Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IN ACTION
Nuclear applications in agriculture
On-the-ground success

Part V

Innovation for a better world

Application of innovative technologies for better nutrition, better production, a better environment and a better life

In a world dealing with changing climates and associated extreme weather events; with emerging diseases that impact human and animal health and spread at unimaginable speed through global travel and trade; with growing populations dealing with poverty and hunger and facing scarce resources and disappearing biodiversity – this portfolio of issues and risks brings to light the urgent need for innovative technologies.

Innovative technologies are providing for a better world and continue to have a major impact on finding solutions and delivering results for the global attainment of the United Nations' 2030 Agenda for Sustainable Development. The application of these technologies is helping to provide better nutrition, better production, a better environment and better livelihoods (the Four Betters) for the planet.

The Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture uses nuclear and related methods to improve technologies for sustainable agriculture and food security worldwide. It delivers results through adaptive research and development at its own Agriculture and Biotechnology Laboratories as well as through annual support and coordination of more than 25 coordinated research projects involving cooperation with about 400 international and national research institutions and experimental stations; it provides capacity building and technology transfer to over 200 national and regional technical cooperation projects; and it offers technical and policy advice to policy makers.

The application of the Joint FAO/IAEA Centre's innovative technologies supports member countries to meet global challenges, not least towards meeting the challenges of the current COVID-19 pandemic. This and related stories are highlighted in this biennial publication.

The Joint Centre's activities in the Four Betters focus on:

Better nutrition

End hunger, achieve food security and improved nutrition in all its forms

- Improving food safety and quality, enhancing food monitoring systems for chemical residues and contaminants, tracing the origin of food, verifying its composition and promoting commercial use of food irradiation
- Strengthening preparedness to radiological emergencies affecting food and agriculture

Better life

End rural poverty and promote inclusive, economic growth

- Assisting member countries in implementing environmentally friendly and sustainable methods to control major insect pests of crops and of veterinary and human importance
- Focusing on area-wide integrated pest management, incorporating the Sterile Insect Technique to enhance food security and international trade
- Aiding member countries in countering the unprecedented threats to modern food systems of COVID-19 and its health and socioeconomic impacts, combined with the impacts of extreme weather events, pest infestations and other unanticipated events

Better environment

Protect, restore and promote sustainable use of terrestrial and marine ecosystems and combating climate change

- Assisting member countries in the design and implementation of innovative and effective plant breeding programmes using radiation-induced mutagenesis through, for instance, gamma rays and X rays, mutation detection and pre-breeding technologies, to enhance food security and sustainable crop production systems worldwide
- Improving resource use efficiency by crops and in cropping-livestock systems, and to protect soil and water resources for sustainable and climate-smart agriculture

Better production

Ensure sustainable consumption and production patterns through sustainable and inclusive supply chains

- Validating and applying innovative nuclear and nuclear-derived technologies for local feed resources and feed optimization
- Providing animal genetic evaluation and integration to breeding; enhancing animal reproduction
- Providing early, rapid diagnoses and control of transboundary animal and zoonotic diseases

GLOBAL

Global fight to detect and combat deadly coronavirus – Joint FAO/IAEA Centre provides crucial equipment and training

In the early days of the world's awakening to the pandemic presence of a deadly coronavirus, the IAEA received numerous requests for technical support in diagnosis and control from its Member States in Europe, Africa, Asia, Latin America and the Caribbean. In response, IAEA Director General Rafael Mariano Grossi assigned the Joint FAO/IAEA Centre to initiate the necessary support activities, taking advantage of its global experience in responding to other disease outbreaks such as Ebola in Africa, Zika in Central America, lumpy skin disease of cattle and peste des petits ruminants in Europe, African swine fever in Asia and avian influenza globally, as well as the critical role it played in the eradication of the rinderpest cattle plague.

> **COVID-19 pandemic response**
> *More than 120 countries turned to us for help. We mounted the biggest operation of assistance in the history of the IAEA*
> **– IAEA Director General Rafael Mariano Grossi.**

When given the assignment by the IAEA Director General, the Joint Centre was already well positioned to take immediate steps in providing the vital technical support. In fact, as soon as the outbreak had emerged in China and neighbouring countries in December 2019, the Joint Centre had immediately initiated a review of existing laboratory procedures for the detection of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing COVID-19. It had also initiated testing of various related methodologies and procedures at its FAO/IAEA Laboratories in Seibersdorf, Austria, in order to determine the suitability and comparative performance of these tests, as well as the associated equipment that could be recommended particularly for developing countries.

The nuclear-derived real–time reverse transcription polymerase chain reaction (rRT-PCR) and genome sequencing were identified as the most appropriate technologies with high sensitivity and high specificity for the rapid detection of SARS-CoV-2. These technologies are already widely used for the detection of avian influenza, Ebola and Zika, among other zoonotic diseases.

The rRT-PCR uses fluorescent dyes to detect the presence of specific genetic material and provides scientists with real-time results on the presence of the viral RNA. Building on this technology, genome sequencing is used to find out more about the virus, such as the cluster it belongs to, which enables experts to understand it's biological clock as well as the ability to track the origin and pathway, crucial information in the fight against this severe pandemic.


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Based on these findings, and with the financial support of IAEA and FAO Member Countries and private companies that had pledged more than EUR 26 million to the IAEA's efforts in helping to tackle the pandemic, the Joint Centre, with the support of the IAEA's Technical Cooperation Programme, initiated the procurement and delivery of rRT-PCR equipment along with diagnostic kits, primers and personal protective equipment through the FAO/IAEA Veterinary Diagnostic Laboratory (VETLAB) network to its VETLAB counterpart laboratories worldwide dealing with the diagnosis of the SARS-CoV-2 virus.

The Joint Centre immediately started to disseminate guidance about the use of the rRT-PCR together with other crucial information, and in a series of scheduled workshops laboratory personnel from Member Countries were made familiar with the detection techniques. Later, when travel restrictions were introduced worldwide in response to the severity of the coronavirus pandemic, it organised webinars to ensure that necessary and vital information relating to detecting the presence of the virus would nevertheless continue to flow uninterrupted.

Through this rapid response, the IAEA, in partnership with the FAO, has to date provided guidance and problem solving on COVID-19 detection to 281 laboratory professionals in 127 countries. The Joint Centre continues to conduct regular webinars to help health care providers in Member Countries adjust their work procedures to cope with the pandemic. And, above all, it has been able to procure and ship 271 detection equipment sets to 127 Member Countries to use in their efforts to fight the pandemic.


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A particular focus of the Joint Centre in its endeavours to assist the world in fighting the COVID-19 pandemic has been directed towards developing countries. Often poor countries do not have the ability to purchase this type of equipment. However, in cooperative efforts with each country, the Joint Centre is able to review and ascertain their needs and to represent them in their purchases to obtain better prices – and, crucially, to follow through with further training – for now, virtual – in how to do the testing properly and efficiently.

First detected at the end of 2019, COVID-19 spread around the globe and was declared a pandemic on 11 March 2020. A year later, towards the end of 2020, it was known to have infected more than 70 million people in 191 countries, while more than 1.5 million had by then died from or with the disease. Technical support provided by the Joint Centre to Member Countries undoubtedly assisted numerous national laboratories in their efforts to assist their governments control the disease, in the diagnosis of people affected, and in the identification and isolation of hotspots in efforts to slow the virus spread within and among countries.

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BELIZE

Veterinary diagnostic tools prevent or control animal disease outbreaks

A generation ago, veterinarians and livestock farmers had few tools to diagnose disease and control its spread among livestock. But today, nuclear-derived technologies, such as the enzyme linked immunosorbent assay (ELISA) and the real-time reverse transcription-polymerase chain reaction (rRT-PCR) tests are widely used by national diagnostic veterinary laboratories. Having these tests available enable the laboratories to support animal health authorities, extension services and farmers in the control of animal and zoonotic diseases that impair animal productivity and trade. Recognizing the critical importance of having access to these types of tests, the Belize Agricultural Health Authority teamed up with the Joint FAO/IAEA Centre to establish the necessary capacity to enable it to make rapid and accurate control checks and diagnoses of animal and zoonotic diseases, hence strengthening its capacities in animal health management and veterinary surveillance to deal with potential outbreaks of transboundary diseases. Today, with its improved laboratory capacity, Belize veterinary officers often have the results, not within weeks but in less than a day.

Across the globe, zoonotic and transboundary animal diseases have the potential to affect millions of livestock and poultry, from large cattle herds to backyard pigs and chickens. These diseases can cause severe economic losses to individual farmers who lose their animals but also to whole countries that are banned from international trade if certain diseases are diagnosed in their livestock sectors. Plus, in the case of zoonotic outbreaks, these diseases can impact human health and food security.

In Belize, rabies is the country's most recent zoonotic disease. But Belize also deals with a host of other diseases, such as avian influenza, Venezuelan equine encephalomyelitis, bovine tuberculosis and bovine brucellosis. Control of these diseases calls for early testing and diagnosis of any existing pathogens in animals, so that preventive measures can be taken before an outbreak happens, or an outbreak can be contained once it has begun. There was a time when the national veterinary laboratory of the Belize Agricultural Health Authority (BAHA) did not have the equipment or expertise needed for early and accurate diagnosis. Because it did not have the ability to accurately diagnose possible pathogens, samples had to be sent to the United States of America for confirmation, which, of course, delayed preventive or control actions in the field.

Recognizing this, and through an IAEA technical cooperation project, BAHA requested the assistance of the Joint FAO/IAEA Centre in establishing its own


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Animal Health Molecular Diagnostic Laboratory. In doing so, it also recognised the crucial importance of field workers having a pre-established plan for sending samples to the national laboratory for rapid testing and for taking proper corrective actions when they received the results.

As part of this cooperative endeavour, critical equipment was provided and laboratory staff trained in the application of nuclear and molecular techniques for the diagnosis and control of the diseases existing in the country. The Laboratory works closely with the national extension offices, so that effective coordination of the surveillance of relevant diseases and the sampling from sick animals is ensured. This has substantially strengthened Belize's capacities in animal health management and has established a veterinary surveillance expertise that enables the country to deal with potential outbreaks of transboundary diseases. Today, the Animal Health Molecular Diagnostic Laboratory even participates in international quality control programmes to certify the efficiency and accuracy of its results.

PCR and ELISA surveillance help contain the spread of animal diseases

In general, molecular (PCR) and serological (ELISA) techniques can be used to test for pathogens and make accurate diagnoses. These techniques can have many variations, depending on whether they are applied for antibody detection, pathogen detection or even the detection of an array of several pathogens. Since the tests were first introduced, they have been continuously improved and adapted at the Joint Centre's FAO/IAEA Laboratories. For example, the original techniques were entirely nuclear, meaning they relied on isotopes; today, they have been modified to avoid the use of radioactive isotopes.

In the past, when veterinary officers in Belize were called to the field to check a suspected outbreak, they had to send samples abroad to laboratories that could conduct the testing. This not only took several weeks, it was also expensive and required security checks because of the biosecurity risks of sending a suspected pathogen. Today, with its improved laboratory capacity, and depending on the type of pathogen and the distance from the field to the laboratory, veterinary officers often have the results from Belize's Animal Health Molecular Diagnostic Laboratory in less than a day.

And Belize is just one of more than 70 countries where the IAEA and the Joint Centre's commitment to fund the establishment and equipping of laboratories and the training of personnel has facilitated improved animal productivity and health, ultimately enhancing farmers' livelihoods as well as contributing to sustainable food security in these countries. As Miguel de Paz, Chief Veterinary Officer of Belize explains, "it is important for the country to quickly detect diseases and take action to stop the spread and avoid affecting the industry in a negative way."


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GLOBAL

Nuclear science helps development of DNA chips for improved animal breeding and increased livestock productivity

Farm animals, so important for food security, provide us with highly nutritious products like milk, meat and eggs. But as global population growth has accelerated, so has the demand for animal produce – putting a severe strain on both farmers and the environment. Simply raising more animals is not an option; this would put even greater pressure on an already strained environment. The solution lies in increasing the productivity of those animals. This is usually done by selecting and breeding superior animals; but this is a slow process and it can take several years to determine their breeding potential. Thanks to advances in nuclear-related genomic technologies, animal breeders across the globe can now estimate the breeding value of their animals on the day of birth. They use DNA chips that contain information on tens of thousands of genetic markers associated with economically important animal traits. The Joint FAO/IAEA Centre assists countries throughout the world in the use of radiation hybrid mapping technologies to develop such DNA chips for important farm animals, including zebu cattle, goat, dromedary camel, alpaca and llama, to sustainably increase animal productivity, improve food security and protect the environment.

