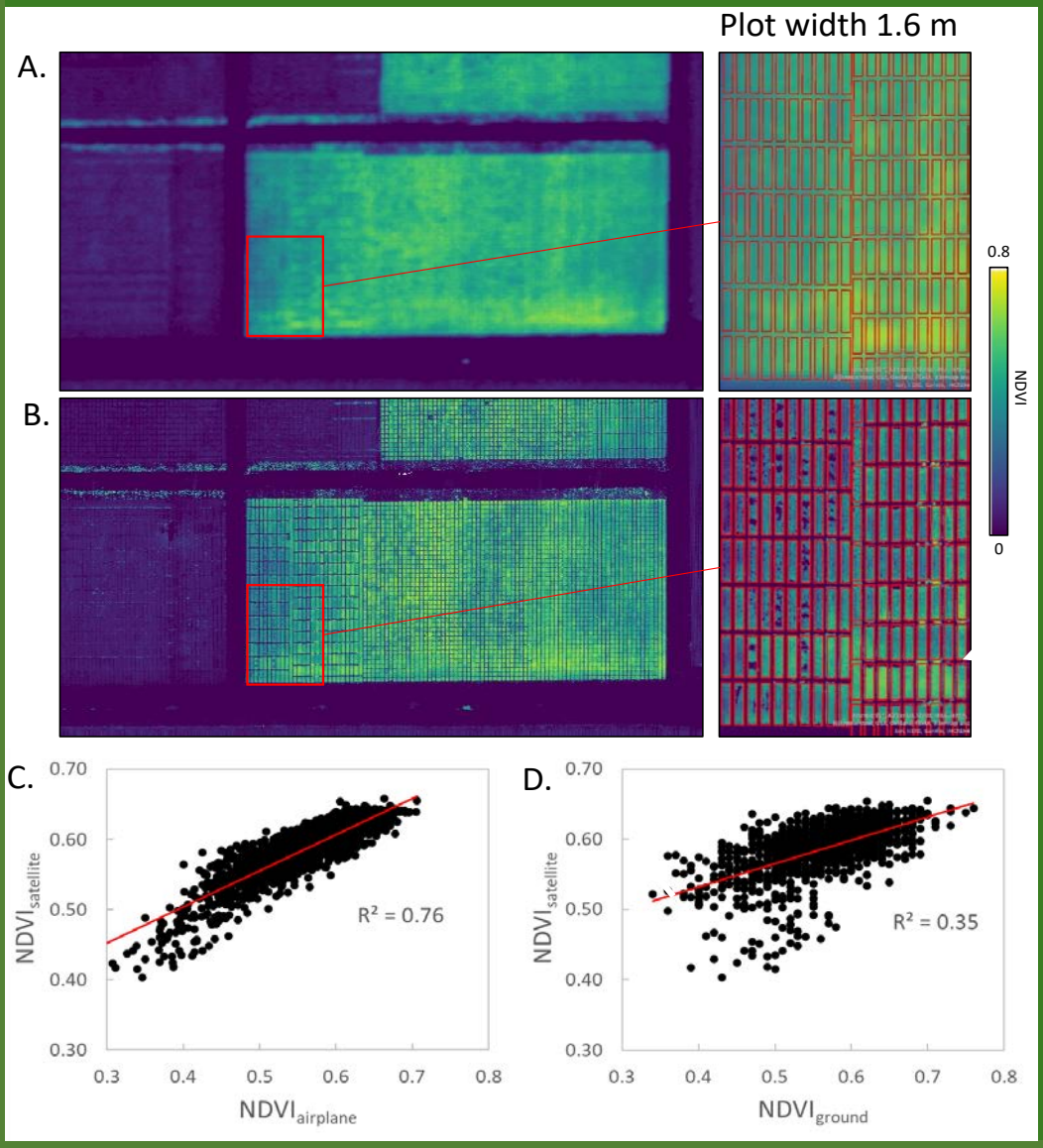


A) UAV image; B) Satellite image of same field; C) Satellite v Drone; D) Satellite v ground-based proximal sensing.

