



Cultivating Plant Diversity for the Resource Poor






A World of Difference

Season after season, year after year, farmers around the world must cope with multiple threats to their crops. The enemy may be too much or too little rain. It may be an outbreak of a plant virus, a weed infestation, destructive insects, or declining soil fertility. It could be frost during the growing season or a devastating heat wave. Such stresses are part and parcel of all agriculture, whether commercial or subsistence-based.

What distinguishes developing-country farmers from their counterparts in the industrialised world is not so much the mix of threats they face, but the resources at their disposal to combat such risks. Even when irrigation, fertilizers, pesticides, and support services are locally available, small-scale farmers in the developing world typically lack the cash or credit to pay for them. This constraint on production often represents the difference between healthy families and hungry families, between decent living standards and intractable poverty.

One powerful way to begin bridging these gaps is to design crop varieties that perform better under the stresses they face, such as drought, acid soils, pests, and diseases. By carefully weaving desired traits into the plants through customised breeding programmes, scientists can help farmers enhance the quality and quantity of their harvests without recourse to costly inputs.



The Generation Challenge Programme is at the heart of a research and capacity building network that uses plant genetic diversity, advanced genomic science, and comparative biology to develop tools and technologies that enable plant breeders in the developing world to produce better crop varieties for resource-poor farmers.



Our Mission and Strategy

The Generation Challenge Programme (GCP) is at the heart of a research and capacity building network that uses plant genetic diversity, advanced genomic science, and comparative biology to develop tools and technologies that enable plant breeders in the developing world to produce better crop varieties for resource-poor farmers. Better-performing crops improve rural livelihoods by increasing farm productivity and income. New income is often invested in children's school fees or in improving the homestead. The urban poor also benefit through lower prices and better quality of food.

From green to blue: Building bridges

The Green Revolution, which began in the 1970s, dramatically boosted farm production through new plant types, irrigation, and fertiliser. Unfortunately, many resource-poor farmers, especially those in marginal agricultural areas, saw few benefits.

The GCP is part of an emerging Blue Revolution. This is a new wave of efforts focused on better water usage and combining cutting-edge research with ecologically sustainable land-use approaches, agronomic applications, and government policies. The Blue Revolution is intended to bring useful and environmentally sound innovations to the small-scale farmers bypassed by the Green Revolution, and to provide solutions for coping with climate change and a global water shortage.

Improved crop varieties alone can't eradicate extreme hunger and poverty. There is little doubt, though, that more productive and sustainable agriculture is essential for enhancing rural livelihoods, improving human health, and creating a solid base for national economic progress in the developing world. Rapid advancements in comparative genomics, molecular breeding, and bioinformatics hold great promise for sustainable farming. These three research areas are essential components to achieving some of the key targets of the United Nations' Millennium Development Goals (MDGs), especially the target to halve, by 2015, the number of hungry people and those living on less than a dollar a day.

Priority research areas: Crops and traits

The Generation Challenge Programme works under a global mandate to produce international public goods (information, technologies, and crop planting material for worldwide distribution and use), and to contribute to scientific knowledge. This research mandate includes exploring the genetic diversity of crops whose germplasm is conserved by the Consultative Group on International Agricultural Research (CGIAR).

The GCP's priority research areas are determined by insights gained from global assessments of poverty and the environment, combined with an analysis of where needs match well with the available genetic, genomic, and breeding resources.

In keeping with the overall objective of boosting crops for marginal environments, drought resistance is the primary trait of concern for the GCP (see box), but other traits and production constraints that affect yield in water-limited environments are also examined.

Drought tolerance: Coping with climate change

The Food and Agriculture Organization of the United Nations (FAO) ranks drought as the single most common cause of severe food shortages in developing countries. In a comparison of food emergencies between 2002 and 2004, for example, drought was involved in 50 to 70% of the cases, significantly outweighing other causes such as conflict, flooding, and economic problems. Consider that more than three-quarters of the world's maize-growing areas suffer up to 50% yield losses each year due to drought.

Global climate change is threatening to make water even scarcer in many parts of the developing world, or to make its seasonal distribution less favourable to agriculture. Drought therefore poses mounting challenges to farmers and scientists alike. For this reason, the Generation Challenge Programme has made drought tolerance in staple crops a major focus of its work.