As the global population has increased, so has the demand for livestock products – the milk, eggs and meat that are so important for human nutrition. Livestock make up 40 percent of the global value of agricultural output and contributes to the livelihoods of almost 1 billion people and to food security worldwide. Looking ahead, in order to keep up with demand, the livestock sector must increase animal productivity by breeding highly productive animals that have an innate ability to provide what is needed – more milk, more meat, more eggs.

Traditionally, livestock improvement is done by selecting and breeding superior animals, but this is a slow and expensive process, as it takes several years to determine their breeding potential. It requires large-scale data recording, following up the productivity of offspring for several generations and recording health and growth issues, all of which mean many years of recordkeeping and interpreting. But now, thanks to technological advances, it is possible to estimate the breeding potential of an animal on the day of its birth, simply by looking at its DNA or genome map.

Genome maps pinpoint the location of specific features on the animal's chromosomes, so-called DNA markers, that are important for example for milk, meat or egg

production. These genome maps are produced using a nuclear technique known as radiation hybrid mapping. Once the full genome is mapped, tens of thousands of such markers are combined onto a DNA chip, which can then be used to determine the breeding potential of the animal. The application of DNA chips derived from such radiation hybrid maps has totally revolutionised the breeding of dairy cattle to increase milk production.

DNA chips guide animal breeding decisions

Until now, DNA chips have mainly been developed for livestock species reared in highly intensive livestock production systems, mostly in temperate zones of developed countries. Although that information can be helpful to breeders in the developing world, it is not sufficient to implement efficient breeding programmes for improving local breeds raised under tropical conditions. The Joint FAO/IAEA Centre is working through several coordinated research projects and IAEA technical cooperation projects with numerous countries in the developing world to identify DNA markers for traits that are of economic importance to the improvement of indigenous sheep, goat, zebu cattle, alpaca, llama, dromedary camel and other species common in developing countries. These markers are subsequently incorporated into specially designed custom DNA chips to implement advanced animal breeding programmes in those countries.

As an important outcome of these projects, sheep breeders in Argentina and Uruguay are now able to cut time and costs by breeding animals with enhanced resistance

to gastrointestinal parasites so that they stay healthier, need less care and require less usage of drugs for worm removal. And cattle breeders in Kenya can now verify the breeding value of imported bulls for use in national artificial insemination programmes aimed at increasing milk productivity. And shortly, many other countries will follow suit, hence providing a major contribution to food security and environmental protection.

As explained by Prof. Musharraf Bhuiyan of the Bangladesh Agricultural University, a participant in the Joint Centre project, "genome-wide typing using DNA chips has helped to identify the right crossbred cattle genotype that suits the local production conditions in Bangladesh. This will help improve the efficiency of national crossbreeding programmes for dairy cattle development in the country."

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INDIA

A new cost-effective DNA testing technique helps sheep breeders increase birth of twin lambs in South India

On certain farms in South India, the lambing season for sheep is becoming more and more a cause for celebration, because these days it is much more likely that their pregnant ewes will give birth to twins or triplets and, in doing so, truly increase the earning potential of many marginal and landless farmers. It all starts with a naturally occurring genetic mutation, FecB, also called the "twinning variant". Now, thanks to a DNA test developed by the Joint FAO/IAEA Centre and implemented by the Tamil Nadu Veterinary and Animal Sciences University (TANUVAS) in South India, rams carrying FecB can be identified and selected for producing breeding ewes that will give multiple births.

There are over 74 million sheep in India, reared mostly by small-scale farmers with fewer than ten animals. Sheep rearing is possible for marginal and landless farmers because in many villages, they can graze their animals on community grasslands set aside for sheep, or they can organize with land-owning farmers to use their fallow fields for grazing in exchange for leaving manure behind that fertilizes the soil. Sheep are well adapted to the low rainfall of India's arid zones and a large proportion of mutton production takes place in India's rural and hilly areas characterized by smallholdings and limited resources.


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Traditionally, ewes give birth to only one lamb at a time; twins or triplets have been quite rare. But thanks to the identification of the FecB gene variant, the odds of multiple births are now greatly enhanced because the presence of this gene variant increases ovulation and lambing rates significantly. FecB gets its name from the words "fecundity" (fertility) and "Booroola". Booroola is a sheep breed known to have high fecundity because of its genetic potential to produce twins and triplets. When geneticists studied the breed, they found that its propensity for multiple births was due to the effects of one major gene – which they named "FecB".

India implements technique for identifying "twinning variant"

Scientists from the Tamil Nadu Veterinary and Animal Sciences University (TANUVAS) in South India helped local farmers introduce rams with the FecB gene variant into breeding of local flocks and, as a result, the first-generation crossbreds produced twins and triplets. However, after breeding the first generation with the known carriers of FecB, breeding in subsequent generations becomes more tricky. Breeders need to identify those rams and ewes that possess the FecB gene variant, but doing so is a complex process involving proper animal identification, data recording and DNA testing to find which animals have the appropriate genetic markers for further breeding.

That problem has now been solved thanks to the introduction of a cost-effective technology developed by the Joint FAO/IAEA Centre at its FAO/IAEA Laboratories in Seibersdorf, Austria. The technology, based on real-time polymerase chain reaction (RT-PCR) genotyping, begins with a very small sample of DNA and amplifies it to a large enough amount to study in detail, in this case to identify sheep carrying the FecB twinning variant. Once the process was shown to work in the laboratory, the technology package was transferred to the Molecular Genetics Laboratory at TANUVAS. Additionally, the Joint Centre supplied electronic animal identification toolkits for the TANUVAS project team to implement a systematic marker-assisted breeding programme to improve fecundity in local sheep.

Building on this success, the Joint Centre developed similar methodologies also for other countries. For example, the Dominican Republic had previously sent sheep DNA samples to New Zealand for testing, making it very expensive for local farmers. Now, with Joint Centre support, its national testing facility can do this testing locally – at five percent of the cost – making it affordable to farmers.

Participating in the same project, local farmers in the Dominican Republic, with flock sizes of around 10 sheep, have found that the new FecB breeding programme means five to eight additional lambs every breeding season. Once these animals reach market age, this can mean an additional income of USD 450 to USD 700 for the farmers. Plus, in addition to extra income for farmers, it also makes sheep rearing a better option for rural development and improving food security.

Professor Murali and Dr Saravanan Ramasamy of TANUVAS both speak highly of the marker-assisted programme that has improved breeding efficiency and twinning rates in South India, explaining that "the support from the Joint Centre helped us provide routine animal identification and DNA testing services to smallholder sheep farmers."

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VIET NAM

Proactive training and equipment provision help diagnose and control outbreak of African swine fever

It was August 2018 when African swine fever (ASF), a fatal disease affecting domestic and wild pigs, was first detected in southern China. When the outbreak was announced, Viet Nam and other Southeast Asian countries immediately joined a coordinated research project organised by the Joint FAO/IAEA Centre to provide proactive support, including a training course for veterinarian diagnosticians, preparing them to move quickly to diagnose ASF. Thus, in February 2019, when Vietnamese officials diagnosed an outbreak of the highly contagious ASF at a family-owned backyard pig farm 250 km from the Chinese border, scientists were already prepared to put measures in place to protect the country's pig farms and its livestock industry and consequently its food security.

African swine fever (ASF) was first identified in East Africa in the early 1900s, over the years resulting in several outbreaks in Kenya, followed by outbreaks in Europe and South America in the 1960s, then Georgia in eastern Europe in 2007. It was detected in Asia (China) for the first time in 2018 and spread further from there. Although first described more than a century ago, control of ASF remains a challenge, in particular because no vaccine is available. The only control measures available call for biosecurity, meaning placing infected areas under strict quarantine, restricting animal movement, cordoning off areas where infection has been found and culling pigs in areas that can even reach up to 15–20 km from the outbreak locality depending on the country's regulations.

In Viet Nam, pork is by far the most popular meat in the national diet. The country is home to 30 million pigs, and pork demand has been increasing by six to eight percent a year. Thus, the arrival of a highly contagious and fatal disease such as ASF required quick and urgent action to diagnose the disease and control its spread.

At the request of Viet Nam and other Southeast Asian countries, the Joint FAO/IAEA Centre provided a training course and the necessary equipment for veterinary diagnosticians from these countries immediately after the news of the August 2018 ASF outbreak in China, focusing on the diagnosis of ASF and other infectious diseases. Armed with this knowledge, when an outbreak of ASF was found in February 2019, Vietnamese experts employed their newly gained capacity for the initial diagnosis – the reverse transcription polymerase chain reaction (RT-PCR) and the enzyme-linked immunosorbent assay (ELISA). The RT-PCR is a method widely used to rapidly make millions to billions of copies of a specific DNA sample, allowing scientists to take a very small sample of DNA and amplify it to a large

enough amount to study it in detail. The ELISA is used to measure antibodies in the blood.

In conducting the RT-PCR and ELISA tests on several farms, the Viet Nam National Centre for Veterinary Diagnosis (NCVD) determined that the ASF virus in Vietnam was identical to the genotype isolated in Georgia in 2007 and in China in 2018. That knowledge helped establish the direction that control measures should take.

Improved diagnostic capability helps protect the pork industry

The pork industry in Viet Nam is not like the pork industry in North America or Europe. As with most Asian countries, Viet Nam has a mix of backyard and commercial pork industries, plus a lot of informal producers, which complicates disease control measures. However, being fully cognisant of local farming practices, and because of training and equipment it received from the Joint Centre, the NCVD was able to rapidly diagnose the disease and control its spread, thereby protecting the country's livestock industry and hence its food security.

Dr Bac Ngo Van, Director of the NCVD, noted that "before the training last year, NCVD had to send suspected ASF samples to reference laboratories abroad for confirmation. This could take between three and four weeks – too long for the timely implementation of control measures. Equipped with the knowledge in-house, we can now test the samples within a day."

Viet Nam's NCVD today has the capacity to screen around half a million samples per year. This places it in a unique position to help contain not only ASF, but also foot-and-mouth disease, leptospirosis, rabies, goat pox and other livestock diseases. In addition, Viet Nam is one of 19 countries in Asia and 45 countries in Africa that are part of VETLAB, a global network of national veterinary diagnostic laboratories, coordinated by the Joint FAO/IAEA Centre. Through this network, members routinely share information about disease status, techniques and equipment. Thus, in addition to Viet Nam's immediate response to the ASF outbreak in China, its membership in the VETLAB network ensures that it as well as neighbouring countries are continually informed and on the alert for potential disease outbreaks in their livestock industries.

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BOTSWANA

From school lunch programmes to livestock exports – advanced national laboratories certify food safety for consumers and export

On every school day in Botswana, more than 330 000 primary school children at government schools know that they will be served a healthy lunch thanks to the government's school feeding programme. They are also assured that this food will be nutritious and safe to eat, owing to the expanded capabilities of the food safety laboratories of the Ministry of Agricultural Development and Food Security and the Ministry of Health. But it doesn't just stop here. In addition to the assured safety of school lunches, the Ministry of Agricultural Development and Food Security also provides safety certification of beef and related animal-based products for local consumers, as well as the validation needed for export, especially to meet the stringent import standards of lucrative markets, such as the European Union (EU). In all these endeavours, the Joint FAO/IAEA Centre has provided essential technical and infrastructural support to establish and strengthen the analytical capacities of the national food safety laboratories and to train laboratory staff.

Botswana is a sparsely populated landlocked country in southern Africa. Seventy percent of its territory is desert yet Botswana is an upper middle income country with one of the world's fastest growing economies – an economy dominated by its diamond, gold and uranium mining activities, but also at the top of the list – its cattle industry. Although the size of the herds has decreased in recent years because of high temperatures and drought impacting the ability to feed livestock properly, livestock still accounts for 80 percent of the country's agricultural earnings, and livestock trade remains a vital part of its national GDP.

The laboratories that the Joint FAO/IAEA Centre has helped strengthen include the Botswana National Veterinary Laboratory (BNLV) and the National Food Control Laboratory (NFCL). With the Joint Centre's support and training, the laboratories are now competent in the application of nuclear, isotopic and related analytical techniques used to test for a range of hazards, such as veterinary drug and pesticide residues, mycotoxins and toxic metals. Laboratory analysts are also trained to perform field and laboratory testing for transboundary animal diseases that can arrive in Botswana from neighbouring countries, and which may also have an indirect impact on food safety, due

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to the use of drugs and related chemicals to control these diseases.

Until these laboratories reached their current certification status, Botswana had to outsource testing by sending samples to laboratories in Europe or elsewhere. But now, with the improved competence, including ISO 17025:2017 accreditation of at least 17 analytical methods, the BNLV can conduct these tests itself, saving the time and burden of transporting test samples abroad. A competent and well-implemented national residue monitoring programme is a prerequisite to establishing and maintaining exports; this has now been implemented and is being further expanded at BNVL with the support of the Joint Centre, hence opening up new and lucrative markets for the country.