International Wheat Yield Partnership

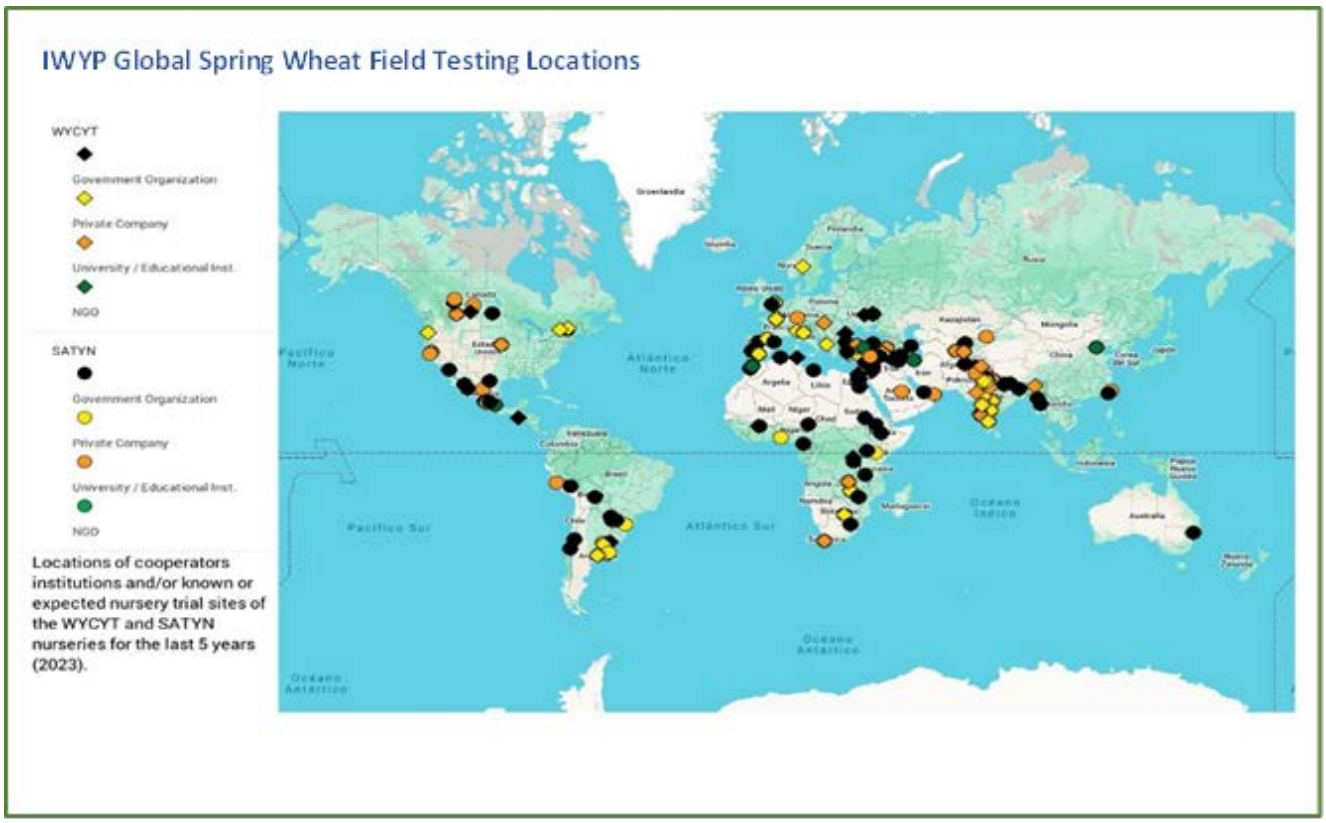
ANNUAL REPORT

2023-24

IWYP International Wheat Yield Partnership

Research to Deliver Wheat for the Future

Contents



Executive Summary

The past year IWYP has continued to generate many kinds of value and impacts important to its many types of stakeholders. Dr Jeff Gwyn retired from being Program Director after being in post from IWYP's beginning. His skills and commitment have been very influential in IWYP's successes.

The Science and Impact Executive Board (SIEB) of IWYP has assessed IWYP relative to its achievements and its potential future programs. It concluded that IWYP should continue as an international integrator of innovations and information pertaining to enhancing grain yields under both good and stressful conditions, targeting those stresses likely induced by climate change. However, given the evolving needs and the new opportunities due to scientific progress since IWYP was founded 10 years ago they decided to a draw line under the past successes and initiate formation of IWYP 2.0. This will be a unique and exciting, impact driven, scientifically progressive translation program, contributing internationally to wheat improvement through its many contacts with breeding organizations, public and private in the north and south.

Detailed field-based trait analyses of IWYP selected lines and their parents over 2023 and 2024 have illustrated that high yields can be achieved by different combinations of traits and alternative developmental strategies during crop growth. This confirms breeders have alternative options for achieving higher yields based on available genetic resources and local environments.

The IWYP Spring Wheat Hub at CIMMYT continued to deliver novel high yielding lines and have them tested in the field in many parts of the world. Five Countries have created 9 varieties from IWYP lines since 2016. Other outstanding results have been obtained with IWYP lines selected using deterministic, trait-driven strategies. Across 22 sites around the world IWYP lines outyielded checks on average by 6%, at some sites outyielding the CIMMYT 2014 variety Borlaug by up to 30%. Clearly, IWYP pre-breeding has produced lines that are not only higher yielding but also provide some resilience in more challenging environments.

The Winter Wheat Hubs in the US and UK are nearing completion of their first cycle of trait introgressions into locally important elite lines and have transferred their first sets of lines to private and public breeders to achieve multi-location field trials in the next year(s) to assess the effects of the new genetic introgressions in elite lines.

A global collaborative project has resulted in the complete genome sequencing of large numbers of wheat lines from the IWYP Hub and coupling of the information with large phenotypic datasets has been initiated. This will produce a wealth of information on yield-related genes, alleles, SNPs and haplotypes and will contribute to data-driven crossing and selection strategies.

Requests for new IWYP lines containing defined traits for validation in trials across the world continue to be high. Similarly, the requests from private and public breeders for trait-enhanced germplasm continue to generate evidence that IWYP's approaches and outputs provide value to local breeding programs.

In 2023 a total of over 200 scientific journal publications since the founding of IWYP recognizing IWYP support and input was achieved. These publications have made a huge contribution to wheat science and breeding research. IWYP "Science Briefs" were published most months to inform the wheat community of the technical progress and new ideas of IWYP. IWYP continued to enhance its presence on social media to deliver its message and progress to a wider audience.

