Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Plant Breeding & Genetics Newsletter

https://www.iaea.org/topics/plant-breeding
https://www.fao.org/agriculture/fao-iaea-nuclear-techniques/en/

ISSN 1564-2569

No. 53, July 2024

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To Our Readers

Cover design: Mauricio Godoy, IAEA

I am honored to address you as the Acting Section Head for Plant Breeding and Genetics (PBG) within the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture.

The PBG Section has been actively involved in major events and R&D activities through Coordinated Research Projects (CRPs) and has continued to provide strong support to the IAEA Technical Cooperation programme. We have engaged in five CRPs, partnered with 81 organizations across over fifty countries, aiming to develop and adapt new technologies and innovative solutions, tools, and techniques in the application of nuclear and advanced technologies for crop improvement. These collaborations include universities, national agricultural research systems, and other international organizations.

As of January 2024, the new cycle of technical cooperation projects (TCPs) has commenced. The PBG Section currently provides technical support to 56 active TCPs at national, regional, and interregional levels across more than a hundred Member States. Our efforts during the first half of 2024 have focused on transferring technology to Member States and sharing knowledge, with an emphasis on applying nuclear and advanced technologies for crop improvement, food, and nutrition security.

Through the TCPs and CRPs, mutation breeding and biotechnologies have been successfully applied in crop improvement, contributing significantly to food and nutrition security worldwide. I am pleased to share one of our Member States' success stories as an example: in Viet Nam, mutation breeding has led to increased productivity in rice and soybean. Currently, mutant rice varieties are cultivated on 3.5 million hectares, resulting in a yearly increase in farmers' income of hundreds of millions of USD. Notably, the mutant rice variety VND-95-20 covers approximately 30% of the total cultivated area of 1 million hectares in the Mekong Delta. For soybean, it is estimated that 60 to 70 percent of the total cultivated area in the country is planted with mutant varieties. There is a preference for high-yielding, short-duration varieties, with the mutant variety DT 2008 being cultivated by approximately 1.5 million farmers.

The United Nations General Assembly declared 2023 the International Year of Millets (IYM 2023) during its 75th session. The FAO led the celebration in collaboration with other relevant stakeholders. As part of this initiative, the PBG Section within the Joint FAO/IAEA Centre launched a new Coordinated Research Project (CRP) focused on the accelerated genetic improvement of key dryland millets for climate change adaptation. This project spans five years, from 2024 to 2028. The project has established a strong partnership, leveraging expertise from various countries, including universities, national research systems, and other international research organizations. The main objective is to develop technology packages utilizing advanced technologies such as genomics and gene editing to accelerate genetic gain and improve millets, with a focus on biotic/abiotic stress resistance and enhanced nutritional qualities.

The FAO hosted the closing ceremony of the International Year of Millets 2023. I had the opportunity to attend a roundtable discussion on 29 March 2024, at FAO Headquarters titled "Research and Development for the Millet Sector". During the discussions, I emphasized that strengthening research capacity and developing innovative farming technologies through research projects are essential steps toward enhancing the productivity of small-scale farmers.

The PBG Section has played a pivotal role in spearheading several successful knowledge-sharing initiatives and events (Page 14). Notably, we organized the highly commended International Technical Webinar titled "Enhancing Agrifood Systems through Climate-Smart and Nutrition-Dense Crops" in collaboration with the FAO Regional Office for Asia and the Pacific. This webinar showcased cutting-edge approaches dedicated to fostering climate-resilient crops with enhanced nutritional value. With participation exceeding 130 attendees from various global sectors, the event underscored our commitment to promoting innovation and collaboration in agricultural development.

We have continued to support Member States in managing fusarium wilt disease through several projects and activities. During the week from 22 to 26 April 2024, the PBG Laboratory (PBGL) hosted a hands-on training course on Fusarium TR4 diagnostics for Common Market for Eastern and Southern Africa (COMESA) countries, in collaboration with the International Plant Protection Convention (IPPC). Concurrently, we organized the second coordination meeting of the CRP on an integrative approach to enhance disease resistance against Fusarium Wilt (*Foc* TR4) in bananas. This provided an opportunity for a joint session with both CRP participants and training attendees. Discussions focused on mutation induction and its application in improving disease resistance in bananas, the development of simple molecular detection methods for field use such as mini-PCR and LAMP, and the isolation of beneficial microbial strains for evaluating their biological control activity against *Foc* TR4.

Research at our laboratory reports important outputs in this regard, especially in relation to the Peaceful Uses Initiative (PUI) project, "Enhancing Climate Change Adaptation and Disease Resilience in Banana-Coffee Cropping Systems in East Africa". The Mchare mutant population previously reported undergoing field trial in hot spot in Tanzania for resistance screening to *Foc* Race 1 have not shown any external *Foc* symptoms in over 45% of the test mutants so far (58 weeks), We expect the number to drop during final evaluation when scoring for Rhizome discoloration (RDI) as some varieties express internal symptoms more clearly than external symptoms.