More proficient, Botswana provides laboratory training to neighbouring countries

Each year, the BNVL tests about 6 000 samples of beef, dairy and feed samples while the NFCL, which includes the school feeding programme, tests about 5 000 samples of cereals, pulses and even peanut butter for the presence of hazards such as aflatoxins, which are potent cancer-causing agents, and heavy metals. Furthermore, as Botswana has become more proficient with its laboratory capabilities, it has been able to help other African countries – such as Zimbabwe, Lesotho, Uganda, Angola, Senegal, Niger, Seychelles – build and expand their own capabilities through offering training to laboratory analysts and sharing their experience in implementing a national residue monitoring programme, as well as accessing and maintaining lucrative export markets.

This training and technology transfer have been carried out under the auspices of IAEA technical cooperation projects as well as the coordinated research activities run and supported by the Joint Centre. Fellows and scientific visitors receive practical and theoretical training on food safety testing at top laboratories throughout the world that collaborate with the Joint Centre, as well as at its own FAO/IAEA Agriculture & Biotechnology Laboratories based in Seibersdorf, Austria.

Amos Ramocha, Chief Scientific Officer of BNLV, in giving an overview of the Joint Centre's support, noted in particular that "the laboratory testing capacity that we have established with the support of the Joint Centre enables us to facilitate food exports, especially beef, while also safeguarding our consumers," and added that "we don't depend on a lot of external testing now and we can also train others in Africa."

Food safety is primarily a public health goal, and there is no specific monetary value attached to health – it is priceless. That said, the NFCL's routine testing of foods is ensuring a safe national food supply and provides an invaluable benefit to the country. From an economic standpoint, by maintaining a high level of testing for export, Botswana has become the ninth largest beef exporter to the European Union, which brings the country an average trade income of USD 80 million a year.

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PHILIPPINES

Vinegar producers suspect food fraud in their industry – isotopic testing proves them right

A vinegar selection on a grocery shelf may not seem like a site of intrigue, but that's exactly what it became in the Philippines when the low prices of some brands aroused the suspicion of other vinegar producers. They felt the prices were too low for the products to be authentic and they were right. In response to the vinegar producers' concerns, the Philippine Nuclear Research Institute (PNRI), with technical advice from the Joint FAO/IAEA Centre, initiated an investigation, using carbon-14 analysis, to test the authenticity of the vinegars on the shelves. After testing hundreds of samples, the investigation found that more than 25 percent of the vinegar products being sold in major supermarkets across the country were made with industrial petrochemicals rather than from natural fermentation. In other words, this was food fraud with the potential to harm consumers. Armed with this information, the Government of the Philippines is now in the process of adopting the PNRI methodology as a national standard for the authentication of vinegar.

Vinegar – or "suka" – is an extremely popular condiment in the Philippines, where it is used as an ingredient in sauces and dips, spiced with ginger, garlic or chili peppers, and in washing and preparation of vegetables. The country's traditional vinegar is made from the sap of the nipa palm, but it can also originate from coconut, sugarcane molasses, apple juice or wine. It begins with carbohydrate raw materials and, through a two-stage fermentation process, becomes a solution of acetic acid.

When asked to investigate suspicious vinegars being sold in Philippine supermarkets, the Philippine Nuclear Research Institute (PNRI) invoked a methodology for authentication using nuclear techniques that had been developed as part of a 22 country Asia-Pacific regional programme supported by the Joint FAO/IAEA Centre. Although the food product being authenticated was different in each country, the overall goal of the project was to train personnel at national food safety institutions in the nuclear techniques used to determine the authenticity of the food in question.

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In the Philippines, this led to PNRI testing 300 vinegar samples from major supermarkets nationwide. The testing consisted of measuring the product's natural background carbon-14 radioactivity, which enabled researchers to distinguish the real vinegar derived from plant fermentation from the vinegar produced from petrochemicals. This is because the carbon-14 radioactivity in vinegar made from synthetic materials or petrochemicals is lower than the carbon-14 radioactivity found in vinegars made from plant materials such as wine or molasses. Stable carbon isotope analysis, which identifies the carbon-13/carbon-12 ratio, can also be used to measure petrochemical versus natural ingredients and can therefore complement the results of the carbon-14 testing.

With 25 percent of vinegars proven fraudulent, the government is updating its vinegar standard

Applying the carbon-14-based and carbon-13-based analyses on these retail market vinegar samples, PNRI researchers found that 5 out of 19 vinegar brands had been adulterated with synthetic acetic acid. They concluded that fake retail vinegars represented a clear case of economically motivated vinegar adulteration that misled consumers for financial gain – a financial gain that was furthermore connected to a potential public health risk. This use of industrial grade chemicals was a potential public health risk, because any chemicals used in foods must be specifically tested to ensure they meet required standards and are fit for human consumption. Synthetic vinegars may contain undesirable levels of contaminants, such as formic acids, or by-products that may be formed during their production process.

As it happened, the vinegar investigation story was ignited in the news media, which spread the word about the proliferation of synthetic vinegar in the Philippines. The Philippine News Agency quoted Agriculture Secretary Emmanuel Piño, who explained that the investigation had uncovered "legitimate issues which I have to raise to protect our local vinegar-makers and the consumers as well," adding that he had "directed the Bureau of Agriculture and Fisheries Standards to set norms for vinegar manufacturing, so that only sour condiments produced through a natural fermentation process should be labelled "vinegar" or "suka".

As a result of the growing public awareness of the potential health risks from fraudulent food products, the Philippine Food and Drug Administration (FDA) assured the public that it would use the PNRI's study results as the scientific basis for an update to the country's vinegar standard. The PNRI investigatory method, which was supported by the Joint Centre, is now being extended to other condiments in the Philippine kitchen to differentiate between natural and synthetic ingredients in, for example, fish sauce, soy sauce and ketchup.

The PNRI and the Joint Centre clearly demonstrated the effectiveness and efficiency of applying carbon isotope analysis to detect food adulteration and protect consumers from potential harm and economic fraud. The work also contributed to protecting the honest vinegar producers and traders in the Philippines who were competing against traders selling synthetic vinegar that could be produced at much lower cost but that carry with it a potential public health risk. Looking to the future, the Philippine FDA has assured the public that it will update the country's vinegar standard, using PNRI's study results as the scientific basis.

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SLOVENIA

Slovenia protects and promotes local dairy products with "*Selected Quality-Slovenia*" certification branding

In Slovenia, savvy food shoppers who seek quality and safety in their purchases, as well as the freshness associated with "buying local", know exactly what to look for when purchasing milk or other dairy products. They look on the package itself for a circular insignia that declares "*Izbrana Kakovost - Slovenija*" – which means "*Selected Quality - Slovenia*". Since the insignia was launched in 2016, more than 1 000 Slovenian dairy producers have successfully qualified for the certification. These producers can rest assured that their genuine products will be tested against a database that contains information on the stable isotopes and trace elements (SITE) unique to Slovenian production. This database, developed by the Jožef Stefan Institute with the support of the Joint FAO/IAEA Centre, provides a SITE "fingerprinting" method that ensures food authenticity and traceability, and in doing so, supports honest traders in the domestic supply chain and deters potential food fraudsters.

The small, picturesque central European country of Slovenia is home to mountain pasture farming and cheese production. Its dairy industry is small but known for the high quality and reputation of its artisanal products, including milk. In 2016 the Slovenian Ministry of Agriculture, Forestry and Food introduced the slogan "Our superfood" to Slovenia. The aim was to promote and to raise awareness of the importance and characteristics of locally produced and processed food. The beneficiaries of the project were both consumers and producers.

To help consumers easily recognize the home-grown or home-produced commodities, it then established the "Selected Quality" national scheme, which led to the creation of the "*Selected Quality - Slovenia*" brand. Today, most milk and dairy products produced and processed in Slovenia have been certified to carry the "*Selected Quality - Slovenia*" branded circular insignia on their packaging.

The producers, by having their products certified as *Selected Quality - Slovenia*, are enabling consumers to make informed choices about the origin and quality of the dairy products they decide to purchase. Public opinion surveys related to food labelling have found that "country of origin" labelling is often high on consumers' list of demands. Whether the reason is patriotism, purported health benefits of regional products, lack of confidence in the quality or safety of foods produced outside their local region, or a range of other reasons, including concerns about animal welfare and food-borne diseases, the world has seen an increase in the establishment of certifications such as Slovenia's Selected Quality. For example, the European Union has registered more than 4 000 products under schemes

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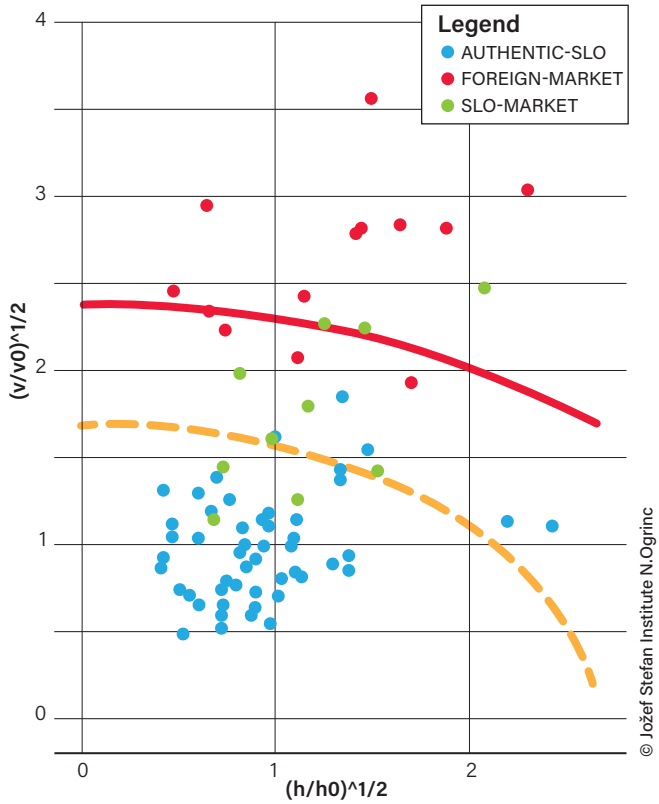
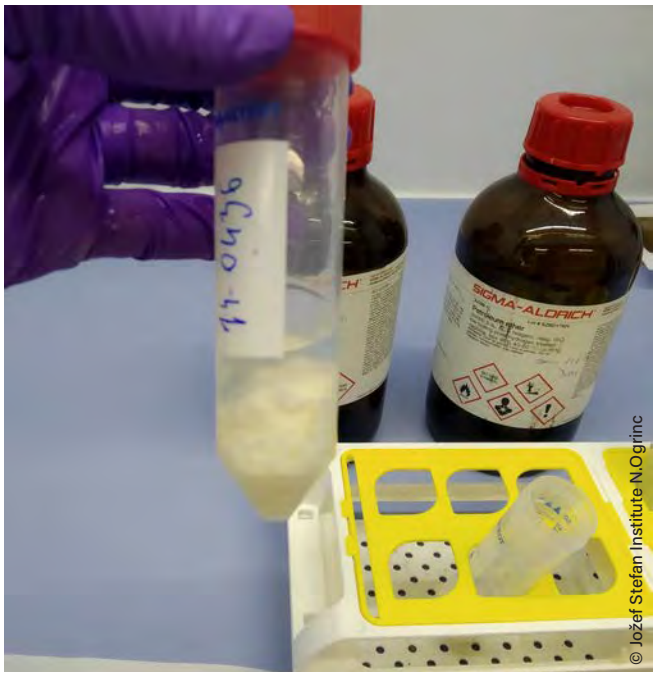
such as Protected Denomination of Origin (PDO) and Protected Geographical Indication (PGI).

Nuclear techniques provide data to verify local products and avoid food fraud

The scientific certification process for a product to be verified as *Selected Quality - Slovenia* began at the Reactor Centre at the Jožef Stefan Institute in Ljubljana, which undertook a coordinated research project from 2016 to 2019, supported by the Joint FAO/IAEA Centre. Working together, they developed a database of the stable isotopes and trace elements (SITE) that characterize and are unique to genuine Slovenian milk and cheese. Now, by comparing products against this database, it is possible to prove their provenance. Eight significant variables, including oxygen and nitrogen stable isotope ratios and the concentration of macro, micro and trace elements, were identified to confirm the origin of Slovenian milk. After compiling the database, the first retail survey began with 25 test samples – 11 declared as Slovenian and 14 from other European countries. Having this database enables *Selected Quality - Slovenia* to differentiate between Slovenian milk and milk produced elsewhere in the European Union.

Because of the benefits this has had in the dairy sector this technology is now being transferred to other higher value food items. According to Professor Nives Ogrinc, Chief Scientific Investigator at the Jožef Stefan Institute, "nuclear techniques facilitated by the Joint Centre helped solve potential milk and dairy fraud issues in Slovenia and the technology is now being further developed to verify the origin of other premium products, such as truffles and fruits." Other FAO and IAEA Member Countries participating in the Joint Centre coordinated research project are using the same technology to build databases to certify foods important to their domestic and trade sectors, such as eggs and pork in Singapore, honey in China, basmati rice in Pakistan and coffee in Jamaica.





