ICRISAT appreciates the support of CGIAR investors to help overcome poverty, malnutrition and environmental degradation in the harshest dryland regions of the world. See www.icrisat.org/funders/ for full list of funders.

We think of them as visionary funders — far-sighted governments, development banks, foundations, charitable organizations, private sector companies, and individuals, who recognize that the elimination of poverty is the key to a peaceful world with food security and prosperity for all.
Message from the Board Chair

Given our ever-changing global needs, ICRISAT continues to work along value chains of its mandate crops. Team ICRISAT and its partners are ever eager to constantly improve in breeding climate-proof nutritious crops that contributes to wellbeing in the drylands.

I am pleased to see that our valuable partnerships in the various sectors accomplished many a milestone in the year. We have launched the world’s first fully automated system for plot monitoring called agCelerant that provides climate solutions for Nigerian Agriculture. In Asia, crop cycle was reduced by half in semi-controlled greenhouse conditions through rapid generation advancement of chickpea. In Eastern and Southern Africa, the Malawi Seed Industry Development Project recorded significant impacts through nutrition-sensitive multi-sectoral interventions. We have set up advanced regional breeding hubs in India, Mali and Zimbabwe. We are focused on operating efficient and agile breeding programs with the use of modern technology. Thanks to all our partners for making this happen.

Positively looking at the future of ICRISAT and the CGIAR, we are hopeful and enthusiastic about the aspiration of the system to enhance the focus and re-live the impact of research. We are keen to contribute and collaborate with our stakeholders to make consistent greater impact in the drylands.

The Governing Board of ICRISAT reiterates its commitment to responsible governance from policy making to implementation to deliver our mission.

Dr Paco Sereme
ICRISAT Governing Board Chair

Message from the Former Director General

I have faith in investment in agriculture research leading to some optimism as we look forward to the next part of the 21st century. ICRISAT for 48 years has delivered varieties and hybrids to farmers and seed companies with great success, but we cannot continue to operate as we have.

In 2019, we launched our modernization program and crop improvement supported by key donors. Product profiles are key to all our crops, defining what the market wants and that defines the priorities of the breeding programs in three regional crop improvement hubs in Hyderabad, Bulawayo and Bamako. The hubs will have improved facilities, improved seed processing and grading systems. We will have rapid generation advancement so that breeding cycles are much shorter. We are digitalizing all data collections. We want to measure the genetic gains in our crops and make sure there is varietal turnover in farmers’ fields that shows significant impact from the upstream research we do through the breeding programs and seed system delivery into farmers’ fields.

We have achieved much in 2019 – this Annual Report has the details – and I look to 2020 as a year of continued delivery of impacts and achievements for ICRISAT and its many stakeholders.

Dr Peter Carberry
Former Director General, ICRISAT

Message from the Director General

Sustainable, productive and impactful – that is what I would want ICRISAT’s work to be over the next years and to be able to achieve the Sustainable Development Goals in the semi-arid tropics by 2030. It is going to be a tough challenge but I think we can contribute in a big way towards achieving them. Leadership, vision and commitment are vital. In order to succeed, we need a good strategy to allow ICRISAT to position itself in this changing world with One CGIAR and the COVID-19 taking precedence over other issues.

I have been looking through the Annual Report 2019 and I am sure you are all proud of the Research for Development impacts in there – reaching millions of farmers, millions of hectares, new varieties, numerous countries, thousands of tons of certified seed and production of millions of tons of grain. The impacts in genomics, watersheds, agronomy, digital agriculture, genebank, nutrition and food systems are impressive. Breeding is a huge part of our work and we need to build and improve the current rate of modernization. We need to bring in all those modern tools out there in all areas – mechanization, digitalization and data management.

ICRISAT is doing a wonderful job and we need to keep building on that. As we move into the future, our key drivers would be productivity, teamwork, partnerships, excellence, resources and opportunities. Our world is never going to be the same again with two imperatives that shape our future work environment. These are new situations; nonetheless they are great opportunities to bring about change. We need to be adaptable and we need to have resilience in this new normal that we are going to encounter as we move forwards.

Dr Jacqueline d’Arros Hughes
Director General, ICRISAT

A wild species of pearl millet shot at ICRISAT glasshouse in Hyderabad.

Photo: S Punna, ICRISAT
A world without hunger is what ICRISAT envisions. With an ever-increasing population, the year 2019 saw us pursue this vision with greater vigor. Mainstreaming nutrition and modernizing the breeding program were top priorities even as we roped in the best of genomic and digital technologies to increase efficiencies and deliver improved farmer-preferred varieties in half the time. Landscape restoration adopting a holistic approach that spans the entire agriculture value chain has shown great impact in improving food security, incomes and climate resilience of farmers. Our partnerships with governments, the public and private sectors, NGOs, NARS and CGIAR partners have helped reap the impacts showcased in this report.

Dr Kiran K Sharma
Deputy Director General-Research, ICRISAT

Growing Livelihoods

- pilot watershed projects in India and Ethiopia show how farmers’ incomes can be doubled with landscape restoration and the use of improved varieties.
- high-yielding and machine-harvestable chickpea variety tested on Indian farms results in tripled yields and savings on labor costs.
- improved groundnut varieties triple yields of seed producers in Africa.

Nutrition

Biofortification and culinary traits for released varieties

1. High grain yield
2. Early maturity
3. Abiotic stress tolerance
4. Biotic stress tolerance
5. Nutrition
6. Grain/pod size
7. Ethanol, biomass, others
8. Culinary
9. Fedder yield
10. Machine harvestability

- High iron and zinc
- High iron and zinc
- Calcium, iron and zinc
- Protein
- Digestibility, protein
- High oleic, protein

Smart Food study shows significant increase in growth parameters (BMI and HAZ) compared to control group in school children fed millet-based meals vs micronutrients fortified, rice-based meals.

Environment & Climate

Digital technologies: Launched the world’s first fully automated system for plot monitoring called agCelerant that provides climate solutions for Nigerian Agriculture. The Meeghdoot App, an ICT-enabled climate tool developed for the Indian government had >50,000 downloads.

