International Maize and Wheat Improvement Center

Harvesting Success

Annual Report

2022

Harvesting Success
Annual Report 2022 • CIMMYT

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SUSTAINABLE DEVELOPMENT GOALS

At the Rio+20 Conference, in June 2012, the United Nations (UN) member states agreed to develop Sustainable Development Goals (SDGs), to build on the eight Millennium Development Goals (MDGs) that had been established in 2000, but were slated to expire in 2015. The UN High-level Political Forum on Sustainable Development held its first meeting on 24 September 2013 to follow up on these SDGs.

CIMMYT contributes to reaching the following SDGs:

Ten of the 17 SDGs relate directly to CIMMYT's mandate. The SDGs guide agricultural, social and economic development until 2030. The entire CGIAR has transformed its work to align with these ambitious goals.

CIMMYT's research for development contributes to a world free of poverty, hunger and environmental degradation. CIMMYT, as part of CGIAR, is striving to help the world reach these goals, such as the empowerment of women, the reduction of greenhouse gas emissions, and the improvement of health and nutrition for the world's poorest people.

About CIMMYT

The International Maize and Wheat Improvement Center (CIMMYT) is an international organization focused on non-profit agricultural research and training that empowers farmers through science and innovation to nourish the world in the midst of a climate crisis. Applying high-quality science while building strong partnerships, CIMMYT works to achieve a world with healthier, more prosperous people, free from hunger, and with more resilient agrifood systems. CIMMYT's research brings greater productivity and higher profits to farmers, while mitigating climate change and reducing the environmental impact of agriculture. Besides maize and wheat, CIMMYT now also works with dryland crops like sorghum, millets, and legumes, to modernize seed production in Africa, while engaging with farmers and breeders.

CIMMYT is a member of CGIAR, a global research partnership for a food-secure future, dedicated to reducing poverty, enhancing food and nutrition security, and improving natural resources.

For more information, visit cimmyt.org.

Content

Message from the Chair of the Board of Trustees

Looking back on 2022, the world is facing unprecedented challenges, which are placing new demands on innovation in agrifood systems, and on climate change adaptation and mitigation. Most of the global issues confronting us a year ago are still with us, and in many ways, they have become more serious. Over the next year, our individual and collective limits will be tested by emerging challenges, such as geopolitical tensions (including migration issues), inflation, accelerated climate change, and a changing food security situation. Governance systems once taken for granted across the globe are now facing greater scrutiny. As the cracks widen and deepen, CIMMYT's capacity to respond must continue to accelerate. We must also improve our ability to anticipate forthcoming challenges and pivot swiftly as needed.

As the COVID-19 crisis loosens its grip, it is important to recognize that scientific research and development contributed to alleviating the suffering caused by the pandemic.

Climate change is robbing the Global South of its potential, and the burden is especially heavy on smallholder farmers. However, there are promising innovations from research, including in the private sector, to adapt to climate change.

The war in Ukraine has lasted for a full year, ending our hopes that peace would prevail quickly. This has cut back on the supply of food, especially grains, to poorer countries, making it clear that global trade is a crucial, if vulnerable part of the world's food security.

Peace and democracy rest on a foundation of food security. The source and quality of food today will help to shape the world that our children inherit.

At CIMMYT, I am delighted and honored to be associated with some of the world's finest agricultural scientists, whose cutting-edge research contributes to solving the challenges of today, while continuing to reduce poverty and improve livelihoods, especially of smallholder farmers.

Just to give some examples from the report you are reading, a review released in 2022 shows that CIMMYT scientists are successfully integrating food systems innovations with climate change adaptation and mitigation. CIMMYT's work on blending flours from different crops demonstrates a way to ease sub-Saharan Africa's dependence on food imports. New maize varieties, which are resistant to heat and drought, are crucial for helping South Asian farmers adapt to a changing climate while improving food security.

All of the stories featured in this report highlight CIMMYT's values: Excellence, Integrity and Teamwork. The CIMMYT team practices crucial behaviors. They listen to farmers, to partners and to each other. They leap forward, with bold, new initiatives. They lead by example, with the high caliber of their work and they learn by doing.

I wish to acknowledge the generosity of CIMMYT's funders. We also continue to streamline our administration and to ensure that efficient operations maximize the amount spent on research, to benefit the world's smallholder farmers.

In January 2022, 31 new CGIAR initiatives were launched to radically realign food, land, and water systems. These initiatives were designed by multidisciplinary teams of scientists from across CGIAR to bring lasting and positive change across five Impact Areas: 1) Nutrition, Health, and Food Security; 2) Poverty Reduction, Livelihoods, and Jobs; 3) Gender Equality, Youth, and Social Inclusion; 4) Climate Adaptation and Mitigation; and 5) Environmental Health and Biodiversity. CIMMYT participates in most of these new initiatives, co-leads several of them, and is now creating new tools and innovations to address the five CGIAR impact areas. With CGIAR research and innovation providing a 10:1 return on investment, supporting the new initiatives provides funders with a clear path to impact for people, climate, and nature.

I also want to thank my colleagues on the Board of Trustees, the leadership at CIMMYT, our talented staff and our valued collaborators for their commitment and insights that make this work a rewarding experience.

The challenges ahead are great, but so is our determination to meet them head-on. These complex global challenges confronting us are systemically rooted. Many are interconnected and interdependent, requiring that we work together. At CIMMYT we welcome your thoughts and partnership in making food security a human right for all. In turn, please count on us to seek to understand (listen more), and to humbly deliver on our commitments and partnerships.

Margaret Bath

All of the stories featured in this report highlight CIMMYT's values: Excellence, Integrity, and Teamwork. The CIMMYT team practices crucial behaviors, such as listening, creating, and delivering research results.

Message from the Director General

As you read this report, I hope that you will find inspiration in it. Research on food systems is addressing some of today's biggest challenges. At CIMMYT we are committed to finding innovative solutions to global issues, such as poverty, climate change and gender inequality.

COVID-19 is still with us, even if parts of the world are recovering. However, in 2022 the struggle of the poor to buy bread has made world headlines. Research at CIMMYT is helping to ease this suffering.

CIMMYT's mandate is as relevant today as it ever was. It is important to acknowledge that CIMMYT continues to achieve many of our goals. For example, in most of the world, rural livelihoods are steadily improving, even as we also rise to challenges such as climate change, and environmental degradation.

CIMMYT is now developing a new strategy, based on three strategic pillars: Discovery, SystemDev, and Inc.

1. **Discovery** includes our core strengths in scientific research and innovation.
2. **SystemDev** tackles today's challenges with a systems perspective.
3. **Inc.** calls upon CIMMYT's ability to generate alternative sources of revenue and innovative ways of working by strengthening public-private partnerships.

The Discovery pillar is highlighted in our long-term experimentation with ecological intensification. CIMMYT researchers are demonstrating that organic fertilizer, crop rotation and other practices mitigate climate change, while improving yields in Africa, Asia and Latin America. We also include an update on our activities on dryland cereals and legumes (sorghum, the millets, groundnut, pigeon pea and chickpea) to further strengthen our mandate.

The SystemDev pillar is featured in the successful strategies and business models for selling maize in Nepal. As smallholder farmers are integrated into modern value chains, women and wage laborers are becoming maize entrepreneurs.

The Inc. pillar (still a working title as we further codevelop and brainstorm on what this pillar could mean), is portrayed in our exploration of the voluntary carbon markets (VCM) allowing farming communities to sell carbon credits as they improve their soil health through sustainable agriculture.

With its creativity, talent and capacity, CIMMYT is at the forefront of efforts to avert a global food crisis, and the climate change disaster.

At CIMMYT, as we implement our 2030 Strategy, we are impact driven, but also humble and respectful of the local context and people's needs. Our work is collaborative by nature. We strive to be generous in spirit and we hold ourselves accountable for our actions.

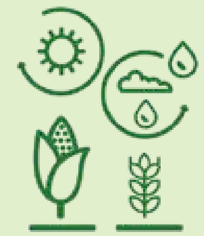
With them, individual actions must always show that we care for each other, our fellow team members. We always bear in mind our final stakeholders, the farmers. With them in mind, we seek to share our excellence while we attract our needed investments to benefit them. We support all our partners, who work closely with farm communities.

Our seven collective steps for a successful 2030 Strategy to realize our 2100 vision of CIMMYT as a global thought leader and change agent for climate resilience, sustainability and inclusive agricultural development for a food-and-nutrition-secure future are to:

1. Address critical issues facing agriculture and wider society
2. Work for the collective benefit
3. Advance knowledge of genetics and agrifood systems
4. Ensure continuing integration of technical advances
5. Target the drivers of demand
6. Build multi-actor, multi-disciplinary platforms to integrate components, and
7. Focus on a broader legacy.

CIMMYT's efforts are helping to lift families out of poverty and hunger, empower women, safeguard the environment and address climate change. This would not be possible without our generous funders, and the collaboration we enjoy with our excellent partners across the world.

Bram Govaerts



At CIMMYT, we are committed to finding innovative solutions to global issues, such as poverty, climate change and gender inequality.

