Modern crop breeding began around 1900. – Tigist Masresra, a technical assistant, working in the Highland Maize Breeding Program at Ambo Research Center, Ethiopia.
Photo: CIMMYT/ Peter Lowe

HOW PLANT BREEDING HELPS TO FEED THE WORLD

Farmers already started to modify plants physically and genetically in order to achieve better yields several thousand years ago. The Director-General of the International Maize and Wheat Improvement Center (Cimmyt) shows how demands on plant breeding have changed over the last four decades and which methods the international research community is developing to master present and future challenges.

By Martin Kropff

Breeding of maize and wheat was begun by early farmers as part of their domestication of naturally-occurring grass species, to better feed their families and communities. Maize comes from a wild ancestor known as teosinte that still grows in Mexico and which farmers began to use at least 7,000 years ago. Bread wheat resulted from natural crosses between emmer wheat and goat grass, likely in the Northern Caspian Sea area some 12,000 years ago. Farmers modified these proto-crops physically and genetically by selecting for bigger grain, better yields, spikes that stayed together rather than dropping seeds, and other qualities of interest.

Modern crop breeding began around 1900, with the rediscovery of Gregor Mendel's laws regarding genetics and inheritance, together with the emergence of formal agricultural research systems in many of today's high-income countries. One key outcome was the development of hybrid maize in the early 1900s; its rapid adoption in the 1930s created much excitement about the potential of genetics to revolutionise agriculture.

HUNGER ALLEVIATION AND DEVELOPMENT – A HISTORICAL CONTEXT

The world food problem has been an ongoing debate at least since Thomas Malthus' book, *An Essay on the Principles of Population*, brought the issue to the fore in 1798, suggesting that population growth inevitably leads to famine. At the dawn of the 20th century, continued discussion on the topic included books such as *The Wheat Problem*, published by distinguished British scientist Sir William Crookes in 1898. The Great Depression of the 1930s severely curtailed demand and led to a global grain glut, but also fuelled a growing awareness that much of the world lacked sufficient food. A seminal paper presented at the League of Nations in 1935 by Frank McDougall, Australian farmer and self-trained economist, and Stanley Bruce, ex-prime minister of Australia, argued for increasing agricultural production to meet the world's nutritional needs. McDougall helped influence US President Franklin Roosevelt to request the first UN conference on world food issues in 1943. Following World War II, acute food shortages in China, Europe, Japan and other countries brought world food and hunger to humanity's attention.

Finally, Cold War politics set in motion a big push for development aid, technical assistance, and food aid from about 1950 on. Dominating discussions of world food security at the time was the sharp rise in population growth in the developing world during 1940-60, driven in part by the Second World War's end and better health, sanitation and control of disease epidemics. Books of the time, including Paul Ehrlich's *Population Bomb*, reflected a revived Malthusian pessimism.

THE GREEN REVOLUTION – A SUCCESSFUL EXAMPLE OF AGRICULTURAL DEVELOPMENT

Against this backdrop, in 1940, US Vice President Henry Wallace, founder of the Pioneer Hi-Bred maize seed company, attended the inauguration of the new Mexican President, Ávila Camacho, and was asked by the country's Minister of Agriculture, Marte R. Gómez, to provide technical assistance to help erase the country's deficit in maize, wheat and bean production. Upon his return, Wallace approached the Rockefeller Foundation for assistance in addressing Mexico's request. With Mexico's support, the Foundation established the Office of Special Studies (OSS) in Mexico in 1943. The following year, young U.S. scientist Norman E. Borlaug joined the team of international experts at the OSS, eventually taking charge of research on wheat.

His work featured several major scientific achievements. Strong resistance to stem rust, a disease that was ravaging Mexican wheat-growing areas, was the first breeding goal. To speed progress, Borlaug found two climatically different locations to grow two generations each year, thus halving the time necessary to produce a variety. Differing in elevation by 2,600 metres and in latitude by ten degrees, the locations also exposed advancing generations of wheat to differing spectrums of diseases, environmental problems and daylengths. The wheat varieties that emerged from this system were more broadly adapted, as well as resistant to stem rust and other diseases.