- Fewer hunger months: Reliance on food aid halves in a study conducted in a Ghanaian climate-smart village and Ethiopian watersheds.
- Scaling up technologies: Watersheds in Africa and India have had requests for replication from governments.
- Climate Research facility set up at ICRISAT headquarters.
- Less land and water conflicts lead to improved prosperity in watershed projects in Ethiopia.

Gender

What women farmers want*

- Insights were generated on gendered seed knowledge, access and use in Uganda.
- GENDER Platform focuses on transforming food systems for gender equality in a climate crisis.
- Gender-responsive Plant Participatory Breeding Programs initiated in Africa.
- South-South collaborations in agribusiness: Participants from 22 African countries (50% women) trained to be entrepreneurs.
- Indigenous women farmers in India influence community diets and earn incomes.

* Contributions from the DSR Grant Legumex and Dryland Cereals led by ICRISAT
ICRISAT Annual Report 2019

**In West and Central Africa**

**CROP IMPROVEMENT FOCUS**

**SORGHUM**
- Biofortified sorghum
  - Nigeria
  - Mali

**PEARL MILLET**
- Commercial hybrids
  - Niger
  - Nigeria
  - Burkina Faso
  - Ghana
  - Senegal
  - Mali
- Dual purpose (Grain and fodder)
  - Nigeria

**AGRONOMY IMPACT**

**DIGITAL INTERVENTIONS**

**Research Highlights**

**CROP IMPROVEMENT FOCUS**

**Biofortified sorghum**

- Lines identified (Nigeria)
- New germplasms screened
  - 320
- Two clusters identified with higher mean values of iron (Fe) and zinc (Zn)
  - Fe 11-90 ppm
  - Zn 8-42 ppm
- Varieties identified (Mali)
  - 6 High Fe
  - 5 High Zn
  - 1 High Fe and Zn

**Commercial pearl millet hybrids** (Niger, Nigeria, Mali, Burkina Faso, Ghana and Senegal)

- Wider adaptability and yield stability
  - ICMH 17711
- Highly adapted to Burkina Faso (ICMH 147007)
- High-yielding and resistant to downy mildew
- Awaiting release in Burkina Faso for commercial use
- Training of seed companies and developing Hybrid Parents Research Consortium is in progress.

**Best dual-purpose millet** (Niger)

- ICMV 167005 and ICMV 167006 were recommended for improving crop-livestock farm system in Niger.

**PROJECT IMPACT (ATASP-1)**

**Sorghum flour makes it to supermarkets** (Nigeria)

- Improving industry interface with flour millers resulted in bringing out *packaged sorghum flour*.
- It came with added shelf life due to techniques developed by the millers. Varieties Samsorg 17, Samsorg 45 and Samsorg 47 suited millers.

**AGRONOMY IMPACT**

**Contour bunds and agroforestry** (Mali)

- Increased water conservation
  - 37.1-19% reduced runoff
  - >2 meters rise in water table
  - 20% soil moisture increase
- Climate-smart village (Lawra-Jirapa in Ghana)
  - Food security status improved, with more than half of the households experiencing fewer than 4 hunger months a year.
- Good Agricultural Practices (Nigeria)
  - Practices that led to increase in sorghum grain yields
    - Improved varieties
    - Seed dressing
    - Tillage practices
    - 30-64% increase in average yield
    - 27-38% experimental plot
    - 1.5-1.1 farmers’ practice

**Fall armyworm – Biological control** (Niger)

- Technique for mass multiplication of the parasitoid Telenomus remus developed for use in biological control.
- Increased food availability due to ISSFM (Mali)
  - ISSFM adopters
    - 664 kg/ha yield
  - Non-adopters
    - 451 kg/ha yield

**DIGITAL INTERVENTIONS**

**World’s first fully automated system for plot monitoring**

- NADIRA – Nurturing Africa’s Digital Revolution for Agriculture
  - interfaced a Geospatial Exploitation Platform (GEP) with the agCelerant digital value chain orchestrator to build the world’s first fully automated system for plot level monitoring. It is prototyped on Google Cloud.

- Adoption and impact of integrated Striga and soil fertility management strategy in Mal (9 fields et-al) (Page 287)

* Agricultural Transformation Agenda Support Program Phase-1
CROP IMPROVEMENT FOCUS

- **GROUNDNUT**
  - Kenya, Zambia, Tanzania, Uganda, Malawi
  - High yield, agronomic and market-preferred traits, drought and disease resistant

- **PIGEONPEA**
  - Kenya, Tanzania, Uganda, Malawi
  - Multi-trait pigeonpea (Kenya) for drought and disease resistant, high-yielding

- **SORGHUM**
  - Kenya, Tanzania, Uganda
  - High-yield with big heads and moderate resistance to lodging. Resistant to stem borer, blast and tolerant to drought

- **PEARL MILLET**
  - Kenya, Tanzania, Uganda
  - High-yield finger millet (Tanzania)

- **FINGER MILLET**
  - Uganda, Tanzania, Kenya, Ethiopia
  - High-yield, agronomic and market-preferred traits, drought and disease resistant

AGRONOMY IMPACT

- Landscape restoration | Ethiopia
  - Crop response to fertilizer

- Legume-maize intercropping | Malawi
  - Nutrient content

PARTNERSHIPS & APPROACHES

- Hybrid Parents Research Consortium operationalized (Kenya)
- Legume-maize intercropping (Malawi)
- Project engagement with policy makers (Kenya)
- Public-private partnerships (Kenya)

Highlights

**CROP IMPROVEMENT FOCUS**

- **Varieties released**
  - Groundnut with agronomic and market-preferred traits
  - 6 varieties (large seeded, preferred for oil extraction, dried and disease resistant, high-yielding)

- **Multi-trait pigeonpea** (Kenya)
  - 2 varieties (drought tolerant, wilt resistant, suitable for dry grain and green vegetable peas, amenable to ratooning)