Recently, we have developed *Foc* TR4-specific probe-free digital droplet PCR (ddPCR) assays to detect and quantify *Foc* TR4 from symptomatic and asymptomatic plant tissue with greater sensitivity and at lower costs. This probe-free ddPCR approach not only enhances cost-effectiveness but also offers exceptional sensitivity and detection levels in low-abundance infected samples. Moreover, PBGL continues to build on our previous work using ddPCR-based rare mutant detection assays in available sorghum mutant lines. Upon subsequent validation of these easy-to-use allele-specific markers, we are pleased to report the development of single nucleotide polymorphism (SNP)-based KASP (Kompetitive Allele Specific PCR) assays for genetic association studies.

We are currently planning to organize a Mutation Breeding Network Meeting from 22 to 26 July 2024, which will include a one-day session on Plant Health Lab and Network. The aim of this meeting is to foster coordination and partnerships with relevant regional and international organizations to enhance responses to transboundary diseases, facilitate germplasm exchange (including unique genetic resources), and leverage nuclear and advanced technologies for crop improvement.

As previously reported, we have initiated a feasibility study on seed irradiation in space to induce genetic diversity and expedite plant mutation breeding. This study investigates the effects of microgravity, cosmic radiation, and extreme temperatures on Sorghum bicolor and *Arabidopsis thaliana*. Currently, Sorghum seeds have shown an increase in the M1 generation in the greenhouse. In the case of Arabidopsis, we are currently in the M2 generation, where DNA structural variations are being initiated to compare the effects of chronic cosmic radiation, X-rays, and gamma rays. Furthermore, Arabidopsis will be further investigated for adaptation to temperature and salinity stress.

I am delighted to share with you that two of our books have been published online as Springer books (page 39): "Mutation Breeding and Efficiency Enhancing Technologies for Resistance to Striga in Cereals" and "Mutation Breeding in Coffee with Special Reference to Leaf Rust Protocols". These books were prepared by previous CRP collaborators. This achievement not only underscores our commitment to advancing crop improvement but also serves as a testament to the collaborative spirit that defines our work.

As you know, on 18 October 2023, the IAEA Director General Rafael Mariano Grossi and the FAO Director General QU Dongyu launched the Atoms4Food Initiative. We are excited about this development and invite partners, collaborators, and Member States to join us in establishing partnerships. By leveraging the power of science and technology collectively, we can boost innovations that unlock the full potential of crops, thereby contributing to food security, poverty alleviation, and the cultivation of sustainable, nutritious crops. This will ultimately transform agrifood systems for better production, better nutrition, a better environment, and a better life worldwide.

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Staff News

Welcome

Ms Susu Alkier (Austria) re-joined PBGL in March 2024 as a laboratory technician. After her internship at PBGL in 2021, she interned at the Austrian Ministry of Agriculture and pursued her online master's in Plant Breeding with a thesis on seaweed at Wageningen University & Research, adding to her master in Agricultural and Food Economics at BOKU University in Vienna, Austria.

Ms Friederike Trognitz (Germany) joined PBGL in May 2024. Friederike studied Plant Breeding and Seed Production in Halle, Germany and began her career by working on potato breeding in Germany. For ten years, she lived with her husband in Lima, Peru, working for the International Potato Center (CIP), and spent the last three years researching resistance to late blight in potatoes at the molecular level. When she came to Austria, she completed her doctorate in Molecular Biology at BOKU University in Vienna, Austria and at the Austrian Institute of Technology (AIT) on the resistance of wild potatoes to late blight.

Over the past ten years, she has worked at the AIT on the beneficial interaction between plants and microbes. She was interested in the biological control of fungal diseases in wheat and potatoes. Friederike conducted laboratory screenings and field trials to find the best candidates for biocontrol. By performing whole genome sequencing of selected strains, she tried to understand the mode of action.

At PBGL, Friederike will create a collection of microbial strains from selected plants. The strains will then be used to test their suitability for suppressing plant diseases such as Fusarium in bananas. The best strains will then be subjected to irradiation to determine whether their biological control abilities can be improved.

She is looking forward to working with IAEA staff and PBGL in particular to share her knowledge of microbes for sustainable agriculture.

Feature Articles

Millets: The Climate-Resilient Solution to Global Food Security Challenges

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Agriculture is facing the challenge of feeding the ever-growing population that is projected to reach ten billion by 2050. While improving crop yield and productivity can address this challenge, the increasing effects of global warming and climate change seriously threaten agricultural productivity. Millets, hardy dryland crops that can grow with minimal inputs in Asian and African countries, are gaining popularity for their nutritional qualities, and therefore are an ideal solution for countries to increase self-sufficiency and reduce reliance on imported cereal grains.

Millets are recognized among the most ancient food grains domesticated for food. The earliest evidence of their cultivation found in the Indus civilization dates back to 3,000 BC. They are currently grown in 131 countries over 74 million ha spread across the globe but are largely concentrated in Asia and Africa. These include three major millets i.e., pearl millet *(Pennisetum glaucum L.)*, sorghum *(Sorghum bicolour)* and finger millet *(Eleusine coracana L.)*; five minor millets i.e. foxtail millet *(Setaria italica L.)*, proso millet *(Panicum miliaceum L.)*, kodo millet *(Paspalum scrobiculatum L.)*, barnyard millet *(Echinochloa frumentacea L.)*, little millet *(Panicum sumatrense L.)*; and two pseudo millets i.e. buckwheat (*Fagopyrum esculentum* Moench) and *Amaranthus* species.

