POSSIBLE BREAKTHROUGHS
SMART VARIETIES

Continually increasing physiological yields over the last decades have had much to do with plant breeding and biotechnology, which keep pushing the potential yield frontier forward. The two main directions for breeding are: breeding for maximum yield under controlled circumstances and developing crops that are more resilient to non-optimal conditions. In the face of projected negative climate change impacts on agricultural production, this last aspect is of particular relevance. Finally, while progress has been made in using plant breeding technologies to improve yields of major crops, genetic diversity and locally developed varieties remain of tremendous importance in building resilient cropping systems, sustaining local livelihoods, and providing a range of ecosystem services.

Description

In spite of the tremendous increase in potential yields of all major crops achieved during the last decades, mainly as a result of progress in plant breeding for increased harvest indexes,[1] the development of new, higher yielding varieties is slowing down. Given present climate uncertainty (see box 1) and resource-constrained conditions, it would be more interesting to make varieties more resilient to biotic stresses (pests and diseases), which would reduce the use of pesticides, and increase tolerance to abiotic stresses (nutrients, water, temperature, salinity), among others, rather than pushing maximum yields for major crops further. Selecting for these traits will make it easier for smallholder farmers to move closer to current attainable yields.[2]

The development of new varieties can be obtained in the laboratory by conventional breeding or by genetic crop engineering. The latter technology involves incorporating desired exogenous genes from other organisms or plant species into a certain crop. Bacillus thuringiensis (Bt) crops are an example of genetically modified, pest-resistant crops in which genes from the bacterium bacillus thuringiensis, which produces a toxin that is harmful to specific insects, have been incorporated into the crop's genome. A recent breakthrough in pest control is the use of "transcription activator-like effector nucleases (TALENs)". These are artificial restriction enzymes that are specific to any DNA sequence and can thus cut and isolate desired genes that can then be engineered into crops. Thanks to this technology, great progress has been made in the control of very harmful bacterial blight in rice. TALENs technology can potentially be applied to a vast range of crops and traits.[4]

Box 1

Impact of climate change on current cropping systems

According to the Intergovernmental Panel on Climate Change (IPCC), rainfed farming system yields could decrease by as much as 50% in large areas of Africa by 2020 as the climate becomes hotter and drier. By 2080, agricultural output could decline by as much as 28% in Africa, 24% in Latin America and 19% in Asia. Agricultural output in India could decline by as much as 38%, and some African countries could experience declines in excess of 50%. Climate change is also anticipated to severely impact biodiversity by causing the significant extinction of species and the loss of ecosystem services essential to food production.

[1]Molden et al. 2010, [2]CA 2007; Fischer et al. 2010, [3]Gonzalez 2011, [4]Li et al. 2012

Description (continued)

DuPont Pioneer and Syngenta, in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT), have also made strides in marker-assisted breeding for water-limited conditions of corn that can yield 15% more than conventional hybrids in water-stressed conditions and equal or even more under optimal conditions. Marker-assisted selection (MAS) is an indirect selection process where a trait of interest is selected not based on the trait itself, but on a marker linked to it, which can be either morphological, biochemical or based on an DNA/RNA variation.

The key role of the preservation and use of traditional seed varieties in building climate resilient cropping systems have been recognized in international policy arenas since the turn of the millennium. The Food and Agriculture Organization of the United Nations (FAO) declared that 75% of the world's food crop diversity was lost in the 20th century as "farmers abandoned local varieties in favor of genetically uniform high-yielding crops."[5]

FAO has identified the loss of genetic diversity when modern cultivars replace landraces as the greatest loss in global agricultural systems. The small genetic resource base makes cropping systems sensitive to diseases and pests and unable to deal with altering rainfall patterns and temperature due to climate change (see box 1). Examples of actions to countervail these threats include the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the United Nations declaration of the year 2010 as the "Year of Biodiversity", and the development of stronger linkages between genetic varieties available in seed banks and cropping systems in the field.

Worldwide there are close to 1,400 gene banks storing approximately 6 million samples of genetic resources for crops.[6] Three-quarters of these samples are stored in Consultative Group on International Agricultural Research (CGIAR) centers.

Also, on the more local level, various organizations aim to further the genetic diversity in cropping systems. For example, NativeSe, a North America-based organization, is training farmers to store, use and multiply genetic crop resources. While industrial agriculture largely uses homogeneous hybrid seeds obtained by controlled pollination between highly inbred lines, in traditional agricultural systems, farmers cross genetically distinct parents, both within and between populations, varieties and species.[7] It has been proved that this practice makes cropping systems more resilient to climate change, making them better able to cope with pests, water shortages and temperature fluctuations.

[5]Gonzalez 2011, [6]InfoResources 2008, [7]NativeSeeds 2012

Geography

Climate change will affect rainfall, salinity levels, temperature, sunshine hours and wind patterns. This will change soil composition and growing conditions worldwide. As a consequence, half of the world's 23 major food crops will lose suitable land in sub-Saharan Africa and the Caribbean by 2055.[8] The selection of the right cultivars helps nations in these regions adapt their cropping systems and create resilient food systems.[9]

Internationally, Peru, Ethiopia, India and China are centers of origin and hotspots of globally important food crops and livestock. Brazil is a center of biodiversity of global importance and also home to important agricultural crops. All five countries, however, face erosion of diversity. For instance, rice varieties in China declined from 46,000 in the 1950s to 1,000 today.[10] The German Society for International Cooperation (GIZ) foresees an important role for these countries and for gene banks to make cropping systems climate proof in the decades to come.