Total investment in IWYP to date (2014-2023) is around US$86M with US$4.3M in 2023-24

Message from the IWYP Board Chair

I am once again pleased to report that IWYP has progressed well along its path of impact and value creation for wheat breeders of the world, perhaps exceeding its ambitious expectations. Especially significant are the new trait-enhanced spring wheat lines that exceed local modern checks in high yielding and low yielding environments- not an insignificant achievement given IWYP was initiated in only 2014. Nine new varieties have been created directly from IWYP lines in five countries—Pakistan, Egypt, Afghanistan, Bangladesh and Iran. Seed is being produced and sold from at least some of these. We have ample evidence that IWYP's efforts are being appreciated by our major stakeholders, who supply farmers with the means to feed the world. IWYP continues to be assessed by its impacts on wheat breeding and on learning how to improve the efficiencies of breeding through new sources of genetic variation and knowhow of what trait combinations generate additional impacts in relevant locations.

The Board of IWYP has assessed IWYP after its 10 years of operation and looks forward to another 10 years, IWYP 2.0, built upon the needs of our stakeholders, the greatly enhanced scientific opportunities and the huge needs. New funding commitments will be required to build IWYP 2.0 but the arguments for its continuing work are strong.

The Board of IWYP continues to be grateful to all stakeholders, including scientists, who seek to deliver the mission of IWYP. The IWYP Board also thanks all those who have invested their time and money into this important task of learning how to provide enough wheat for future generations.

Richard Flavell, DSc FRS
Board Chair

Message from the Program Director

I am excited to have joined IWYP as the new Program Director following the retirement of Dr. Jeff Gwyn who led IWYP since its inception. The International Wheat Yield Partnership was founded to enable wheat breeders to achieve increases in productivity at a rate faster than is seen today by providing breeding programs with novel germplasm, optimized traits and new breeding tools that are sorely lacking. These new genetic resources encompass traits, coupled with the tools to track them, that breeders do not have the resources to discover or the infrastructure, equipment or expertise to translate and develop on their own. IWYP has seen successes in pushing beyond climate resilience *per* se by not merely safeguarding current yield levels but also raising them when presented with stresses associated with changing climatic conditions.

Over the past 10 years, IWYP has generated great value. IWYP's research outputs have filled unique and highly efficient translational pipelines to assess the new innovations by private and public breeding programs. IWYP has delivered over 300 new higher yielding lines with novel traits evaluated in over 1100 global field trials. I firmly believe that IWYP have much to be proud of by applying scientific innovation and global collaboration to advance food security in a changing climate. As we close the last 10 years of IWYP, we are poised to initiate an exciting new chapter for IWYP going forward.

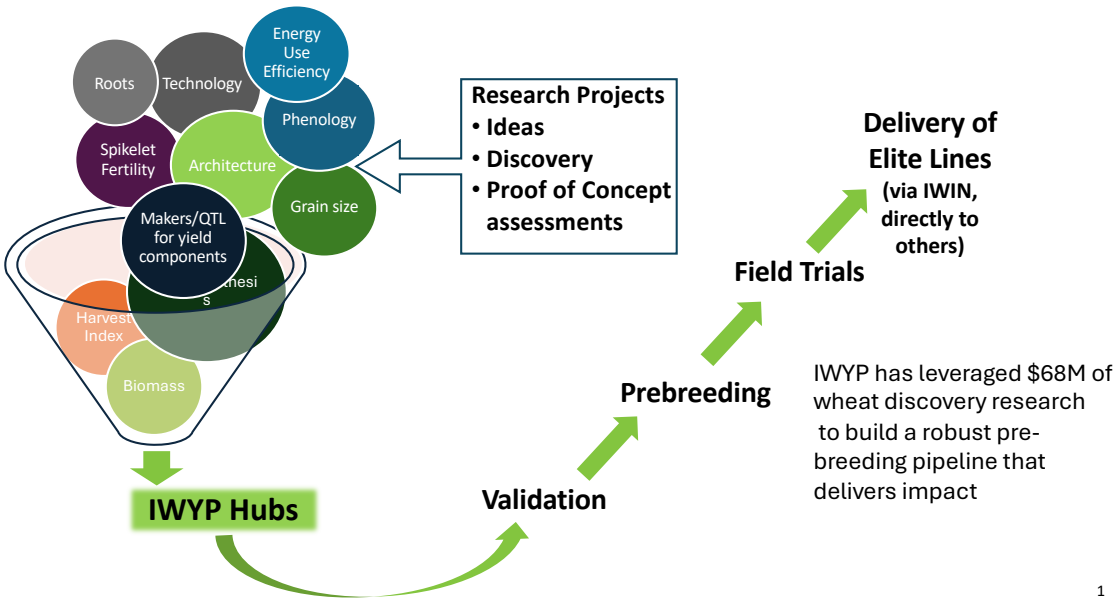
Jeffrey Rosichan, PhD
Program Director

IWYP Strategy, Outputs and Impacts

Wheat is the most widely grown crop and supports the basic qualities of life for so many in the world. Shortfalls in production are predicted to increase over the coming decades. IWYP therefore was founded to provide value to wheat production systems by learning and teaching how to increase yields faster and by delivering needed improved germplasm and the associated knowledge to public and private breeders, in both the Global North and Global South. IWYP's activities therefore transcend the value chain from discovery into plant breeding and occasionally into variety production through its many partners.