India, Sudan, Niger, Nigeria, and Mali are the top five countries cultivating different millets and jointly account for 47% of the total millet area. The top millet-producer countries are India, the United States, Nigeria, China, and Ethiopia contributing 53% to millet production. Millet's cultivation has witnessed vast changes during the last six decades. Like other crops, there is an enhancement in their productivity from 0.7 t/ha in 1961 to 1.3 t/ha in 2020 registering an increase of 73% due to the development and adoption of new cultivars and agronomic production technology (FAOSTAT, 2023). However, the area under millets declined by 21% during the last six decades. Despite this, millet production has still gone up by 34% due to a tremendous increase in the mean productivity during the period from 1960 to 2020.

Millets are well known for their adaptation to dryland agro-ecologies of the arid and semi-arid tropics and are produced in regions characterized by low to moderate rainfall (200-600 mm) and high maximum temperatures (42-46°C). Millets also possess a good ability to adapt to marginal lands and soils with low fertility. Therefore, there is a renewed interest in millet production, for several reasons. Firstly, millets have an in-built tolerance to water stress and supra-optimal temperatures due to their morpho-physiological, molecular, and biochemical characteristics that confer upon them better tolerance to environmental stresses than the major cereals. Secondly, millets are highly nutritious, with high calcium, iron, potassium, magnesium, and zinc contents, besides other essential nutrients such as vitamins, amino acids, and fatty acids. Thirdly, being C4 crops, millets have greater potential to utilize atmospheric CO_2 for biomass accumulation per unit of water used and thus are recognized as crops with low carbon- and water footprints. Because of these attributes, millets are considered "climate-smart crops", and thus can play a vital role in the livelihood of the poor and malnourished populations, provide food and nutrition security, and help achieve the first three sustainable development goals of the United Nations i.e., reducing poverty, zero hunger, and good health and well-being.

Millets are the primary source of energy in the semi-arid regions and drought-prone parts of Africa and Asia. Millets have much higher genetic variability for essential minerals including zinc, iron, and calcium when compared to other cereal crops. Pearl millet, which has been biofortified with high Fe, offers twice as much iron as contemporary wheat varieties. A recent study reported that students in Indian schools who received 232g of Fe biofortified pearl millet flour daily had a 65% decrease in their iron deficit (Pompano et al. 2022). Promoting millet consumption would remain the key issue for increasing their demand in the market as food, feed, and industrial raw material through government policies, awareness programs, and as an effort to diversify the agri-food production system. Strengthening of value-chain of millets will ensure sustainability and help create an ecosystem for millet promotion.

Now, increased emphasis is required on genetic improvement to develop new cultivars, using new tools and technologies. Large germplasm collections (>137,000 accessions) of millets are available in the international and national gene banks and adequate genetic variation has been reported for various agronomic traits. Diversification of the genetic base, discovering new traits conditioning tolerance to multiple biotic and abiotic stresses, and greater yields are essential to make millets more adapted and productive to challenging production environments. The efficiency and precision of breeding can be enhanced through the development and application of high-throughput genomic tools, precision phenotyping, and rapid generation advancement (RGA) protocols.

The progress made in the genomic resource of millets has taken a good pace in the recent past. The complete genomes of sorghum, pearl millet, finger millet, and foxtail millet have been made available, while proso millet has seen a significant increase in genomic research and the creation of a reference genome, and other small millets, such as little millet and kodo millet, have little genomic resources. These developments in genomic resources coupled with the availability of high throughput phenotyping facilities now offer opportunities to rapidly map and deploy genes of agronomic importance and to rapidly sequence lines to mine and map genes of interest. The other recent tool is the rapid generation advancement technique, which may produce up to three to four generations of millets each year. When used with the full suite of breeding acceleration techniques, RGA can make it possible to take four crop cycles in a year (https://www.icrisat.org/first-public-research-facilityto-put-agriculture-on-fast-forward-launched-at-icrisat/). With such new facilities in place, we can now move towards the new era of speed breeding in millets where genetic gains are poised to take a further leap.

So far, millets varieties have been developed mainly through conventional breeding methods. The yield barrier in small millets can be broken by a male sterility system and exploiting heterosis, and genomics-assisted crop improvement, together with better crop management and mechanization. Genomics assisted breeding will facilitate the identification of novel alleles and genes with superior agronomic performance and resistance to biotic and abiotic stresses to accelerate small millets improvement. Biotechnology techniques such as tissue culture and genetic engineering reported in related crops could potentially support small millets improvement. The rapid development of sequencing technologies can generate millions of sequences reads at a low cost and in a short time irrespective of whether there is prior sequence information or not. Next generation sequencing techniques enable the molecular characterization of an entire set of small millets germplasm. These techniques could be used in crops such as little millet, kodo millet, and job's tears where genome decoding has not yet been done. Similarly, comparative genomics facilitates the exploration of orthologous genes of important traits in less studied crops with available genome sequence information from rice and foxtail millet. The emergence of genome editing techniques allows the modification of the genome of small millets to enhance production and stress tolerance.