CIMMYT by the numbers 2022

69 **unique maize** varieties and
62 **unique wheat** varieties resulting from our work

+450
maize and wheat seed shipments annually from our headquarters to more than 100 countries, with a total of 426K individual seed packets

+4M
accumulated downloads from our publication repository

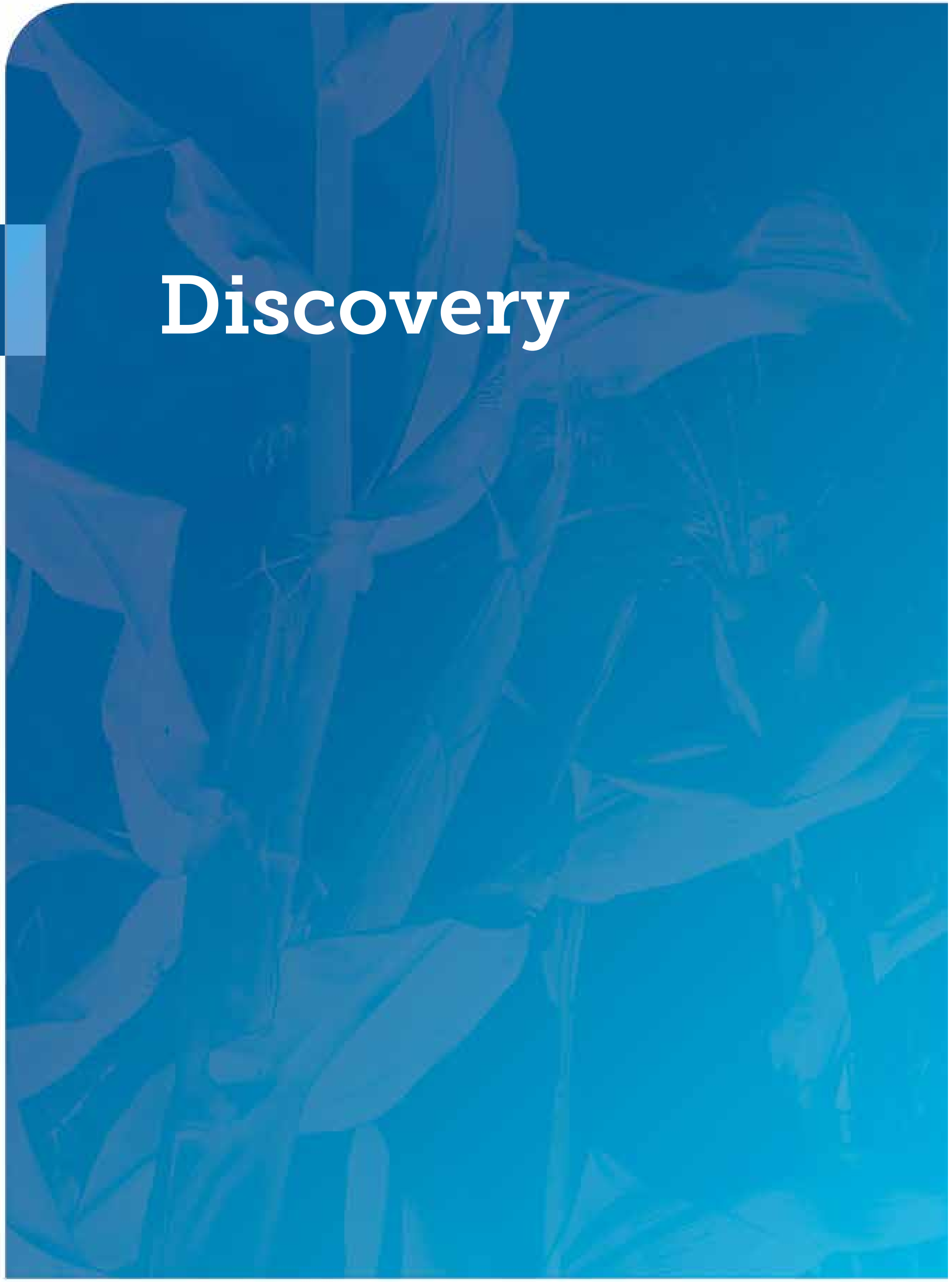
+40
knowledge-sharing webinars with our researchers and collaborators

404
peer-reviewed journal articles published

+612K
downloads from our publications repository

1,185
sta˜ of 52 nationalities

166K
followers on social media and followers on social media and 125,200 video views on YouTube



Discovery

Long-term experiments show that ecological intensification stores carbon and restores soil health

Organic fertilizer and rotations with fertility-improving crops improve maize yields and sequester carbon. ©Christian Thierfelder / CIMMYT.

New evidence suggests that climate change can be mitigated by using some ecologically-sound farming practices. Long-term experiments, of 10 years or more, in Africa and Europe, show that yields of maize and other key crops are improved when farmers use ecological intensification practices. These include crop diversity (such as intercropping and crop rotation), planting fertility-improving crops (especially legumes), and applying manure or other organic fertilizer. Ecological intensification can be high yielding, while saving on mineral fertilizer, especially nitrogen, reducing greenhouse gas emissions.

Agriculture needs long-term experiments to assess the consequences of farming practices over time. It only takes a few years to destroy soil health, but much more time to rebuild it. Because of annual variations in the weather, trials must be repeated for several years. Painstaking, quantitative research over many years by CIMMYT has shown that in the long-run, farmers can increase their harvests, while reducing greenhouse gas emissions. With ecological intensification, agriculture does not have to be a cause and a casualty of climate change.

Agriculture contributes to climate change, which also makes farming more difficult.

Agriculture needs long-term experiments to assess the consequences of farming practices over time.

Conservation (Left) vs. conventional (Right) agriculture during El Niño. ©Christian Thierfelder / CIMMYT.

Fortunately, some of the practices that help farmers adapt to climate change also mitigate its effects. Excessive soil tillage, pesticides and mineral fertilizers increase carbon emissions, so curbing their use could help global agriculture to return to a "safe operating space," according to work by CIMMYT.

CIMMYT scientists contributed to a study on long-term experiments in Europe and Africa, published in *Nature Sustainability*. Data from more than 30 experiments show that ecological intensification (crop diversity, fertility-improving crops and organic fertilizer) increases the yields of maize, wheat and other staple crops, especially when mineral nitrogen fertilizer is used at low rates. Ecological intensification may take some years to show its benefits, so long-term experiments are crucial for measuring their value over time.

Diversifying farms, with intercropping or crop rotation, reduces weed pressure, pests and diseases, lowering the demand for chemical pesticides. Fields of diverse crops yield more than monocrops, and provide a buffer against the negative effects of extreme weather.

Excessive nitrogen application does not necessarily increase yields as it may be washed away if the soils are too depleted. In Africa, such soils have sometimes been called "non-responsive soils" and there is no easy fix to bring them back into production. However, adding crop residues and animal manure at the soil surface increases soil carbon, which holds more nutrients and makes them available over time, as plants need them. This also restores the soil's health and biodiversity.

Adding crop residues and animal manure at the soil surface increases soil carbon, which holds more nutrients and makes them available over time, as plants need them.

Aerial view of long-term trials. ©Christian Thierfelder / CIMMYT.

Results from the long-term experiments show that increased tillage does not raise yields, but it often leads to soil erosion, depletion and compaction, suggesting that plowing can be reduced, saving on fuel expenses.

Conservation agriculture, one strategy of ecological intensification, is based on the three principles of crop diversification, keeping the ground covered with crop residues and minimizing soil disturbance. At long-term experiments at six research locations in four countries (Zimbabwe, Zambia, Mozambique and Malawi) yields of maize varieties were significantly higher when all three principles of conservation agriculture were applied, especially when the crops were diversified with legumes. Moderate rates of nitrogen fertilizer can enhance yields in conservation agriculture.

"*These long-term experiments show that it is possible to sequester more carbon into the soil, although it requires sufficient amounts of crop residues and a conducive diversification strategy. This has beneficial effect on our climate as less greenhouse gases, especially carbon dioxide, are being emitted*," says Christian Thierfelder, a principal cropping systems agronomist at CIMMYT in Zimbabwe, who has led the long-term experiments in southern Africa.

Diversified crops improve yields. ©Christian Thierfelder / CIMMYT.

Christian Thierfelder
Principal cropping systems agronomist

"Farmers in Asia, Africa and Latin America can harvest more maize and other staple food crops while lowering their production costs and improving soil health. It has been important to gather data over several years, because it takes time for ecological intensification and conservation agriculture to bear fruit. It is also necessary to assess these systems under a changing climate as cropping seasons become increasingly variable. Conservation agriculture is especially beneficial in areas with low or moderate rainfall. So, ecological intensification and conservation agriculture can help farmers adapt to climate change while keeping their soil fertile."

Feeding a warmer world: a digital review of CIMMYT's research on climate change

Farmer Gashu Lema harvests improved variety Kubsa wheat in his own field. Gadulla village, Mojo, Ethiopia. ©Peter Lowe / CIMMYT.

CIMMYT is prominent in global conversations about climate and food systems, as shown by a recent digital review. In partnership with some of the top institutions in the world, CIMMYT has published on climate change in almost 2,500 books, peer-reviewed articles, and in popular media. Text mining shows that CIMMYT's work on climate change is integrated with efforts to improve food systems. Our publications on climate change have been hyperlinked to over 55,000 web pages from 150 countries. CIMMYT forms part of a large climate network, and plays a leading role in scientific discourse.

A systematic review, *Systematic Documentation of CIMMYT's Work in the Food Production—Climate Change Nexus*, has shown that CIMMYT is prominent in the global discussion on climate change and food systems. Text mining, and the analysis of hyperlinks and social networks showed that CIMMYT publications are a key influence on scientific discourse.

Data came from four sources: 1) the climate change news page on the CIMMYT website, 2) the repository of CIMMYT publications, 3) an online index in SCOPUS of peer-reviewed articles by CIMMYT-affiliated authors, and 4) by tweets citing CIMMYT.

Text mining showed that from 2006 to 2021, the CIMMYT website posted 444 news items under "climate change." This news frequently linked climate change adaptation and mitigation with food security, CIMMYT's primary objective. In the past five years, CIMMYT's research agenda has expanded towards developing resilient food systems with low-carbon emissions, reflected in concepts such as "carbon sequestration," "emissions reduction," and "energy conservation."

CIMMYT has published on climate change in almost 2,500 books, peer-reviewed articles, and in popular media.

FIGURE: Countries identified in climate-related knowledge products in the CIMMYT Repository.

Of 5,396 publications (1960-2021) placed in the repository, nearly half (2,463) mentioned climate change, focusing on "capacity development," "farming systems," "innovation," and "technology transfer." In the last five years, the increasing mention of "adaptation and mitigation" and "sustainable innovation" demonstrate CIMMYT's expanding interest in integrated approaches to building on-farm resilience. CIMMYT's research on climate change and food systems includes most countries in the world, spanning South Asia, sub-Saharan Africa and Latin America.

Text mining of the 3,612 CIMMYT publications (1974-2021) listed on SCOPUS reveal that climate change is mentioned in work on "farming systems," "food security," and "technology transfer," along with "mixed cropping," "stress" and "yield," a sign that CIMMYT puts climate crisis at the forefront of its actions on food systems research. This is also evident from the analysis of tweets where CIMMYT and climate change are associated with "adaptation and mitigation," "productivity," "profitability," "climate-smart agriculture (CSA)," "precision agriculture," and "nutrient management." In the past decade, "gender equity" has gained prominence on CIMMYT's research agenda for food systems and climate change.