Wheat improvement is the goal of many scientists and breeders. The comparative advantage of IWYP comes from its international Partnership structure comprised of private and public breeding organizations and government agencies that support plant science. This generates its ability to embrace, translate and distribute innovative science originating anywhere in the world. A special feature of IWYP and the means to deliver on its mission are the Translational Hubs at CIMMYT (MEX), Kansas State University (USA) and the National Institute of Agricultural Botany (GBR). These Hubs provide access, evaluation and distribution systems to breeding programs around the world for both spring and winter wheats.

The IWYP Strategy Includes Discovery to Testing and Delivery



IWYP's value and impacts updated through 2024 are many and varied. While the outputs in publications and training have high value in the research scientific community, it is the release of information and assays on traits, assessed and validated in elite germplasm, that are of major value for the breeding community. Because the latter are the route to farmers and harvested wheat yields around the world, these outputs and impacts are now the more important outputs for IWYP, given its mission and strategy. That is why requests by breeders for the new IWYP trait-enhanced lines, the yield results in many different environments around the world and the relevance of the lines to creation of new varieties are of increasing importance to IWYP and its stakeholders (see **Table, page 8**). It is here where future outputs and impacts of IWYP will be particularly important for assessing the ongoing value of IWYP for helping improve harvested yields of one of the world's largest crops.

Defining IWYP 2.0, the New Program for the Coming 10 Years

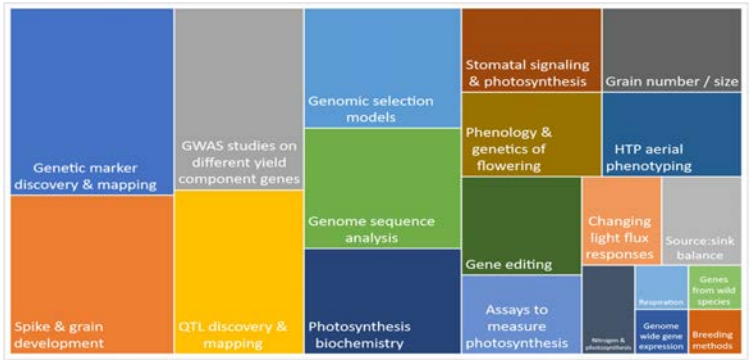
Over the last year, the Science and Impact Executive Board (SIEB) of IWYP has been assessing IWYP and planning its next phase. This has involved evaluation of technical progress as well as consultations with stakeholders and the international wheat scientific community. IWYP was founded to boost the translation of discoveries into breeding programs around the world and thereby impact food and nutritional security. Since the start of IWYP the global needs for more wheat production on less land and in more places have increased. Thus, the rationale for IWYP has grown stronger. This makes Translational Hubs central to its ongoing mission of enhancing global food security because they find the ways to progressively raise yields through provision of trait-improved, validated germplasm to breeders around the world, especially where conditions for growing wheat are challenging in the face of climate change.

Also, since the initiation of IWYP, the sciences underpinning knowledge of plants and crops, driven by digital technologies, have opened many more opportunities for translation of knowledge into forms relevant to and needed by wheat breeders. The combination of the increased needs and the growth of new science-driven opportunities imply a substantially different future compared with that when IWYP was started in 2014. The SIEB of IWYP therefore sees it fitting and appropriate to draw a line under the past 10 years, fully recognizing the huge successes and impacts of IWYP, and to launch the second 10-year program, IWYP 2.0.

IWYP 2.0 will be (i) Impact driven, (ii) more ambitious, (iii) exploiting extensively new technologies of digital phenotyping, already well established within IWYP, (iv) increasingly driven by knowledge of the trait combinations necessary for yield increases in specific wheat growing environments (v) increasingly driven by DNA analyses of its germplasm and advanced selections, (vi) greatly expanding its sharing of knowledge and technologies between its scientists, (vii) partnering more closely with other organizations driving the frontiers of wheat improvement and (vii) communicating its knowledge to help others benefit from its progress and insights.

New funding commitments will be required to sustain and enhance the mission of IWYP, and to generate the impact we seek in the fast-changing world of science. These will therefore remain an ongoing priority for the IWYP Board.

IWYP 2.0 Integrates Tools and Technologies Across the Hubs to Accelerate Wheat Breeding



IWYP Spring Wheat Translational Hub at CIMMYT

The program at the IWYP Spring Wheat Hub at CIMMYT utilizes cutting edge high throughput phenotyping (**see cover page**) to assess many traits introduced from research that are likely to influence yield and its subcomponents to validate their effects. To link combinations of traits with yield, it introduces the best traits into elite lines through ideotype-driven, deterministic pre-breeding and then selects high yielding lines with different sets of traits. The best lines are then tested in a range of environments by breeders around the world **(see Map on page 1)**. Many of these collaborators return field trial data which inform which traits and combinations are boosting yield and in which environments, enabling the Hub to adjust its translation strategy accordingly. These collaborators can select lines to use as parents in their local breeding programs or even develop them further into varieties. The new high yielding lines are then deconstructed to understand which combinations of traits program high yields in specific environments and how they interact.

