat varieties that serve as a resource for trait introgression in cultivated wheat.
- The identification of genes and molecular genetic markers that induce different wheat root phenotypes suitable for maximizing yield under different environments have been shared with public and private wheat breeding programs.

26.5 What It Takes to Establish and Fund an International Collaborative Platform; the Example of IWYP

26.5.1 Defining the Need

The need for a collaborative and coordinated international program or platform to address a specific global grand challenge requires a clear strategic purpose which sets out why such an approach is more likely to succeed than separate national programs. The key drivers for establishing IWYP were assuring food security for an increasing global population recognizing climate change impacts, a mismatch between supply and demand, risks of spikes in wheat prices and leveling off in the rate of yield growth. Forecasts indicated a substantial gap between projected demand and what wheat yield improvements could be achieved, at least in a business as usual scenario, i.e. continue with current incremental yield improvements. The overall analysis identified an urgent need to address this predicted shortfall forecast for the world's most widely grown crop. A strategy to deliver a step-change improvement in yield was therefore necessary.

26.5.2 Creating Awareness and Testing for Interest

The scale of the challenge demanded a collaborative approach that brought together the best researchers from around the world for both discovery and translational research. This could only succeed if stakeholders worked together as one team, sharing resources, results and implementing coordinated regional evaluations of new germplasm. An international conference convened by USAID at CIMMYT secured support for such an approach and program.

The next key step was to determine if support for funding could be secured in principle. Representatives from funding organizations from the UK, USA and Australia guided the development and brought in independent scientific input from world leaders in plant sciences who would not be directly involved with IWYP. A conference with key international development agencies and invited experts was convened and coordinated by the UK's BBSRC and hosted by the Government of Mexico. Here, the strategic need, proposed approach, key goals and an outline governance and review structure was presented. Support was quickly forthcoming from several funders, along with emphasis on the importance of involving the private sector in the partnership. This initial support proved to be a vital step to open up the detailed planning for the program and its scope.

26.5.3 Planning Governance and Operations

The next stage involved detailed planning and design of an effective governance structure, whilst addressing inevitable differences in national approaches and processes. To ensure acceptability, international best practice were adopted in areas such as independent international peer review and assessment criteria, program management, monitoring and evaluation of project milestones and key indicators of success. Regular meetings were agreed to assure discussions on new data and knowledge and to receiving advice and challenge from peers and partners.

26.5.4 Adding Value Through Program and Project Management

The major reason to have an international program is to generate more information, greater impact and added value beyond that originally envisaged. Project management needs to play a major role here by stimulating an open ambience of collaboration, belief in the common goals and the value of achieving more by additional collaborations. Such interactions can also lead to sharing of equipment, students, postdocs and skills, etc. This can be crucial where field work to assess outcomes is necessary but technical or staff support is not available in each institution. Project management should not only stimulate generation of added value but also monitor, track and communicate progress between the participating laboratories, Funders, and the scientific and other communities. This is important because individual scientists and Funders can then see the added value that comes with such partnerships. Management also needs to produce documents that increase transparency such as an Annual Report, a Strategic Plan and other papers that communicate the scientific novelty such as lists of publications, technologies and know-how. A high-level oversight Board of stakeholders is needed to assess progress, address problems, budget issues and for strategic planning.

26.5.5 Delivering Added Value

A worthwhile platform should generate added value and impact. IWYP therefore had to establish centralized “Hubs” to validate, develop, combine and test outputs from the discovery projects. This is important in agriculture because a discovery in a non-agricultural environment or a non-elite genotype may not be worthwhile taking further, and so learning this early is important to maximize efficiency. The principal IWYP Hub for spring wheat is currently based at CIMMYT, although other places are also involved in validation and testing. This Hub focuses on field-based testing of outputs, pre-breeding and testing of discoveries in elite genetic backgrounds. Two winter wheat IWYP Hubs in the US and the UK been established with additional financial inputs from private companies to stimulate uptake by breeding programs. It is important to recognize that the Hubs retain the responsibilities to bring added value to the discoveries made by other scientists and funding agencies.