Millets possess complex genomes, with traits often controlled by multiple genes and influenced by various environmental factors. The presence of undesirable genes or "linkage drag" may be associated with desired traits, making their selection and incorporation into new varieties challenging. Mutation breeding, a form of non-transgenic genetic improvement, offers a valuable approach to enhancing small millets. It induces novel genetic variations, offering a wider range of traits for selection. This increases the chances of obtaining desirable traits such as improved yield, disease resistance, drought tolerance, nutritional quality, and adaptability to specific agro-climatic conditions. Gamma irradiation is envisioned as the primary mutagen, but other radiation sources may be explored (X-ray, ion beam). Induced mutation has been hugely successful in crop breeding in seed propagated and vegetatively propagated crops including 3,283 mutant varieties from around 228 crop species. Thus far, 1621 cereals including 24 millet, 18 sorghum, 13 buckwheat, 5 pearl millet, 3 amaranthus, 2 finger millet, and 1 foxtail varieties have been developed - Mutant Variety Database - Home (iaea.org). Several scientists and papers highlighted the importance of mutation breeding in millets as hybridization is very difficult due to small flower size in most of the millets. Mutation breeding has been intensively applied in India and 13 small millet mutant cultivars in finger millet, kodo millet and little millet were released (Vetriventhan et al 2020). Additionally, Jency et. al. 2020 results highlighted that induced mutagenesis enhances lodging resistance and photosynthetic efficiency of kodo millet.

In addition to conventional breeding and genomics-assisted improvement, a comprehensive and coordinated transdisciplinary collaboration across the agronomy, biomedical, food science and technology areas is required in order to shift the status of small millets out of 'minor and underutilized' crops' group. Additionally, public–private partnerships, public awareness, farmers' engagement across the countries who are interested in small millets research and promotion will be needed to incorporate small millets-based food products as an important source of nutrients in diets. Given the changing climate scenario and prevailing hidden hunger, greater research, and developmental focus on small millets (and other traditionally important crops) is the key to achieve food, feed, and nutrition security.

Beyond genetic improvement, the new millet cultivars are to be brought into the seed production chain to augment productivity in farmer's fields. The farmers' average yield of millets is 22-44% lower than the yield realized at the demonstration on the farm. Hence, the immediate goal could be to bridge the existing yield gaps. The productivity of all millets can be easily increased from their current levels of productivity which would require integration of water conservation, adopting the newest high-yielding crop cultivars, integrated nutrient management, and integrated insect-pest and disease management. There is a need for all relevant stakeholders viz. agriculturists, policymakers, academicians, researchers, and industry players to combine all elements of production, farm-level storage, primary processing, procurement, storage, transportation, secondary processing, and consumption to help evolve a roadmap for a millet value-chain for the revival of millets. Such a millet value-chain-based revolution will ensure sustainability and help in creating an ecosystem for millet promotion. Millets have gained a great focus at the global level in 2023, as the year was celebrated globally as the 'International Year of Millets' to create awareness about millets to eventually promote their consumption and production, and such efforts have already initiated opportunities to make millets more productive, competitive, and relevant to future farming.

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Millets in Africa: Importance, Challenges, and Potential for Innovation

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Millets are gluten-free, high potential, niche opportunity crops due to their climate resilience, rich nutritional compositions, various health benefits, and extended grain storage quality. In sub-Saharan Africa (SSA), millets lack formal R&D support and funding for improvement, product development and marketing. There is a lack of modern varieties, crop management practices and market access for millets. There is a need for coordinated R&D for genetic enhancement and pipeline pre-breeding and breeding programs to enable the deployment of high-performing and market-preferred varieties through integrated crop improvement programs to realize the full potential of African millets.

Socio-economic importance of millets

Africa is endowed with several value-adding indigenous genetic resources such as pearl millet (*Pennisetum glaucum* [L.] R. Br.) and finger millet (*Eleusine coracana* [L.] Gaertn.). Millets are under-utilized and under-researched ancient crops supporting more than 500 million people in SSA and Asia. Millets are cultivated across 75 countries globally, spanning an area of 33 million hectares (FAOSTAT, 2022). Annual millet production reaches 32.8 million tons globally, with Africa accounting for 42% of production. The grains are used for food (e.g. to prepare bread, couscous and porridge), malting (e.g. distilled spirits, local beers and non-alcoholic beverages) and feed (e.g. livestock and poultry) (Rani et al. 2024). The stalks are used for livestock feed, thatching of houses and fuel. Almost all millet is produced by smallholder farmers for household use in South Saharan Africa.

Millet grains are gluten-free and has a low glycemic index. The grains have high phenolic compounds that are not found in fruits, vegetables, and other grains. Also, the grains are rich in protein, calcium, phosphorous, and iron and contain a relatively high amount of thiamine, riboflavin, and niacin. Therefore, regular consumption of millet lowers the risk of diabetes and obesity, anemia, constipation, cancer, celiac, treatment for diarrhea improves cholesterol levels and reduces the risk of cardiovascular diseases. Grain millet is an excellent source of essential nutrients than maize, wheat, oat, and rice. Thus, millets present an alternative and value-adding crop for food security and economic development across the value chains in drier regions of SSA.

Constraints to millet production

Millets are grown in over 75 countries worldwide, including 27 African countries in Eastern, Western and Southern Africa. SSA has a high demand for millet grains, which is met through local production and informal regional trades. The total area and production of millets are not well known because the data from pearl millet, finger millet, and other minor millet types are reported together. Moreover, millets genetic gains for yield and balanced nutritional compositions of millets are low due to the limited research and development support compared with the major staple crops. Also, there is no product development or commercialization of millets in the region. Limited formal trade and lack of established value chains and value-addition contribute to low commercialization of the crop despite the unique dietary and health benefits.