Multiple Crop Development Strategies Enable High Yields in Spring Wheat

Learning how to assemble combinations of trait variants to achieve higher yields is an important goal of the pre-breeding program at the IWYP Spring Wheat Hub at CIMMYT.

Field assessments during 2023 and 2024 of many trait variants and their parents have shown that very high yields can be obtained through different growth strategies during crop development. Two contrasting strategies involve the formation, retention or loss of tillers and spikes. [It is usual that tillers and spikes form and then some fraction withers around the stages of anthesis or later, resulting in fewer spikes contributing to grain yield.] The results indicate that the main differences between the two strategic paths are:

- In Path 1 lines invest less in tillers and water-soluble carbohydrates (WSC) pre-heading than in Path 2, with lower above ground radiation use efficiency (RUE) before grain fill, probably investing more resources below ground. However, they have higher fruiting efficiency, more grains per spike and grains per spikelet and a higher thousand grain weight.
- In Path 2 lines store more WSCs in temporary tillers (perhaps sacrificing root growth), resulting in more final spikes/m2, grains/m2 and a longer relative grain-filling duration.

These results show that it is possible to assemble different combinations of traits, presumably by genetic recombination, in crossing programs and to select different trait combinations during subsequent generations, to achieve the same very high grain yields. This confirms breeders have different options to fit the preferred crop growth strategy to the available genetic variation, local environment and management systems, without compromising yield potential.

Defining in detail alternative growth and trait development strategies by assaying the key traits that determine equivalent high yields enables alternate trait combination ideotypes to be adopted as objectives in breeding programs. It also enables specific deficiencies of lines to be identified, thus setting new objectives for enhancing their yields further in new rounds of breeding or editing. It will be important to assess the different pathways to high yields in other environments where the timing and extent of tiller formation, loss, spike properties and carbon distribution during development may need to be different for high yields. Such studies are underway.

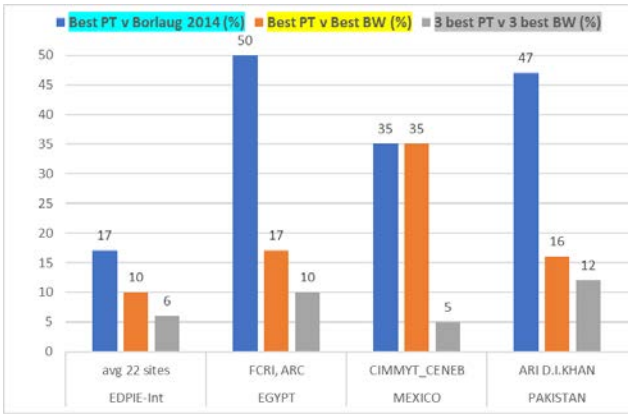
Major Yield Gains in Diverse Trial Environments

In 2014 IWYP was founded to include a spring wheat pre-breeding program to assemble improved yield traits efficiently while also incorporating more unusual/exotic chromosome segments. The program was to explore whether high yields could be achieved in ways different from other breeding programs across the world, including that of the Bread Wheat Program at CIMMYT. It was hypothesized that diversifying science-based spring wheat breeding approaches could provide benefits for breeding programs around the world.

In 2023 and 2024, i.e. 10 years after IWYP was founded, international trials have been grown at 22 sites in collaboration with HeDWIC, a sister program to IWYP, to assess how the IWYP spring wheat lines, assembled and selected in Mexico to have highest yield potential under CIMMYT conditions, perform in different environments, including those with different temperature profiles. The trial included 58 lines from the IWYP pre-breeding program at CIMMYT, 80 diverse CIMMYT advanced Bread Wheat Program lines and 12 elite lines from Australia to serve as comparative checks.

In the trials run by cooperators around the world the best IWYP PT (physiological trait) line (averaged over all 22 sites) outyielded the baseline CIMMYT check variety, Borlaug by 17% (See Figure; the variety Borlaug was the new CIMMYT Bread Wheat (BW) elite line in 2014) and the CIMMYT checks by 6%, averaged across all 22 sites, while the best IWYP line expressed 10% more yield than the best CIMMYT Bread Wheat line. These results imply that the IWYP Hub's deterministic pre-breeding approaches for yield potential at the CIMMYT high yield potential sites in Mexico are useful for generating favorable gains in performance at many other international sites with more challenging environments.

Noteworthy are the IWYP lines that expressed outstanding yields at specific sites in Egypt and Pakistan (see Figure). At a site in Egypt the best IWYP Hub line produced 17% more grain yield than the best CIMMYT Bread Wheat check, while the mean of the best 3 IWYP lines yielded 10% over the mean of the best 3 Bread Wheat Program's controls. At one site in Pakistan the best IWYP Hub line expressed 16% more yield than the best CIMMYT Bread Wheat control line at the site, while the mean of the best 3 IWYP Hub lines outyielded by 12% the mean of the best 3 CIMMYT Bread Wheat checks at the site. Among these sites the best IWYP Hub line yielded at least 35% more than the variety, Borlaug. Given these results generated in the trials by the breeders at these sites in Egypt and Pakistan it is not surprising that the breeders have created varieties from particularly high performing IWYP lines (see below). We conclude that (i) substantial progress in yield improvement has been achieved since IWYP was founded in 2014 and (ii) focusing on trait stacking and incorporating lines with unusual pedigrees is having significant positive impact on many of the breeding programs and environments being served by IWYP across the world.