- **High-yielding finger millet** (Tanzania)
  - 1 variety (High-yielding with big heads and moderate resistance to lodging. Resistant to stem borer, blast and tolerant to drought)

**AGRONOMY IMPACT**

- Doubled-up legumes (Malawi)
  - Simulated maize-legume integration showed: 50% saving in fertilizer costs for maize production

- Developed a fertilizer use guide (Ethiopia)
  - Able to predict crop response to fertilizer application using remote sensing and ground truthing with a precision level between 65-75%

- Terraced-treated farms (New refrigerated, Ethiopia)
  - 25-54% higher crop yield compared to non-terraced farms

- Impact of water spreading weirs (Ethiopia)
  - Harnessed flood re-greens degraded rangelands 46 ha degraded rangelands 10-12 t/ha biomass produced on average in a year

**Impact of AVCD project - Phase I (Kenya)**

- Community seed system established
  - 34 tons of seed shared with 10,664 farmers
  - 89 trained seed growers currently run the seed system

- Contribution to the County Nutrition Action Plans
  - 36 community health volunteers trained
  - 882 caregivers trained on consumption of diverse diets

- App for market information
  - Farmers learn to use a digital application ‘Source trace’ that supports farmer registration, E-extension, aggregation and marketing.

**Public-private partnerships (Kenya)**

- Sorghum and Pearl Millet Hybrid Parents Research Consortium operationalized.

**Working with governments (Malawi)**

- Malawi Seed Industry Development Project II impacts:
  - ICRISAT’s nutrition-sensitive multi-sectoral intervention was selected by Dedza district nutrition coordinating committee as a best practice.
  - Submission of rigorously tested groundnut-based recipes to the Malawi national recipe book.
  - A food safety curriculum on aflatoxin contamination was developed to be incorporated in the national nutrition training manuals.

- Innovation transforms livelihoods of pastoralists in Ethiopia

- Accelerated Value Chain Development Project of Feed the Future
- Seed of select drought tolerant cereals and legumes.
**CROP IMPROVEMENT FOCUS**

**CHICKPEA**
- **RapidGen**
- Dry root rot and wilt resistant

**SORGHUM**
- Improved forage and high ethanol

**PIGEONPEA**
- Wilt, sterility mosaic and blight resistant

**GROUNDNUT**
- High oleic
- Bold seeded
- High oil and confectionery

**PEARL MILLET**
- Heterotic groups identified
- Biofortified + Blast resistant

**CLIMATE RESEARCH**
- New facility set up for climate change research on plant protection

**CAPACITY BUILDING**
- Groundnut production and aflatoxin testing

**AGRONOMY IMPACT**
- Soil health interventions
- Rainwater harvesting
- Corporate Social Responsibility initiative

**HIGHLIGHTS**

**CROP IMPROVEMENT FOCUS**

**CHICKPEA**
- **RapidGen advancement**
- Crop cycle reduced by half under semi-controlled greenhouse conditions
- **Generations per annum:**
  - Normal practice
  - Earlier protocol*
  - RGA protocol
- *Developed by ICRISAT

**SORGHUM**
- **Stable resistance to wilt** (India)
- **6 genotypes** identified across multilocations

**PIGEONPEA**
- **Pod borer and Helicoverpa tolerance**
- ICC 506EB tolerant to pod borer and Helicoverpa armigera was shared with NARS partners for multi-location testing.

**GROUNDNUT**
- **First ‘high oleic’ variety released** (India)
- Salient features: Longer shelf life and health benefits
- A fast-track breeding strategy employing genotyping, phenotyping and RGA resulted in the development and commercialization of high oleic lines in just eight years.

**PEARL MILLET**
- **Heterotic groups identified** (India)
- This information on seed and restorer parents can be used to generate new higher-yielding series of hybrids.
- **High Fe and Blast resistant** (India)
- 7 lines identified

**SORGHUM**
- **Improved forage quality** (India)
- Hybrid CSH 24 MC [52% in vitro organic matter digestibility (IVOMD)] was recognized for revolutionizing forage production in India.
- 150 high biomass sorghum lines with more than 55% IVOMD identified for commercializing.
- For every 1% increase in IVOMD, there is a >5% increase in animal weight gain and milk yield.

**GROUNDNUT**
- **Wild seeded groundnut with market traits** (Bangladesh)
- Lines from multilocation testing advanced to national testing
  - 2 early-maturing lines (ICGV 00338, and ICGV 02038)
  - 1 drought-tolerant line (ICGV 07219) with bold seed size of 40-60 counts/ounce

**Rapid detection tools for allergens** (India)
- **ELISA** protocol was standardized for precise detection of groundnut allergens.
- *Enzyme linked immunosorbent assay

**CAPACITY BUILDING**
- Groundnut production and aflatoxin testing
- Vietnam | Myanmar | Bangladesh | Laos PDR
- **Improved forage quality**
- **50 sweet sorghum lines** with more than 22% brix content identified for commercial ethanol production.
- **Ethanol per ton of biomass**
  - 40-45 liters/ton
  - Currently available cultivars
  - 56 liters/ton
  - Identified 50 lines

**DID YOU KNOW?**

- **Dry root rot and wilt resistant**
- **Pod borer and Helicoverpa tolerance**

**CLIMATE RESEARCH**
- New facility set up for climate change research on plant protection

**CAPACITY BUILDING**
- Groundnut production and aflatoxin testing
- Vietnam | Myanmar | Bangladesh | Laos PDR

**AGRONOMY IMPACT**
- **Soil health interventions**
- **Rainwater harvesting**
- **Corporate Social Responsibility initiative**

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**Source:** ICRISAT Annual Report (2018-19). Figures as of December 2019

**316** improved varieties/hybrids were developed in partnership with the Indian NARS as of 2019.

**41,796** germplasm accessions were repatriated.

Many of these varieties are first of their type and have covered a lot of area under crops in the country.