The hyperlink analysis revealed that CIMMYT publications are widely disseminated. The 2,463 items in the CIMMYT repository have been hyperlinked on 55,151 web pages, in over 150 countries. Articles and books were the most frequently shared publications. Google Books alone cites CIMMYT's work on climate change over 3,000 times. Outlets such as the Food and Agriculture Organization of the United Nations (FAO) and the Agricultural Knowledge Resources and Information System Hub for Innovations (KRISHI) of the Indian Council of Agricultural Research (ICAR) also help to spread CIMMYT's research.

CIMMYT'S research on climate change and food systems includes most countries in the world, spanning south asia, sub-Saharan Africa and Latin America.

CIMMYT's publications on climate are listed on 13,630 URLs from 2,543 unique "dot com" domains (e.g., scholar.google.com and link.springer.com) and on 12,467 URLs from 1,334 "dot org" domains (cgiar.org, semanticscholar.org, fao.org, etc.) CIMMYT is prominent on social media discourse on food systems and climate change. For example, on Twitter, CIMMYT exchanges information on climate change with many different actors. Links with the 75 most important ones are shown in this figure.

An analysis of the SCOPUS references shows that CIMMYT publishes on climate change with some of the world's top institutions, from Mexico, the USA, India, Europe, and across the developing world.

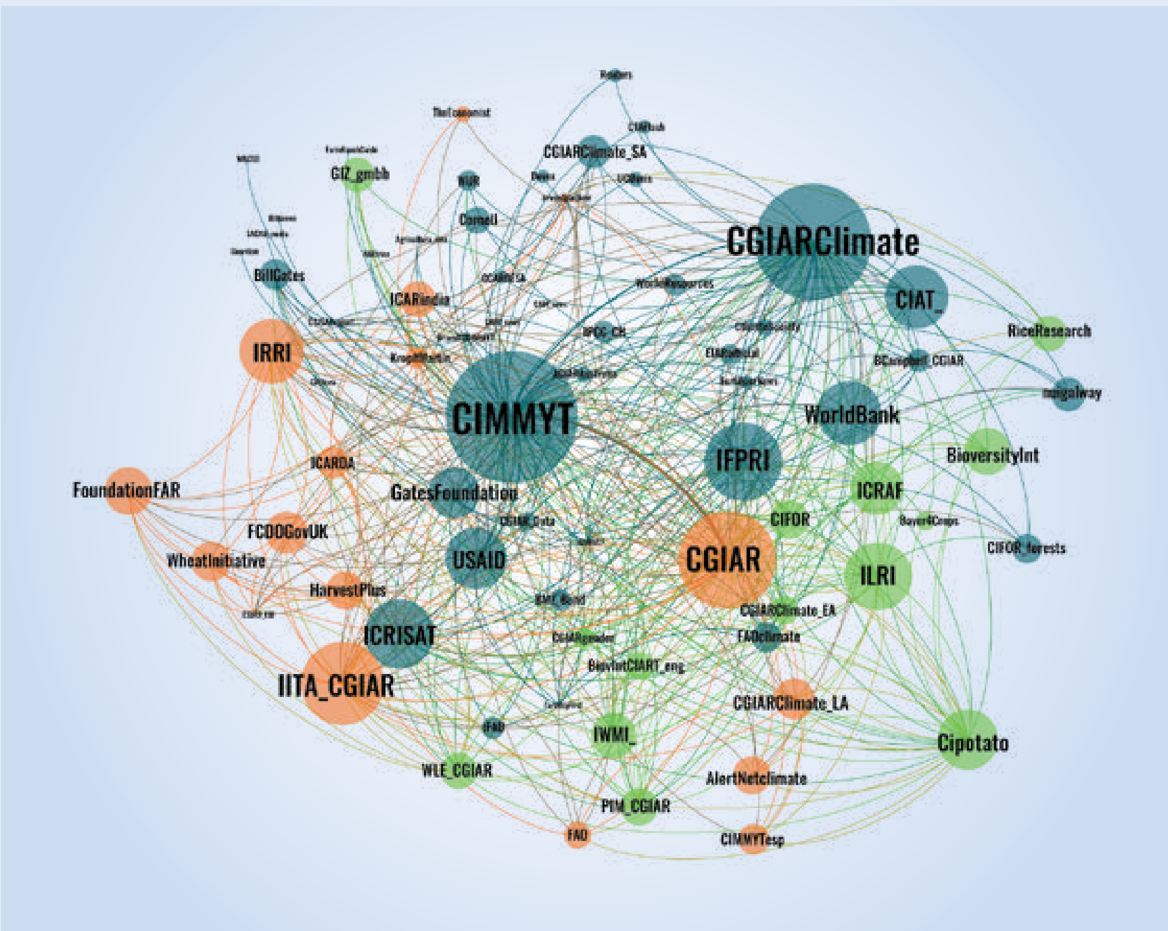
"There has been a big shift in CIMMYT's food systems climate change work in the past ten years. Now, CIMMYT integrates the climate crisis across its objectives and throughout its actions around food systems research," says Tek Sapkota, leader of CIMMYT's Climate Change Science Group.

Tek Sapkota

Senior scientist and leader of CIMMYT's Climate Change Science Group

"There has been a big shift in CIMMYT's food systems climate change work in the past ten years. Now, CIMMYT integrates the climate crisis across its objectives and throughout its actions around food systems research."

FIGURE:
The top 75 nodes that mention climate change on CIMMYT's Twitter network. Parameters: force-directed graph, with node size partitioned as Eigenvector Centrality, colored by modularity class. Nodes = 75 accounts, edges = 518 connections



On target with heat-tolerant hybrid maize seed deployment in South Asia

Seed company representatives examine heat-tolerant maize at a demo in Raichur, India. ©UAS Raichur.

Millions of smallholders in South Asia make a living from maize, over 11 million farmers in India alone. However, less than 20% of the maize crop is irrigated, making it vulnerable to today's warmer, drier and less predictable climate. Seed companies across South Asia now have the option of deploying high-yielding, heat stress-resilient maize hybrids developed by CIMMYT, which is meeting its targets for deploying the new heat-resilient maize seed suitable for hot, dry agroecologies of South Asia. A 2022 adoption study shows that under stressed conditions, the new hybrids enable smallholder farmers to harvest more, and improve their incomes.

Maize helps to support millions of farm families across South Asia. Over 80 percent of that grain is produced without irrigation, making the crop vulnerable to climate change, which is already bringing hotter weather and more frequent droughts to South Asia. Since 2012, CIMMYT's Heat-Tolerant Maize for Asia (HTMA) project has worked with six government institutions and 22 private seed companies and farmer cooperatives in Bangladesh, Bhutan, India, Nepal, and Pakistan, creating new maize hybrids, based on elite, Asia-adapted germplasm from CIMMYT.

In South Asia, over 80 percent of maize grain is produced without irrigation.

About 1000 metric tons of heat-tolerant maize seed was distributed to smallholder farmers in South Asia by 2022.

During Phase-1 (2012-2017), CIMMYT identified specific heat-stressed areas in South Asia, and established a heat stress phenotyping network. The work led to the identification of genomic regions and candidate genes that confer heat tolerance on maize. CIMMYT licensed 35 stress-tolerant maize hybrids to partners in South Asia, including the public sector and seed companies. CIMMYT also gave early generation improved maize lines to partners, so they could generate their own proprietary lines.

The new heat-tolerant maize hybrids developed by CIMMYT were deployed from 2018 to 2023. CIMMYT is partnering with 21 small and medium-sized seed companies in Bangladesh, India, Nepal and Pakistan, besides Corteva Agrosciences, to develop a pipeline of improved heat-tolerant maize hybrids available to smallholder farmers.

During the scaling out of improved seed, CIMMYT has been particularly targeting women and vulnerable groups using on-farm demos, field days (many especially for women), small seed packs, and multimedia. Women have appreciated the new hybrids as the plants stay green longer, and provide better fodder for livestock during the lean season.

By 2022, 20 high-yielding, heat-tolerant hybrids have been officially released in South Asia, including Bangladesh (5), Bhutan (1), India (8), Nepal (3), and Pakistan (3). These hybrids have been planted on an estimated 50,000 hectares. Nepal, which was once dependent on its neighbors for 90% of its hybrid maize seed, is now becoming self-sufficient.

About 1000 metric tons of heat-tolerant maize seed was distributed to smallholder farmers in South Asia by 2022, slightly above CIMMYT's target, as shown in this Figure. According to, P. H. Zaidi, leader of CIMMYT's HTMA project, "*We have enjoyed excellent support from government agencies, who realize the urgency of adapting to climate change. Close cooperation with seed companies has also been crucial. The increasing demand for this seed from the farmers has also helped all the stakeholders to stay on target. The farmers are now increasingly aware that climate change is a reality, and we need innovations to adapt to it.*"

A heat-tolerant hybrid (CAH153, extreme right) and popular commercial hybrids severely damaged by fall armyworm in demo field, Hyderabad, India. ©CIMMYT.

