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Nuclear Science for Food Security

IAEA says plant breeding technique can help beat world hunger

Vienna, 2 December 2008 – The International Atomic Energy Agency (IAEA) today called for increased investment in a plant breeding technique that could bolster efforts aimed at pulling millions of people out of the hunger trap.

IAEA scientists use radiation to produce improved high-yielding plants that adapt to harsh climate conditions such as drought or flood, or that are resistant to certain diseases and insect pests. Called mutation induction, the technique is safe, proven and cost-effective. It has been in use since the 1920s.

“The global nature of the food crisis is unprecedented. Families all around the world are struggling to feed themselves,” says Mohamed ElBaradei, Director General of the IAEA.

“To provide sustainable, long-term solutions, we must make use of all available resources. Selecting the crops that are better able to feed us is one of humankind’s oldest sciences. But we’ve neglected to give it the support and investment it requires for universal application. The IAEA is urging a revival of nuclear crop breeding technologies to help tackle world hunger.”

For decades the IAEA, in partnership with the Food and Agriculture Organization of the United Nations (FAO), has assisted its Member States to produce more, better and safer food. In plant breeding and genetics, its expertise is helping countries around the world to achieve enhanced agricultural output using nuclear technology.

Already more than 3000 crop varieties of some 170 different plant species have been released through the direct intervention of the IAEA: they include barley that grows at 5000 meters (16,400 ft) and rice that thrives in saline soil. These varieties provide much needed food as well as millions of dollars in economic benefits for farmers and consumers, especially in developing countries.

But with increased investment and broader application, the technology could positively impact the health and livelihood of even greater numbers of people. And as world hunger grows, the need has never been more urgent.

A global food crisis

This year, shortages combined with increasing demand have created a new global food crisis. At its root: adverse weather conditions linked to climate change, the diversion of land for the cultivation of bio-fuels, and a tendency to live on food credit.

"For decades most of the developed world has lived on readily available, cheap and diversified food, enjoying plentiful amounts but seemingly with little or no need to invest in agriculture," says Qu Liang, Director of the FAO/IAEA Joint Division of Nuclear Techniques in Food and Agriculture. "Food crises were always dealt with by relief organizations, through food aid and donations, and disappeared as quickly from the headlines as they appeared. Now, with the earth's resources dwindling, we are reaping the results of decades of under-investment in agriculture."

Today, food shortages and sky-rocketing prices are pushing millions of people deeper into the poverty and hunger cycle. As a result, social unrest and food protests, some violent, have flared in countries around the globe.

As usual, the poor are hardest hit by rising prices. In addition to the more than 850 million people worldwide who were already going hungry, millions more now are being pushed below the one-dollar-a-day poverty level. This is undermining progress not only towards meeting the most important of the eight Millennium Development Goals, that of cutting hunger and poverty by half by 2015, but also targets on education, child and maternal mortality reduction, and containing the spread of major diseases.

"The year 2008 was a wake-up call to the realization that world food production was unsustainable and vulnerable to factors such as climate change and energy demands," says IAEA Deputy Director General Werner Burkart, who heads the Department of Nuclear Sciences and Applications. "The big issues are interlinked. With energy increasingly being produced from corn, soya and other crops, there is growing competition between food, feed and fuel for soil, water and human and financial resources."

Unmasking hidden potential in plants

Nature provides every species with the potential to develop many different characteristics—for example, the height of a plant, its yield, its susceptibility or resistance to disease. All of these possibilities are written into a plant's blueprint, its genome, but only a few are expressed. Over a long period of time, a plant can adapt itself to different conditions through a process of spontaneous mutation and natural selection.

It was the survival of certain edible plants amid adverse conditions that first attracted hunter-gatherers thousands of years ago. They selected the robust, easy to harvest wild grains, consumed the crop and saved the seeds for planting the following year. Modern plant breeding was born.

"We call spontaneous mutation the motor of evolution," says Pierre Lagoda, Head of the FAO/IAEA Joint Division's Plant Breeding and Genetics Section. "If we could live millions of years and survey billions of hectares (acres) of land with 100 percent precision, we would find variants with all of the traits we're looking for but which have mutated naturally."

"But we can't wait millions of years to find the plants that are necessary now, if we want to feed the world. So with induced mutation, we are actively speeding up the process."

Today, scientists apply mutagens—for example, gamma rays or chemicals—to accelerate the process. Unlike genetic modification, which introduces new material into a plant's genetic makeup, induced mutation simply accelerates the natural process of spontaneous changes occurring in plants.