[8]Bioversity International 2010, [9]FAO 2011, [10]GIZ 2011

Energy

- Insecticide resistant crops imply less fuel consumed for pesticide applications.
- New corn hybrids are 11% more nitrogen efficient than old hybrids.[11]
- Water and nitrogen-efficient crops require less fertilizer use and less energy for pumping and fertilizer application.
- Herbicide tolerant rice needs less water for weed control and less energy for pumping.[12]

Water

- Aerobic rice consumes 30-50% less water than inundated rice.[13]
- Drought-tolerant corn uses less water and yields 6-15% more than conventional hybrids under water-stressed conditions.[14]

Local varieties

- Dryland seed varieties often have lower water requirements with similar or higher production than high-yielding varieties. Drylands are important stores of genetic variability for crops that are adapted to harsh, uncertain and low-input environments.[15]
- Plants have shorter growth cycles, longer roots, water stores in roots and trunks, and dormancy during dry seasons.[16]
- The brown tepary bean (Phaseolus acutifolius) is relatively drought resistant as it can access water from large soil volumes thanks to its large taproot and can reduce water losses by folding up its leaves.
- The use of mixed seed reduces crop failure risks when faced with irregular rainfall patterns
- In Guatemala, farmers grow varieties with different growing seasons or sow a mixture of different varieties in the same field such as varieties of beans that tolerate drought along with those that prefer wetter conditions.

[11]Ciampitti and Vyn, 2012, [12]Kumar et al., 2008, [13]Bouman et al., 2002; Pinheiro et al., 2006, [14]WBCSD, 2009, [15]GIZ, 2010, [16]GIZ, 2010

Productivity

Major crops

- Rice varieties developed by the Chinese super-rice breeding program of the International Rice Research Institute (IRRI) are already nearing 12 t/ha – the same also being attained by hybrids grown in eastern China. A 50% increase in rice biomass is deemed possible if the C_3 photosynthetic path is converted to a C_4 photosynthetic path.[17]
- Potential yields for wheat are estimated at 13 t/ha under average conditions and 19 t/ha under optimal conditions – a 50% increase over what is currently possible.[18]
- Syngenta has recently introduced hybrid barley in Europe, alongside a new integrated farming approach. Hybrid barley has shown yields of up to 13.7 t/ha compared to 8-10 t/ha of inbred varieties.[19]
- An analysis by Qaim and Matuschke[20] on the impacts of transgenic cotton in developing countries showed a yield increase of 20% while using 50% less insecticides.
- Cereal yield growth would decrease to 0.7% every year (0.8% in developing countries), and average cereal yield would reach some 4.3 t/ha by 2050, up from 3.2 t/ha at present.[21]
- Research in heterosis (improved or increased function of any biological quality in a hybrid offspring), molecular breeding and genetic engineering suggest that gains from genetic sources could be increased by at least 50%, the rate needed to generate 60% more staples by 2050 without major increases in food prices.[22]

Local varieties

- Understanding the genetic diversity of Cherimoya (*Annona cherimola*) species helped identify "elite" selections to improve production.[23]
  – As a result of improved quality, in Ecuador the market value of cherimoyas rose from US$ 0.07 to US$ 1.00 /kg between 2006 and 2009.
- Ethiopia has a unique genetic diversity of cultivated, semi-wild and wild Arabica varieties with different disease resistance, environmental adaptation and quality features. The genetic diversity of coffee in Ethiopia is of global importance for the breeding of varieties that are adapted to future uncertain environmental conditions and that are disease resistant.[24]
- Due to the excellent drought resistance of the often-overlooked foxtail millet variety, farmers can make a living in the dry areas of northern Karnataka, India.[25]
- The use of intra-specific phenotypic variability of three millet species (finger millet, little millet and Italian millet) adapted to different climatic conditions has enabled villagers of a hilly area of Tamil Nadu, India, to raise their income by 30% while providing a more nutritious food than cereals like wheat and rice.[26]

[17]Sheehy et al. 2007, [18]Reynolds et al. 2011, [19]Syngenta 2012, [20]Qaim and Matuschke 2005, [21]Fisher et al. 2010, [22]Edmeades et al. 2010, [23]Bioversity International 2010, [24]GIZ 2011, [25]GTZ 2006, [26]Gruere et al. 2007,

Costs and benefits

- Higher yields found in hybrid seeds are not always synonymous with higher profits, as highlighted in a study by Gene Campaign in Jharkhand, India.[27]
  - Hybrid rice is more prone to diseases than local varieties and requires higher investment in both fertilizer and pesticide.
  - Hybrid seeds cost US$ 3.85/kg while farmers can reproduce local seeds.

Climate change[28]

- Rice emits large quantities of methane (CH_4) per growing season, mainly due to permanent flooding of paddy fields:
  - Dryland rice (India) is between 30 and 50 kg CH_4/ha
  - Wetland rice (China) is between 200-1100 kg CH_4/ha
- Reducing CH_4 emissions can be achieved by:
  - Growing aerobic rice under upland conditions. Upland rice currently comprises about 12% of world rice area but yields only 4% of global rice production.
  - Using distinct drainage periods in mid-season or alternate wetting and drying of the soil in wetland cultivation.
    - Results in 7-80% less CH_4 emissions; however, nitrous oxide (N_2O) emissions increase.
- Cumulative N_2O emissions from soils during pre-rice fallow and rice and post-rice fallow and wheat range from 6.9 to 13.7 and 2.6 to 3.4 N_2O-N/ha/season respectively.
- In wheat, the major greenhouse gas (GHG) is N_2O emitted in short-term pulses after fertilization, heavy rainfall and irrigation events.[29]

[27]Sahai et al., [28]Based on a 100-year time frame, the greenhouse warming potential (GWP) of CH_4 is 21 times higher whereas the N_2O is 310 times higher than the reference value for CO_2 (IPCC 1996). [29]Wassmann et al. 2004

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