Once an effective management system, oversight Board and the sharing, stimulation and oversight of science has been established this can be used for further exploitation and additional initiatives, both international and within a country, to generate added value.

26.6 Higher Level Networks

26.6.1 The Wheat Initiative's Expert Working Groups

The Wheat Initiative (WI) was established in 2011 following endorsement from the G20 agriculture ministers as part of a program to enhance global food security. The membership is made up of national research funding agencies, international research organizations and industry. The Wheat Initiative encourages and supports the development of a vibrant global wheat public-private research community sharing resources, capabilities, data and ideas to improve wheat productivity, quality and sustainable production around the world. The WI comprisess public and private researchers, educators and growers working on wheat to develop strong and dynamic national and transnational collaborative programs.

The current membership of the Wheat Initiative includes 14 countries, two CGIAR centers and six companies. A further five countries contribute as observers https://www.wheatinitiative.org/.

The Expert Working Groups (EWGs) are the scientific working force of the WI (Fig. 26.4). Currently there are ten scientific EWGs and one focusing on Funding. The EWGs bring together international experts in each field of expertise, to share ideas, knowledge, information, resources and data and identify international research priorities. There are presently 635 members from 47 countries in the EWGs from research organizations, universities, government and industry. A core task of

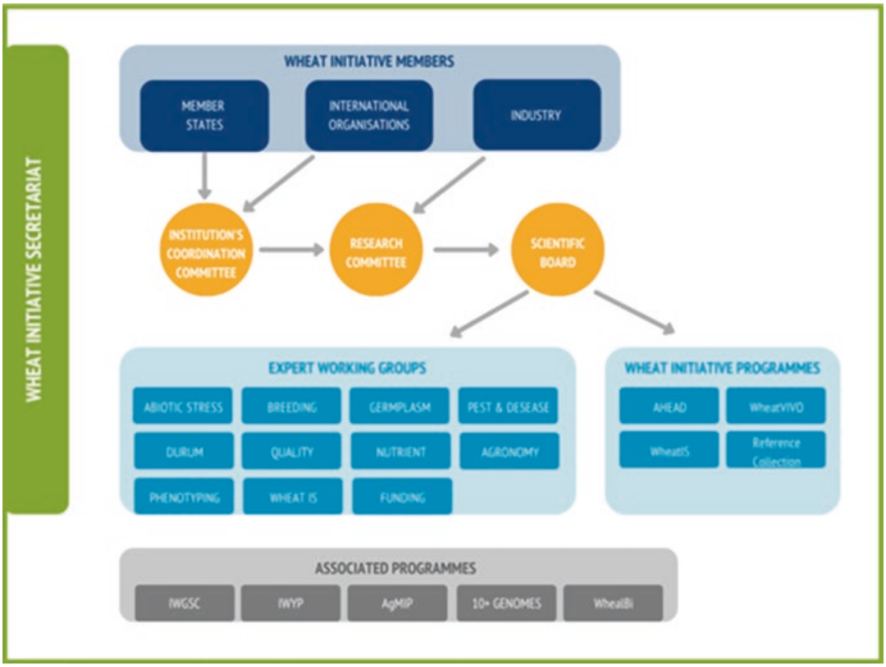


Fig. 26.4 The organization and management of the Wheat Initiative

the EWGs is to define global research priorities in their area of expertise and develop strategies to address these priorities. Each EWG also serves as a forum to bring researchers together to discuss major research advances and identify research gaps where increased investment or collaboration would be beneficial. A further role is to support and encourage the exchange of information, data, resources and explore opportunities to share capabilities.

The activities of the EWGs are supported by the secretariat and through a series of tools for information exchange. These include the Wheat Information System (WheatIS – http://wheatis.org), WheatVIVO (http://www.wheatvivo.org/), quarterly newsletters, weekly Media Briefs, and a biennial International Wheat Congress.