Exposure to radiation changes a plant's blueprint at one position in the genetic code, creating a variant that is different from the parent plant. Huge numbers of mutants are produced in the search for desired traits—perhaps a resistance to certain diseases or pests, or an ability to thrive in saline soil or drought conditions. Those that seem promising are selected and turned over to plant breeders who work to incorporate that quality, perhaps by cross-breeding, into indigenous plants.

"But we're not producing anything that is not produced by nature itself," says Pierre Lagoda. "For example, up until now nature has produced 140,000 distinct varieties of rice all with different characteristics—there's rice that is tall, rice that grows in water or dry climates or in salty soil. All of these expressions of the potential of rice are in the rice itself."

An effective tool

Induced mutation is an important part of the solution to the world's food crisis. "We are not the only solution to the world's food crisis but we offer a tool, a very efficient tool, to the global agricultural community to broaden the adaptability of crops in the face of climate change, rising prices, and soils that lack fertility or have other major problems," says Pierre Lagoda.

Through its Technical Cooperation Programme, the IAEA provides the tool and the expertise, but national agricultural research systems and plant breeders take the next step, selecting and cross-breeding plants to achieve the desired result.

Plant breeding can be done in several ways. The classical way can take seven to ten years. A breeder looking for pest resistance, for example, might find the characteristic in a wild variety that has poor quality and yield. This will be crossed with a plant that does have good quality and yield, and any offspring combining the desired traits will then be selected and propagated.

Hybrids, the product of crosses, are only as good as the source parents. With many decades of monocultures, the variations amongst candidate parents have become very narrow. This endangers food security as resistance to yet latent biotypes of pests and diseases and extreme weather conditions may have become severely eroded. Additionally, it is becoming increasingly difficult to prospect for plant genetic resources across national boundaries.

The solution to both bottlenecks is to artificially induce the variations that plant breeders so obviously need. Mutation induction produces millions of variants. Breeders then have to screen for the desired traits and crossbreed. Nature can help this process. If improved varieties are planted in a diseased field, the survivors will be the resistant ones.

Because fewer pesticides are needed for disease and insect resistant crops, they are environmentally friendly and reduce the expenses of poor farmers. But this safe, proven technology still faces some resistance. One reason is public concern surrounding words like radiation and mutation. “I understand that people are suspicious of these technologies, but in our case it’s important to understand that in plant breeding we’re not producing anything that’s not produced by nature itself,” says Pierre Lagoda. “There is no residual radiation left in a plant after mutation induction.”

A strong case for induced mutation

Mutation induction technology is a powerful tool to help fight the food crisis on a sustainable level. Already it has yielded impressive results, providing food security and marked economic gain for a growing list of countries around the world. In Japan alone, the Institute of Radiation Breeding (IRB) calculates that crops developed using mutation induction generated economic returns of nearly US$ 62 billion against US$ 69 million invested during the period 1959 – 2001. That translates into a remarkable 900 fold return on investment, and this in the public sector.

CASE STUDY VIETNAM
An ancient crop rejuvenated

Farmers have been growing rice in Vietnam for thousands of years and it is the country’s most important food staple. But climate change, soil degradation and a rapidly growing population have over-stretched agriculture's ability to meet increasing demands.

In the search for improved high-yielding rice crops, capable of withstanding stress factors such as insect pests and salt polluted paddies, the IAEA and counterparts like the Cuu Long Delta Rice Research Institute in Can Tho have developed more than a dozen mutant varieties. The most important breakthrough came in the mid-1990s with the introduction of the so-called VND series, a shorter variety which prevented the crop from falling over and made it easier to harvest.

The latest variety, VND95-20, is now the most widely used in Vietnam—occupying 30% of the one million hectares (2.47 million acres) of rice-growing area in the Mekong Delta. It thrives in the delta's saline conditions and has a good resistance to a major insect pest, the brown planthopper. Another in this series, VND99-3, can be harvested three times a year, within 100 days of planting the seeds, greatly improving food security for the nation's 84 million people.

In little more than a generation Vietnam has become one of the world's top rice producers, exporting to 20 countries around the world. According to the Institute of Agricultural Sciences for Southern Vietnam, three induced varieties of rice produced a total net profit for farmers of US$348.4 million last year alone.

CASE STUDY KENYA

Plentiful, golden wheat from barren lands

Kenya's hot and barren dry lands were long considered unfit for agriculture, serving at best as a grazing area for wild animals and livestock. But today the landscape is more picturesque and productive, lined with fields of golden wheat yielding precious grain for the country's farms and families.