Millets are climate-smart crops that adapt to grow under harsh and marginal conditions in semi-arid and tropical regions of Africa and Asia. The crops have C4 photosynthesis system, allowing them to become water and radiation efficient. Therefore, millets are cultivated in drought-prone environments, infertile, poor, and saline soils with extreme temperature conditions and low crop failure risk, resulting in lower crop productivity (< 1 ton/ha). Furthermore, millets production in SSA involves the largest and poorest individuals who are food insecure, with rampant malnutrition and reduced welfare outcomes (Kheya et al., 2003).

In SSA countries, farmers still use unimproved traditional varieties or landraces, which are low yielders, far below the crops' potential yields (4 to 6 t/ha, even higher). Additional production challenges of millets are bird damage, diseases (e.g. anthracnose, blast, mildew and smut), insect pests (e.g. grasshoppers, shoot fly, pink stem borers, aphids, and fall armyworm), and parasitic weeds (e.g. *Striga* species). For instance, downy mildew disease of pearl millet caused by *Sclerospora graminicola* (Sacc.) Schroet, is the most widespread and destructive disease of pearl millet in Western Africa and India. Severe and early-onset and post-flowering drought stress and extreme temperatures associated with climate change often cause crop failures. Lack of production inputs and resources and poor market access are additional challenges.

Globally, only a few improved finger millet and pearl millet varieties have been released for consumer-preferred traits. There is a need for coordinated breeding and genetic innovations and the development of technologies to unleash millet's true potential for yield and nutritional value. High grain yield, tolerance to biotic and abiotic stresses, early maturity, desirable seed color, compact head type, threshability, end-use quality, bird damage tolerance, and high marketability are preferred traits by millet growers and consumers.

Potential for innovation

Almost all millet improvement programs in SSA focus on conventional breeding for pure line selection through germplasm introduction, collection, characterization, selection, and variety recommendation. Minimal research has been conducted on variety development through trait integration using controlled crosses, mutation breeding, genomic-assisted breeding, tissue culture, and proteomic tools. Investing in robust millet improvement is vital to accelerating its breeding progress and agronomic management practices to enable its potential to address food security challenges in Africa (Ndudzo et al., 2024).

Demand-led millet breeding has to respond to the demands of the clients and the market for higher adoption. Conventional and mutation millet breeding delivers good seeds for food security and climate change adaptation. Boosting the production and productivity of millet in SSA effectively reduces poverty and enhances local, regional, and international trade. This can be achieved through improved millet technologies and innovations (e.g. climate resilient, disease and pest tolerant, nutritious and market-preferred varieties and modern crop management methods). The new technologies can directly impact food production, food security, human well-being, and local, regional, and global trade. These technologies will transform agriculture at small- to medium-sized family farms and commercial farms. The value chains of millets involve farmers or farmers associations, seed multiplication farmers, traders, consumers, and research programs, including National Agricultural Research Systems (NARS), universities, and international R&D partners.

Substantial amounts of millet genetic resources (cultivated and wild types) are maintained by different gene banks useful in variety design and product development with end-user preferences. The long-term availability of these genetic resources requires germplasm enhancement, utilization, and conservation, which requires funding, international collaboration, and partnerships. The genetic variability can be harnessed further to integrate essential traits into candidate varieties through conventional and mutation breeding methods. Breeding and genetic innovations such as genomics-assisted breeding, mutation breeding to create more genetic variability and genome editing would accelerate millet breeding and new variety design and deployment.

There is a need to explore and enhance the male sterility system as an essential strategy for developing hybrid seeds in millets. A limited number of functional genes, QTLs, molecular markers linked to various economic traits are reported in millets. Published reference genome can be employed in millet breeding programs. Concurrently, enhancing genomic research and capacity development is required in the NARS and Universities involving international collaborators. There is a need to develop new climate-smart millet cultivars tolerant to biotic and abiotic stresses and rich in nutritional value that meet consumers' needs and market demands. Therefore, current, and future millet improvement programs should integrate yield, nutritional value-attributing traits and local adaptation. This can be achieved by integrating conventional and mutation breeding methods with advanced genomic techniques such as marker-assisted selection, genomic-assisted breeding, and genome editing.

Future Perspective

Mutation breeding is an alternative method for genetic enhancement for millet breeding and genetic analysis (Ganapathy et al., 2021). Pearl millet is a cross-fertilizing crop, while finger millet has small bisexual cleistogamous florets, making artificial emasculation and pollination tedious and time-consuming for genetic recombination and selection. The International Atomic Energy Agency (IAEA), through its Coordinated Research Projects (CRPs) mobilized selected millet research institutions in Africa to collaborate on millet research projects of common interest areas. The CRPs in Africa foresees millet as a critical crop for building the future of African agriculture. Millets' demand, scale, and scope as commodity crops to derive products and market opportunities across the value chains require a coordinated research program for new partnerships. This will expand opportunities and transform the public and private millet breeding and seed sectors. Millet coordinated research program is a flagship program that will attract considerable interest within Africa and internationally.