26.6.2 Multi-crop Networks

Traditionally, most private sector investment in agriculture has focused on a few, select large acre row crops, and high value vegetable crops, leaving many globally important food crops under-resourced. Given the urgent need to feed more people, there is increasing emphasis to produce nutritious, affordable food on thriving farms through efficient crops that increase yields with fewer inputs. Achievement of this ambitious goal requires an increase in both public and private investment to increase crop diversity and on farm profitability. Crop diversity creates greater economic security for farmers, offers environmental benefits and can increase food security. Farmers growing a range of crops may be able to sell to multiple markets and supply chains. Additionally, some crops can improve soil, filter water and reduce climate emissions.

A major hurdle toward meeting these needs is the significant decrease in public funding for agricultural research in the last decade (Fig. 26.5). In the Global South the problem has been seen for several decades. In the meantime, private sector investment has steadily increased. Much of the increase in private sector investment is driven by the acceleration of technology development and implementation of that technology into those major cash crops grown in the developed economies. The funding imbalance has left many, traditionally public funded crops under-resourced and technology poor. This gap leads to greater inequity for many important food security crops to meet the growing global demand for food, particularly in the face of climate change.

In this context we need to have a look at the situation in the poorest countries. While private sector Ag R&D investments in middle income countries have significantly increased, and investments of top investors are shifting to the private sector, the situation for the poorest countries is very different. No changes were observed since 1980, when for every dollar of AgR&D spent in high-income countries, just 3.5 cents was spent in the low-income countries. Thirty years later, the gap has widened. In 1980, high income countries spent on a per capita basis 13.25 $ vs 1.73$ in the poorest countries (7.7 fold difference) while in 2011, high income countries spent 17.73$ per capita compared with 1.51$ in the poorest country (a 11.7 fold

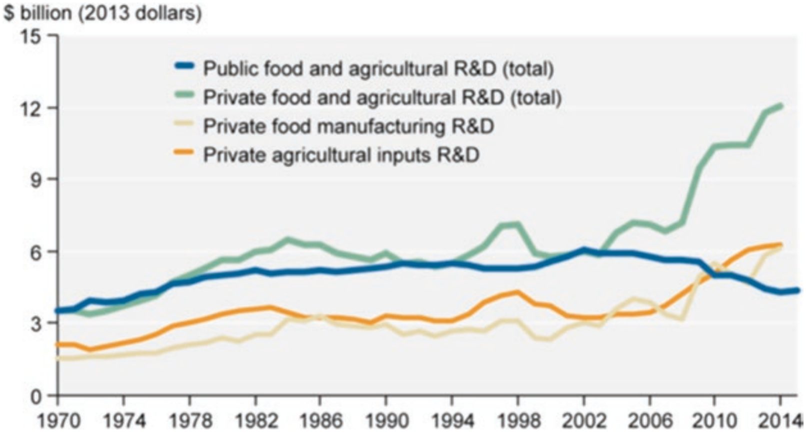


Fig. 26.5 A comparison of public and private crop research funding over time, real (inflation-adjusted) dollars, 1970–2015. Note: Private agriculture research funding data are through 2014; public agricultural research funding is available through 2015. (Reprinted with permission from [23])

difference). This is dramatic, since in the poorest countries' population growth is highest, agriculture plays a key role for economic development, but investments in Ag R& D are among the lowest in the world [24]. However, stagnant Federal funding and increased private research investments has led to new funding models and opportunities. To leverage this opportunity, the United States Congress created the Foundation for Food & Agriculture Research (FFAR) in the 2014 Farm Bill. FFAR was asked to build public-private partnerships that pioneer the next frontiers of agriculture research. Through public-private partnerships, federal investments are doubled – and often garner more than a 1:1 match. Public-private partnerships enable stakeholders both inside and outside the food and agriculture industry to convene. The convening capabilities of FFAR and the depth of relationships with wide-ranging stakeholders create an atmosphere of collaboration that is unique within the agriculture research community. It is not every day that competitors join forces to address a common challenge, but FFAR's mission helps unusual partners work together for the common good.

To date, FFAR has brought together over 500 diverse stakeholders to form these unique partnerships that support innovative science addressing today's food and agriculture challenges. Research focuses on imminent challenges where science is either filling a knowledge gap or developing a solution previously deemed impossible. When private-sector partners participate in research with FFAR the results likely are closer to application. At the same time, research is made available to the public so breakthroughs can be implemented widely and swiftly.