Studies in India (Karnataka and Odisha states) and in Nepal (the Terai region) showed that the heat-tolerant maize hybrids out-performed the commercial hybrids currently on the market, especially under drought and heat stress. For example, in a 2022 study of 180 maize farmers in Karnataka, published in *Frontiers in Sustainable Food Systems*, under optimum conditions, the stress-tolerant maize hybrids performed at par with the commercial hybrids. However, under stressed conditions, the new hybrids made a huge difference. Smallholders increased their yields from two tons per hectare to three tons per hectare when they planted the stress-tolerant hybrids from CIMMYT. As an added benefit, under severe drought conditions, the heat-tolerant hybrids yielded larger grains and ears than commercial hybrids, so farmers could sell the new maize for an additional $10 per ton ($216 vs $206). According to the study's lead author, CIMMYT scientist Atul P. Kulkarni, "*Farmers who planted the CIMMYT hybrid earned $148 per hectare more than the non-adopters, who did not even recover their investment. In a drought year, in a rainfed environment, non-adopters lost on average $31 per hectare.*" Kulkarni goes on to say, "*The farmers who adopted the new maize hybrids were very much like their neighbors who did not plant the new seed. The adopters and the others were of similar ages and educational backgrounds. The adopters were not simply the richest farmers. The non-adopters even planted slightly more land to maize than the adopters.*"

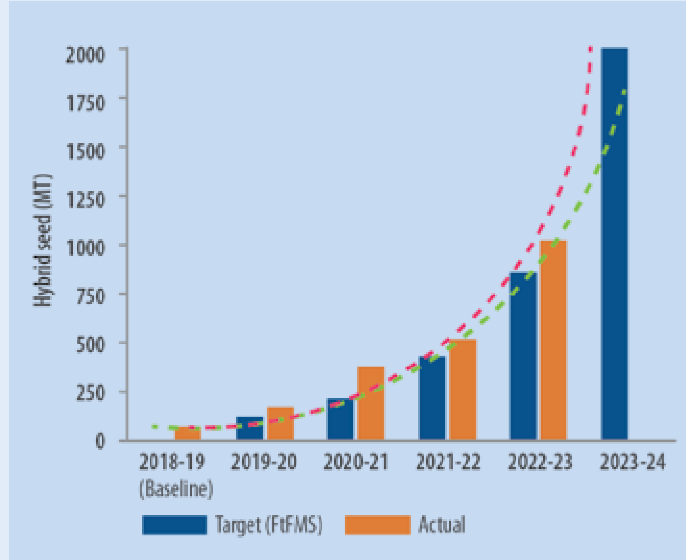


FIGURE:
Certified seed deployment in South Asia.

The biggest difference between the two groups of farmers is that those who saw the new hybrids at a field day were about a third more likely than their peers to plant the stress-tolerant maize. "*This means that just making farmers aware of the new stress-tolerant hybrid maize will encourage many of them to try it out*," says Kulkarni.

Genotypic variability for heat and drought-tolerance at harvest. ©CIMMYT.

Better wheat, better flour

A blended flour can perform as well as one made only from wheat. ©CIMMYT.

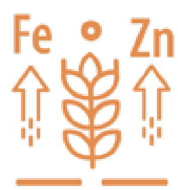
Two recent efforts at CIMMYT aim to improve the quality of bread wheat. A new genetic assay will bring down the cost and increase the speed of identifying more nutritious wheat varieties, to reduce dietary deficiencies of iron and zinc, and to improve the nutrition of children globally. Blending flours made from wheat and from other crops will allow African countries to produce more food with less imported grain.

Two lines of work at CIMMYT promise to improve the quality of wheat, and the availability of flour.

Iron and zinc are essential micronutrients, which can be supplied from wheat, whether it is imported or grown domestically. Children fail to develop properly if their diet lacks these minerals. Increasing the iron and zinc content in the world's wheat supply would be a boon to global nutrition.

Conventional plant breeding can create wheat varieties that are rich in iron and zinc, but these efforts are hampered by naturally-occurring, high levels of phytic acid in some wheat varieties. Phytic acid binds to iron and zinc, preventing them from being absorbed in the human digestive tract.

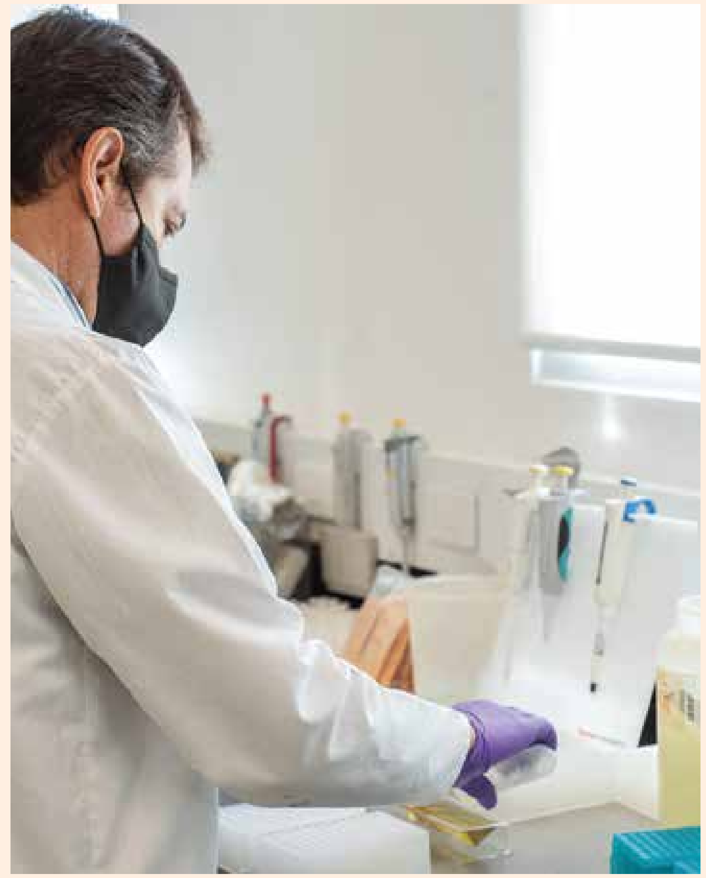
The solution is to select for wheat varieties that are low in phytic acid, and high in iron and zinc. However with prevailing technology, such breeding can take several years.



Increasing the iron and zinc content in the world's wheat supply would be a boon to global nutrition.

A recent three-year study by CIMMYT and partners, led by Zhengyu Wen, and published in *Frontiers in Plant Science*, has found a way to quickly assay for phytic acid, by determining the amount of phosphate released after treatment with a commercially available enzyme. Genetic markers were found on five wheat chromosomes, making it possible to select for the target genes early in the breeding program, to reduce the content of phytic acid. According to Maria Itria Ibba, a CIMMYT scientist who participated in the study, *"This protocol is based on the same principle as the one for a certain commercially available assay. But unlike that one, our protocol does not require that researchers buy a kit. This new protocol greatly reduces the cost of the analysis, which should make it easier to use in low and middle-income countries. It will also speed up the breeding of high-yielding, nutritious wheat varieties."*

Wheat quality can be enhanced genetically, or in the flour mill.



CIMMYT has created a faster, less expensive way to test for phytic acid. Gabriel Posadas at the Wheat Quality Lab in Texcoco, Mexico. ©Alfonso Cortés / CIMMYT.

Other work at CIMMYT is showing how the dependency on wheat imports can be reduced by blending flours from wheat and from other crops. In East Africa, wheat growers have not been able to keep pace with the spiraling demand for flour to make bread, chapatis, biscuits, and even pizza, while millers must compensate for the reduced availability of imports from Russia and Ukraine. In Nairobi, one bakery alone uses 15,000 tons of flour every month. Since the 1980s, Kenya's wheat harvest has stagnated at about 200,000 tons per year. Only 10% of the country's wheat supply is produced domestically, while the Russian invasion of Ukraine has choked supplies and raised costs of imported wheat.

Harvesting wheat rich in essential minerals in Juchitepec, State of Mexico, Mexico. ©Peter Lowe / CIMMYT.

In Nairobi, one bakery alone uses 15,000 tons of flour every month.

Pouring wheat improved variety Adiyta into the floor duct of a seed cleaning machine at Unique Seed Co. Pvt. Ltd. Dhangadhi, Kailali, Nepal. ©Peter Lowe / CIMMYT.

"To make blended flours a commercial reality, we will need policies that stimulate the production and marketing of alternative crops and their use in flour production," explains CIMMYT's Global Wheat Program director, Alison Bentley. *"Millers may have to invest in new equipment. We will also need research that ensures availability to meet milling demands and understanding of the functional properties of new blended flours. Marketing research will be important to introduce consumers to the new flour blends, and to ensure demand for the baked goods."*

Wheat may be getting more expensive, but it is still available on the global market at a consistent quality. Substitute crops, grown nationally, may not be available in the amounts and quality needed. Boosting their supply will require investments in production and marketing, as well as partnerships with smallholder producers and other actors on the food and seed value chains.

Blending wheat flour with milled cassava, sorghum or millet has been proposed as a viable solution which could reduce wheat imports while creating more demand for traditional crops such as sorghum and millet, which can adapt to climate change.

Millers and bakers in Africa would use more millet if the grain was always free of stones and other impurities and if the cost of millet was lower.

Thanks to its white color, cassava flour is an attractive solution for flour millers. However, in Nigeria, cassava flour was unpopular, partly because of few policy incentives, but also because wheat was cheap, until recently. Millet is a healthy food, and this hardy plant performs well in East and West Africa. Millers and bakers in Africa would use more millet if the grain was always free of stones and other impurities and if the cost of millet was lower. White sorghum is another option to blend with wheat flour. It could be used for 15% of the flour in bread, and 20% in biscuits.

Maria Itria Ibba
Head of the Wheat Quality Laboratory and Cereal chemist

"This protocol is based on the same principle as the one for a certain commercially available assay. But unlike that one, our protocol does not require that researchers buy a kit. This new protocol greatly reduces the cost of the analysis, which should make it easier to use in low and middle-income countries. It will also speed up the breeding of high-yielding, nutritious wheat varieties."

Plant phenotyping: wheat trials via a global network

CIMMYT's plant breeders evaluating wheat lines in Metepec, State of Mexico, Mexico. ©CIMMYT.

Recognizing the importance of evaluating promising wheat lines in target environments, in close collaboration with national and regional breeding programs, CIMMYT has promoted networks of plant breeders, such as the International Wheat Improvement Network (IWIN) and the precision, field-based wheat phenotyping network. This cooperation allows countries to freely access valuable genetic resources and associated data to boost their food security and adapt to climate change.

CIMMYT hosts the world's largest network for collaborative wheat breeding. The International Wheat Improvement Network (IWIN) brings together hundreds of breeders and agricultural scientists working in over 100 countries to evaluate CIMMYT's diverse wheat accessions. CIMMYT selects the best lines from across breeding pipelines to distribute through IWIN. This voluntary network tests about 1,000 new wheat lines every year at over 300 sites. In 2021-2022, participants included public research (45%), the private sector (30%) and universities (24%).

As part of IWIN, local researchers test hundreds of wheat lines in many different environments, to determine how the plants will respond to various pests, diseases and other stresses. As a first step, collaborators request wheat materials at the following link: https://www.cimmyt.org/resources/seed-request

IWIN brings together hundreds of breeders and agricultural scientists working in over 100 countries to evaluate CIMMYT's diverse wheat accessions.