Our Approach

Launched in 2003, the Generation Challenge Programme – also called Generation – is one of three independently-governed pilot programmes under the Challenge Programme initiative of the CGIAR. Generation unites three sets of partners: CGIAR research centres, other advanced research institutes, and national agricultural research programmes in developing countries. This collaborative approach allows Generation partners to tap into a significantly larger collective pool of scientific expertise, funding, information, and other resources. The arrangement also allows Generation to conduct research on genetic questions that cut across crop species and thereby apply innovations in one area or commodity to other areas. Investigating traits in one species or plant type may provide vital clues to unlocking similar traits in others.

The GCP emphasises the generation of international public goods, particularly improved breeding material and new biotechnologies for use by plant breeders and other researchers in developing countries. The idea is to construct a toolbox of genetic materials and methods geared toward the development of crop varieties that are better equipped to defend themselves against the complex physical and biological constraints that hinder millions of poor farming families from reaping reliable harvests of staple crops.

What is....?

Genetic diversity: The combination of different genes found within a population of a single species, and the pattern of variation found within different populations of the same species.

Generation's five component subprogrammes are:

- Subprogramme 1 – **Genetic Diversity of Global Genetic Resources**
- Subprogramme 2 – **Comparative Genomics for Gene Discovery**
- Subprogramme 3 – **Trait Capture for Crop Improvement**
- Subprogramme 4 – **Genetic Resources, Genomic and Crop Information Systems**
- Subprogramme 5 – **Capacity Building and Enabling Delivery**

This five-pronged approach is designed to harness the current worldwide momentum behind the generation of data on DNA and gene function and channel it into investigating the genetic diversity of the world's staple food-crops, so that knowledge of these crops can be used to improve them and make real, positive impacts on farmers.

To extend its reach, Generation is building an 'integrated platform' of molecular biology and bioinformatics tools, freely available to researchers the world over. The GCP complements this by supporting national researchers through capacity building, which helps to create an environment conducive to national innovation. Since some staple crops receive little attention from privately funded research because they are not big cash earners, this empowerment of public scientific institutions is a critical step in ensuring that Generation's benefits find their way to the fields, kitchens, and wallets of resource-poor farmers.



SUBPROGRAMME 1

Genetic Diversity of Global Genetic Resources

Embedded in the DNA of thousands of crop varieties and their wild relatives is a vast wealth of genetic diversity. Within this array are genes that allow, for example, certain sorghum races to thrive with less water than others, some wheat varieties to tolerate low temperatures, and particular potato cultivars to resist blight. While classical plant breeding has introduced many advantageous traits into staple food crops, researchers have so far analysed only a tiny fraction of the available genetic diversity. Fortunately, today's advanced molecular techniques provide keys to unlock and use that diversity on a previously unimaginable scale.

But identifying gene networks responsible for complex traits such as tolerance to drought or low soil fertility is a bit like looking for a needle in a haystack. While the haystack is a treasure trove of genetic diversity, winnowing through it can be costly and labour-intensive, especially for researchers in developing countries. It is a scientific burden best borne by several institutions working in partnership. This is the role of Generation's Subprogramme 1 (SP1). It is charged with exploring the structural and functional diversity of the world's food crop genetic resources.

SP1's raw material is the seeds and other genetic material – collectively known as germplasm – that is conserved in nearly 1,500 national

What is....?

Germplasm: An individual, group, or clone representing a genotype, variety, or species held in a collection and capable of being reproduced. In the case of crop conservation, the most common forms of germplasm are seeds, living plants, and tissue cultures.

and international genebanks. It also includes germplasm from the breeding populations of active crop improvement programmes. SP1 researchers have identified 35,000 samples ('accessions') to represent the diversity of 21 of the CGIAR's target crops from collections around the world.

Target materials are characterised ('genotyped') with the help of molecular markers (chemical signposts indicating the presence of desirable genes) in order to examine the available genetic diversity within a set of crops. Genetic diversity refers to the genes and alleles in a plant's DNA that determine how the plant looks and functions in its environment. By the end of 2005, over 800,000 datapoints

What is....?

Genotyping: Identification of the overall genetic constitution of an individual organism, as opposed to its total physical appearance or 'phenotype'.

had been produced. This information is complemented by data available from genebanks, such as geographic origin and climate data, pedigree maps and physical descriptions of plants ('phenotypic' information). With this information, SP1 researchers can distil these large germplasm collections into smaller 'reference sets' that accurately represent the variation within a given plant species, providing useful and manageable sets of germplasm for breeding.