Lines Requested By Breeders, Public And Private

IWYP has been sending out evaluated products from its crossing and selection (pre-breeding) Program to well over 100 plant breeding programs around the world. These lines have unusual genetic backgrounds because they are built from lines containing chromosomal segments from landraces and ancestral diploid species and selected based on their high biomass (radiation use efficiency). To date, 342 new lines have been tested at 1167 sites around the world.

YEAR	WYCYT	# New Lines	Government (NARS)	Education	Industry	TOTAL
2012	1	23	32	4	1	37
2013	2	35	41	10	4	55
2015	3	36	75	9	21	105
2016	4	22	79	10	23	112
2017	5	24	82	7	23	112
2018	6	21	91	11	22	124
2019	7	27	64	7	21	92
2020	8	26	63	11	30	104
2021	9	29	72	14	31	117
2022	10	32	72	8	31	111
2023	11	36	60	13	28	101
2024	12	31	56	11	30	97
TOTAL		342	787	115	265	1167

Nine Varieties Created From IWYP Pre-Breeding At CIMMYT

Each year new crosses are made to combine high radiation use efficiency (RUE) with lines with high sink traits and recombinant seletions made based on their high yields under the high yielding environments at CIMMYT in Mexico. This gives plant breeders around the world the chance to assess the IWYP selections in their environments. Wheat breeders in Pakistan, Egypt, Afghanistan, Bangladesh and Iran have converted lines into varieties based on their local performances. While it is not the primary intention of IWYP to generate varieties, the conversion of them into local varieties is a welcome achievement and signifies that the new genetics and strategies of combining source and sink traits is generating valuable outputs for wheat breeding and farmers.

Year	Name	Country	Cross / pedigree
2013	Pakistan-13	Pakistan	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN
2016	Borlaug-16	Pakistan	SOKOLL/3/PASTOR//HXL7573/2*BAU
2017	Kohat 17	Pakistan	SOKOLL/WEEBIL
2018	Cascabel	Bangladesh	SOKOLL/W15.92/WBLL1 (SQWA or SUGA)
2020	Kunar 20	Afghanistan	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1
2022	Misr 7	Egypt	WBLL1//PUB94.15.1.12/WBLL1/3/MUCUY
2023	Misr 9	Egypt	BCN/WBLL1//PUB94.15.1.12/WBLL1/3/MUCUY
2024	WGE000006939945	Pakistan	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SERI/BAV92//WBLL1
2025		Iran	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1

IWYP North American Winter Wheat Breeding Innovation Hub

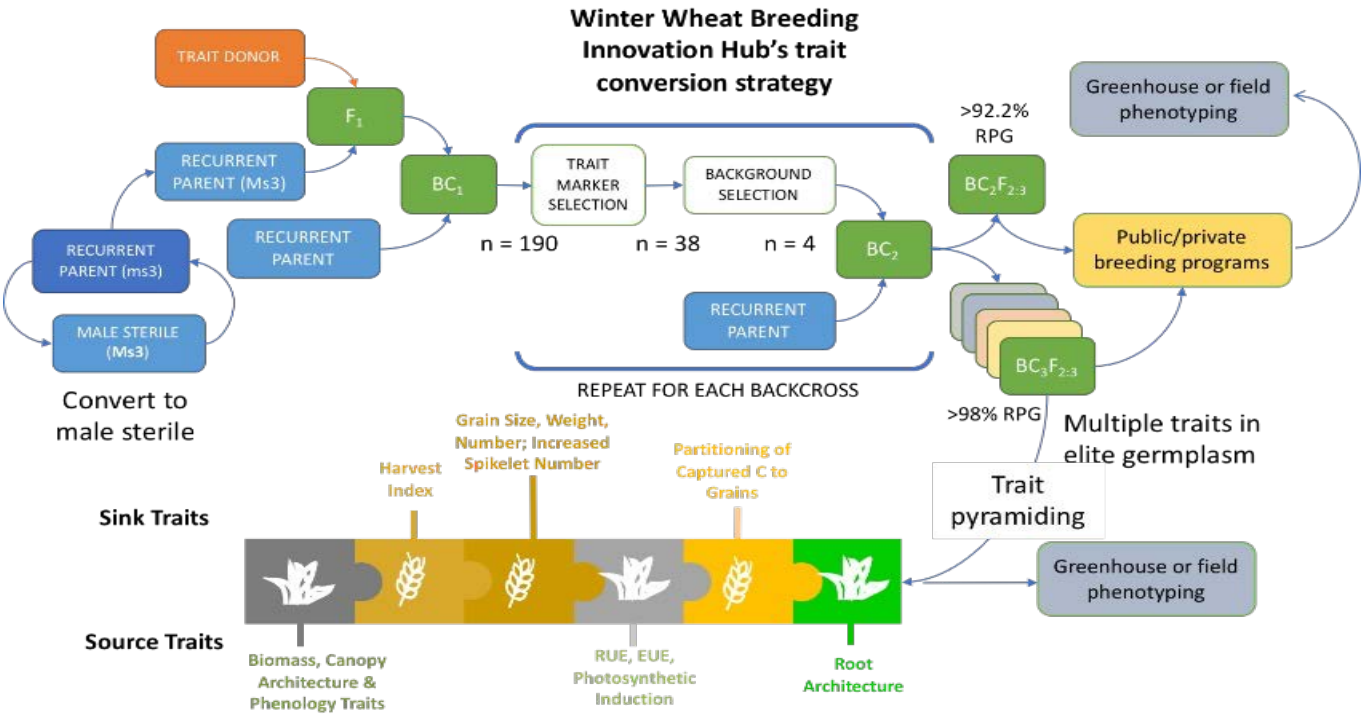
The IWYP North American Winter Wheat Hub (NA WW Hub), based at Kansas State University in the US, is funded by a grant from USDA NIFA and supported by five private companies as well as five US State Wheat Commodity Boards.