FIGURE 3: Global phenotyping network. ©CIMMYT.

Next, CIMMYT sends the researchers wheat seeds as part of a "nursery" (actually, a cardboard box full of healthy seed.) The seed is checked by CIMMYT and by country authorities, and it is chemically treated, to avoid spreading pests or diseases. Each line of wheat is packed in a separate, carefully labelled envelope. In 2022, over 2,000 of these seed collections were sent to more than 300 collaborators in 71 countries.

The collaborators collect data about the performance of each wheat line, using a standardized protocol. CIMMYT uses advanced technologies to analyze the data efficiently, and then make it available online, as a public good. You can see the results at the following links:

https://orderseed.cimmyt.org/iwin/iwin-results-1.php

https://data.cimmyt.org

https://www.cimmyt.org/resources/data

In 2022, over 2,000 of these seed collections were sent to more than 300 collaborators in 71 countries.

Testing wheat in Bolivia. ©Carolina Saint Pierre / CIMMYT.

These data also allow breeders at CIMMYT to determine which traits will be demanded for future wheat varieties.

After testing the wheat lines from the nursery, collaborators can choose to release some of them as varieties in their own country. Or breeders can cross the new lines with elite local varieties, as the parents of future releases.

IWIN is linked to other initiatives, like the precision, field-based wheat phenotyping network. "Phenotyping" refers to the evaluation of plant traits, including those influenced by the genes, environment, management, and their complex interactions. Wheat varieties of known genetic traits can be tested in many places in the same year, using standardized, good agricultural practices, to see how the genes will be expressed in different environments. "*In this way the germplasm can be more efficiently screened and results achieved much faster*," says Carolina Saint Pierre, Partner Network coordinator. She adds, "*The goal of the phenotyping network is to more precisely evaluate certain key traits, such as disease resistance, or yield in hot and dry environments. We choose locations that are disease hotspots or because they are analogues for future climate.*"

Breeders in the phenotyping networks collect and share data to coordinate their work, as they evaluate responses to wheat performance from India to Uruguay, to accelerate the release of high-yielding wheat varieties which are disease-resistant and tolerant of heat and drought. The phenotyping networks also complement research activities under way for diseases, heat, drought and yield in Kenya, Ethiopia, Turkey, Mexico and other countries.

Sharing CIMMYT's germplasm collections allows the material to be tested in a wide range of geographies. Each nursery, with its 50 to 228 entries of wheat, helps plant breeders to develop the wheat varieties that will make their nations more food secure, while helping farmers to adapt to climate change. CIMMYT freely shares valuable genetic resources as global public goods. Collaborating breeders reciprocate with data, which CIMMYT transforms into public information. The data also helps CIMMYT's research to remain demand-driven, so that superior wheat varieties are released to farmers in a timely fashion.

Carolina Saint Pierre
Partner Network coordinator

"The goal of the phenotyping network is to more precisely evaluate certain key traits, such as disease resistance, or yield in hot and dry environments. We choose locations that are disease hotspots or because they are analogues for future climate."

Breeders evaluating seeds for more effective wheat resistance. ©CIMMYT.

Taking stock of genetic gains in tropical maize breeding programs

Breeding activity by the CIMMYT team at the Maize Doubled Haploid Facility at Kiboko, Kenya. ©CIMMYT.

CIMMYT has been monitoring the genetic gains in 11 maize breeding pipelines across the tropics. These pipelines already hold the maize for the near future, including lines that are not only higher-yielding, but also climate-resilient, and resistant to major diseases and pests.

A third of the world's land that is planted to maize is in the tropics, especially in the low- and middle-income countries. Over the past 25 years, maize production in these countries has nearly doubled. This is due as much to bringing more land under cultivation as it is to developing and deploying new, higher-yielding maize. Yet, it is no longer feasible to keep expanding the amount of land devoted to maize, and the focus needs to be on improving productivity.

Breeding for higher yield in stress-prone tropical environments means developing improved varieties that can adapt to the changing climate, including drought, heat, diseases, and insect pests.

In the tropics, maize breeding relies largely on partnerships between CGIAR, the national agricultural research systems (NARS) and the private sector. The improved maize germplasm that these collaborative regional maize breeding networks develop and release as new varieties and hybrids over the next few years are already in the breeding pipeline. At the same time, it is important to monitor the progress being made by the breeding programs, by estimating the genetic gains for grain yield and adaptation to climate change.

CIMMYT has been monitoring the genetic gains in 11 maize breeding pipelines across the tropics.

A recent global study examined genetic trends in 11 of the tropical maize breeding programs implemented by CIMMYT in collaboration with partners in sub-Saharan Africa, South Asia, and Latin America. The study, published in 2022 in *Scientific Reports*, analyzed data from 4,152 advanced breeding trials in 28 countries from 2010 to 2020. The results are encouraging. Genetic trends for increased grain yield per hectare per year reached up to 138 kg per hectare per year in Eastern and Southern Africa, 118 kg per hectare per year in South Asia, and 143 kg per hectare per year in Latin America.

To put these numbers in perspective, from 1973 to 2012, genetic gains in the tropics were more modest, boosting maize yields by just 62 kg per hectare annually, an increase of just over 1% a year.

"*Previously, breeding programs measured success by the number of varieties they released*," explains B. M. Prasanna, director of CIMMYT's Global Maize Program. "*Of course, we would like to see new varieties being released and made available to the smallholders, but only if they out-perform the older varieties. We especially need to track the potential of the new maize germplasm developed by breeding programs to not only increase yields, but also to provide improved yield stability, especially through adaptation to warmer, drier environments in the tropics.*" explains B. M. Prasanna.

Besides drought tolerance, CIMMYT has also been breeding for heat tolerance in South Asia since 2012, together with partners. Substantial progress is being made in developing improved maize germplasm with heat tolerance, incorporating resistance to major diseases. CIMMYT is also working closely with some of the national partners in sub-Saharan Africa (e.g., NARO in Uganda) for monitoring and increasing genetic gains in its maize breeding programs.

B. M. Prasanna
Director of CIMMYT's Global Maize Program

"Of course, we would like to see new varieties being released and made available to the smallholders, but only if they out-perform the older varieties."

Modern tools and approaches, including doubled haploidy, three-season nurseries, molecular marker-assisted breeding, and rapid-cycle genomic selection, are now making maize breeding faster and more efficient. This is important as the genetic gains need to further increase to meet the present and future needs.

Finally, while genetic gains in breeding programs are being significantly improved, it is equally important to ensure that the seed of these improved varieties is delivered to smallholder farmers, with the help of stronger seed systems and extension programs.

A recent global study examined genetic trends in 11 of the tropical maize breeding programs implemented by CIMMYT in collaboration with partners in sub-Saharan Africa, South Asia, and Latin America.

KALRO-Kiboko Research Center in Kenya, a major hub for CIMMYT-NARES collaborative maize breeding in Eastern Africa. ©CIMMYT.

Neglected no longer: Africa’s promising dryland crops

A group member harvests groundnut in Tanzania. ©Susan Otieno / CIMMYT.

Familiar cereals and legumes have fed Africa for centuries. Crops like sorghum, the millets, pigeon pea, chickpea, and groundnuts are well-adapted to the semi-arid tropics, and they will strengthen Africa’s food security in a changing climate. CIMMYT is working with national agricultural research and extension systems (NARES) to modernize seed production while engaging with farmers, breeders and others to design the future varieties that will meet the demands of farmers and other value chain actors.

Some of the favorite food crops in sub-Saharan Africa, such as groundnut (peanut), cowpea, pigeon pea, chickpea (garbanzo), sorghum, pearl millet and finger millet, are well-adapted to dryland ecologies in Africa and worldwide. These legumes and cereals are expected to fare well in the changing climate.

Sorghum is an ancient crop of African origin, which is naturally drought- and heat-tolerant. The groundnut is an important source of food and oil in East and Southern Africa, where it is grown mainly by smallholders, often women. Groundnuts are high in proteins, as are pigeon peas, chickpeas and cowpeas. These crops are rich in vitamins and minerals, and they are adapted to drought and to poor soils. They are often eaten by the farm family, but they also find a ready market when offered for sale. However, Africa’s cherished crops face challenges including uneven seed quality, climate change, pests and diseases, which threaten farmers’ harvests. All of the dryland crops need to be bred for even greater drought resistance, plus the specific pests and diseases that attack each one.

Crops like sorghum, the millets, pigeon pea, chickpea, and groundnuts are well-adapted to the semi-arid tropics, and they will strengthen africa’s food security in a changing climate.

As the national agricultural research and extension systems (NARES) have become more sophisticated, CIMMYT is changing the way it engages with them. Instead of CIMMYT breeding new crop varieties and asking the NARES to evaluate them, CIMMYT co-develops varieties with the NARES in different environments. Then promising lines can be shared with other partners for evaluation and eventual release.

In August, 2021, CIMMYT was asked to lead the Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA) project, as part of CGIAR’s Global Science Group on Genetic Innovation. With funding from the Bill and Melinda Gates Foundation and the United States Agency for International Development (USAID), the project is breeding new varieties and strengthening seed systems to increase the productivity, and resilience of these nutritious food crops, and to help African farmers feed the continent.

CIMMYT has started breeding sorghum, the millets, and groundnut. It is supporting breeding programs for pigeon pea and chickpea. CIMMYT shares funds and breeding responsibilities with the NARES. Improving farm biodiversity with these dryland crops will help to manage climate change by moving away from dependence on crops like rice, maize, and wheat.

In the past, the dryland crops were under-valued by formal research, but even when new varieties were released, adoption was low. CIMMYT will improve adoption by promoting gender equity, and by gathering social science data to ensure that new varieties meet the demands of men and women farmers, processors, consumers, and other such “market segments.” Descriptions of the traits that market segments need in a new variety are called “product profiles.” CIMMYT will breed new varieties with these traits. Then the most promising advanced lines will be evaluated by farmers, and the NARES.

CIMMYT has started breeding sorghum, the millets, and groundnut. It is supporting breeding programs for pigeon pea and chickpea.

Farmers assessing improved varieties of sorghum in Burkina Faso. ©Baloua Nebie / CIMMYT.

Currently, in Africa the informal sector handles at least 95% of the seed of these dryland crops. To further speed the adoption of new varieties, CIMMYT is engaging with small and medium seed companies, to distribute seed to farmers.