Food fraud is estimated to cost the global food industry USD 10 to 15 billion per year, according to the US-based Grocery Manufacturers Association, though some estimates are considerably higher. This equates to approximately 10 percent of global food production. While many instances of food fraud are associated with economic, environmental and sustainability losses, a substantial number of such incidents have had disastrous effects on consumer health and well-being.

In Slovenia, awarding the *Select Quality – Slovenia* insignia to top quality products sends messages to both consumers and producers. Its insignia on a package tells consumers that it is a local product with a short supply chain and proven quality. And producers who submit to the certification are showing customers that they are committed to safety and quality systems that can be verified with state of the art techniques.

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UGANDA

Fast reaction of Ugandan food safety laboratories helps curb deadly food poisoning outbreak

On 12 March 2019, surveillance teams of the Uganda Ministry of Health began to receive reports that health care centres in the Karamoja region were overrun with patients apparently suffering from food poisoning. A team was immediately dispatched to investigate. In addition to representatives of the President, the Prime Minister, the Ministry of Health, the United Nations and the police force, this team included experts from two of the country's main laboratories: the Uganda National Bureau of Standards (UNBS) and the Directorate of Government Analytical Laboratory (DGAL). These laboratories were well equipped, thanks to their participation in capacity-building initiatives and coordinated research projects of the Joint FAO/IAEA Centre. Support through these projects included technology transfer, training and state of the art laboratory equipment. Also, participating personnel had gained expertise in analytical protocols that made them uniquely suited to join the investigation and the laboratories had the people and tools needed to assess samples. Through the swift laboratory response, the team was quickly able to trace the food poisoning outbreak to a shipment of fortified cereal distributed in Karamoja. With that knowledge, the outbreak was quickly contained. The greater level of capacity and preparedness in the region is now being utilized to also train food safety experts from other countries.

The emergency investigation into a food poisoning outbreak in Karamoja, one of the poorest regions in Uganda, profited greatly from the expertise of the Uganda National Bureau of Standards (UNBS) and the Directorate of Government Analytical Laboratory (DGAL) personnel and the capacity of their laboratories. During the investigation UNBS and DGAL carried out independent testing of various samples of the suspected food in terms of safety, quality and toxicology, as well as samples from the patients. The parameters analysed included mycotoxins, pesticides, toxic metals and pathogenic microbes. Other substances were investigated elsewhere.

Although hundreds of people were affected and there were at least seven fatalities, the local people were well aware that the outbreak could have spread much further and affected even more people if the laboratories had not been in a position to intervene promptly. In this particular case, the timely response was made possible through the expertise of personnel and the capacity of the laboratories that had been strengthened through the support of the Joint FAO/IAEA Centre, and which had included transfer of analytical technology, expert

missions and technical advice, training courses, delivery of essential equipment and the introduction of state of the art analytical facilities at DGAL and UNBS.

In Uganda, the agriculture sector employs more than 70 percent of the working population and accounts for a quarter of the country's GDP. The Joint Centre's support of the two Ugandan laboratories was carried out under its mandate to assist Member Countries by building laboratory capacity in the areas of food safety and food quality. Thus, in addition to equipping laboratories and training personnel to provide critical tests, such as those required for the food poisoning investigation in Karamoja, it also helps facilitate international trade and enhance food security. Having in-country laboratories available to conduct the tests required for dealing with food safety emergencies, instead of having to outsource these to laboratories in other countries, saves crucial time and costs when responding to an outbreak.

National laboratories effectively handle routine food analysis and food safety emergencies

The role of UNBS and DGAL goes far beyond merely reacting to outbreaks or crises as and when they happen. UNBS establishes and promotes the use of standards that protect public health and ensure safety, while DGAL provides a full range of analytical services for monitoring the environment and food and water supply, and also ensures public safety and health. Thus, they are committed to staying ahead of emergencies, undertaking food safety sample testing for potential hazards such as, among others, mycotoxins in plant and animal products, pesticides in field crops or veterinary drug residues in animal products as well as toxic metals.

Ongoing support by the Joint Centre to Uganda's food safety laboratories includes testing on a broader range of hazards using radio receptor assays that, among others, can detect the presence of veterinary drugs, pesticide residues and mycotoxins, and confirming outcomes with chromatographic-spectrometric techniques supported by stable isotope methods that work as "fingerprinting" techniques to detect and identify very low concentrations of chemicals, in this particular case residues and food contaminants, and distinguish these from other materials.

The Director of DGAL, Kepher Kuchana Kateu, spoke with pride about the growth of DGAL's capacity, "thanks to the Joint Centre's support, our laboratory has the equipment and the know-how to run routine food testing and analysis as well as to handle major food safety emergencies."

Deus Mubangizi, manager of the UNBS Testing Laboratories, added his thoughts on how the support from the Joint Centre has impacted Uganda, where "the issue of food safety has gone a notch higher with the establishment of modern food safety laboratories at the UNBS by the Government of Uganda and through the technical capacity in food safety built with support from the Joint Centre. This has put Uganda at a higher level of preparedness in the region, and this capacity is now being utilized also to train food safety experts from other countries from Africa and other regions." Some of the countries that have already benefited from this capacity built in Uganda include, among others, Eritrea, Seychelles, Sierra Leone, Sudan and the United Republic of Tanzania.

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ARGENTINA

Pest-free areas of Patagonia and Mendoza oases opening trading path for exporting cherries to China

Argentina's most southern region, Patagonia, and two oases in the Mendoza Province, its northern neighbour, are home to 2 000 ha of cherry orchards. However, until 2002, most of these areas, which occupy the arid zone of central-west and southern Argentina, were also home to the Mediterranean fruit fly. This meant it was necessary to subject their produce to expensive quarantine treatments in order to export to important markets such as China. But in 2006, after five years of working with the Joint FAO/IAEA Centre on a pest management plan that included the sterile insect technique, the whole of Patagonia and Mendoza's South and Central Oases were proven fruit fly free, opening the door to increasing exports, currently worth USD 27.2 million.

The Mediterranean fruit fly (medfly) is one of the world's most reviled and feared agricultural pests because of its devastation of crops and its impact on trade. Major importing countries require exporters to prove they are medfly free before initiating trade – the presence of one 5 mm medfly larvae in a multi-tonne agriculture shipment can result in the entire cargo being rejected. The medfly has been present in Argentina since the 1930s. It arrived after a slow migration across South America that began when it arrived in Brazil in 1901, possibly in a shipment of citrus from the Mediterranean region.

The medfly's arrival in Argentina affected both fruit production and trade, and the battle began – initially with conventional chemical control methods, using insecticide sprays in fruit orchards and a fumigant post-harvest treatment. However, in addition to these treatments costing USD 3 million to apply each year, fumigation is gradually being reduced because of its negative impacts on fruit quality, the environment and public health. In the early 1990s, working with the Joint FAO/IAEA Centre, the National Plant Protection Organization (SENASA) went in a different direction. It established the National Fruit Fly Control and Eradication Programme (PROCEM), which added an environment-friendly and cost-effective component, the sterile insect technique (SIT), within its pest management plans for Patagonia and Mendoza's Central and South Oases. The cooperation with the Joint Centre included technology transfer to support the application of the SIT.

The SIT, as a pest control component, calls for the mass-production of male medflies, sterilizing them with irradiation and then releasing them over target areas to mate with wild, indigenous females. Because the males are sterile, the matings produce no progeny. If this is done continuously over a number of insect generations, the population is gradually reduced and can reach the point of total population eradication.

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The SIT has been used in Argentina since 1992. As a result, parts of Patagonia were declared fruit fly free in 1999, the rest in 2006. Similarly, parts of the South Oasis in Mendoza were declared fruit fly free in 2003, the rest in 2006, and the whole of the Central Oasis in Mendoza was declared fruit fly free in 2004. However, even with the achievement of eradication, the inherent threat of medfly re-emergence becomes an issue that must be constantly controlled. Phytosanitary emergency plans are therefore implemented in these regions in the event of a new outbreak of the pest. It is an ongoing battle that Argentina has learned to deal with in order to maintain and take advantage of its pest free status.

Chinese customs officials accept Mendoza and Patagonia pest free status

In 2018 and 2019, China, the world's largest fresh fruit market, dispatched customs representatives on three technical visits to do their own verification of the fruit fly free status and, after the third visit, China agreed that fresh fruits from Patagonia and the Mendoza oases were indeed free of fruit flies, and therefore met the necessary requirements for air freight shipments, and that the post-harvest cold treatment was no longer required.

In 2019/2020, Argentina exported 5 600 tonnes of cherries, shipped by sea with a post-harvest cold treatment, to a value of USD 27.2 million. According to Anibal Caminiti, Executive Manager of the Association of Integrated Cherry Producers of Argentina (CAPCI), a third of those exports were bound for China. Further, he explained that "with about 2 000 ha used for cherry production located in the recognized fruit fly free area of the Patagonia Region and the Central and South Oases of the Mendoza Province, this certification is crucial for the success of this industry." 2020/2021 will be the very first growing season after China accepted its fruit fly free status and forfeited on the need for post-harvest cold treatment.

In order to maintain the pest free status, the preventive release of sterilized males continues twice weekly in high-risk areas. The isolation of the Patagonia region and the Mendoza oases helps maintain that status, because they are far removed from other territories, so there is less risk that medflies might arrive from outside these areas. Mendoza had built its own facility for mass-rearing medflies needed for the SIT in 1992, but to ensure that the control continues unabated, it replaced it in 2007 with a more modern facility. This facility now produces more than 400 million medflies a week that are used to maintain the SIT in the Mendoza oases as well as in Patagonia. And now there are even plans to expand the use of the SIT also to the citrus-producing regions in the northeast of Argentina.

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ECUADOR

Isolated fields receive targeted pest control – opening new export markets for non-traditional fruits

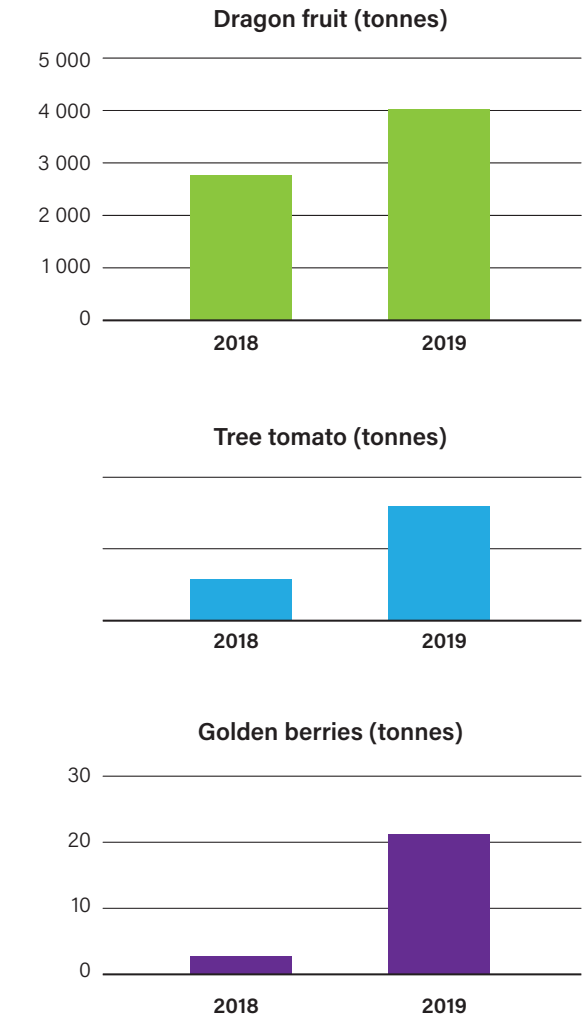
In 2019, Ecuador exported almost USD 3 billion worth of fruits and vegetables, mainly bananas, plantain and mangoes. Now, looking to the future, Ecuador has a new set of fruits to export, namely dragon fruit, tree tomatoes and goldenberries. If they don't sound familiar, that's the point. Ecuador has found the advantage of adding non-traditional fruits to its trade portfolio. Worldwide, traditional fruits such as apple, peach, pear, mango and citrus are produced in huge volumes and often suffer from low prices due to market saturation, while the market for the non-traditional fruits is still highly elastic. Ecuador has also found solutions to keeping pests under control in these crops. Each week, with the support of the Joint FAO/IAEA Centre, Ecuador imports 3 million sterile Mediterranean fruit flies in the pupae stage, a cost-effective way to implement the sterile insect technique in its non-traditional fruits' fields with pinpoint accuracy.