**High-yielding groundnut variety ICGV 91114 has financially benefited farmers in Odisha and Andhra Pradesh states.**
In pigeonpea, significant changes in crop phenology were observed with increased temperature and CO₂ as compared to ambient.

**PIGEONPEA**

Wilt and Sterility Mosaic Disease resistant and Blight tolerant (India)
- 10 lines identified. These were shared with NARS.
- ICPL 332 WR (TDRG 4) resistant to wilt and tolerant to pod borers and Helicoverpa released in Telangana.

**CLIMATE RESEARCH**

Developed state-of-the-art climate change facilities such as CO₂ and temperature gradient tunnels, free air CO₂ enrichment facilities and open top chambers to study population dynamics, lifecycle of pathogens, pest and disease expression and host response under simulated climatic conditions.

- In pigeonpea, significant changes in crop phenology were observed with increased temperature and CO₂ as compared to ambient.

**CAPACITY BUILDING**

Training NARS staff and private companies (Vietnam, Myanmar, Bangladesh and Laos PDR)
67 trainees from the government agriculture department, NGOs, private seed companies and research centers

*National Agricultural Research System (NARS)*

**AGRONOMY IMPACT**

**Watershed impact in Andhra Pradesh and Karnataka states (India)**

The project bagged the National CSR Award for betterment of the lives of nearly 20,000 people through integrated watershed management in Kurnool, Andhra Pradesh and Vijayapura, Karnataka.

Rainwater conservation and improved water use efficiency (WUE) through construction of farm-based ponds and other community structures resulted in water storage of 200,000 m³.

- 30-60% farm losses reduced due to access to water
- 10-50% increase in crop yields with improved nutrient and crop management practices
- 500 women farmers involved through livestock-based activities and kitchen gardens.

**Soil test-based nutrient management in Odisha (India)**

*Increase in crop productivity*

- 10-40% finger millet, pigeonpea, groundnut, rice and maize

*Interventions*

- 40,265 soil samples analyzed
- 30 sites of learning established

- An online portal on soil health maps was set up (URL: http://111.93.2.168/odsoil/).

**Watershed impact in Bundelkhand (India)**

- Identified high water harvesting potential
- ~ 20% of the planned rainwater harvesting structures were executed

**Impact:** ~ 0.5 million m³ of water was made available in the region.

- Increased cropping intensity

25-80% average increase in yield

- Impacts led to reversing migration of smallholders who had left farming a decade ago.
An efficient and advanced crop breeding program contributes to higher genetic gains. Our breeding programs are designed to be focused, agile, cost-effective, and efficient. Here’s how we are staying ahead of the curve.

**Why?**
Modern breeding programs contribute towards food security by increasing rate of genetic gain in farmers’ fields and overall farm productivity.

**Why now?**

- **Food security:** Maintaining a steady growth of sustainable food production is critical to achieving the UN Sustainable Development Goal of Zero Hunger (UN SDG 2) by 2030.
- **Climate change:** Breeding climate-resilient crops that can give high yields in a changing climate is the need of the hour.
- **Nutrition:** With over 640 million inhabitants in the semi-arid tropics, we need crops that are nutritious and environmentally resilient.

**Why us?**
We work in the semi-arid tropics, home to over 2.5 billion people, most of whom are smallholder farmers. Our crops are grown in these regions and conditions, making them the staple food for many people.

**A short (hi)story**
In 1990, CCS Haryana Agricultural University (CCSHAU) released an early-maturing pearl millet hybrid HHB 67, which was rapidly adopted by farmers in north-western India and by 2002, was cultivated on approximately 774,000 ha in southern Haryana and central Rajasthan.

When Downy Mildew (DM) disease attacked it and started affecting crop yields, CCSHAU and ICRISAT together developed HHB 67 Improved, using marker-assisted back-crossing (MABC), among other techniques. This high-yielding, DM-resistant hybrid was released in 2005.

Most pests/diseases attack suddenly, with very little warning and little reaction time, e.g. Blast infestation in pearl millet in Asia and Africa in the past decade. Developing blast-resistant pearl millet is one of the top priorities due to demand from NARS breeders and seed companies.

Modernization of our breeding programs will enable responding to such threats on time, with quality and speed by utilizing and integrating latest tools and technologies.

**Regional Crop Improvement Hubs (RCIH)**
Regional Crop Improvement Hubs set up in India, Zimbabwe in Eastern and Southern Africa (ESA) and Mali in West and Central Africa (WCA) to stimulate and support breeding programs in the region. Each hub, led by a Regional Breeding Lead, to work across the disciplines of breeding, physiology, integrated crop management, and genomics and trait discovery for delivering better product faster.

**2019 updates**
- Crop Improvement Operations Team set up
- Regional Breeding Leads for Asia and ESA recruited
- Crop Improvement Operations Team Lead for Asia appointed
- Product Placement Lead for Asia and ESA appointed.

https://www.icrisat.org/individual-crop-improvement-operations-merge-into-a-single-entity-for-greater-efficiency/
2 Market-driven product profiles

Developing concept notes and product profiles with a focus on markets.

2019 updates

- >570 stakeholders consulted
- Three product concepts defined to complement NARS* activities in West Africa
- Two product profiles for groundnut identified
- Product concepts developed for pigeonpea (3) and chickpea (4) in ESA
- Consultation meetings held with partners.

*National Agricultural Research Systems (NARS)

https://www.icrisat.org/breeding-future-ready-crops/

3 Seed inventory management and mechanization

Accurate, faster operations with precise cataloging and use of mechanized tools.

2019 updates

- Further progress made on digitalization of seed inventory at ICRISAT Hyderabad
- Seed processing mechanization infrastructure purchased - expected to save US$ 300,000 within two years and hours of labor
- X-Ray Fluorescence facility set up at WCA for grain iron (Fe) and zinc (Zn) analyses in pearl millet, sorghum and finger millet
- Near Infra-Red Spectroscopy (NIRS) machines installed to quantify protein, oil, ash and oleic acid in groundnut
- HarvestMaster for grain weight and moisture content assessment
- Fully barcoded field plots and seed storage labels
- In ESA, genebank renovated and modernized; workspace optimized; standard operating procedures for infrastructure and safety guidelines developed.