To address the issue of the wheat plant falling over, known as "lodging", under the heavier grain, Borlaug crossed the Mexican wheats with a source of dwarfing genes and by the late 1950s had developed semi-dwarf wheat varieties that not only resisted lodging but had a new plant architecture in which more dry matter was apportioned to the grain. The result was a quantum leap in yield that brought Mexico self-sufficiency in wheat production.

Dr Norman E. Borlaug conducting a training course for wheat breeders at the experiment station in Ciudad Obregón, Mexico, 1963.

Photo source: unidentified

In the early 1960s, South Asia was facing mass starvation and extreme food insecurity. To combat this challenge, scientists and governments in the region began assessing the value of the Mexican semi-dwarf wheat varieties for their countries. Trials in India and Pakistan, based largely on professional contacts established by Borlaug who had been visiting the region since 1960, were convincing and demonstrated high yields that offered the potential for a dramatic breakthrough in wheat production. Founded in Mexico in 1966, the International Maize and Wheat Improvement Center (Cimmyt) had emerged directly from and amalgamated many programmes and professionals from the Office of Special Studies and similar regional collaborations on the two crops. When harvests in South Asia fell drastically short for two years in a row, threatening famine, Borlaug, who was leading Cimmyt wheat research, organised in 1966 a shipment to India of 18,000 tons of the semi-dwarf Mexican wheat seed and, in 1967, 42,000 tons were shipped to Pakistan.

In combination with appropriate fertilisation and management practices, the new wheat varieties raised yields enormously in India and Pakistan. By 1969, Pakistan was self-sufficient in wheat, and India had boosted national wheat production to the unprecedented level of 17 million tons. These successes gave impetus to local breeding programmes and to changes in government policy that favoured agriculture. Other wheat-producing countries began to follow suit and the spreading revolution in agriculture benefitted millions of farmers and consumers. Together with the development and spread of improved rice and maize varieties and farming practices, the phenomenon was called the "Green Revolution".

Upon receiving the 1970 Nobel Peace Prize for his contributions to the Green Revolution, Borlaug cautioned that the achievements were temporary measures to buy time for governments to address exploding world populations and associated problems. Critics of the Green Revolution have cited the environmental consequences of intensive cultivation, including soil degradation, chemical pollution, aquifer depletion, and soil salinity, as well as of the differential socioeconomic impacts of the new technologies. Notwithstanding, it is unclear what alternative scenario would have allowed developing countries to meet the human needs posed by the massive population expansion of the 20th century, and without triggering more deforestation. At the same time, greater awareness about environmental impact and constraints has shifted the focus of research towards sustainable approaches, in the decades following the early Green Revolution.

THE GLOBAL FOOD SYSTEM UNDER PRESSURE

After declining for nearly a decade to around 770 million, the number of hungry people – those who fail to get enough calories for healthy and productive lives and essentially go to bed hungry at night – has increased in the last three years to more than 850 million. Intensified and widespread conflicts and migration have contributed significantly to hunger, but rising temperatures, more frequent droughts and flooding, and evolving and spreading crop diseases and pests are ruining harvests, intensifying farmers' risks and reducing local and global food security.

A landmark 2015 study by the insurance market Lloyds's of London showed that the global food system is under significant pressure from potential, coinciding shocks, such as bad weather combined with crop disease outbreaks. Other research has demonstrated that, for wheat, the declining area sown world-wide, together with massive stockpiling by China, which is the world's number-one wheat producer but is not exporting surplus wheat, is masking significant risk in global markets. A drought or serious pest or disease outbreak in a key wheat-growing country could tighten markets, reducing access to grain and leading to price spikes that most sorely affect the poor, who spend much of their income simply to eat each day.