Ecuador started exporting dragon fruit, a sweet cactus fruit native to Central America and high in vitamin C, in 2018. Exports of tree tomatoes, which, as the name implies, are tomatoes that actually grow on trees, and goldenberries, which have ancestors that date back to the Inca cuisine, began in 2019. Although new to Ecuador's export roster, these non-traditional fruits have quickly found a market, with exports of USD 22 million to the United States of America alone in 2019. But before those exports could begin, Ecuador first had to rid the crops' growing areas of the Mediterranean fruit fly (medfly), one of the world's most damaging agricultural pests. Unless an exporter can show there is no medfly presence in the growing area, all shipments will be banned by importing countries.

Thus, Ecuador adopted an integrated pest management programme that incorporated several monitoring and control methods, including the sterile insect technique (SIT). The SIT is a highly regarded, environment-friendly, cost-effective and successful pest control method. It requires mass-rearing and sterilization of male insects using irradiation. Once sterilized, the males are released over target areas to mate with wild, indigenous females of the same species and, as the males are sterile, there is no reproduction.

If this is done continuously over a number of insect generations, the population is gradually reduced and can reach a point of total population eradication. That said, and although the SIT is environment-friendly, it still requires substantial investments in infrastructure to build and maintain insect mass-rearing and sterilization facilities and to train staff. It therefore becomes

Exports of non-traditional fruits from Ecuador to the USA



increasingly cost effective when used over large land areas where pests are present. In Ecuador, however, the non-traditional fruits grow in isolated highland valleys across only some 3 000 ha.

Ecuador imports its sterilized medflies instead of rearing them

Ecuador saved the expense of investing in a large rearing facility by establishing a purchasing arrangement with an enormous insect-rearing facility in Guatemala that can produce up to 2 billion sterile medflies a week. With this arrangement, made possible through technical support provided by the Joint Centre to the Ecuadorian Agency for Regulation and Control of Plant and Animal Health (AGROCALIDAD), Ecuador now imports 3 million sterile medflies, still in the pupae stage, each week. After arrival, they are transferred to a specially built fly emergence-and-release facility where they are kept under prescribed environmental conditions until adult emergence begins. As they emerge, they are fed a diet of sugar, yeast protein and water for 3–4 days, until they reach sexual maturity. Then they are transported in vehicles to the highlands where they are released over the fields of non-traditional fruit crops.

The non-traditional fruit production areas are supported by Ecuador's National Fruit Fly Management Project, which is also advised by the Joint Centre. According to Patricio Almeida, Executive Director of AGROCALIDAD's Plant Health Control, and in addition to opening export markets, "the significant reduction of fruit fly damage resulted in increased yields," and further, "the agricultural sector benefited from direct and indirect jobs that have been created along the production and export chains."

As far as Ecuador is concerned, now that the country has both pest-free areas and areas of low pest prevalence, it is able to export to the United States of America, and markets are opening in Japan and China. And, uniquely important, its arrangement with the large insect-rearing facility in Guatemala has shown that it is possible to use the SIT also on a smaller scale with high value crops that have substantial market potential.

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GLOBAL

Pilot mosquito control projects find success using sterile insect technique

Half the world's population has the potential to benefit from pilot projects currently being spearheaded by the Joint FAO/IAEA Centre, which is testing ways to incorporate the sterile insect technique (SIT) into mosquito control strategies. The antagonist in this effort is the ***Aedes*** mosquito, a 4–7 mm long insect that can carry a number of debilitating and even deadly viruses, including dengue, which is now the world's most common mosquito-borne disease infecting some 400 million people a year. Thanks in part to more than USD 5 million in grants from the United States of America (USA), 34 FAO and IAEA Member Countries are now collecting baseline data and 13 of them are participating in small-scale pilot projects to develop a SIT package for mosquitoes that can be transferred to the field. The US grants were triggered primarily by outbreaks of the Zika virus but, with a successful SIT, the results will cover all viruses that the *Aedes* mosquitoes transmits, including yellow fever, chikungunya, West Nile and dengue, as well as Zika.

Mosquitoes – sometimes you hear them but don't see them until it's too late. That's because, although they may be tiny, they can detect carbon dioxide in our breath, our body heat and odours on our skin. They know exactly where to land to feed on a human's blood, leaving behind at best a painful, red and itchy bump or at worst, they can transmit an array of dangerous viruses.

The *Aedes* mosquito has now spread around the world, often carrying the pathogens for diseases with it. "Half the world's human population is now at risk of dengue," said Dr Soumya Swaminathan, WHO Chief Scientist, discussing the *Aedes* spread and the piloting of the sterile insect technique (SIT) for its control. "Despite our best efforts, current attempts to control it are falling short. We desperately need new approaches, and this SIT initiative is both promising and exciting."

The SIT is mainly used to control insects that are damaging to agriculture, such as fruit flies and moths. The SIT process calls for the mass-rearing of insects, sterilizing them (ideally males only) in a gamma or X-ray chamber, and then releasing the males in an infested area to mate with wild females. Because the males are sterile, there is no offspring, so the population is suppressed. It is an environment-friendly process that has been used on an array of other insect pests.

For example, each week, rearing facilities in Mexico and Guatemala produce and release more than a billion sterile male Mediterranean fruit flies (medflies) and, in doing so, they are protecting multibillion-dollar agricultural industries. Similar scenarios are repeated in countries around the world that incorporate the SIT in their pest management programmes.

Scientists seek mosquito "sexing strain"

The world became highly aware that the *Aedes* mosquito also carries the Zika virus during an outbreak that emerged in 2015–2016 and was tracked in more than 60 countries – bringing with it the threat of birth defects and neurological complications. This outbreak triggered the US government, and to a lesser extent, Japan and the United Kingdom, to endorse a grant for the Joint Centre to assess the feasibility of developing and implementing an SIT package for *Aedes* control. But ensuring that this process would be both time- and cost-effective required a way to separate males from females. To be successful, only the males should be sterilized and released. In mosquito vector species, it is usually the female that bites and may transmit the pathogens. Looking for potential solutions, the goal has been to identify a "sexing strain" for *Aedes* mosquitoes – in other words, to find a trait that differentiates male *Aedes* from females so that only males will go through the entire development process. For example, with the medfly, scientists at the FAO/IAEA Laboratories in Seibersdorf, Austria, developed a sexing strain in which female eggs cannot survive temperatures above 34°C. So, by putting all eggs in water and heating them to 34–35°C, only the males survive and hatch. Now, the goal is to find a helpful sexing strain for *Aedes* mosquitoes.

In this endeavour, scientists now appear to have found a process to help tackle this problem. Using radiation, they induce mutations that result in physical traits unique to females and males, which will subsequently enable scientists to clearly differentiate the two sexes.

Although this mosquito suppression SIT package is still in the validation phase, with pilot tests involving the release of male-only *Ae. albopictus* mosquitoes, these tests are achieving good results, such as in China with 95 percent, in Singapore with 90 percent and in Spain with 80 percent suppression. Countries seriously affected by dengue and Zika have shown substantial interest in testing this technology as it can help suppress mosquitoes that are increasingly developing resistance to insecticides, which are also negatively impacting the environment.

Many steps lie ahead in addition to identifying a scalable sexing strain, such as the need for cost-effective mass-rearing of male *Aedes*. Imagine how many mosquitoes will have to be reared to suppress populations across cities and towns as well as in less populated areas. But scientists say that it is doable and herald the possibility of controlling diseases by releasing billions of sterile male *Aedes* instead of spraying insecticides that damage the environment.

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SOUTH AFRICA

Citrus growers of South Africa adopt SIT – freeing their orchards of destructive moths

Each year, South Africa's 1 200 citrus growers export over 120 million cartons of fruit to more than 100 countries, and in the process of growing, harvesting and shipping, they support some 120 000 jobs. But there was a time when South Africa's citrus farmers were reporting enormous losses. This was back when one of the world's most feared pests, the false codling moth (FCM), established itself in South Africa and then proved able to develop resistance to any new insecticide that came on the market. This led to the industrial and governmental partners, with support of the Joint FAO/IAEA Centre – embarking on a well-received and highly successful project to develop and implement a sterile insect technique (SIT) pest control programme – to suppress the FCM in South Africa's citrus orchards.

In the citrus-growing regions of South Africa, the false codling moth (FCM) is such a perilous pest; if left untreated, it can cause crop losses exceeding 80 percent. Many lucrative markets, such as Europe and the United States of America, consider it a phytosanitary quarantine pest and, in 2018, the European Union (EU) named it a "regulated pest", which when applied to global food trade means that the EU will not accept a shipment from an area where the pest is found. There is also zero tolerance for FCM in several other important export markets, meaning that if one larva is found in a citrus consignment, the entire shipment will not be released for export.

Traditionally, most citrus farms in South Africa managed insect pests such as the FCM with full-cover insecticide applications. In addition to being very costly, the applications can require up to 10 000 litres of water per hectare. Further, most of these toxic insecticides are broad spectrum, which have serious deleterious environmental effects, such as destroying the natural enemies of pests within the orchard as well as causing secondary pest outbreaks. All these efforts to manage FCM populations with insecticides were failing because the pest quickly developed resistance to any new chemical product that came on the market. This made research and development of the SIT package to suppress FCM in South Africa a logical direction.

The SIT is widely recognized as an important element of area-wide integrated pest management approaches for selected insect pests. The environment-friendly process involves the mass-rearing and radiation-induced sterilization of a target pest. This is followed by the systematic area-wide release of sterile males, by ground or air, targeting the entire pest population over a defined area. The released sterile males mate with wild, indigenous females, but there are no offspring, which leads to the suppression of the pest population in subsequent generations.

The SIT has been applied with great success at a large scale against a host of reviled agricultural or livestock pests around the world, such as the Mediterranean fruit fly, the New World screwworm fly and the tsetse fly. South Africa itself already had a long history of using the SIT against agricultural pests, having initiated a successful SIT programme against the Mediterranean fruit fly in 1997. But adapting the SIT for the FCM in South Africa required research in radiation biology, mass-rearing, handling and release techniques. The United States Department of Agriculture (USDA) along with the Joint FAO/IAEA Centre provided expertise and access to a network of specialists working on using the SIT against other pests. The USDA supported the project because it wanted to have an efficient tool on hand, should the pest be introduced to the USA.

South Africa success comes with public/ private partnership

Whereas most SIT programmes are government owned and implemented, the operational programme that emerged in South Africa was unique, as it was implemented by Xsit, a private company that took its name from the "sterile insect technique" acronym. It was co-founded by the South Africa Citrus Growers Association and the government, to industrialize the technique, but now is fully owned by the Citrus Growers Association, which makes it one of only three SIT operations in the world that is privatized. A business manager, rather than a scientist, runs the operation while staff entomologists take care of its science and technical needs. Farmers sign contracts with Xsit, which delivers the necessary sterile moths during the season and also monitors the suppression of FCM in the orchards. From an initial testing area of 35 ha in 2006, the area under release increased to 1 500 ha in 2007 to more than 18 000 ha in 2020. The facility is currently capable of producing 60 million moths per week to cover up to 22 000 ha.

In addition to allowing South Africa to continue exporting its citrus without fear of shipments being banned because of presence of FCM, farmers are relieved that they have "gone green", no longer using chemical insecticides, which means no fear of residues on the citrus. "SIT has allowed us to go green and not use chemicals against the moth anymore," says Piet Smit, who produces 11 000 tonnes of citrus a year on 250 hectares of land. "We also no longer have problems with insecticide residue levels on the fruit."

This is not only better for the crop, it is also better for public health and the environment. And for sure, it is better for the South African economy, which currently is ranking second in the world of fresh citrus exporters. Its citrus industry represents a success story of labour-intensive and high-value agriculture-led growth, with 2019 exports totalling 126 million cartons with a value of USD 1.4 billion. With support from the government to expand market access and improve port infrastructure, the industry is well poised to be a major player in supporting the national economic strategy.

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BURKINA FASO

Breaking the spell of Striga parasitic witchweed with newly developed Striga-resistant sorghum

When farmers in Burkina Faso look across their sorghum fields and see the purple flowers of the Striga weed, that means it's already too late. The damage has been done – underground. Taking its name from the Latin word for "witch", which aptly reflects the way this parasitic weed hijacks a crop, Striga, or witchweed, attaches to the roots of crop plants and sucks out their water and nutrients. As a consequence, the Striga scourge has expanded to more than 50 million hectares of cropland in sub-Saharan Africa and Asia where it causes annual grain losses valued at more than USD 7 billion and affects 300 million people. A search for a long-term sustainable solution for dealing with this devastating parasite began in 2016 when ten countries in Africa and Asia joined a coordinated research project launched by the Joint FAO/IAEA Centre seeking to develop Striga-resistant varieties of sorghum, rice and maize.