The Crops of the Future Consortium (COTF) is one of FFARs earliest consortia. The private sector participants of COTF represent seed companies and technology providers. Partners work closely together to identify key research gaps of common interest to the industry, define pre-competitive space and collectively de-risk new areas of research. This approach allows competitors to jointly fund the research, use the results in their internal R&D to develop products, and then compete in the market with those products. Key to the success is understanding and navigating how to deal with IP issues. It is critical to discuss data sharing and IP up front and get buy in from prospective private sector funders to make this model work. Consortia funding aligns well with non-exclusive access to technology. Further, using and leveraging public dollars requires that there be public benefit from the research. In COTF, mechanism to do this benefit the scientific community, the companies and the end users of the research.

For example, COTF also is participating in funding a large project with CIMMYT and the Bill and Melinda Gates Foundation focused on accelerating genetic gains in corn and wheat. This research is looking to shorten the breeding cycle and introduction of new varieties from what currently takes 8–10 years. This research also provides a path for translation to other crops once validated in corn and wheat.

26.7 Delivering Proofs of Concepts for Research Ideas Through Translational Research and Pre-breeding

Demographic and environmental factors stress the urgency to boost yield potential and climate resilience – yield stability. Ideas are suggested by academia, many stemming from studies with model species in controlled environments but satisfactory proofs of concept in a breeding context are prerequisite. The translational step is essential to ensure results will hold up under realistic field conditions [3]. Thus the last stage of translational research must ultimately show proofs of concept in the field, across an appropriate range of target environments, and using relevant, up to date germplasm whose genetic backgrounds encompass the collateral traits needed to make a new cultivar marketable [25] (see Fig. 25.9). In this way, translational research provides the link between more upstream research and crop breeding-through networks like IWYP, HeDWIC and IWIN- adding value to both.

26.8 Networking to Train the Next Generation of Crop Scientists

Networks of the type described here provide ample opportunity for capacity building, whether as part of a graduate degree or other opportunities for young scientists and technicians to learn about different methods and approaches in a new context. For example, CIMMYT's research platform in the Sonora Desert, jointly sponsored by the Mexican Government, IWYP and now FFAR, has helped train 12 PhDs over the last 10 years. The HeDWIC project formally initiated a Doctoral Training Program in 2020 which is already supporting 3 young scientists, to conduct novel research into: root imaging and growth analysis under heat and drought; identifying high throughput proxies for 'minimum data set' traits used in crop simulation modelling; and remote sensing to identify pigments associated with photoprotection at breeding scale, mentored by experts at Nottingham, Purdue and Hohenheim, respectively. The IWYP graduate program broke new ground in the areas of photosynthesis, partitioning and lodging research using realistic field conditions, e.g. [26–31]. In each case graduate committees comprised expertise from very different research fields, whose expertise and experience were complementary to producing results that not only demonstrated new science but also technologies ready for application in wheat improvement.

26.9 Key Concepts

Translational research capitalizes on prior large investments in upstream research; collaborative networks widen access to expertise, environments and infrastructure.

26.10 Conclusions

Co-authors of this chapter considered it important to emphasize that a continuum in breeding, from basic to applied research is vital since few scientists occupy the applied research space where validations of novel technologies and proofs of concept for crop improvement hypotheses are rigorously tested in a breeder-friendly context [32]. There is no scientific reason why these areas are neglected; perhaps partly because of the effort involved, funding constraints and perhaps due to silos that form for a variety of reasons. However, networking among scientists across the spectrum of research from pure to applied is an effective way to fill this space. Furthermore, the synergy that is created adds robustness to scientific conclusions while translational research and pre-breeding add societal value to investments made in science. Networks allow results from upstream plant science to have application in downstream problem-solving research. Given the increased demand from a growing population, the fact that new temperature records are being set annually and that water resources and soil fertility are on the decline in many parts of the world, science needs to become more efficient, and networking is a proven method for boosting modern plant breeding.

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