A Cimmyt field worker demonstrating the emasculation of a wheat spike at Cimmyt Headquarters.

Photo: CIMMYT/ Alfonso Cortes

For example, the number-one food crop in sub-Saharan Africa, maize, has been under siege over the last decade from more frequent droughts and outbreaks of new pests and diseases in the region. Among these are the deadly viral disease maize lethal necrosis and the fall armyworm, an insect pest from the Americas that appeared in Nigeria in 2016 and has since overrun the continent, gravely reducing local availability of the vital food grain.

Approaches to overcome these challenges need to be multi-sectoral and include providing access for farmers to seed of stress-tolerant, disease-resistant crops, along with inputs that ensure their productivity and sustainable, locally-suited cropping systems.

Drought-tolerant maize hybrids and varieties developed by Cimmyt and partners using conventional breeding (cross-pollination + repeated generations of intensive selection) provide a grain yield advantage of at least 25-30 per cent over non-drought tolerant varieties in sub-Saharan Africa under drought stress. This can give farmers a harvest where there is none for non-drought tolerant varieties, reducing farmers' risk of losses.

Breeding for drought tolerance and disease or insect resistance in maize involves selection for yield under carefully managed stress; that is, creating controlled drought or artificial infestations / infections on experiment station plots and selecting the plants that yield grain. Associated methodologies were pioneered, refined, and documented by Cimmyt over several decades. Through selective support for infrastructure, training, and other assistance, the organisation expanded the capacity in partner countries to screen for drought tolerance and resistance to common diseases and pests, as well as supporting the emergence of competitive, high-quality seed markets and companies to promote farmers' use of stress tolerant varieties.

The climate challenge

Agriculture and food systems account for up to 29 per cent of greenhouse gas emissions, and at the same time will be profoundly affected by the rapidly changing climate. Agriculture also accounts for about 70 per cent of water withdrawals globally.

Decades of research and application by scientists, extension workers, machinery specialists, and farmers are refining and spreading practices that conserve soil and water resources, improve yields under hotter and drier conditions, and reduce the greenhouse gas emissions and pollution associated with maize and wheat farming in Africa, Asia, and Latin America.

Supporting the sustainable intensification of farming in those regions, the practices include reducing or minimising soil disturbances such as tillage, retaining crop residues and using crop rotations – three practices known collectively as "conservation agriculture" – as well as other climate-smart farming approaches. Technologies for intensified, irrigated wheat cropping systems allow farmers to apply nitrogen fertiliser in the precise dosages and at the time needed by plants, thus reducing nitrous oxide emissions and nitrate runoff into water systems.

As is evident from the above, science can help address the complex issues facing agriculture today, but continued policy attention and investments in agricultural research for development are crucial.

Hidden hunger and malnutrition

In addition to those who eat too little, the diets of two billion persons world-wide lack essential micronutrients – Vitamin A, iron, or zinc – and this especially affects the health and development of children under five years old. An approach known as biofortification, involving the creation of micronutrient-dense staple crops using breeding, can improve nutrition as part of an integrated, food systems strategy. Cimmyt, various institutions of the Consultative Group on International Agricultural Research (GCIAR), and numerous national research organisations and scaling partners have in recent years developed and released more than 60 improved varieties of maize and wheat in 19 countries of Africa, Asia, and Latin America. Their grain features enhanced levels of the essential micronutrients zinc or pro-Vitamin A.

REAFFIRMING THE ROLE OF GLOBAL CROP BREEDING

In partnership with national institutions, international agricultural research has been extraordinarily successful in supplying world food needs, particularly considering how quickly population has grown and with the added demands of crop use for animal feed. Much of this success can be attributed to investments in the genetic improvement of crops. International collaboration in breeding and climate-smart farming practices will and must continue to be a central pillar of improving human welfare. Sustained support is required so that high-quality scientists and development specialists can continue to work across borders and offer farmers productive and environmentally-friendly technology.

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