4 Optimized breeding schemas

Enhanced breeding schemas such as Single Seed Descent and General Combining Ability to increase selection accuracy and intensity while retaining sufficient levels of genetic diversity.

2019 updates

- Workshop held with Excellence in Breeding platform (EiB) for understanding simulation platform to evaluate various breeding schemas
- Increased breeding efficiency by adoption of Breeding Costing Tool in ESA.

5 Advanced molecular tools

Advanced technology for accurate prediction of genetic value for long-term gain.

2019 updates

- Several markers for traits in pigeonpea converted to High Throughput Genotyping (HTPG), expected to facilitate early screening, marker-assisted back-crossing (MABC)
- Improved efficiency of early generation selection in chickpea for Ascochyta blight
- Identified Single Nucleotide Polymorphism (SNP) markers in pearl millet for iron and zinc content
- Trait-based genotyping for shoot fly resistance, drought tolerance, fertility restoration in sorghum and blast resistance in finger millet.

https://www.icrisat.org/first-ever-high-yielding-chickpea-variety-developed-using-marker-assisted-backcrossing-abc-released-in-ethiopia/
Digitalization and data analytics

Data science, machine learning and artificial intelligence contribute to significant reduction in time taken to deliver varieties with desirable traits.

2019 updates

- Automated experimental design generation (crosses, trials, germplasm inventory) using Breeding Management System (BMS)
- Crosses made within BMS
- Digital data collection using tablets with appropriate software (e.g. FieldBook)
- Digitalized germplasm lists
- Barcodes for research plots to track seed and genotyping samples
- Genomic Open-Source Breeding Informatics Initiative (GOBii) database: data loading and development of user-friendly breeding tools
- Breeding view and GenStat software being utilized that enables analysis of unbalanced data and fitting mixed models.

RapidGen

Generation time is a game changer for achieving maximum genetic gains in crop plants. Generally, it takes seven to eight years to develop homozygous (identical) lines after hybridization with one crop generation produced per year. For instance, the Rapid Generation Advancement protocol (RapidGen) allows the production of six to seven generations of chickpea in a year under controlled glasshouse conditions.

2019 updates

- RapidGen streamlined in partnership with industry (Corteva Agriscience) and the University of Queensland, Australia
- Infrastructure set up for RapidGen Protocol Optimization and production for mainstreaming RapidGen in the Asia hub
- Effects of varying photoperiod and temperature for chickpea, pearl millet, sorghum and groundnut optimized
- Methods to enable high density sowing to produce healthy, viable seeds optimized for rapid generation cycling. These can be used at multiple stages of crop breeding programs
- Pearl millet and sorghum breeding programs to transition to RapidGen beginning 2020.

Structured multilocation trials

Planned multilocation trials for data to accurately estimate yield, determine pattern of response for genotype/agronomic treatments and provide reliable guidance for selecting the best genotypes or agronomic treatments for planting in future years and at new sites.

2019 updates

- Increase in pearl millet varieties/hybrids from 100 to 150 in multilocation testing trials
- Advanced pearl millet lines evaluated at 15 locations in WCA representing target environments for three product concepts of Sahelian and Sudanian zones. Totally, 90 sites per season will be used
- Strategic multilocation trials for chickpea and groundnut carried out.

Capacity building

From genomics to operations to data analysis, capacity building among scientists, farmers, extension workers and other stakeholders is an ongoing process.

2019 updates

Breeding

- Leadership Training workshop on change management, team building and behavioral change in Arusha, Tanzania (30 participants)
- Excellence in Breeding Platform Annual Meeting in Amsterdam focused on modernization of CGIAR centers’ breeding programs
- Training on using digital seed catalog, seed roadmap, MEASURE platform for MEI platform (91 participants)
- Digitalization of breeding programs and data management (63 participants).

Genomics

- Training on next-generation genomics for crop improvement
- International workshop on genomic selection for crop improvement for participants from India, Australia and UK
- Organized 10K Chickpea Sequencing Initiative involving University College of London, BGI-Shenzhen and ICRISAT.

Data management

- Extended advanced data science support to 10 crops of the Indian Council of Agricultural Research (ICAR)
- Introduced digital interventions in NARS partners in ESA and WCA through Tropical Legumes III, HOPE2 and AVISA3 projects.

https://www.icrisat.org/hands-on-training-for-modernizing-crop-breeding-programs/

1 Monitoring and Evaluation of Agri-Science Uptake in Research & Extension; 2 Harnessing Opportunities for Productivity Enhancement for Sorghum and Millets (HOPE); 3 Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA)
Breeders’ equation

What is genetic gain? The amount of increase in performance achieved in a generation through targeted selection determined in a crop breeding program by the following breeders’ equation:

\[
\Delta G = \frac{i \cdot r}{\sigma_A}
\]

The initiative to streamline our crop improvement programs is a concerted effort to accelerate genetic gains in our mandate crops, resulting in faster delivery of varieties with higher yields, better nutritive value, stronger resistance to biotic/abiotic stresses and other desirable traits. These will help smallholder farmers in the dryland regions achieve financial and nutritional security, while causing minimal impact on the environment.

Acknowledgements

We thank our funders and partners for supporting us in our initiative to modernize breeding. We are confident that cutting-edge breeding programs can make a difference to smallholder farmers by providing them with climate-resilient, agro-ecologically adapted and nutritious crops.

Vision

A prosperous, food-secure and resilient dryland tropics

Mission

To reduce poverty, hunger, malnutrition and environmental degradation in the dryland tropics

Approach

Inclusive Market-Oriented Development (IMOD)

ICRISAT leads

ICRISAT is a partner in

ICRISAT-India (Headquarters)

Patancheru, Telangana, India

icrisat@cgiar.org

We believe all people have a right to nutritious food and a better livelihood.
Genetic Gains

Decoded genome sequences for two subspecies of cultivated groundnut leading to improved understanding of genome organization, gene function and groundnut improvement.