Coordinated millet research and development in Africa will advance the breeding and dissemination of new millet varieties that respond to farmer needs and market demand, based on demand-led principles with emphasis on pearl millet and finger millet, crops that are under-utilised or under-valued, but which have potential benefits, such as climate resilience, nutrition, trade or value-added products. The CRP on African millets will support the goals of the NARS, universities, and private sectors across all value chain members in advancing millet production by large numbers of small-scale producers in several countries. The CRP involves eastern, central, western and southern African countries, including South Africa (African Centre for Crop Improvement [ACCI] of the University of KwaZulu-Natal), Namibia (Directorate of Agricultural Research and Development, Ministry of Agriculture, Water and Land Reform), Burkina Faso (Institute of Environment and Agricultural Research [INERA]), and Ethiopia (Ethiopian Institute of Agricultural Research [EIAR]). The CRP will involve flagship projects that will significantly contribute to transforming the millet industry in Africa and internationally.

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Innovations of Millets in China

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Introduction

Foxtail millet and broomcorn millet are climate-resilient crops that thrive in arid and infertile conditions, making them ideal for grain production in low-productivity regions of China. Annually, China cultivates 1.4 million hectares of foxtail millet annually, accounting for 80% of the global planting area and 90% of its total production. Additionally, China's broomcorn millet is grown on 0.6 million hectares each year, representing 30% of the global planting area. These grains are primarily cultivated as sustainable crops in the drylands, barren lands, and saline-alkaline soils common in Northern, Northwestern, and Northeastern China.

The Importance of Millet Breeding in China

The domestication of foxtail millet (*Setaria italica [L.] Beauv*.), derived from the wild green foxtail (*Setaria viridis [L.] Beauv*.), can be traced back to approximately 16,000 years. (*Panicum miliaceum*) holds the distinction of being the cereal with the longest history of cultivation in China, as evidenced by archaeological findings from northern China.

It is believed to have been domesticated from *Panicum ruderale (Kitag.)* in northern China or neighboring regions of East Asia around 8000 BC.

Chinese researchers have made noteworthy strides in both breeding and theoretical research on the inheritance of key morphological traits, water usage, growth physiology, and cultivation techniques. These efforts and their outcomes have been meticulously documented in several publications. Through the analysis of population structure using simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers, the global foxtail millet germplasm has been distinctly categorized into spring-sown and summer-sown types, correlating with their geographical distribution. The genetic diversity of foxtail millet is found to be on par with that of rice. Following the publication of the reference genome of foxtail millet, a haplotype map was constructed based on 0.85 million SNPs identified from sequences of 916 varieties worldwide. Additionally, 512 quantitative trait loci (QTL) were identified across five environments. An ethyl methane sulfonate-induced mutation library was established, and several critical genes were isolated and characterized. The inaugural International Setaria Genetics Conference (ISGC) was held in Beijing in 2014, significantly boosting Setaria's status as a model organism. Consequently, both foxtail millet and green foxtail have garnered increasing attention from researchers globally.

Challenges in Enhancing Millet Production in China

Foxtail millet holds a special place in the Chinese agricultural landscape, predominantly consumed as food. The market places a high premium on quality, particularly traits such as carotenoid content, palatability, and ease of cooking, which significantly influence consumer preferences. Breeders and cultivators are acutely aware of these attributes, and their quality is pivotal in determining the suitability of varieties and cultivation techniques for the industry. Currently, the millet varieties are predominantly characterized by loose plant types with low population densities, which largely contribute to their relatively low yields. Additionally, breeding for herbicide resistance and developing mechanized, simplified cultivation methods are paramount for enhancing the efficiency of industrial production. The crude protein content of millet straw can exceed 13%, earning it recognition as a high-quality forage grass within the Gramineae family. Looking ahead, forage millet harbors vast market potential.

The lack of outstanding breakthrough in germplasm innovation and insufficient reserve of backbone parents are issues that need to be addressed in the development of new foxtail millet varieties:

(1) **Germplasm for Dense Planting**: Effective germplasm must combine reasonable plant type with outstanding stress resistance. This includes erect and compact morphology paired with disease and pest resistance, shade tolerance, and efficient use of water and fertilizer. Improving the erect and compact plant type can enhance ventilation and light transmission under dense planting conditions, increase photosynthetic efficiency, and reduce disease and pest incidence.

(2) **Resistance to Lodging**: Lodging resistance remains a challenge in foxtail millet production. Dwarfing breeding is an effective strategy to address this issue, as shorter plants are less prone to lodging.

Potential for innovation in Millets in China

In the long-term goals for the development of the foxtail millet and broomcorn millet industries in China, it is essential to evaluate and deeply analyze the genetic background of the core resources of these two crops. Additionally, the development of high-throughput and precise phenotyping identification technologies under production environment conditions is crucial. Analyzing the molecular basis of important trait formation and constructing efficient gene editing technology, whole-genome selection technology, and intelligent design breeding technology are key components in comprehensively improving the quality and level of breeding.

Carrying out technological innovation and integrating intelligent, information-based, green, and efficient production methods for foxtail millet and broomcorn millet is the basic guarantee for improving production levels and industry development.