For the new trait introgressions, 11 elite recipient lines were selected to include all winter wheat classes in the US. Fifteen different IWYP yield traits, several disease resistance loci and gene variants derived by gene editing have been introduced by backcrossing. The seeds of many of the introgressed lines are now being increased. Field trials began in late 2024 to test the effects of the new genetic variants in each of the elite genetic backgrounds. Six lines carrying some of these introgressions have been handed off to both public and private breeders. Use of the Ms3 male-sterility trait being developed at the North American winter wheat hub has potential to significantly shorten the breeding cycle and thereby shorten the timeline for the IWYP hubs to release pre-breeding material to the private and public sector (see figure below).

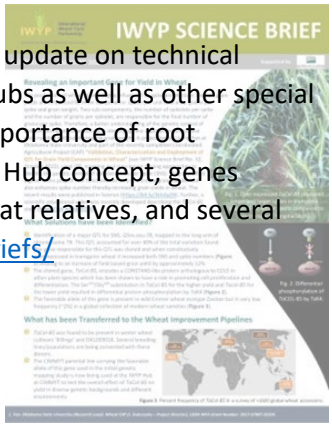
IWYP European Winter Wheat Hub

To serve the European winter wheat market areas, the IWYP European Winter Wheat Hub is based at the National Institute of Agricultural Botany (Niab) in the UK and funded by a group of IWYP private industry partners.

The first cycle of trait introgression began in 2021 by the selection of two target traits relating to hybrid seed production. These traits are being introgressed into 6 representative UK, French and German elite wheat varieties. Seed of lines converted for these traits was made available to the private industry partners. A second cycle of trait introgression began in 2022 when 3 different source and sink traits were selected. It is planned that converted lines could be made available for field evaluation towards the end of 2025.

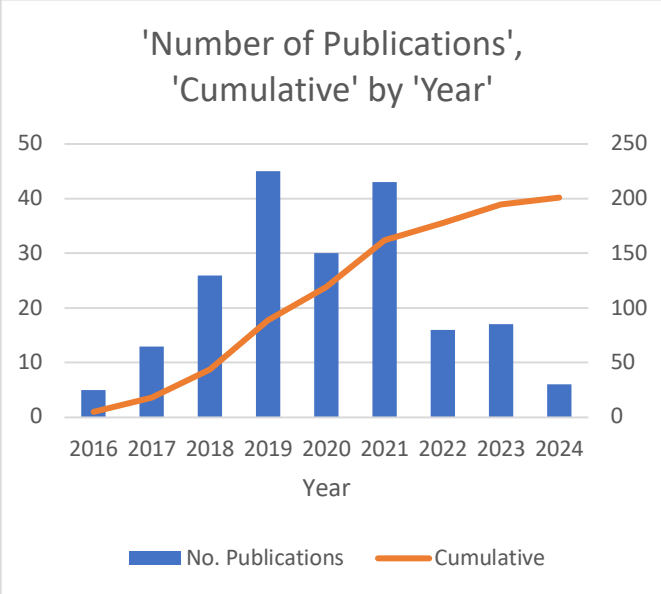


IWYP Science Briefs



IWYP continued to publish its Science Briefs last year. Each 1-page Brief provides an update on technical progress from IWYP research projects, Aligned Projects or the IWYP Translational Hubs as well as other special topics. This past year's topics included building climate resilience into wheat, the importance of root architecture, Wiring Diagrams for designing more productive crops, the IWYP Super Hub concept, genes affecting the number of grains per spike, mining for yield determining alleles in wheat relatives, and several others. All Science Briefs can be downloaded from https://iwyp.org/iwyp-science-briefs/

IWYP Research Publications



In 2024, the number of publications in major scientific journals emanating from studies carried out by IWYP-associated scientists and institutions exceeded 200. Assessment of the 200+ papers provides a robust picture of IWYP's scientific emphases and achievements. Collectively they represent leading edges of wheat research over the past 10 years. They make a powerful collection and illustrate how wheat research has been transformed and positioned to launch the next decade's breakthroughs. The full list is available on the IWYP website (https://iwyp.org/publications/

Underlying this impressive number of publications is the large numbers of people working together collaboratively in international teams, with many being trained early in their careers (more than 200 to date).