The wheat is a new variety—high yielding and resistant to drought. It was developed at Kenya's Agricultural Research Institute (KARI) using induced mutation technology. Working closely with the IAEA through a number of projects and under a regional programme called AFRA (African Co-operative Agreement for Research, Development and Training related to Nuclear Science and Technology) KARI successfully released its first mutant wheat variety in 2001.

Called Njoro-BW1, the wheat was bred to be tolerant to drought but it is also high yielding, produces excellent baking flour and has good resistance to wheat rust, a virulent strain of fungus threatening the region's farmlands. Today Njoro-BW1 is grown on more than 10,000 hectares (24,700 acres) of Kenyan farmland.

Wheat is the second most important cereal crop in Kenya after maize. Even with new varieties the country meets only one third of its needs and must import the rest at vastly higher prices. Plant breeders at KARI believe mutation techniques are among the best options for Kenya to develop better wheat varieties and other crops.

The signs are promising. A new wheat variety, code-named DH4, has many of the same good characteristics as Njoro-BW1. But DH4's grains are hard and red, a sign they are rich in protein and an excellent source of premium baking flour, qualities highly prized by farmers for their market value.

CASE STUDY PERU

Barley that thrives in the high Andes

Few plants survive in Peru's high Andes. At altitudes of up to 5000 meters (16,400 ft) above sea level the conditions are extreme: thin, poor quality soil, little water, sharp frosts. Barley is an important food for the three million people living in the Peruvian Andes. It is hardy, meaning it will grow in marginal areas, but in the past yields were meagre and fell far short of needs.

With the support of the IAEA, Peru's National Agricultural University, La Molina, has launched nine improved varieties of barley, all produced using radiation induced mutation. These stronger, healthier varieties now cover nine percent of Peru's barley producing area, or about 135,000 hectares (333,600 acres). In the high Andes, harvests now produce some 1200 kilograms per hectare (0.54 tons per acre), an increase of 50 percent against earlier levels, which translates to roughly $9 million a year.

The latest variety, Centenario, is the best to have been produced in Peru so far. Released by plant breeders in 2006, its premium quality and larger-than-average sized grains have had a far-reaching impact on growers and users alike. And the yields are extraordinary. In the central area of the country farmers are now producing up to 4000 kilograms of this high-quality barley per hectare (1.78 tons per acre).

Such yields are impossible to achieve at high altitudes. Still, farmers in the high Andes now produce enough grain to meet their personal food needs, with plenty left over to sell for processing into pearl barley, flour and flakes. Small factories have been set up which work together with farmers in a collective initiative, further benefiting the lives and incomes of poor communities. Within a decade, the lives of one-time subsistence farmers in Andean communities have been turned around.

CASE STUDY SUB-SAHARAN AFRICA

Cassava promises food security and income for millions

Cassava's large starchy roots are the staple food for millions of people in sub-Saharan African countries such as Ghana, Nigeria and Sierra Leone. Experts say if a major disease or catastrophe should strike the cassava crops, there would be widespread famine.

It's hardly surprising therefore that plant breeders are trying to improve existing cassava varieties. They face many challenges: cassava is susceptible to the mosaic virus, and its roots contain hydrogen-cyanide which makes them poisonous if consumed without processing. At the same time, in many places the crop is grown by subsistence farmers who do not properly prepare the soil for planting, resulting in very low yields. In Ghana, for example, yields as low as 10 tons per hectare (4.46 tons per acre) are the norm—far lower than in other cassava-growing countries.

IAEA scientists are collaborating with plant breeders in several African countries, using nuclear techniques to improve the safety of cassava and enhance its nutritional content, yield and disease resistance.

In Ghana, with IAEA support, an induced mutant cassava variety, Tek Bankye, has been released to wide acclaim. Its modified culinary qualities make it the preferred variety in this country where cassava is consumed up to three times daily in many households. Meanwhile, recent trials carried out by Ghana's Biotechnology and Nuclear Agriculture Research Institute have resulted in yields as high as 40 tons per hectare (17.84 tons per acre).

To underscore the importance of this crop in the region, the governments of Ghana and Nigeria have set up Special Presidential Initiatives for Cassava. The initiatives aim at massively boosting the production of the crop and using it to drive the starch export market.

A global collaborative network

The IAEA and the Food and Agriculture Organization of the United Nations (FAO) formed the Joint Division in 1964 in the belief that Member States were best served if the complementary strengths and activities of the two international organizations were applied in partnership. The Joint Division works with other food agencies and plant breeding centres, universities and regional agricultural groups, providing induced mutation expertise and support where needed.