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Millets in the U.S.A.: Importance, Challenges, and Potential for Innovation

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Millets are small-seeded annual cereals cultivated worldwide as food, feed, fodder, and fuel, and include finger (*Eleusine coracana*), pearl (*Pennisetum glaucum*), proso (*Panicum miliaceum*), kodo (*Paspalum scrobiculatum*), foxtail (*Setaria italica*), little (*Panicum sumatrense*), barnyard millet (*Echinochloa esculenta*), etc. Millet crops are resilient grains that thrives in semi-arid rain-fed conditions, primarily grown in Asia and Africa, and they are characterized by less water and fertilizer demanding than many other common cereals. Millets are gaining popularity in North America due to their nutritional benefits and adaptability to diverse climate conditions. With the renewed interest and emerging markets for millets, there is a need to breed new varieties to achieve the potential yields and also to meet future demands.

Globally, millet crops are emerging as a key solution for sustainable farming and food security. Millets can be categorized into two primary types: (1) major or naked grains and (2) minor or husked grains. "Naked grains" include sorghum (*Sorghum bicolor*), pearl millet, and finger millet, which lack a tough, indigestible husk. After harvest, these millets require minimal processing and are ready for consumption. In contrast, "husked grains" refer to millets like proso, foxtail, and barnyard, which possess an inedible seed coat and therefore require 'dehulling' (removing husk) before consumption. Millets offer a powerhouse of nutrition, have a high fiber content, and are naturally gluten-free, all advantages as a food source and for consumers with certain dietary restrictions. The seed contains high levels of micronutrients such as calcium, iron, and phosphorus. Millets are slowly metabolized, preventing a sharp rise in blood sugar; therefore, incorporating millet into the diet has been suggested for diabetes prevention and management. The high protein content of millets makes them an ideal choice for vegetarians and vegans in the U.S., Europe, and the Asia-Pacific region.

Millets are known for their drought tolerance and resilience, but different species have different origins and adaptability. Overall, millets are emerging as a crucial solution to safeguarding food security amidst changing climatic patterns, thanks to their ability to withstand extreme heat and drought. Millets are versatile because they support quick forage production, facilitate double cropping, and catch cropping, and promote cover crop practices. Farmers can diversify their practices using millet in rotations, minimize crop losses, and enhance soil conservation. Introducing millets as part of crop rotation could improve soil health and increase biodiversity, but farmers would need guidance and support for effective implementation. Policy revisions to incentivize diversification and sustainable practices are needed to address this barrier for the introduction of new crops such as millets into the existing cropping systems. Since millets are not as widely recognized or consumed as grains like wheat and corn, they require significant marketing and educational campaigns to build consumer awareness and demand. The existing agricultural infrastructure in the US, with its specialized equipment, processing facilities, and distribution networks, is tailored for current major crops. Adapting this infrastructure for millet production may necessitate new investments.

Further research and development are needed to optimize millet varieties for different US regions, improve agronomic practices, and innovate processing technologies. This advancement will require investment in agricultural research and extension services. Policy revisions to incentivize diversification and sustainable practices are needed to address this barrier to introducing new crops into the cropping system.

The U.S.D.A.'s Germplasm Resource Information Network (GRIN) maintains and distributes millet crops suitable for the U.S. production regions. University programs, for example in Kansas, Nebraska and Georgia, work on germplasm characterization and breeding. Small companies are also active in millet research and breeding. However, additional efforts are needed to develop genetic diversity and new and improved cultivars for farmers. Recently, Iowa State University initiated a finger and proso millet breeding program (Fig. 1).

Figure 1. Field and greenhouse images of millets in Iowa State University, Ames, USA.

Tremendous opportunities exist for developing millet varieties suited to the U.S. agroclimatic conditions. A coordinated effort is needed among breeders, agronomists, physiologists, pathologists, and molecular geneticists, among other disciplines, to produce improved germplasm and prepare farm-ready varieties. It is also necessary to identify suitable growing regions and planting windows to expand this crop into new areas, which is crucial to unlocking its full potential. Appropriate farm management and production research are required, and continued efforts to build the value chain are critical. Millet research and breeding will benefit from knowledge from other crops, and principles of cyber-agricultural systems can be easily integrated for a rapid innovation. Millets provide a unique and exciting opportunity for U.S. agriculture.

Proso millet production and industry in the USA

Proso millet is the only millet in the United States of America (USA) that is commercially grown for grain (Fig.2A). Foxtail millet (also known as hay millet) and pearl millet are the other two millets, which are grown for forage in the USA. Kansas State University has a pearl millet breeding program; however, there is no commercial production of grain pearl millet currently in the USA. Proso millet is reported to have been domesticated about 10,000 years ago in central and Eastern Asia. Proso millet is known as millet and hog millet in the U.S., broomcorn millet in China, common millet in Japan, Korea, and other Pacific Asian countries, 'Hersey' millet in Germany, and French white in France. It is widely cultivated in India, China, Nepal, Africa, Russia, Ukraine, Belarus, Middle East, Turkey, and Romania. Proso millet is grown primarily in the semi-arid central High Plains of the USA (Fig.2B). It is the most important rotational crop in the winter wheat-based dryland farming system in this region because of its low water requirement and short-growing season. Proso millet is very critical for sustainable wheat production in the region because when used in a wheat-based rotation, it improves wheat productivity in several ways (e.g. preserving deep soil moisture for wheat, controlling winter annual grass weeds in winter wheat, reducing disease and insect pressure). Although it can be grown in most of the United States, about 80% of proso millet acres are in three states Colorado, Nebraska, and South Dakota (Fig.2C).