The new tetraploid groundnut genome sequences for A. hypogaea sps. hypogaea and A. hypogaea sps. fastigiata are available to researchers and plant breeders across the globe to aid in the breeding of more productive and resilient groundnut varieties.

### Chickpea accessions resequenced

429 accessions from 45 countries resequenced to gain insight into genome diversity, domestication and agronomic traits.

39 scientists from 21 research institutes around the world were involved in the project.

### Role of staygreen QTLs in sugar metabolism

Dissected role of staygreen quantitative trait loci (QTLs) in sugar metabolism and transport in post-flowering drought conditions and identification of candidate genes. The results suggest that abscisic acid signaling plays an important role in post-flowering drought-induced remobilization of sugars to the reproductive sinks.

### Nutrition focus

- India’s first High Oleic groundnut
- Aflatoxin-resistant groundnut: With technical proof of concept demonstrated, the stage is set to progress to early development, and regulatory strategies towards product development. Collaborations with West African NARS (Senegal, Nigeria and Mali) are in place to enable the release and utilization of these technologies.
- Diabetic friendly, low glycemic index hybrid pearl millet

### Cultivated groundnut genome sequence cracked

- Genomics-assisted breeding for commercial cultivation
  - Molecular breeding (India)
    - First molecular breeding products released among oilseed and pulse crops in India
  - 2 groundnut varieties with high oleic acid content – Girnar 4 (ICGV 15083) and Girnar 5 (ICGV 15090)
  - 2 chickpea varieties for drought tolerance and Wilt resistance (Pusa Chickpea 10216 and Super Annigeri11)

- Marker-assisted backcrossing
  - In Ethiopia, Geletu, a high-yielding and drought-tolerant chickpea variety using MABC was released.
  - 3,822 kg/ha was the highest grain yield recorded
  - 15% yield advantage over control variety Teketay

- Acquisition, characterization and distribution of germplasm (Genebank activities)
  - 15,000 seed samples distributed in 15 countries
  - >2,000 new accessions characterized
  - >19,000 accessions tested for seed viability
  - Promising germplasm sources identified
    - Multi-trait specific accessions in sorghum
    - Yield and nutrient specific accessions in kodo millet
  - Assessed diversity

- Wild Cajanus species for pigeonpea improvement
  - Pre-breeding lines in initial varietal trials (India) 2018-20 crop season
  - 6 high-yielding pre-breeding lines selected for trials
  - 1,400-3,000 kg/ha is the average yield potential
  - This development is significant on two counts. One is of pre-breeding lines, especially in mid-early maturity duration group, directly reaching the varietal pipeline. The second is the utilization of wild Cajanus species for broadening the ‘stagnant’ genetic base of pigeonpea cultivars in India.

- Pre-breeding lines shared with NARS (India & Myanmar) for evaluation across locations for yield and related traits.
  - 10 high yielding
  - 23 disease resistant
  - 20 salinity tolerant

- Accession, characterization and distribution of germplasm (Genebank activities)
  - 1,325 unique germplasm accessions assembled from regional genebanks
  - >10,000 accessions regenerated
  - >6,600 accessions tested for seed health
  - Developed genomic resources for Proso millet, kodo millet and little millet
  - Standard Operating Procedures
    - Two documents on germplasm acquisition and safety duplication were published.
Innovation Systems for the Drylands

>5,000 farmers in at least 10 districts made better decisions on planning and managing their farms through direct ICT-enabled agro-advisories since 2016.

Crop livestock integration and marketing (Malawi)

A project based on systems and value chain diagnostics initiated investments in a series of leverage points that support high potential livestock value chains, for developing scalable interventions.

3 district level Innovation Platforms feed into national level policy dialogue

≈ 900 farmers were trained and mentored on diversified crop and fodder production

South-south collaboration (India Africa Forum Summit)

Trainings were conducted on setting up small-scale food processing enterprises, food testing laboratories and scaling-up business in the fruits and vegetables processing industry.

Drone-based technologies

Acquiring and testing novel sensor-based technologies for accelerating development of climate resilient and nutritionally dense crop products.

ICT-enabled climate services climate change services impact (India)

Improved on-farm water use efficiency (Zimbabwe)

70% farmers reduced irrigation frequency

86% reported increases in yields of > 25%

43% reported increases in income

Policy makers agree to scale up technology

The National Zimbabwe Government Director of Irrigation agrees to scale up this strategy. ACIAR agreed to fund a second project.

30 irrigation schemes will use the technologies

~3,400 farmers on 1,380 ha to benefit by 2021

New methods of crop monitoring using machine learning algorithms (Asia and Malawi)

Landsat data on Google Earth Engine: Used to derive agriculture cropland extent and area in Asia.

Moderate Resolution Imaging Spectroradiometer: Monitored changes in the cultivation of pigeonpea and groundnut in Malawi using time series satellite imagery for sustainable food systems.

Indigenous women farmers train to be ‘nutrition entrepreneurs’ (India)

In partnership with the Government of Telangana, food processing units were set up to procure local produce and make products for government’s food and nutrition schemes in schools and welfare centers in the tribal regions of Telangana.

80 farmers formed into 8 Joint Liability Groups

Each group will operate a unit and share profits

Estimated impact

100 farmers to benefit

20% increase in incomes

1.5 tons of food to be processed per day

Groundnut Primary Processing Centres impact (India)

3 centers were established in three villages

They are run by farmer members of a Food Producer Company (FPC) on a service-based model.

Postrainy season 2019 results

33 tons of groundnut was processed

US$ 645 extra income earned by FPC

The project was supported by the Walmart Foundation. The FPC has around 6,000 farmer members.

~3,400 farmers on 1,380 ha to benefit by 2021

30 irrigation schemes will use the technologies

~3,400 farmers on 1,380 ha to benefit by 2021

App for climate advisories (India)

The Meghdoot App, an ICT-enabled climate tool in collaboration with India Meteorological Department, Indian Institute of Tropical Meteorology and Indian Council of Agricultural Research is targeted to reach entire India.