At the FAO/IAEA Joint Division Plant Breeding Unit in Seibersdorf, Austria, research is currently focused on three major tropical crops—rice, banana and cassava—all key to the developing world and, in particular, to Africa.

Chikelu Mba, who heads the unit, estimates that some 100 countries currently use induced mutation technology. Those lacking the research facilities send seeds to Seibersdorf for irradiation. The seeds are then returned to the plant breeders for further testing and selection. The unit also provides expert support in all mutation induction technologies and, most importantly, training for fellows from Member States.

"What we do is develop technologies that make the induction and identification of the mutants more efficient. We make use of screening methodologies in our greenhouses, or we take advantage of certain bio-technologies that are relevant to our work," says Chikelu Mba.

"The food security aspect of our work is producing plants with higher yield and which are resistant to major diseases; or which grow in poor or damaged soil," he says. "But we also recognize that agriculture should be a business, a vehicle for getting the farmers out of poverty, and we want to help countries work towards that goal."

Worldwide application

Plants produced (with or without IAEA assistance) using induced mutation are cultivated throughout the world. Others are being developed, seeking to enhance agriculture and resolve problems caused by climate change or disease/insect pests.

Some examples of projects underway:

Algeria: To give date palm trees protection against Bayoud Disease.

Costa Rica: To control bean web blight disease. This will be especially helpful to small-scale bean farmers.

Nigeria: To develop cowpea varieties resistant to insect pests.

Philippines: To develop higher yields and improved quality of non-seasonal varieties of fruit and nut crops such as mangosteen and cashew.

Sierra Leone: To develop high-yielding rice varieties adapted to low-input agricultural systems.

South Africa: Drought-tolerant mutant cowpea currently in farmer participatory trials.

Zambia: Two new finger millet varieties developed and field tested in northern Zambia with promising results of higher yield. The new varieties should bring more food, better nutrition and cash to farmers.

Zimbabwe: To develop drought and disease tolerant mutant grain legumes suitable for resource-poor smallholder farmers.

Some examples of successfully released mutant varieties:

China: Up to 2005, a total of 638 mutant varieties of 42 plant species were released, covering nine million hectares (22.24 million acres) of planting area. Increased cereal production brings economic benefits of roughly US$ 420 million a year.

Egypt: Three mutant varieties of high-yielding, disease and insect resistant sesame are bringing higher economic returns than standard varieties.

Ghana: Cassava variety 'Tek Bankye', with improved cooking quality, released to wide acclaim. Trials underway to produce higher-yielding, disease resistant cassava, with improved starch content.

India: Mutant groundnut series 'TAG' has early maturity, high pod growth and greatly improved harvest rates. Total domestic seed sales amount to 132,000 tons and cover 6.5 million hectares (16.06 million acres).

Italy: Pasta, Italy's favourite food, is made with mutant varieties of durum wheat and contributes tens of millions of dollars each year to farmers' income.

Japan: The fungus resistant mutant 'Gold Nijesseiki' pear is widely grown, sold and consumed. Economic contribution amounts to some US$30 million annually and has financed plant breeding research for the whole country.

Kenya: A new wheat variety 'Njoro-BW1' was bred to be drought tolerant. It is also high yielding, produces excellent baking flour and has good resistance to wheat rust, a virulent strain of fungus threatening the region's farmlands.

Pakistan: A mutant producing better quality and higher yielding crops quadrupled cotton production in Pakistan within 10 years of release (1983-1992), and now accounts for 70% of all cotton grown in the Punjab. Economic contribution: US$20 million a year.

Peru: In the high Andes, stronger, healthier varieties of barley grow at altitudes of up to 5000 meters (16,400 ft), producing harvests of some 1200 kilograms per hectare (0.54 tons per acre). This is an increase of 50 percent against earlier levels, which translates to roughly US$9 million a year.

Scotland: The mutant barley varieties 'Diamant' and 'Golden Promise' are the progenitors of most barley used in whisky production in Scotland, contributing millions of dollars a year to farmers.

Sudan: Banana variety 'Albeely' producing up to 100% higher yields and improved quality.

Turkey: A chickpea mutant was successfully released with enhanced yield potential, higher seed protein, early maturity and resistance to blight.

USA: The grapefruit variety 'Rio Star', with its characteristic bright red coloured flesh, now accounts for 75 percent of the highly lucrative US grapefruit production.

Vietnam: From the mid-1990s on, eight mutant rice varieties were released, each with high quality, increased yield and tolerance to soil salinity. Since 2000, the area cultivated with mutant rice varieties reached 2.5 million hectares (6.18 million acres) in southern Vietnam.