CIMMYT has three sustained interventions with networks of NARES, CGIAR, universities and small and medium enterprises (SMEs):

1. Regional crop improvement networks are established.
2. CGIAR and NARES programs are shared for a greater regional impact.
3. The networks receive capacity development.

At a meeting in August 2022, in Dar es Salaam, Tanzania, teams of NARES met from six East African countries (Malawi, Mozambique, Sudan, Tanzania, Uganda and Zambia). Plant breeders and social scientists (including gender specialists) shared groundnut product profiles, written on templates developed by CGIAR's Excellence in Breeding (EiB) platform and the Initiative on Market Intelligence (IMI). CIMMYT encourages each country to define its own product profiles and market segments, but comparing notes allows national breeders to collaborate on traits of regional importance. The meeting was also a first step towards creating a regional network with CIMMYT and the national programs for groundnut breeding. The network will breed groundnuts with more food oil, and with resistance to rosette virus, a key plant disease.

The Sorghum and Pearl Millet Crop Improvement Network for West and Central Africa met in September 2022, with CIMMYT and NARES from Burkina Faso, Mali, Nigeria, Niger, Senegal, Ghana, Togo, and Chad, along with three West African seed companies, three farmer organizations and the French Agricultural Research Center for International Development (CIRAD). The Network finalized definitions of market segments and identified crop traits that are key at the regional level.

Farmers evaluate groundnut at the Nachingwea station in Tanzania. ©Susan Otieno / CIMMYT.

Farmers discuss the potential of sorghum hybrids. ©Baloua Nebie / CIMMYT.

The Chickpea and Pigeon Pea Improvement Network Workshop was held in Nairobi in November 2022 with CIMMYT and partners. In December, breeders from Kenya, Tanzania and Malawi visited the Ethiopian Institute of Agricultural Research (EIAR) and selected 506 lines for sharing.

In Ghana, CIMMYT and the Savannah Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI) are writing product profiles for cowpea and sorghum, as well as for groundnut. In East Africa, CIMMYT and the Kenya Agricultural and Livestock Research Organization (KALRO) are writing product profiles for pigeon pea, and chickpea.

Progress with seed has been rapid. By the end of 2022, CIMMYT's partners had reached 4.8 million farmers with 30,600 tons of seed of improved legume and cereal crops, enough to plant nearly a million hectares.

CIMMYT is also engaged with a related CGIAR initiative, Crops to End Hunger (CtEH), to improve crop breeding and seed production of food crops in various African countries. In late 2022, CIMMYT started projects with CtEH to improve seed production for sorghum, millets, groundnut, pigeon pea, chickpea, and maize in Kenya.

A second CtEH project, the Kiboko Research Station Upgrade, introduces cold storage to improve inter-country transfers of improved seed, while installing solar energy to power facilities without emitting carbon.

The CtEH project, Enhancing Genetic Gain of Crops for Resilience through Modernization of ISRA-CNRA Bambey/Senegal Research Station will build an irrigation system for year-round crop breeding of sorghum, millets, and groundnuts. The project will screen varieties for resistance to various crop diseases and to the parasitic weed, striga.

"These crops have the advantage that they are well known in Africa," says Harish Gandhi, CIMMYT's breeding lead for dryland legumes and cereals. *"People know how to grow and prepare them. These nutritious foods can sometimes be made a bit healthier, or they can be bred to resist serious plant diseases. They perform well in the drylands, and they can play a role in adapting to climate change. This will be good for consumers and for smallholders, especially women, who can improve their incomes with greater access to modern seed."*

In 2022, CIMMYT hired new staff, and now has over 20 people working on these important cereals and legumes in Kenya, Senegal and Mexico.

The Chickpea and Pigeon Pea Improvement Network Workshop was held in Nairobi in November 2022 with CIMMYT and partners.

The power of one germplasm bank: combined and streamlined

In 2022, CIMMYT combined its maize and wheat germplasm banks into one. The maize and wheat collections each have their own curators, but most other staff work on both crops, for added efficiency. Modern protocols, like vacuum-sealed seed packets with QR codes, allow seed orders to be filled faster than before.

In 2022, CIMMYT's Wheat and Maize germplasm bank operations were unified to achieve greater efficiency, speed and quality of every process. Previously each crop had its own separate staff. Now, there is still one curator for maize and another for wheat, but most other team members work on both crops.

"*CIMMYT had one of the world's biggest wheat and maize collections. Now, with new technologies in fields like molecular characterization and data management, we are facing a new era for germplasm banks, and we are transforming the living archive collections into a bio-digital resource center,*" says Carolina Sansaloni, wheat curator for the germplasm bank, and genotyping and sequencing specialist.

The germplasm bank has 126,000 accessions of wheat and 28,000 of maize, gathered from over 150 countries. The material is shared with farmers and plant breeders and other researchers from national agricultural research systems (NARS), universities, and advanced research institutes across the world. In 2022, CIMMYT distributed 3,180 wheat accessions, including 171 within Mexico. In maize, 4,652 accessions were shared, including 1,469 in Mexico.

Germplasm bank members work in a united bank for greater effectiveness. ©Carolina Sansaloni / CIMMYT.

The maize and wheat collections each have their own curators, but most other staff work on both crops, for added efficiency.

The germplasm bank is now cleaning its inventory, removing redundant materials, and putting seed back into the collection in smaller, vacuum-sealed packages. New labels with QR codes make the packages easier to track.

"*We introduced the concept of the 'kangaroo package.' Accessions in the active collection are organized with five packages ready for distribution, one for seed health tests and another for viability analysis,*" explains Carolina Sansaloni. "*With this approach we can greatly reduce the time needed to distribute the materials while we increase the longevity of the seeds.*"

In 2022, the wheat collection reached its target of making more than ninety percent of the collection viable, healthy and available for distribution; it is expected that during 2023 the maize collection will also exceed 90% for these criteria. During the year, CIMMYT carried out 10,000 germination tests on its stored seed, to ensure that it was viable. Twenty thousand tests will be done in 2023.

Carolina Sansaloni
Wheat curator for the germplasm bank, and genotyping and sequencing specialist

"CIMMYT had one of the world's biggest wheat and maize collections. Now, with new technologies in fields like molecular characterization and data management, we are facing a new era for germplasm banks, and we are transforming the living archive collections into a bio-digital resource center."

As a safeguard, CIMMYT's wheat collection is backed-up at other locations: 98% of the accessions are also held at the Svalbard Global Seed Vault in Norway, and 94% at the United States Department of Agriculture (USDA) Agricultural Genetic Resources Preservation Research in Fort Collins, Colorado. While 77% of the maize collection is also held in safety duplicate at these two locations, it is expected to reach 90% during 2023.

Seventy percent of CIMMYT's wheat accessions have been genetically characterized using next-generation sequencing technologies. With this information, CIMMYT developed a global wheat diversity analysis to understand and unlock the biodiversity conserved in the germplasm bank, allowing the targeted exploration of genes in the near future. Currently the germplasm bank is starting to use this genetic "fingerprint" (sequence) data together with climate, soil and other variables from the collection site for each accession to identify novel genetic diversity that breeders need to develop the varieties that are in demand.

3,180 Wheat accessions
4,652 Maize accessions

In 2022, CIMMYT distributed 3,180 wheat accessions, including 171 within Mexico. In maize, 4,652 accessions were shared, including 1,469 in Mexico.

Locating small, pre-labeled seed packets in the germplasm bank. ©Carolina Sansaloni / CIMMYT.

CIMMYT and the Alliance of Bioversity International and CIAT created a community of practice of Latin American national germplasm banks. This is building and improving regional collaboration among 33 institutions in 14 countries. These partners have prioritized training to enhance their individual and collective effectiveness. CIMMYT hosted three training events during 2022, two virtual workshops and an in-person course in November. Twenty-four people from 13 countries met for five days to share information and to get to know each other. CIMMYT's streamlined germplasm bank is sharing cutting-edge knowledge of wheat and maize conservation and genetic resources with the region's experts.

During 2022, opportunities were found to increase the number of maize accessions that CIMMYT can regenerate each year. "*We now have permission from Mexico's National Service for Food and Agricultural Health, Safety and Quality (SENASICA), to regenerate maize accessions both on CIMMYT's experimental stations and at other locations, so we can better select suitable environments to multiply accessions that originate from many countries and diverse ecologies. In each regeneration cycle the new seed will be compared with the original, using molecular markers, to ensure that the original collection has been faithfully reproduced*", says Alberto Chassaigne, seed systems specialist and maize curator for CIMMYT's germplasm bank.

Alberto Chassaigne

Maize curator for the germplasm bank, and seed systems specialist

"We now have permission from Mexico's National Service for Food and Agricultural Health, Safety and Quality (SENASICA), to regenerate maize accessions both on CIMMYT's experimental stations and at other locations, so we can better select suitable environments to multiply accessions that originate from many countries and diverse ecologies. In each regeneration cycle the new seed will be compared with the original, using molecular markers, to ensure that the original collection has been faithfully reproduced."

Germplasm bank staff with seed samples. ©CIMMYT.

Tigist Masresra, technical assistant, Highland Maize Breeding Program. Ambo Research Center, Ethiopia. ©Peter Lowe / CIMMYT.

SystemDev

Strengthening collaborative maize breeding networks in Latin America

Field day participants with elite maize hybrids at El Batán station in Texcoco, Mexico. ©CIMMYT.

CIMMYT has a long history of collaborative maize breeding in Latin America. A new effort, the International Maize Improvement Consortium—Latin America (IMIC-LatAm) strengthens maize breeding programs of the national agricultural research systems (NARS), universities, and seed companies. CIMMYT provides elite maize inbred lines, which partners use in their own breeding programs.

Nurturing collaborative breeding networks allows CIMMYT and a diverse range of partners to test advanced maize germplasm. Breeding becomes faster, so new and more productive hybrids reach the farming communities sooner.

Since 2011, CIMMYT has partnered with national agricultural research systems (NARS), universities, and small and medium-sized enterprises that make up the Collaborative Evaluation Network in Mexico (CEN-Mexico). The network has evaluated hybrids developed from CIMMYT maize germplasm. Forty of these hybrids were released in the Mexican seed market by the partner institutions.