The reference sets are key products of the research; they allow greater in-depth analyses of functional diversity. But so are the molecular characterisation methods and standards that SP1 is developing and making widely available to national researchers. This methodological support enables national researchers to assemble their own germplasm sets and compare them with the GCP's international reference set.





SUBPROGRAMME 2

Comparative Genomics for Gene Discovery

What is....?

Genomics: The application of recent advances in biotechnology, computing, and telecommunications to manipulate heritable traits in living organisms. It centres on gene mapping and sequencing and uses the resulting data to identify the functions of genes, how they are controlled, how they interact, and where they are located on chromosomes.

At the heart of Subprogramme 2 (SP2) is explaining the differences in the appearance of plants of the same species when viewed by the naked eye – some tall, some with more seeds, some more susceptible to certain diseases. This physical evidence ('phenotype') illustrates the vast and complex genetic diversity present in each species. By looking at gene function and interaction within and across plant genomes, scientists can discover new genetic variations and learn more about how genes determine plant responses to different environments. SP2 builds on ongoing work in comparative genomics, sequence databases, and quantitative trait loci (QTL) mapping.

SP2 uses several methods to locate desirable genes. Within a given species, SP2 uses physical and genetic maps, markers, and molecular tools to pinpoint genes of interest. Because Generation's mandate covers different crops and their genomes, the GCP aims to apply new knowledge from one species to other species. The genes identified in SP2 can be directly used in plant breeding programmes to improve crop tolerance to pests, diseases, and drought.

What is....?

Quantitative trait loci: Regions of a chromosome in which genetic variation between members of a population is associated with complex traits such as tolerance of cold, drought, and other non-living (abiotic) environmental stresses.

SP1's work on genetic diversity and the genomic analyses of SP2 flow into each other, and both feed into the breeding activities of Subprogramme 3 (SP3). SP1 identifies germplasm – for genetic studies in SP2 – that confers useful traits that may be directly incorporated into SP3 or other breeding programmes. Using high-precision phenotypic evaluation, gene function can be associated with ideal plant phenotypes. This validation of gene function in breeding material in target environmental conditions is a joint effort between SP2 and SP3.



Students learn how to measure leaf canopy temperature at a GCP training course.
Photo credit: James Gethi



SUBPROGRAMME 3

Trait Capture for Crop Improvement

The Generation Challenge Programme is committed to delivering the innovations of genomics research to plant breeders for greater efficiency in the development and dissemination of improved germplasm to resource-poor farmers. SP3 plays a special role in this task. Working closely with national, regional, international, and private breeding programmes in developing countries, SP3 links the GCP's upstream research to downstream product development.

SP3 uses the genetic diversity information identified in SP1 and the genes characterised in SP2 to develop low-cost and user-friendly markers for breeding programmes. The markers allow the transfer and

'pyramiding' (incorporating useful QTLs from the primary gene pool into popular cultivars displaying good agronomic traits) of favourable genes through marker-assisted selection. SP3 then evaluates and validates these genes in diverse breeding populations. As an aid to breeding complex traits like drought tolerance, marker-assisted selection can dramatically shorten the time required for field release of improved products. The techniques and strategies developed by SP3 have to be cost-effective to ensure rapid and efficient use by national researchers, and they must also benefit farming communities in developing countries.

Plant breeders in the developing world are fundamental to the success of SP3. They develop and deliver adapted crop varieties to farmers and help keep trait identification on target. The Capacity Building Subprogramme (SP5) co-ordinates training of national researchers in molecular breeding methods.

SP3 projects have successfully established effective 'communities of practice' and team-based research collaboration across disciplines, crops, and types of institutions. For example, a project titled *Unlocking the Genetic Diversity in Peanut's Wild Relatives with Genomic and Genetic Tools* links advanced research institutions in Europe and the USA with a CGIAR centre and national researchers in Africa, Asia, and Latin America.



What is....?

Phenotypic information: Details of the physical appearance of an organism, as determined by interactions between its genetic makeup (genotype) and environmental influences.



Researchers at the Institut National de la Recherche Agronomique in Morocco prepare plants for genetic analysis. *Photo credit: Hamid Narjisse*

What is....?

Marker-assisted selection: In the context of agriculture, the use of unique sequences of DNA to verify the inheritance of traits in the offspring produced by a breeding programme. The markers are chemical signposts indicating the presence of a particular gene or genes, such as those that code for disease resistance. They make breeding more precise and accelerate the process because plants under observation do not have to grow to maturity in order to determine whether the desired trait has been inherited or not.