Estimated impact

650 districts to be reached
CRP-GLDC highlights

Adoption and ex-post impacts of improved cowpea in Nigeria
Over 20 improved varieties released
Adoption led to a 17 percentage point increase in household income and a 5 percentage point reduction in the incidence of poverty
929,450 people lifted out of poverty (Manda et al. 2019b)

Early-maturing chickpea cultivars in Myanmar
Study on release of 10 cultivars (1976 to 2018)
Cropped area under improved chickpea increased from 67% in 2001-02 to 97.7% in 2017-18
51% productivity gains; unit cost reduction at US$ 129/ton
Progress by Flagship Program (FP)

FP1: Priority Setting and Impact Acceleration
• Ex-ante nutritional impact assessment identified early-maturing sorghum with tolerance to drought and resistance to insect pests, and drought-tolerant cowpea varieties (WCA), intercropping-compatible pigeonpea varieties, early-maturing sorghum varieties and hybrids with tolerance to drought (ESA), and Fusarium wilt, root rot, and Botrytis grey mold (BMG)-resistant chickpea varieties in (SA).
• Identified user preferred traits for rainy season (white, large, globular and lustrous grains) and postrainy season sorghum (high starch, medium protein content and higher protein digestibility) to update product profiles in India.
• Research on gender and youth, youth realities, aspirations, transitions and opportunity structures in Uganda, Ethiopia and Tanzania, and youth engagement in seed systems in Mali and northern Nigeria. Read more

FP3: Integrated Farm and Household Management
• Strategies for tackling new pests: Assessed spatial and temporal distribution of emerging diseases of chickpea and pigeonpea (India)
• Intercropping studies: Evaluated agroecologies for soybean, cowpea, groundnut, pigeonpea and sorghum (Mozambique, Malawi, Burhina Faso and India)
• Established demonstration plots: 236 soybean (36% women) and 185 cowpea (39% women)
• Doubled-up legume systems: > 110,000 people benefit (Malawi)
• Decision support tools developed to assess impacts of legume-based technological interventions (Burkina Faso and Ethiopia). Read more

FP4: Variety and Hybrid Development
• 26 GLDC cultivars commercialized.
• Developed high oleic groundnut, cream seed-coated pigeonpea and large-seeded chickpea to meet industry needs, and machine harvestable chickpea and lentil for youth employment.

FP5: Pre-breeding and Trait Discovery
• Identified 44 drought-tolerant wild cowpea lines that were crossed with elite varieties and incorporated into pre-breeding.
• Generated over 700K data points in all GLDC crops to develop markers.
• Advances made in the development of genomic selection in chickpea, groundnut, pearl millet and sorghum; identifying quantitative trait loci/ marker trait associations (QTLs/MTAs) for priority traits, transcriptomics data and epigenetic data on biotic and abiotic stresses in chickpea, and introgression and pyramiding of identified QTLs in breeding elite lines.
• Two high oleic groundnut lines (India) and three chickpea lines (India-2, Ethiopia-1) released.
• Identified candidate genes and markers for early and late flowering and adaptation to high temperature and dry environment in pearl millet using genome-wide association study.
• Established protocols for genome editing, second-generation transformation (pearl millet), systematic mutant population, genomic selection models, phenotypic screening, rapid generation turnover platform (pearl millet and sorghum), early stage leaf blast screening (finger millet) and high-quality draft genome assemblies (chickpea and pigeonpea). Read more

FP6: Common Bean for Markets and Nutrition
• Released 2 drought-tolerant, high-yielding, early-maturing varieties with high Fe and Zn, good marketability, palatability and tolerance to major diseases (Uganda).
• Improved varieties released (Zimbabwe and South Africa).
• Improved beans promoted and seed access through small packs (Tanzania, Uganda, Burundi, Kenya, Rwanda and Zimbabwe).
• Threshing and solar bubble dryer technologies introduced.
• Market survey conducted to identify and characterize yellow and other bean corridors. Read more

Cross-cutting areas

Gender
• Gender-responsive variety development in sorghum and millet in WCA. Identified the most important traits for each value chain.
• Gained insights on opportunities available to women farmers in soybean seed systems in Mozambique.
• Generated primary data and insights on lentil farming, innovations and women empowerment in rural landscapes.
• Innovation on threshers, processing of beans to provide business opportunities for women.

Youth
• Teamed up with universities in Tanzania, Uganda and Ethiopia to lead youth studies
• ABC-PABRA and IMARA TECH to develop labor saving technologies and ensure access to smallholders through mechanization service providers.

Capacity Development

Short-term programs trainees (All academic degrees including PhDs)

```
90,045
216,384
26
45
```
Female
Female
Male
Male

Publications

80 peer-reviewed publications
85% 50% Peer Reviewed Open Access > 340 knowledge products

List of publications

GLDC Annual Report 2019

ICRISAT Annual Report 2019

Climbing beans in Rwanda
0.8 million farming households increase productivity and food security
Raised per capita consumption expenditure by 0.9% and bean consumption by 2.8%
Additional 117,480 tons of bean consumed by 4.4 million people annually
4,714 households lifted out of poverty annually

Climbing bean technologies in Rwanda

Early-maturing chickpea cultivars in Myanmar
Study on release of 10 cultivars (1976 to 2018)
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Male
Male

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85% 50% Peer Reviewed Open Access > 340 knowledge products

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GLDC Annual Report 2019

ICRISAT Annual Report 2019
3) Protein study: Combinations of millets and legumes studied showed they made a complete protein and highly digestible protein with a basket of micronutrients. Published in *Cereal Chemistry*.

2) Myanmar: A small pilot study showed that millets and pigeonpea meals had a positive impact on the extent of wasting and underweight children between 2-14 months; and sensory evaluations in the community showed on average 4 out of 5 for all recipes and products. Published in *Journal of Food and Agriculture*.