With a changing climate expanding the areas where Striga can take root and attack crops; with farmer's preferred crop varieties effectively lacking resistance to the devastating parasitic Striga weed, also called witchweed; and with the environmental, health and financial problems associated with chemical control of this scourge, Striga has become a huge problem across sub-Saharan Africa and parts of Asia where it infests up to 50 million hectares of cropland, impacts 300 million people and, each year, causes more than USD 7 billion in losses to an array of cereal grains. Add to this the fact that a single Striga plant produces hundreds of thousands of seeds that remain viable for up to 20 years.

While Striga control techniques have included herbicides, crop rotation, fertiliser, intercropping or the use of fungi for biological control, all have had limited success. In a sustained effort to combat this scourge, ten FAO and IAEA Member Countries , including five in sub-Saharan Africa, joined forces with the Joint FAO/IAEA Centre to fight Striga using plant mutation breeding to develop Striga-resistant crop varieties. One of these countries was Burkina Faso.

Philipe Nikiema, a scientist at Burkina Faso's Environmental Institute for Agricultural Research and a participant in the Joint Centre's coordinated research project (CRP), pointed out that "Striga threatens food security in rural areas where it has been expanding and taking over millions of hectares, including those owned by poor farmers." Hosted as a fellow at the FAO/IAEA Laboratories in Seibersdorf, Austria, where the research for resistance to Striga was initiated, he was excited to see what he called "the power of nuclear technology applications for inducing novel genetic diversity," adding his hope that affected African countries "will finally restore production of cereals in the heavily Striga-infested areas in Africa."

Plant breeding using induced genetic variation speeds up the process of natural selection through irradiation of traditional seeds, and then screening them as they grow in laboratory and later under field conditions to determine if the sought-after trait is present in the new seedlings. In this particular case, the desired trait was resistance to Striga. And, indeed, in the first two years of the project over 100 mutant lines showed potential for Striga resistance. Once identified, these were planted in laboratories and glasshouses, where they were closely monitored and subsequently verified.

In the next step, the verified resistant lines will be evaluated in farmers' fields across several locations, tested for stability of performance and, finally, released in the participating countries. This step also includes seed propagation, which usually takes two to three years, so that these can later be disseminated to farmers. In addition to the countries participating in the CRP, the Striga-resistant lines have the potential of being adopted or adapted for cultivation also in other Striga-affected countries. According to Nikiema, the impacted countries, including his own, Burkina Faso, "will benefit from the new improved sorghum lines developed through this project."

Success with sorghum's Striga-resistance can apply also to other cereals

Another outcome of the CRP and its laboratory studies, according to Joint Centre Technical Officer Abdelbagi Ghanim, has been the discovery of different mechanisms of resistance in the developed mutant lines, which, he explained, "includes ensuring that the crop plant does not produce or produces only very low amounts of a stimulant that would normally attract Striga; that it grows stronger barriers that prevent Striga from attaching to its root to absorb water or nutrients; and that it is able to launch a hypersensitive necrotic defence response that protects it from the weed. These different resistance mechanisms provide an opportunity to combine various mechanisms and, in turn, to produce cereal crops with even more durable resistance to Striga."

While the CRP began with a focus on developing Striga-resistant sorghum for farmers in Burkina Faso and other affected countries, parallel work is going on to develop Striga-resistant varieties also of maize and upland rice in Madagascar and Sudan. In addition, as Nikiema points out, "the results of the project will also help to understand the physiological and molecular bases of host–parasite interaction to enable the development of further durable solutions to restore cereal production and boost food security in Africa."

Looking ahead, scientists are working to involve both public and private sectors in the seed propagation and distribution of the urgently needed resistant varieties to farmers for both household and commercial production in Striga-prone areas. As Nikiema emphasizes, "for all these African farmers, the availability of Striga-resistant sorghum, maize and upland rice varieties will be a huge breakthrough that will improve livelihoods for rural communities and contribute to food security."

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CHINA

A dire fungus threatens global banana industry – new Cavendish banana line shows resistance

The world's most popular fruit, banana, represents 75 percent of global tropical fruit trade. This means that each year, more than 116 billion tonnes of banana are harvested in the 150 countries that grow the crop. Annual global banana production is valued at USD 36 billion and the industry provides income or food to 400 million people. These numbers make it especially concerning when one considers that the entire commercial banana industry is under threat from a dire fungus called TR4 that is lethal to the Cavendish banana – a variety that accounts for 99 percent of all bananas sold commercially. To counter this threat, the Joint FAO/IAEA Centre and counterparts in China and other countries have used mutagenesis – the process of creating genetic mutations – and tissue culture technologies to develop Cavendish lines that have inherent resistance to this fungus.

Its full name is *Fusarium oxysporum* Tropical Race 4, but in today's multi-billion dollar global banana business, it is known – and all too well – simply as TR4. TR4 is a deadly soil-borne fungus that has been circumnavigating the globe for decades, and now threatens the world's entire commercial banana crop. First observed in Southeast Asia in the late 1960s, it spread to Australia, the Middle East, Africa and, in 2019, was reported for the first time in Latin America.

Mainly spread through movement of contaminated soil, surface water or planting materials, this is a particularly malicious pandemic fungus that attacks the roots of banana plants and blocks water channels into the plant, causing it to wilt. Its impact is enormous because it attacks the Cavendish, which, at 99 percent, is by far the world's most important export variety.

Improving crops using traditional crossbreeding requires plants to flower and produce seed. In the case of cultivated bananas, such as the Cavendish, this is especially problematic because it is seedless. This may make it tidy to eat, but being seedless, it is also sterile. Its reproduction comes through vegetative propagation. In other words, all Cavendish bananas are clones and if something affects one, it affects all. But it doesn't just stop there. TR4 also affects many other varieties of bananas grown by small-scale farmers for local consumption.

Ironically, the Cavendish rose to popularity in the 1950s when the previous industry favourite, the Gros Michel variety, was attacked by a different *Fusarium* strain. When the Cavendish was found to have natural resistance to that strain, the commercial banana industry retooled and gave all energy to introducing – growing, harvesting, transporting, marketing – the Cavendish.

Now, history repeats itself with another *Fusarium* attack; only, the Cavendish has no resistance to this TR4 strain. That said, retooling for another banana variety would be an enormous undertaking – one which hopefully can be avoided thanks to genetic mutation technology combined with the tissue culture techniques developed by the Joint Centre.

To tackle the problem on a concerted scale, in 2015, the Joint Centre established a coordinated research project (CRP), bringing together six countries particularly threatened and already facing the rampage of the fungus – China, the largest banana producer in the world, the Philippines, Malaysia, South Africa, Iran and Mauritius – to focus on developing TR4-resistant Cavendish varieties. In addition, a Latin American programme based in Ecuador is also in design, through an IAEA technical cooperation project, to develop locally adapted banana varieties for TR4 resistance.

Genetic mutation techniques lead to fungus-resistant Cavendish lines

The technologies that the Joint Centre has developed with its CRP participants calls for using mutagenesis techniques, such as gamma ray irradiation of *in vitro* plants or plant cells, to induce novel genetic diversity, followed by laboratory-, greenhouse- or field-based screening techniques to identify resistant lines. In this case, "*in vitro*" entails the harvesting of small fragments of plants or even individual cells that can grow and create new plantlets in the laboratory under sterile conditions. Once the resistant plantlets are replicated, they can be replanted in the same area as the infected plants without fear of the fungus present in the soil because they are resistant to TR4. And, once planted, the resistant banana plants will flower in 12 to 18 months.

Using a combination of mutagenesis and *in vitro* tissue culture techniques, China's Guangdong Academy of Agricultural Sciences (GDAAS) in Guangzhou has now been successful in developing a new Cavendish line with TR4 resistance, which it has multiplied in the millions and sent to different provinces across the country for field testing. Other CRP partners have also produced promising TR4-resistant or -tolerant banana plants that are now entering further testing. Ultimately, these lines will also need to be tested for commercially important traits, such as their ability to withstand transportation and, of course, meet consumer preferences, such as size, texture and taste.

Globally seen, this is indeed a remarkable breakthrough in the worldwide efforts to fight the TR4 pandemic that is currently causing USD 400 million in direct damage each year. According to Yi Ganjun, Vice-President of the GDAAS, "the exciting results of having a new 'local' banana variety resistant to TR4 gives tremendous hope to the banana farmers who have successfully tested the new plants in field trials."

But these results do not stop at the "local" level. As the CRP that supported this work now comes to an end, a book that will share all protocols developed by the CRP participants will be prepared and published "open access", so other countries, such as those in Latin America, which are just starting to face the TR4 pandemic, will profit from the knowledge that the CRP participants have already acquired. The hope is therefore very much alive that consumers may continue to enjoy their favourite fruit – the Cavendish.

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PAKISTAN

Land planted with improved cotton varieties doubles as farmers see increased yields and income

In Pakistan, cotton is a major driver of the economy, responsible for almost one percent of the country's GDP. As with other cotton-producing countries, Pakistan must deal with erratic weather changes that have the potential to cripple the cotton sector. For more than 50 years, Pakistan's Nuclear Institute of Agriculture and Biology (NIAB) has therefore worked particularly hard to stay ahead of the curve in supporting its cotton sector, collaborating with the Joint FAO/IAEA Centre to develop improved cotton varieties that are more adaptable to changing weather patterns and that, at the same time, produce higher-quality cotton and have increased yields. Within just the three years from 2016, NIAB has released four mutant varieties that not only have higher yields and withstand high temperatures and heavy rains, but also have superior fibre quality that brings a higher price on the textile market.

Cotton is an enormous segment of Pakistan's agriculture landscape. Grown as a cash crop by smallholders as well as by large industrial growers, cotton fields cover 1.8 million hectares in eastern Pakistan's Punjab province. In 2018, twenty percent of that land was planted with mutant varieties but, by 2019, this had already increased to 40 percent. The fact that the farmers choose to plant the mutant varieties on 774 490 ha is a remarkable testament to the benefit they recognize in the improved varieties developed by Pakistan's Nuclear Institute of Agriculture and Biology (NIAB) with the support of the Joint FAO/IAEA Centre.


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Four new varieties have emerged from the NIAB/Joint Centre collaboration since 2017, yet each represents many years of development at NIAB's laboratory. In this laboratory cotton seeds are irradiated with gamma rays. The irradiation induces mutations in the plants; these, however, will not be visible until the plants are grown to maturity. Thus, once irradiated, thousands of plantlets are grown in an experimental nursery at NIAB and only those that show promise are transferred to experimental fields around Pakistan where they are subject to the prevailing climatic and soil conditions.

Monitored as they grow, those that show the best agronomic performance and fibre quality are selected for further testing until, after being monitored through several growing seasons, the new variety is chosen and presented to Pakistan's cotton farmers. The farmers are most often introduced to these new varieties through "farmer field day" events, during which NIAB ensures the inclusion of cotton growers, including smallholders, who participate in the field trials, thus paving the way for farmer adoption of new varieties that promise more yield and high quality cotton and, thus, more income.

Throughout the NIAB/Joint Centre's collaboration, farmers have seen continuous and very positive results.

A cotton mutant variety released in the mid-1980s led to additional incomes of USD 486 million for cotton growers, including smallholders, between 1986 and 2004. The four most recent varieties, released to farmers between 2016 and 2018 today cover more than 40 percent of the cotton-growing area of the country. With an estimated 1.7 million of its citizens engaged in growing cotton, and an increase in the land dedicated to cotton cropping, Pakistan today ranks fifth among all cotton-producing nations.

To uphold this accomplishment, NIAB continues to provide delivery mechanisms that allow novel traits and associated marker technologies to flow from publicly funded research through to exploitation in commercial breeding, thereby delivering novel and improved varieties that ensure the sustainability of Pakistan's cotton industry and the livelihoods of its farmers. Dr Manzoor Hussain, Deputy Chief Scientist and Group Leader of NIAB's cotton breeding programme, observes that during the last five years, when cotton productivity in Pakistan was severely hampered by high temperatures and heavy rains, four NIAB varieties released during 2016-2018 outperformed commercial standards by 30-40 percent in harvested yields. As he says, "their ability to continue fruiting and retain the bolls under the pressures of the changing climate, and their enhanced tolerance to sucking insect pests, contribute to this excellent performance".

Fifty years of collaboration sees continuous advances

The story of the NIAB/Joint Centre collaboration goes back to the 1970s, when the Joint Centre initiated a programme of continuous technology transfer and capacity building. In the past decade, this has included training and workshops focused particularly on developing improved cotton varieties that have tolerance to drought and high temperatures, combined with good agronomic performance.

But the Joint Centre collaboration and support expand beyond Pakistan's borders. Pakistan has the facilities for seed irradiation, the necessary level of expertise and also the willingness and desire to share its knowledge with its neighbours. Thus, in 2016, the IAEA established a technical cooperation project in the region that, with the help of the NIAB, offers training courses and introduces technology for induced genetic diversity in cotton to Bangladesh, Myanmar, Cambodia, Thailand and Syria. With this support, these countries have developed – for the first time – local and specific cotton mutant lines that are now going through the trials necessary for release to each country's farmers.