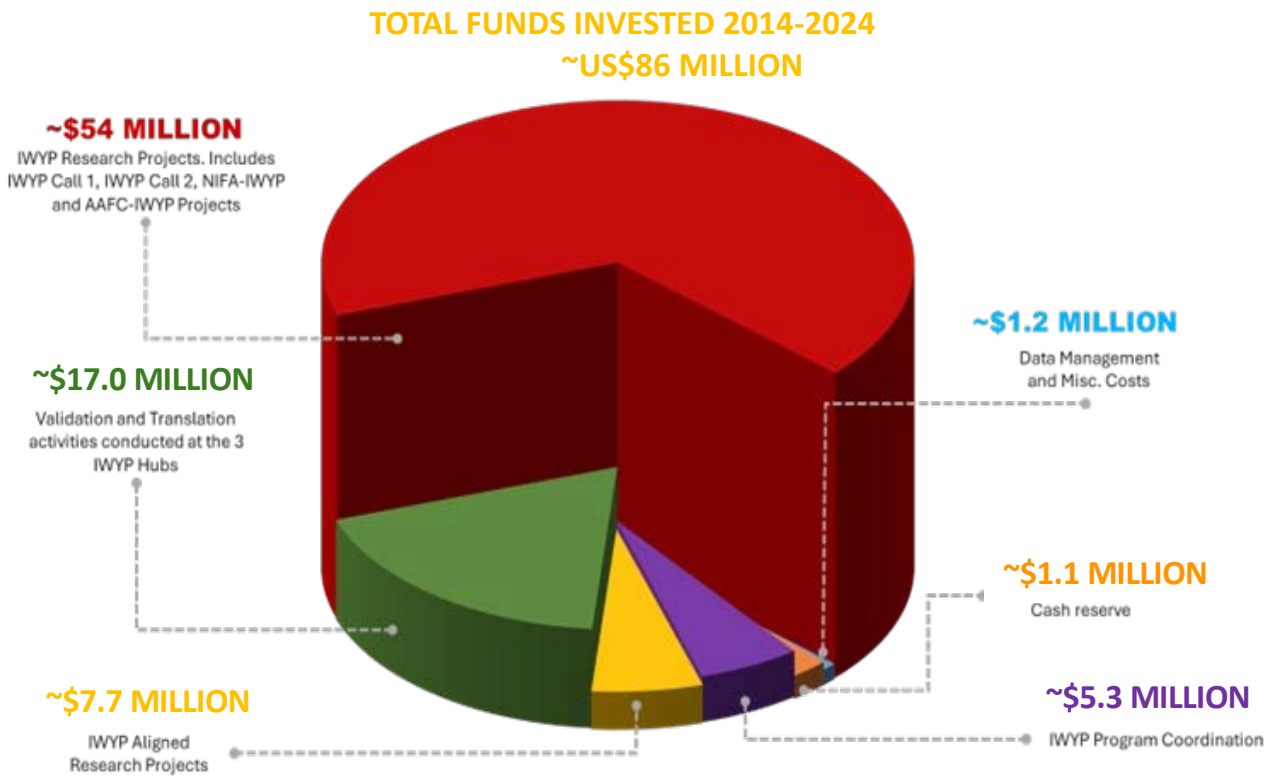
IWYP Program Conference

The last annual IWYP Program Conference was held online in September 2023. Over 80 scientists from many parts of the world attended and interacted during the two-day Conference. The active participation in the IWYP Program Conferences signifies that the global wheat scientific community remains connected and interested in the IWYP Program. Due to the leadership transition, no IWYP Program Conference was held in 2024. A new IWYP Program Conference is planned for Fall 2025.

Finances and Funding

Since the initiation of IWYP operations in 2015, the working model of coordinated and integrated scientific research tied to centrally coordinated pipelines of downstream development has been managed via a centralized accounting system.

The IWYP Science Program has been funded mostly by a group of IWYP Partners (BBSRC, USAID, GRDC, USDA-NIFA, SFSA and AAFC). IWYP also accounts for the large in-kind contributions made by a variety of activities within the Program. The total investments made by the range of partners, directly or indirectly since the inception of IWYP, amounts to ~US$86M. Over the period 2023-24 the total funds invested in IWYP were ~US$4.3M. During this past year, funds have continued to be spent on the Spring Wheat Hub at CIMMYT (USAID, BBSRC, private members), The North American and European Wheat Hubs, and the value-adding coordination, scientific management and communication activities. At the end of 2024, about $1 million remains in reserve for 2025. This reserve, with additional pledged funds and new funds that must be raised during the coming years will support the continued validation, translation and scaling up of the current research discoveries into significantly higher yielding wheat germplasm and breeder-friendly tools for transfer to varietal breeding programs globally. There is a robust translational pipeline that will require several more years of field trials.



Partners and Funders

IWYP was founded on a collaborative approach bringing together public and private research organizations from many countries. Importantly, IWYP is a formal “Partnership” between public funding agencies and the private sector who collectively are critical to the success of IWYP and play multiple roles in the organization. These include defining strategic direction through to active engagement in the utilization of IWYP outputs and working together to bring new wheat varieties to farmers containing IWYP innovations via the IWYP Translational Hubs. The benefits and value creation have flowed to and from both the private and public sectors. The public institutions have provided financial support for research and development, generated new scientific knowledge via research, and delivered novel traits, germplasm and tools for breeding. The private sector has been key in guiding IWYP activities so that they remain commercially relevant and is investing in their product development pipelines to bring IWYP innovations to farmers. As of 2024, IWYP relies on support and strategic direction from 12 public funding and research organizations and 8 private industry partners.

Funding Organizations and Research Institutions

Private Industry Members

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Research to Deliver Wheat for the Future