Smart Food setup to be led by Africa and Asia with the formation of Smart Food Executive Council following signing of MoU by:

Trademark of the Smart Food logo and tagline approved and formally registered in India.

Smart Food strengthened with three new ambassadors:

Dr Lalla Malika Issoufou
First Lady of Niger

Chef Anahita Dhondy

Chef Ranveer Brar

Dr Yemi Akinbamijo’s feature article in *The Globe Post*: *Superfoods can’t save our broken system – But Smart Food can.*

Who will join the other ambassadors based in London, Paris and Senegal:

Chef Mick Elysee
Chef Anto Cocagne
Chef Aistou M’Baye
Culinary blogger Dienaba Traore

* Body mass index (BMI); Height-for-age Z-scores (HAZ).

**Communications at a glance**

2019 > In the media

**Project Syndicate**

Goats Against Climate Change

As students map the weather, an Indian village beats its water woes

The New York Times

Grew Faster, Grew Stronger: Speed Breeding Crops to Feed the Future

**The Times of India**

Genes of climate-resistant chickpea varieties identified

>30 media articles


2019 > Social media

**Twitter**

30,500 followers ▲ 30%

**Facebook**

22,941 likes ▲ 16%

**LinkedIn**

28,857 followers

Nearly doubled

A LinkedIn post on the World Day for Combating Desertification and Drought gathered the highest number of impressions – almost 90,000 – last year.

A tweet at the conclusion of the Big Data in Agriculture Convention garnered 12,620 impressions – one of the highest ever.

A tweet mentioning Bill Gates’ reference to work done by CG centers was the top tweet in September with almost 10,000 impressions.

Campaigns on UN days, ANH Academy Week, UNCCD COP14, Africa Green Revolution Forum-AGRF, Global Commission on Adaptation report release, Global Science Conference on Climate-Smart Ag, Big Data in Agriculture 2019 Convention and International Plant Protection Congress.
2019 ➤ Publications

266 Total ICRISAT publications
196 ISI publications
296,217 Publication downloads
36 Books and book chapters
8 Policy briefs
790 ICRISAT authors
1037 IARIS co-authors
253 Happenings newsletter articles

2019 ➤ Products and initiatives

143 Design outputs
94 Photo and Video assignments

Policy briefs and flyers on Natural Resource Management work in Ethiopia - Impacts of the Yewol watershed project and successes in the Afar region. A poster was also developed. A decision guide was created on acid soil reclamation for use by both farmers and policymakers. 1,996 views on CG space with 1,010 downloads in the last six months.

2019 ➤ Visitor engagement

19,198 visitors in 488 groups visited ICRISAT headquarters in India.

2019 ➤ Web

Views 991,965
Users 320,438
▲ 7.8% ▲ 5.1%

Mobile engagement
Happenings visitors
▲ 12% ▲ 86%

Maximum visitor engagement increase in Mali - 25.71%, followed by Zimbabwe - 14.9%

2019 ➤ Communications for change

Inaugural Niger national millet fair by the Government of Niger.

Food display at the fair

At the African Green Revolution Forum (AGRF)

Smart Food Culinary Challenge organized with 58 student chefs from 16 culinary institutes across India.

Our staff

999 People
27 Nationalities

Gender
Age

ICRISAT Governing Board in 2019

Trilochan Mohapatra
Vice Chair, ICRISAT GB

Sissel Rogne
Norway

Wendy Umberger
Australia

SK Joshi
India

Rachel K Chikwamba
Zimbabwe, opted Sep 2019

Paco Sereme
Burkina Faso
Chair, ICRISAT GB

Prabhu Pingali
USA, from April 2019

Folasade Ogunde
Nigeria

Sanjay Agarwal
India

Laurie Tollefson
Canada

Peter Carberry
Australia
Director General

India | 733 Mali | 64 Niger | 46 Malawi | 37 Zimbabwe | 27 Kenya | 21 Ethiopia | 16 Nigeria | 15 Uganda | 2
Burkina Faso | 7 Mozambique | 6 Australia | 4 Germany | 3 Cameroon | 3 Rwanda | 2 United Kingdom | 1 Ireland | 1
Benin | 2 Brazil | 1 Senegal | 1 USA | 1 Czech Republic | 1 South Africa | 1 Austria | 1 France | 1 Chad | 1 Belgium | 1

Views

Happenings visitors

Cameroon

Zimbabwe

Australia

Canada

Zimbabwe

Nigeria

India

USA

United Kingdom
Projects

Contribution to grant revenue by project size
(in US$ thousands)

- Small (<100) 1%
- Medium (100-500) 5%
- Large (>500) 94%

Financial summary

Top ten donors for 2019 (in US$ thousands)

- CGIAR 13,322
- BMGF 11,238
- India 11,185
- USA 10,912
- CGIAR CONSORTIUM 4,125
- Ireland 1,775
- GCDT 1,666
- EU 1,654
- CARE 907
- Niger 710

Partners

- Academic 28
- CGIAR 13
- Foundations 5
- International NGOs 3
- Local NGOs 44
- Governments 11
- Seed Companies 13
- Private Industries 33
- NARS 13

Balance Sheet

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<td>Assets</td>
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<td>Cash and Cash Equivalents</td>
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<td>Investments</td>
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<td>Accounts Receivable</td>
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<td>Liabilities</td>
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<td>Accounts Payable</td>
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<td>Payments in advance from donors</td>
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<td>- Undesignated</td>
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<td>Permanently Restricted</td>
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<tr>
<td><strong>Total Liabilities &amp; Net Assets</strong></td>
<td>73,039</td>
<td>81,730</td>
</tr>
</tbody>
</table>
ICRISAT works in agricultural research for development across the drylands of Africa and Asia, making farming profitable for smallholder farmers while reducing malnutrition and environmental degradation. We work across the entire value chain from developing new varieties to agribusiness and linking farmers to markets.

ICRISAT appreciates the support of CGIAR investors to help overcome poverty, malnutrition and environmental degradation in the harshest dryland regions of the world. See http://www.icrisat.org/icrisat-donors.htm for full list of donors.