SUBPROGRAMME 4

Genetic Resources, Genomic, and Crop Information Systems

True to its name, the Generation Challenge Programme generates volumes of data, adding to the enormous global library on plant genetic and genomic resources. This 'raw material of knowledge' needs to be quickly and efficiently captured, stored, and distilled into useful information. It must then be made available in standard formats for easy review and analysis by crop scientists around the world. Most of Generation's partner institutions already have advanced information systems. The task of Subprogramme 4 (SP4) is to link these existing systems into a global network, design new software and methods that enhance network performance, and serve as the electronic backbone and scientific memory of the programme.

Also known as the Bioinformatics Subprogramme, SP4 is building a global, open-source information platform. Essential features are open and easy access for users, rigorous quality control of data,



A Moroccan scientist investigates a plant sample under a microscope.
Photo credit: Hamid Narjisse

standardisation of formats, and the use of Web services that enable cross-software communication.

One of SP4's most important tasks is helping GCP partners to modernise their data storage and analysis tools to better handle genomic applications. For example, an SP4 project involving several CGIAR centres and one US institution has promoted the use of a software tool, called Comparative Map and Trait Viewer (CMTV), for analysing genetic data sets. CMTV displays a plant's chromosomes as vertical bars. Colour coding is used to show which regions of the chromosome are strongly or weakly correlated with the trait under study. Developed by the US-based National Center for Genomic Research in collaboration with CIMMYT scientists, CMTV has been released under an open-source license that will allow other research organisations to develop it further. Training national researchers in the software began in late 2005.

SP4 also creates tools to support the research and capacity building conducted by the other subprogrammes. A software package called iMAS that can help with marker-assisted selection was completed in 2006 and is now available to national program scientists and molecular breeders everywhere.

While Generation sets the quality requirements for its far-flung decentralised network, member institutions bear responsibility for building and maintaining the local infrastructure – hardware, software, and bioinformatics expertise.

For more on Generation's bioinformatics platform, visit www.generationcp.org/bioinformatics.

What is....?

Open Source: A method and philosophy for software licensing and distribution designed to encourage use and improvement of software written by volunteers by ensuring that anyone can copy the source code and modify it freely.





SUBPROGRAMME 5

Capacity Building and Enabling Delivery

Although Generation conducts upstream research, it is committed to ensuring that its outputs – elite genetic materials, tools, methods, and information resources – are put to good use downstream, in the applied research and crop development carried out by national-level scientists, especially in developing countries. Subprogramme 5 (SP5) is at the core of that overarching commitment to product delivery.

On the client side, SP5 helps build the technical capacity of scientists in developing countries and their institutions. Within the Challenge Programme itself, it ensures that all Generation projects have a practical product-delivery plan, jointly developed with prospective users.

Building the capacity of national researchers is essential. On the one hand, national research organisations – departments within ministries, publicly funded institutes, and university faculties – well understand



Claude Welcker, an instructor at a GCP training course, demonstrates principles of proper field phenotyping. *Photo credit: James Gethi*

the needs, aspirations, and production constraints of resource-poor farmers in their target regions and are mandated to assist them. On the other hand, many such national research organisations in the tropics and sub-tropics lack the expertise and funds to deliver the services they were created for in the first place. And in recent years, the funding situation has worsened. Not surprisingly, the technological divide between developed and developing countries is widening.

SP5 supports student and postdoctoral research through fellowships and travel grants, and provides tailored capacity building in marker-assisted selection, phenotyping methods, and bioinformatics applications.

SP5 bridges the other subprogrammes by ensuring that capacity building activities throughout the GCP enhance the ability of developing country scientists to deliver better crops to farmers. Part of its work, then, is to monitor training activities embedded in the research projects of the technical subprogrammes.

SP5 also assists with the development of delivery plans for each GCP project, which ensure that for all project outputs a user at a national programme has been identified to receive those outputs and, where possible, is engaged in the project itself.

Besides its capacity building work, SP5 is also home to Generation's policy research on intellectual property and access and benefit sharing.

For more on Generation's Capacity Building activities, visit www.generationcp.org/capcorner.php.



For further information, contact

Generation Challenge Programme

Hosted by the International Maize and Wheat Improvement Center (CIMMYT)

Apdo. Postal 6-64106600 Mexico, D.F. Mexico

Km 45 Carretera Mexico-Veracruz, El Batan, Texcoco, Mexico

Tel: +52 55 5804 2004

Fax: +52 55 5804 7558

Email: info@generationcp.org

Web: www.generationcp.org