Up to 7,630 tons of hybrid maize seed developed with CIMMYT germplasm are sold annually in Mexico. At least three field days are held every year where partners evaluate elite maize germplasm from CIMMYT. In 2022, the CEN-Mexico network planted 71 pre-commercial (Stage 5) hybrid maize trials at 65 sites in Mexico.

Breeding becomes faster, so new and more productive hybrids reach the farming communities sooner.

CIMMYT partners at a field day evaluating elite CIMMYT maize germplasm. ©CIMMYT.

Seed companies manage these trials with their own resources, allowing CIMMYT to collect performance data, advance best-bet hybrids and deploy the new hybrids through partners more efficiently. In October 2022, four new hybrids were made available to the partners (CIM20LAPP1C-9, CIM20LAPP1C-10, CIM20LAPP1A-12, CIM20LAPP1A-11). These hybrids are high-yielding, drought-tolerant, and resistant to ear rots and to fungal leaf diseases.

In 2021 CIMMYT and over 25 partners started a new network, the International Maize Improvement Consortium—Latin America (IMIC-LatAm). Partners include NARS institutions, universities, and seed companies in Mexico, El Salvador, Guatemala and Brazil. Evaluating hybrids is the main purpose of CEN-Mexico, but IMIC-LatAm goes a step further, as partners choose elite inbred lines from CIMMYT and use them to breed their own lines and hybrids.

IMIC-LatAm is similar to consortia established by CIMMYT in Asia (IMIC-Asia) and Africa (IMIC-Africa).

In 2022, CIMMYT held two field days in Mexico: at the Ernest W. Sprague Experimental Station in Agua Fría, Puebla, and at the El Batán Station in Texcoco (CIMMYT headquarters) where IMIC-LatAm and CEN-Mexico members reviewed 718 early generation (Stage 2) and advanced inbred lines (Stage 3). Members from Mexico, El Salvador, Guatemala and Brazil selected 272 of these lines, which are now being used in the partners' own breeding programs. The traits preferred by the partners included high yield, good plant height, and low ear position for easier mechanical harvesting.

"*We have had an encouraging response from the partners, who have enthusiastically attended the IMIC-LatAm and CEN-Mexico field days. Now they are testing the inbred lines in their own markets, and multiplying seed to sell new, publicly-announced CIMMYT hybrids. This helps us to move quickly to breed more hybrids with good yield potential and with disease resistance and climate adaptation. Some of these new hybrids will be ready for release by 2025,*" says CIMMYT maize breeder, Félix San Vicente.

In 2021 CIMMYT and over 25 partners started a new network, the International Maize Improvement Consortium—Latin America (IMIC-LatAm).

CMMYT´s current catalog for Latin America has 35 elite maize hybrids: https://maizecatalog.cimmyt.org/.

Félix San Vicente
CIMMYT
Maize breeder

"*We have had an encouraging response from the partners, who have enthusiastically attended the IMIC-LatAm and CEN-Mexico field days. Now they are testing the inbred lines in their own markets, and multiplying seed to sell new, publicly-announced CIMMYT hybrids. This helps us to move quickly to breed more hybrids with good yield potential and with disease resistance and climate adaptation. Some of these new hybrids will be ready for release by 2025.*"

An emerging maize market improves livelihoods in Nepal

Farmer Dhanmaya Pakhrin and her neighbors Sharada Lopchan and Kranti Tamang shelling hybrid maize on her verandah in Rambasti, Kanchanpur, Nepal. ©Peter Lowe / CIMMYT.

Commercial, hybrid maize production is spreading quickly in Nepal. CIMMYT is organizing and training farmers, and has created a network that brings together feed millers, seed dealers, banks and financial institutions, and local and provincial governments. The network is facilitating investing in the commercial maize value chain, setting and adopting standards and facilitating new market linkages for grains produced by smallholder farmers. Smallholders are taking part, including women, harvesting more and improving their livelihoods.

A CIMMYT project, Nepal Seed and Fertilizer (NSAF), is helping smallholders, including women, get into the business of growing maize to sell to feed mills. Nepal currently uses about 540,000 tons of maize to make poultry feed every year. Since 80% of this grain is imported, there is plenty of demand to produce maize locally. The Terai lowlands of Nepal could provide about 40% of this maize, by planting in the spring, when most land lies fallow. Feed millers and seed companies were encouraging farmers to plant spring maize as early as 2020.

However, to seize this opportunity, some changes needed to be made. A CIMMYT review found needs for extension, marketing, finance and the alignment of government policy. By 2021, CIMMYT was training extensionists and lead farmers in crop

Nepal currently uses about 540,000 tons of maize to make poultry feed every year.

and soil management, and co-financing farmer investment in tools and equipment. CIMMYT set up the Maize Commercialization Model (MCM), that included a network for stakeholders. Local and provincial government officials who attended MCM meetings were encouraged to implement their own programs with stakeholders. Traders and feed millers were urged to share market standards and prices with each other. CIMMYT used a systems approach to engage these different value chain actors meaningfully.

By 2022, training had been given to 2,260 households from 65 farmer cooperatives, from 19 municipalities across Nepal. Farmers began to buy hybrid seed and apply recommended rates of chemical fertilizer, while adopting advice on weeding, irrigation, and pest management. In 2022, these farmers produced 3,232 tons of maize on 548 hectares, an average yield of 5.9 tons, more than twice the national average of 2.5 tons.

In 2022, project farmers earned $900,000 from maize, an average of $367 per household. Thirty-five percent of the project farmers were women. "*It has been gratifying to see the changes in farmers' lives in such a short time*", says Dyutiman Choudhary, a scientist in market development and coordinator of the NSAF project. "*Having a few hundred dollars extra per year from engaging in commercial maize farming allows some of the women farmers to think beyond satisfying basic household needs. They now find it much easier to buy medicine, as well as shoes, uniforms and notebooks, so their kids can go to school.*"

Millers were pleased that the Nepali maize met international standards. Bumper harvests required more storage space. A farmers' cooperative in Raptisonari municipality built a new storage unit, with 75% of the funding coming from the provincial government. A trader in Bardiya constructed another maize store, with his own funds. Traders and millers began to invest in improvements to keep the maize dry, such as concrete floors and electric fans. Buyers started to take vehicles into the maize-producing areas, looking for smallholders with maize to sell. Farmers also kept about 15% of their maize harvest, to eat at home, and to feed to their livestock.

Government policy is also starting to align with the growing interest in maize. In 2022, nine local governments invested $2.37 million in the maize value chain.

Nepal's demand for maize was matched by the possibility of planting in the spring fallows of the Terai lowlands. CIMMYT seized this opportunity, with farmer training, and by helping some groups buy equipment, while linking public and private actors into a network that could invest in the fast-growing market for commercial maize.

By 2022, training had been given to 2,260 households from 65 farmer cooperatives, from 19 municipalities across Nepal.

During field day, women farmers use a mini tiller for direct seeding maize in Ramghat, Surkhet, Nepal. ©Peter Lowe / CIMMYT.

Stable markets help farmers adopt conservation agriculture

Soil under conservation agriculture practices in Texcoco, State of Mexico, Mexico. ©Francisco Alarcón / CIMMYT.

Some of farmers' biggest problems are high production costs, volatile grain prices, and the lack of a secure market. Several CIMMYT projects are now linking Mexican farmers to food manufacturers, through local traders. Following advice on conservation agriculture (CA), crop nutrition and improved irrigation, farmers save money and water, while rebuilding the soil. Yields are up, and so are farmers' earnings.

Several related experiences by CIMMYT in 2022 show that by following conservation agriculture (CA), and other ecological practices, grain farmers can lower their production costs, while harvesting more, saving irrigation water, and improving the soil. After several years of piloting this approach, the effort has grown to impact over 70,000 hectares and about 4,000 farmers, who are so pleased with the results that they are strengthening their ties with the food processors, and agreeing to trade more grain in the future.

Ironically, while the world does need more food, individual farmers are often anxious about where they will sell their harvest. So CIMMYT is linking farmers in the states of Sonora, Guanajuato, Michoacán, Querétaro, Sinaloa, and Jalisco to local buyers who

Following advice on conservation agriculture (CA), crop nutrition and improved irrigation, farmers save money and water, while rebuilding the soil.

Producers from Sinaloa, Mexico, participating in the Support for Responsible Sourcing project in Mexico, promoted by Kellogg's and CIMMYT. ©Francisco Alarcón / CIMMYT.

give technical assistance to growers, while providing commercial agreements to sell the grain to food manufacturers like Kellogg's, Nestlé, Bimbo, PepsiCo México, Trimex, Ingredion and Heineken. Farmers also receive training in workshops or during local demonstration events.

Responding to local needs, each CIMMYT project promotes slightly different technologies, but most include soil and water conservation, and environmentally-sound pest control. Farmers receive training and support to adopt conservation agriculture practices such as minimum tillage, crop rotation, and leaving the crop stubble as a soil cover.

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Farmers and their advisors find solutions to fit local farming systems. For example, conventional tillage can cost $275 or more per season, while direct seeding (or planting on permanent beds) saves on tractor time and fuel expenses, cutting costs to less than $165.

Soil analysis allows farmers to see how much nitrogen their soil has, and how much it needs, so mineral fertilizers can be applied at the most efficient rate. This saves on fertilizer, and reduces losses of nitrogen into the atmosphere and into the groundwater. For even greater efficiency, some innovative farmers dissolve mineral fertilizer into water, and apply it to their crop as ferti-irrigation, for example through drip systems.

Sometimes, improving irrigation is simply a matter of soil leveling, to distribute water evenly around the field. Irrigation can also be optimized by using precise water flows, and shorter pipes (less than 350 meters). Improved irrigation can save 40% of the water: lowering costs, avoiding waterlogging and preventing lodging (as plants are less likely to fall over when the soil moisture is just right). Farmers who use water-saving techniques can produce a kilo of barley for Heineken with 641 liters of water vs 864 liters for the conventional practices.

Pest control includes sex pheromone traps to attract and kill fall armyworms, avoiding insecticide sprays. CIMMYT projects with Ingredion, Bimbo, PepsiCo Mexico, and Trimex treat seed with beneficial fungi, like Trichoderma, to prevent diseases. Instead of spraying insecticides on a regular basis, farmers first scout for pests, and if needed, apply low-impact insecticides, or less-toxic mineral fungicides if there are diseases. CIMMYT is testing intercropping with various legumes, to improve soil fertility. Intercropped fodder radish shelters beneficial insects like lady bird beetles that prey on pests.