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SUDAN

Genetic mutation produces drought-tolerant groundnut variety, increasing yield by 27 percent, doubling farmers' incomes

Tafra-1, a new and extremely well researched and tested drought-resistant groundnut variety developed for Sudanese farmers, gets its name from "tafra", the Arabic word for mutation. It is a product of induced genetic diversity, carried out by Sudan's Agricultural Research Corporation and supported by the Joint FAO/IAEA Centre. The development of the variety was guided by local farmers who participated in its selection and who can now take advantage of its ability to grow with only 250 mm of rain a year, compared with traditional varieties that require 350 mm. The farmers also benefit from its yield, which is 27 percent higher than traditional varieties, hence paving the way for Sudan's return to being a leading groundnut producer, improving food security in the country and providing much-needed foreign exchange.

Sudan was once one of the world's top groundnut exporters. But when climate change brought devastating droughts to the region, it significantly affected farmers' abilities to produce this crop, impacting both individual livelihoods and the national economy. Considering that 76 percent of the groundnut crop was produced by smallholders, it became especially important to find a way to support the farmers – and also for Sudan to regain its status as a major groundnut exporter.

Starting in the 1990s, a collaboration of Sudan's Agricultural Research Corporation (ARC Sudan) and the Joint FAO/IAEA Centre, through IAEA technical cooperation projects, undertook a programme of using induced genetic diversity to develop improved varieties of Sudan's most important crops, such as groundnut, but also banana, sorghum, tomato, cowpea and pearl millet. Thus, when climate change began to impact the groundnut crop, this collaboration increased its focus on developing a new groundnut variety that would thrive in Sudan's difficult arid environment. Enter: Tafra-1.

Tafra-1 was developed at the El-Obeid Agricultural Research Station of the ARC Sudan through plant breeding using induced genetic variation, and field testing of the groundnut mutants was initiated in 2007. Groundnuts, also known as peanuts, flower above ground but their nutritious shelled seeds stay underground until harvested, when they are consumed by locals for their flavour or exported on the oilseed market. Although Sudan's light sandy soil qualifies as groundnut friendly, Sudanese farmers reduced the amount of groundnut they grew because they believed the environment was unfriendly and switched to less lucrative produce.

That's what makes the current expanses of healthy groundnut plants thriving in the fields of North Kordofan State so encouraging. The groundnuts now planted here are the new drought-resistant Tafra-1 that require only 250 mm of rain a year, compared with the 350 mm required by the traditional varieties. But they will not be harvested for local consumption or for lucrative export markets. These groundnuts have been planted to produce seeds for future harvests. With the support of the country office of the FAO in Sudan, the Sudan Ministry of Agriculture and Natural Resources and the El-Obeid Research Station are producing Tafra-1 seeds for subsequent large-scale distribution to Sudanese farmers.

The projected plan is to engage 100 farmers in seven villages to produce 68 tonnes of Tafra-1 seeds on 42 ha. This means that by the end of next year, enough seed will be produced to supply all 230 000 potential groundnut farmers in North Kordofan State, so that they can take advantage of Tafra-1's ability to thrive in Sudan's harsh growing conditions.

Groundnut farmers participate in variety selection

Developing a new crop variety though induced genetic variation is a multi-step and multi-year process and, as was shown with the development of Tafra-1, each step of the process is critical. This process involves irradiating a supply of traditional seeds to generate random mutations, and then screening these as they grow. Any changes in the plants are monitored to see which could be helpful in meeting the farmers' needs – in the case of groundnut, a change that makes the plants tolerant to drought.

Throughout the process, farmers were involved in deciding which lines should be selected for further testing. According to Elgailani Adam Abdalla, Director of the El-Obeid Agricultural Research Station, "it's important to include farmers and allow them to select the variety that best fits their needs." This demand-driven and participatory selection process increases the likelihood that farmers will eventually adopt and use the selected variety once it is released.

And the groundnuts now being grown for seeds in North Kordofan State are just the beginning. With its aim to multiply seeds for large-scale use, the Ministry of Agriculture and Forestry has found that farmers who participated throughout the process have started to multiply seeds on their own due to Tafra-1's high performance. Its drought tolerance, combined with a 27 percent higher yield, means that groundnut farmers can make up to USD 28 more per hectare per harvest, hence almost doubling their income.

Looking ahead, Abdalla predicts that, as neighbours see participating farmers increasing their yields, they too will initiate Tafra-1 cultivation, first in order to harvest seeds and then to plant their groundnut crop. According to Abdalla, "it's now possible to see a future with Sudan producing enough groundnuts for domestic consumption and for the export market, which represents a very important step towards improving food security and livelihoods in western Sudan and providing much needed foreign exchange."

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BENIN

From orphan crop to export crop – soybean now adds to Benin economy thanks to biofertilizer

Gone are the days when soybean was considered an orphan crop in Benin. Just a decade ago, Benin scientists at the University of Abomey-Calavi and the National Agricultural Research Institute of Benin, working with the Joint FAO/IAEA Centre, introduced farmers to biofertilizers and the natural process of nitrogen fixation to improve soil quality and boost soybean production. By preparing demonstration plots to introduce local farmers to this approach and supplying the biofertilizer, farmers observed and adopted the techniques and Benin saw its soybean production increase from 57 000 tonnes in 2009 to 220 000 tonnes in 2019 – enough to take soybean from orphan crop to export crop. And now Benin trains scientists from other countries who want to copy this success.

Over the centuries, farmers have known that if they grow certain legume crops in one season, the soil will be better for their grain crops in the next season. Today, of course, this is more than indigenous knowledge. Science has found that when legumes are harvested, they can leave a nitrogen-rich residue behind in the field. The residue decomposes as a natural fertiliser that will nourish the next crop.

Recently, the Joint FAO/IAEA Centre, through the University of Abomey-Calavi (UAC) and the National Agricultural Research Institute of Benin (INRAB), brought another element to the process, introducing the use of natural biofertilizer to the cropping system. A biofertilizer contains microorganisms that induce the legumes to produce nodules on their roots – and those nodules "fix" the nitrogen. Scientists in the Joint Centre's FAO/IAEA Laboratories identified the specific bacteria needed for the Benin soybean field conditions. The process calls for adding a small amount of the bacteria to the peat in which it multiplies. Then farmers can spread the bacteria-laden peat as a biofertilizer on the soil or mix it with the seeds before they are planted.

Scientists have quantified this process with an isotopic


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technique that calls for adding nitrogen-15 isotope fertiliser to the soil, which traces the movement and uptake of commercial fertiliser. Once in the field, the nitrogen-15, a stable isotope of nitrogen, can be used to measure how efficiently nitrogen fertiliser in the soil is used by crops and how much nitrogen the crops capture from the atmosphere, so the amount of fertiliser can be adjusted as needed. Scientists can also use this method to determine which legumes will increase yield and improve soil fertility when included in the cereal-based cropping systems of particular fields.

To introduce these benefits, Benin partnered with the Joint Centre to establish demonstration plots and determine when and how much biofertilizer to use. Farmers could observe the changes in the field, which raised their interest in cultivating soybeans and intercropping with cereals. Once the correct usage schedules were determined, the biofertilizer was released to the Ministry of Agriculture and partner NGOs for distribution to farmers. "Inoculation promotes the development of nodules at the roots and thus increases the fixation of atmospheric nitrogen. It is a cost-effective way to increase yields, while improving and maintaining soil fertility," said Nestor Ahoyo Adjovi, Scientific Director of INRAB.

With the collaboration of the UAC and INRAB, and with the support of the FAO and IAEA, the Ministry of Agriculture disseminated the technology and information to more than 15 000 farmers. As these gradually adopted the method of nitrogen fixation and biofertilizer use, the yields of legumes almost quadrupled from 2009 to 2019, with no – or very little – commercial nitrogen fertiliser. "The production and deployment of the inoculum reduces the amount of nitrogen fertiliser required, which means farmers spend less on production," said Pascal Houngnandan, soil microbiologist at the UAC. Benin now exports 40 000 tonnes with a value of USD 19 million each year, making it an income earner for both local farmers and the Government of Benin.

But that's just part of the story. Benin farmers have also learned to intercrop their soybean with cereal crops and, because the soybeans enhance soil fertility, the cereal yields have increased by 30 to 50 percent almost without the use of commercial nitrogen fertilisers. It is estimated that farmers save a cumulative USD 4 million on fertiliser costs each year. In addition to the financial benefit, this also bodes well for the environment because nitrogen fertilisers have the potential to be harmful – if not applied correctly, they can emit as greenhouse gases or they can leach into the soil, polluting the groundwater.

The positive results are now visible in fields across Benin.


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The area of nitrogen-fixing legumes included in cereal cropping systems increased from 64 000 ha in 2009 to 200 000 ha in 2019, the yields from 57 000 tonnes to 220 000 tonnes – enough to take soybean from orphan crop to export crop – and its value grew from USD 6.6 million to USD 109 million during the same period.

Although there were problems initially with producing sufficient biofertilizer to accommodate the number of farmers who wanted to adopt the technology, as well as with the marketing of the greatly increased harvests, these were overcome through the training of scientists at UBC to produce the biofertilizer, and the involvement of NGOs such as the Sojagnon Association and the Green Innovation Centre for the Agriculture and Food Sector in Benin to improve the soybean value chain. To facilitate this effort, the Joint Centre trained 50 scientists and technicians in 23 research facilities in the elements of nitrogen-fixation and biofertilizers. Now, Benin scientists are passing on their knowledge, conducting training in neighbouring countries, while countries such as Chad, Niger and Haiti have sent fellows to Benin for hands-on training.

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BURUNDI AND THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

Cassava crops no longer taken for granted – demonstration plots show farmers how precise application of nutrients can double or triple yields

Cassava – a staple food crop in many parts of the world – plays an increasingly important role in global agricultural efforts to cope with food insecurity under changing climates. Central to the diets of more than 800 million people, cassava is an important animal feed and is used as an element in starch-based industrial products. Today, cassava is the third largest source of carbohydrates worldwide, after rice and maize, yet it is mainly farmed by smallholders who traditionally cultivate it for local consumption using poor farming practices, meaning no fertilisers and no water inputs. Hence, climate change and declining soil fertility are negatively affecting cassava yields while demands for it are increasing. Scientists from the Institute of Agricultural Science of Burundi and the National Agricultural and Forestry Research Institute in the Lao People's Democratic Republic, working closely with the IAEA and the Joint FAO/IAEA Centre, therefore set out to raise the understanding of local farmers of the importance of good soil, nutrient and water management practices to increase cassava yields – and therefore farmers' income. Pilot projects were set up in the two countries, 8 000 km apart, to optimise cassava yields, using an isotopic technique for pinpointing cassava's fertiliser needs and, as a result, more than doubling yields in both countries.

According to Theogene Ntakarutimana, a smallholder farmer in central Burundi who consented to his farm becoming a demonstration plot for introducing new cassava farming practices, "seeing is believing." He was one of 80 farmers in Burundi and 60 in the Lao People's Democratic Republic (PDR) who were the initial partners of projects focused on increasing cassava yields. Working with the Joint FAO/IAEA Centre, and through an IAEA technical cooperation project, the Institute of Agricultural Science of Burundi (ISABU), the National Agricultural and Forestry Research Institute in Lao PDR (NAFRI) and farmer associations in these countries invited farmers to set up one of their fields for demonstration. The demonstration fields would show the outcome of using best soil, water and fertiliser management practices. In this case, the fertiliser was a combination of nutrients, including nitrogen, phosphorus and potassium – and a nuclear technique would help determine how much to use of each, as well as the best way and time to apply them during the growing season. At the same time, on the neighbouring fields, the farmers practiced as usual.


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The project found that most farmers thought of cassava as a crop not needing additional nutrient input. In order to show the farmers the advantage of adding nutrients, scientists from ISABU and NAFRI worked with local farmers on the demonstration plot, first adding fertiliser to the soil and then, with the support of the Joint Centre, using nitrogen-15, a stable isotope, to measure how the cassava reacts – how much nitrogen it takes up after the application, how much is lost to the atmosphere as greenhouse gases, and how much remains unused in the soil. This overview of the nutrient scenario enabled the scientists to devise a fertiliser strategy to share with other local farmers – so they would know how much, when and where to apply plant nutrients.

"We involved farmers from the beginning," said Ernest Vyizigiro, Head of the Institute of Agronomic Sciences at ISABU. "We conducted several training courses and hosted a farmer field day, where we took farmers to the research centre and demonstration plots." Because the demonstration fields were open for all neighbouring farmers to observe, it did not take long for these to adopt the fertiliser regimen the project had formulated. "Everyone who visits my farm and sees the way I am farming and producing cassava, they get excited," said Ntakarutimana. "I used to have a low yield, about 12 tonnes per hectare, but because of the enhanced practices, my production increased to 33 tonnes. Other farmers are asking about the methods I have applied, and everyone is eager to learn." In Laos, some farmers were initially hesitant to apply new methods to their traditional practices, explained Siviengkhek Phommalath of NAFRI, but interest is slowly growing as news of demonstration plots have spread by word of mouth and attracted more curious farmers.

When this project started, the participating farmers in both Burundi and Laos were averaging 10 tonnes of cassava per hectare. Adopting the new formula for adding precise amounts of fertiliser brought the participating Burundian farmers to an average of 33 tonnes per hectare and the Laotian farmers to 37 tonnes per hectare. Looking ahead, the potential for cassava yield is 60 to 80 tonnes per hectare, which means they still have an enormous opportunity for continued growth.

Right now, Africa produces 55 percent of the world's cassava, followed by Asia with 34 percent. Cassava contributes more to the world's caloric budget than any other food except rice and wheat, which makes it a virtually irreplaceable resource against hunger. To reach more farmers and further spread best practices, the Joint Centre continues to work with counterparts in Africa and Asia to make easy-to-follow brochures for farmers in their local language. As a result of growing interest from other countries following the successes in Burundi and Lao PDR, the IAEA's Technical Cooperation Programme has recently launched a regional project to develop and disseminate best practices for cassava production in West, Central and East Africa.

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IAEA
Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

MALI AND MAURITANIA

One drop at a time – drip irrigation takes water and fertiliser directly to where it is needed

One drop at a time, smallholder farmers in Mali and Mauritania have been improving their crop productivity, increasing incomes and putting more food on their tables, all thanks to introducing drip irrigation to their fields. While the process itself is relatively simple, requiring only a water tank and a series of pipes that take small amounts of water and fertiliser directly to the crops' roots, the process begins with training scientists to use the isotopic nitrogen-15 technique and soil moisture sensors to determine the precise amounts of fertiliser and water that the crops need. Scientists from the Université de Ségou in Mali and the National Centre for Agricultural Research and Agricultural Development in Mauritania received training from technical staff of the Joint FAO/IAEA Centre and then passed their knowledge on to the farmers, teaching them to operate drip irrigation in their fields so they can maximize their fields' productivity while conserving resources. With this system, farmers can reduce water consumption by as much as 60 percent.

High temperatures, changing rainfall patterns causing water scarcity, and sandy soils with low fertility are adding to the severe problems already faced by smallholder subsistence farmers in rural Africa. It is especially severe for women farmers who most often have responsibility for watering crops, which in extremely arid countries, such as Mali and Mauritania, often require long walks to water sources, returning home carrying heavy buckets and then watering the crops without knowing how much water they actually need.

Mali and Mauritania were among 16 African countries participating in an IAEA technical cooperation project that introduced smallholders to drip irrigation practices. This involved setting up irrigation systems in the fields to deliver the precise amount of water and fertiliser directly to the plants through a network of pipes and tubes, thus reducing water losses through evaporation or due to water draining below the plants roots. This system not only saves time, it also means saving the cost of the excess fertiliser as well as the energy and time needed to spread it. Because the amount of water and fertiliser can vary according to the crop and type of soil, two nuclear techniques were used to gather needed information: a stable isotope technology that determines the efficiency of a plant's uptake of nitrogen fertiliser, and a moisture neutron probe that determines soil moisture content.

In both countries, and with the support of the Joint FAO/IAEA Centre, soil moisture sensors were used to monitor the amount of water in the soil so that the water requirement of the crops could be determined and the right amount delivered at the optimal time to ensure no wastage. Similarly, the stable isotope of nitrogen-15 was applied in experimental plots to determine how well and

how efficiently the plants could take up fertiliser. Fertiliser is not easily accessible in these countries and, when available, it is expensive, so it needs to be used sparingly. Scientists used these findings to determine the precise amounts of fertiliser that farmers should add to the water so it would go directly to the plant at its right growth stage.

In order to ensure that farmers are well initiated in the drip irrigation scenario, trained scientists in both countries remain on the ground to offer support throughout an entire growing season. With this knowledge, the farmers also learn that they can adjust the recommended amounts of water and fertiliser, when necessary. With this system, they save water, labour and fertiliser expenses and, above all, they are able to grow more food, even at the edge of the desert.

In Mali, the 500 smallholders, mostly women, who participated in the project reported a 37 percent increase in crop yield, a 43 percent reduction in water used for irrigation and a 45 percent increase in income. The increase in yield meant they had enough to feed their families and extra to sell at the market. Looking ahead, Dr Daba Coulibaly established a partnership with Sahel, a collaboration of Mali's University of Ségou and the Institute of Rural Economy (IER), to further expand this drip irrigation initiative to benefit many more smallholders.

In Mauritania, where the project also introduced drip irrigation to hundreds of smallholders, more field sites are currently being set up. Baba Ahmed Ould Naghra, Director of the National Centre for Agricultural Research and Agricultural Development, reported that, with the farmers' cropping possibilities increasing, there are increased employment opportunities, which means young people are more likely to stay in their villages to work instead of

migrating to cities. Habi Ali Niane, president of a local women's cooperative, reported that the women in her village have seen "higher income, more food on our tables and an increase in our productivity," and, because they don't have to travel as often to collect water from faraway wells, it "saves them a lot of time and physical labour."

Mali and Mauritania are just two of 16 African countries that participated in this regional IAEA project, and in all locations, the project has seen the benefits expand as neighbouring farmers recognize improvements in the fields of those participating in the project. According to Justin Diallo, Head of the Statistical Office, Monitoring, Evaluation and Communication at the Regional Directorate of Agriculture in Ségou, "the producers often faced a water problem, especially during the dry season. With the installation of the new drip irrigation system and the training they received, they learned to better manage the water requirements of crops," and, he said, "tomato cultivation, once abandoned, is now making a comeback."

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MOROCCO

Tracing nuclear fallout helps farmers win fight against soil erosion

Over 40 percent of Morocco's agricultural land suffers from soil erosion, in part due to a combination of harsh climatic conditions, deforestation and overgrazing, but also because of poor cultivation methods. Of course, farmers recognize erosion in their fields, when, after rainfalls, they see rills and the accumulation of mud at the foot of slopes, on roads and in the murky water of rivers and reservoirs. But they are often unaware that they may have contributed to the problem themselves or, further, that by making changes in their farming practices, they can improve the situation. Recognizing this, Morocco's National Centre for Energy and Nuclear Science and Technology, working with the Joint FAO/IAEA Centre, set up a research project in northern Morocco using nuclear techniques to quantify and demonstrate the amount of erosion taking place on small hillside farms, and then worked with the local farmers to introduce conservation measures that could slow or stop the erosion now and in the future.

On a small farm located on a hillside in the Tangier-Tétouan region of northern Morocco, El Haj Abdeslam cultivates five hectares of chickpea and cereal. The income from his crops feeds his family of seven and is his sole source of revenue. However, over the years, constant erosion degraded the quality of his land and made his farm less and less productive. At the same time, the eroding soil from his and neighbouring farms often ended up in reservoirs, polluting their water sources and reducing the water storage capacity. And this is just one localized story. Looking at the bigger picture, Morocco's farmers lose more than 100 million tonnes of soil each year while its reservoirs lose more than 75 million m^3 of water storage capacity. And taking it one step further, Morocco is part of a global situation that sees as much as 36 billion tonnes of fertile soil being lost from agricultural systems each year through soil erosion.


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In 2016, Morocco's National Centre for Energy and Nuclear Science and Technology (CNESTEN), working with the Joint FAO/IAEA Centre, set up a research project at Abdeslam's farm where they tracked the presence of caesium-137 in the soil to measure the amount of erosion that had taken place on his sloping land. Caesium-137 first appeared on earth as radionuclide fallout from the nuclear testing undertaken in the 1950s and 1960s. As this particular radioactive isotope was not occurring in soil before those nuclear tests, and because it bound strongly to soil particles where it landed, scientists can now map erosion and sedimentation by monitoring its redistribution. Using this technique provides long-term information about soil erosion rates, which is not possible with other measuring methods, plus this method can trace soil redistribution over large areas.

"Once we knew where the erosion hotspots were, we tested several soil-conservation methods using nuclear techniques to see how we could improve the situation.

We adapted and combined different conservation methods already being used worldwide to see what worked best in Morocco's environmental and agricultural conditions," said Moncef Benmansour, Head of the Centre of Water, Soil and Climate at CNESTEN.

A main goal of the project was to establish a dialogue between scientists and farmers, raising farmers' awareness of the importance of the recommended measures because it is critical that the farmers adopt the research results. That said, farmers in this region survive under harsh environmental and market conditions – they must use all their energy and resources to feed their families, with very little time to plan for the future. Conservation measures may prevent further deterioration of the soil's production potential and yield but, as the positive effects of soil conservation are long term, most farmers will not comprehend the importance of changing their agriculture practices today in order to prevent tomorrow's erosion.

Because the CNESTEN scientists understood this problem with the farmers' acceptance of conservation recommendations, they focused on recommending affordable and efficient measures that would show also short-term benefits. Their recommendations included initiating crop rotation of chickpea and cereals, undertaking no-till cultivation that leaves the crop residues in the field to reduce water from running off and conserve it for the next crop, and dividing the long, cultivated slopes by rows of fruit trees and shrub strips to intercept the water running off the fields. With those three measures, the farmers saw runoff substantially reduced, they could use the saved water for the crops and yields increased immediately. These results had a significant effect on Abdeslam and his neighbours who often face long periods of drought. Now, armed with the knowledge of how to preserve soil and save water, farmers in the area are now very willing to implement the conservation measures the scientists suggested.

"We have now reduced soil loss by 40 percent in the Tangier-Tétouan region and by 60 percent in the Casablanca-Settat region," Benmansour reported. "The Ministry of Agriculture and the High Commission for Water and Forests and the Fight against Desertification are using the project results to expand soil-conservation efforts to more farmers throughout the country."

And El Haj Abdeslam, whose farm has already benefitted from the project, says the results have been monumental, "since the scientists helped me to conserve my soil, my farm has been producing 20 to 30 percent more with less input, and my income has gone up."

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The FAO-IAEA Partnership

The FAO-IAEA partnership, through the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, is a powerful example of interagency cooperation, unique in the UN family – a fusion of complementary mandates, common targets, joint programming, co-funding and coordinated management. Its close cooperation with both parent organizations has brought with it greater efficiency and shared approaches, responding to the needs of Member Countries and providing services and results to them and the international community at large.

The Joint FAO/IAEA Centre's activities are carried out through two major delivery mechanisms: coordinated research projects and technical cooperation projects. Coordinated research projects are funded by the Joint Centre's regular budget and are implemented through global research networks; technical cooperation projects are funded by the IAEA's technical cooperation programme through voluntary contributions from Member Countries to carry out technology transfer and capacity building.

A key strength of the capacity building, technology transfer and research tools supported by the Joint Centre derives from the intimate links between on-ground demand and adaptive research, as well as between institutions and farmers in Member Countries. This facilitates continuous feedback between R&D activities and field validation, as well as remedial action, if necessary, at any stage in the capacity building and technology transfer process.

Through its focus on nuclear applications in food and agriculture, the Joint Centre provides dedicated solutions that contribute towards national, regional and global attainment of the Sustainable Development Goals.

- Improved mutant varieties to increase farmer income and livelihoods
- Superior irradiated vaccines to reduce livestock mortality and increase productivity
- Sustainable market access through increased and validated food quality
- Support technologies to counter global threats of pandemics to modern food systems

- Mutation breeding to improve crop yield and enhance nutritional value
- Sterile insects to reduce food loss caused by major insect pests
- Radioimmunoassays to improve livestock nutrition and production

- Improved water and nutrient use efficiency to reduce water pollution and scarcity
- Minimized agrochemical runoff in agriculture to ensure safe drinking water
- Optimized agricultural practices in water-related ecosystems for effective water management

- Irradiation technology to reduce post-harvest food loss and minimize food waste
- Monitoring residues in foods to ensure food safety
- Monitoring chemical residues and contaminants in foods to ensure food safety

- Minimized greenhouse gas emission to strengthen climate resilience
- Improved crop varieties to strengthen adaptability to climate change
- Control of transboundary animal and plant diseases under changing climatic environments
- Sterile insect techniques to control insect pests invading in previously inhospitable areas

- Radio- and stable isotopes to assess soil erosion and combat land degradation
- Mutation induction to increase plant biodiversity
- Remediating impact of nuclear and radiological contamination

- Coordinated global research network for nuclear science and application in agriculture
- Enhanced international support to implement targeted capacity-building
- Increased collaboration with global stakeholders to support sustainable development goals

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