These novel practices translate into lower costs and higher yields. Farmers growing maize for Bimbo reaped 11.1 tons per hectare vs just 6.7 on neighboring farms. Wheat for Nestlé yielded 6.7 tons per hectare, 20% higher than regional averages in official government statistics. Farmers who sold maize to Kellogg's were able to stabilize their yields, and increase their profitability by at least 20%.

"*The arrangements vary with each project and each firm. In collaboration with CIMMYT, these firms support farmers in their transition towards more sustainable practices, and while some offer financing to farmers to achieve this, they all provide training and technical support through CIMMYT. In 2022 alone, the companies bought more than 100,000 tons of maize and more than 55,000 tons of wheat from farmers in Mexico who often struggle to find a place to sell it. The farmers save money, preserve the value of their land, improve their incomes and minimize their risks, while the firms have a secure and local source of high-quality cereals. So everybody wins*," says Louis García, who coordinates responsible sourcing actions at CIMMYT.

José Guadalupe Flores, national hub coordinator, adds, "*And because this is CIMMYT, we always include research in our work. We are gathering data on fertilizer and water use, soil preparation and pest control, along with yields, costs and benefits, so that our projects can be a model of conservation and improved livelihoods, on a global scale.*"

Producers from Guanajuato, Mexico, at a training event organized by the CIMMYT Bajío Hub. ©Francisco Alarcón / CIMMYT.

CIMMYT is testing intercropping with various legumes, to improve soil fertility. intercropped fodder radish shelters beneficial insects like lady bird beetles that prey on pests.

Inc.

Voluntary carbon markets can help smallholders mitigate climate change

With the right tools, smallholders can trade on voluntary carbon markets and keep carbon in the soil. ©CIMMYT.

CIMMYT is developing the protocols to help farm communities take part in voluntary carbon markets (VCM) to support climate change mitigation. Under this approach, farmers would be paid to adopt agricultural practices that sequester carbon in the soil. CIMMYT and partner platforms would provide measurement, reporting and verification (MRV) services, using soil testing, digital tools, and satellite imagery. Farmers who could sell carbon credits on this private market would be motivated to use sustainable agricultural practices.

Agrifood systems are linked to a third of global greenhouse gas (GHG) emissions, but receive only 3% of public financing. This irony motivated CIMMYT to develop an approach to access funding to support a just transition to low-carbon agriculture, by encouraging smallholders to participate in voluntary carbon markets (VCMs), which would pay farmers or their organizations to emit less carbon.

This approach would allow CIMMYT to attract green finances to support transformation towards new, low-carbon agrifood systems.

As of 2022, about 2,300 global businesses have pledged to reduce greenhouse gas emissions to zero. These promises are expected to boost the demand for carbon credits. By the end of this decade,

This approach would allow CIMMYT to attract green finances to support transformation towards new, low-carbon agrifood systems.

Measuring carbon sequestration. ©CIMMYT.

an estimated $6 billion to $10 billion worth of carbon credits could be traded on VCMs. In late 2021, CIMMYT started a VCM pilot activity in India, with limited but encouraging results. In August 2022, CIMMYT established the Carbon Markets Team, to explore ways to participate in the unregulated and often opaque VCMs.

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Within the VCMs there is a concern about the quality and the integrity of carbon offset credits, and if there will be enough of them to meet demand. To address these issues, global oversight of VCMs will be provided by the new Integrity Council for the Voluntary Carbon Market (ICVCM), an international council of 430 experts from 250 NGOs, universities, companies, and financial institutions. VCMs are now adopting the ICVCM's new standards for high-quality carbon credits, based on solid science.

"*This is a major challenge for the VCMs, but an interesting opportunity for CIMMYT, which is widely recognized as a credible, science-based innovation broker, with a proven track record in agricultural science and a true concern for smallholders' welfare. These elements position CIMMYT as a relevant market player in this fast-evolving market*," explains Ramiro Ortega Landa, CIMMYT's program rural finance specialist and the Carbon Markets Team leader.

Based on the best practices and lessons learned from its Indian pilot experience, CIMMYT plans to expand its carbon market activities to Mexico, where it has already identified two potential partner platforms, and eventually to Ethiopia (or another African country). These experiences would generate a strong knowledge base to develop improved business models for the global agricultural carbon market, while benefitting rural communities as they help to mitigate climate change.

"*Carbon credits incentivize adoption of sustainable agricultural practices that address the climate crisis, addressing the resource limitations faced by many smallholder farm families*," says Sieg Snapp, director of the Sustainable Agrifood Systems Program at CIMMYT.

Sieglinde Snapp

Director of the Sustainable Agrifood Systems Program at CIMMYT

"Carbon credits incentivize adoption of sustainable agricultural practices that address the climate crisis, addressing the resource limitations faced by many smallholder farm families."

Harvesting fresh ears of good-quality hybrid maize. ©Wasim Iftikar.

Top Funders 2022

(in thousands of U.S. dollars, based on 2022 research execution)

Funder	
Bill & Melinda Gates Foundation	49,033
CGIAR Research Initiatives/ Platforms (Note 1)	31,802
United States Agency for International Development (USAID)	14,637
Federal Ministry for Economic Cooperation and Development (BMZ)	3,909
Foundation for Food and Agriculture Research (FFAR)	1,991
Food and Agriculture Organization of the United Nations (FAO)	1,002
Ministry of Agriculture and Farmers Welfare, Republic of India	866
Ministry of Agriculture and Rural Affairs, People's Republic of China	841
African Agricultural Technology Foundation (AATF)	754
Biotechnology and Biological Sciences Research Council (BBSRC)	575

(amounts exclude deferred depreciation effects)

Note 1: Contributions to the World Bank Trust fund from: Australia, Belgium, Bill & Melinda Gates Foundation (BMGF), Canada, Denmark, France, Germany, India, Ireland, Japan, Republic of Korea, The Netherlands, New Zealand, Norway, Sweden, Switzerland, UK (FCDO), United States Agency for International Development (USAID) and World Bank.

Other funders in 2022

Agrovegetal S.A.

Alliance for a Green Revolution in Africa (AGRA)

AMAZONE-Stiftung

ARVALIS - Institut du végétal

Australian Centre for International Agricultural Research

Bayer de México S.A. de C.V

Bioversity International

Borlaug Institute for South Asia

CABI

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Centro Internacional de Agricultura Tropical (CIAT)

Cervezas Cuauhtémoc Moctezuma, S.A. de C.V.

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

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Context Global Development (CGD)

Corporación Colombiana de Investigación Agropecuaria (Agrosavia)

Department of Agriculture (DoA), Thailand

Development Fund, Norway

Digital Green Foundation (DGF)

Driscoll's Operaciones, S. A. de C. V.

Global Center on Adaptation (GCA)

Global Crop Diversity Trust

Grupo Bimbo, S.A.B de C.V., Mexico

Grupo Trimex, S.A. de C.V. (Trimex), and PepsiCo, Inc. (PepsiCo)

Henan Agricultural University

Indian Council of Agricultural Research, India

Ingredion México S. A. de C. V.

International Center for Agricultural Research in the Dry Areas (ICARDA)

International Food Policy Research Institute (IFPRI)

International Institute of Tropical Agriculture (IITA)

International Livestock Research Institute (ILRI)

International Potato Center (CIP)

Kansas State University

Kellogg Company México

Kobe University

KOCH Agronomic Services LLC

Lancaster University

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Ministry of Foreign Affairs of Japan (MOFA), Japan

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Nestlé México S.A. de C.V.

Norwegian University of Life Sciences

Pennsylvania State University

Provivi, Inc.

Purdue University

Queensland Alliance for Agriculture and Food Innovation

Rothamsted Research

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Various private-sector companies, Mexico

Virginia Polytechnic Institute and State University

Walmart Foundation

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Bram Govaerts
Director General a.i.

Kevin Pixley
Global Genetic Resources Director and Deputy Director General, Breeding and Genetics

Sieglinde Snapp
Director, Sustainable Agrifood Systems

Daniela Vega Lira
Chief of Staff

*Leadership Team members and job titles in this list reflect membership as of December 31, 2022.

Board of Trustees

Served during 2022

Acronyms

AVISA	Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa project
BBSRC	Biotechnology and Biological Sciences Research Council of the United Kingdom
BISA	Borlaug Institute for South Asia
BoT	Board of Trustees
CA	Conservation agriculture
CEN-Mexico	Collaborative Evaluation Network in Mexico
CtEH	Crops to End Hunger
GHG	Greenhouse gas
CIMMYT	International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maíz y Trigo)
COVID-19	Coronavirus Disease 2019
CSA	Climate-smart agriculture
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization of the United Nations
FCDO	Foreign, Commonwealth & Development Office
FFAR	Foundation for Food & Agriculture Research
GIZ	German Agency for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH)
HTMA	Heat Tolerant Maize for Asia project
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas
IITA	International Institute of Tropical Agriculture
ISRA-CNRA	Senegalese Institute of Agricultural Research (Institut Sénégalais de Recherches Agricoles)
ICVCM	Integrity Council for the Voluntary Carbon Market
IMIC	International Maize Improvement Consortium
IWIN	International Wheat Improvement Network
JIRCAS	Japan International Research Center for Agricultural Sciences
MAIZE	CGIAR Research Program on Maize
MCM	Maize Commercialization Mode
MDGs	Millennium Development Goals
MRV	Measurement, reporting and verification
NARES	National agricultural research and extension systems
NARO	National Agricultural Research Organisation (Uganda)
NARS	National agricultural research systems
NGO	Non-governmental organization
NSAF	Nepal Seed and Fertilizer project
SADER	Mexico's Secretariat of Agriculture and Rural Development (Secretaría de Agricultura y Desarrollo Rural)
SDGs	Sustainable Development Goals
SENASICA	Mexico's National Service for Food and Agricultural Health, Safety and Quality (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria)
UAS-R	University of Agriculture Sciences, Raichur
UN	United Nations
USAID	United States Agency for International Development
VCM	Voluntary carbon market
WHEAT	CGIAR Research Program on Wheat
$	Unless otherwise indicated, all currencies are expressed in U.S. dollars

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