A B C

Fig 2. (A) Proso millet in Nebraska, (B) Semiarid High Plains of the USA, and (C) Proso millet production region in the USA.

In the US, millet production varied significantly depending on years and market price. Below is the trend of proso millet production in the USA during the last 10 years (2014-2023) based on USDA-NAAS data.

- Total Areas of production average: 192,551 hectares (157,895 – 268,551 ha)
- Total production average: 311,311 tons (227,273 – 454,545 tons)
- Yield: 1.174 tons/ha (1.18 – 2.13 tons/ha)
- Sales price: $220/ton ($132 - $484/ton)
- Value: $73 million ($36 – $134 million)

There are only seven varieties (inbreds only, no hybrids) of proso millet available for commercial cultivation in the US. Compared to other crops (e.g., wheat, corn, and rice) proso millet breeding, genetics, and genomic research are extremely limited. The University of Nebraska is the first (started in 1965) and renowned for proso millet breeding, genetics, and genomic research. The overall goal of this program is the genetic improvement of proso millet through conventional and molecular breeding. Proso millet varieties commonly grown in western Nebraska are Horizon, Sunrise, Huntsman, Earlybird, Sunup, Dawn, and Plateau. All these varieties were developed and released by the University of Nebraska. Pateau is the only waxy-type and others are non-waxy type varieties.

While millet is commonly used in human food, it is used mostly mainly in the birdfeed industry in the USA. The use of proso millet for human consumption both as food and alcoholic beverages (beers, whiskey) has recently been observed in the USA. Expansion of value-added products using millet is on the rise, with some of the common millet-based food items in the market being ready-to-eat snacks (crackers, puffs, bars), flour mixes, cereals, pasta, etc. Several millet-based food and beverage companies in the USA are marketing their products in regular and specialty grocery stores, health food stores, and online.

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Announcements

Mutation Breeding Workshop and Participation at the Plant and Animal Genome Conference (PAG 31)

San Diego, United States of America, 12-17 January 2024

Project Officers: I. K. Bimpong and N. Warthmann

The Plant Breeding and Genetics (PBG) Subprogramme of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture organized its second workshop under the theme “plant breeding” at the Plant and Animal Genome Conference (PAG 31). The focus of the workshop’s presentations was on the latest advances in combining genomics, bioinformatics and biosystems as well as mutation breeding to support various areas of food and agricultural research, as well as the use of artificial intelligence with speed breeding in diverse crops.

The workshop provided a forum for the global plant mutation breeding community to share information and resources, align methodologies, and build collaborative projects in order to take full advantage of the genomics revolution.

Distinguished speakers included academic, industrial, and government researchers and experts, namely, Michael J. Thomson (Texas A&M University, USA), Kenneth McNally and Platten Damien (both from IRRI-CGIAR, The Philippines), Suresh D. Pillai (Texas A&M University, USA), Lee Hickey (UQ and QUAAFI, Australia) and Manish K. Pandey (ICRISAT-CGIAR, India). Over fifty participants (twenty female and thirty male researchers) attended the workshop.

International Year of Millets (IYM) 2023 Closing Ceremony

FAO, Rome, Italy, 29 March 2024

The Food and Agriculture Organization of the United Nations (FAO) has facilitated the implementation of the International Year of Millets (IYM) 2023, successfully raising awareness of, and directing policy attention to the nutritional and health benefits of millet consumption. Additionally, it has highlighted the suitability of millets for cultivation under adverse and changing climatic conditions and emphasized the benefits of creating sustainable market opportunities for producers and consumers. Moreover, FAO has promoted sustainable production systems for millets.

FAO hosted the closing ceremony of the IYM 2023: as part of it, a roundtable discussion titled "Research and Development for the Millet Sector" was organized on 29 March 2024, at FAO Headquarters. Fatma Sarsu, Acting Head of PBG Section was an invited panelist, and as such presented ongoing millet-related projects at the Joint FAO/IAEA Centre. She also provided insights into ongoing technical cooperation initiatives aimed at bolstering capacity and facilitating technology transfer to promote the cultivation of novel millet varieties and the adoption of climate-smart agricultural practices in developing nations. Moreover, she highlighted the recently initiated Coordinated Research Project titled "Accelerated Genetic Improvement of Key Dryland Millets for Climate Change Adaptation". This project aims to expedite the development of new millet varieties to address food and nutrition security and adapting to climate change challenges.

International Technical Webinar - Enhancing Agrifood Systems through Climate-Smart Crops and Nutrition-Dense Crops

Online Event, 25 April 2024

This webinar is the outcome of a collaboration between the IAEA through the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture’s PBG Section and the Regional Office for Asia and the Pacific of the FAO. The webinar shed light on innovative strategies centered around climate-resilient and nutrient-dense crops. The event, which drew over 130 participants from diverse backgrounds worldwide, underscored the urgency of integrating these crops into mainstream agricultural practices towards a resilient and sustainable agrifood system.

The event emphasized the crucial role of legumes in complementing these crops through intercropping, boosting sustainability and production on marginal lands. It also highlighted the significance of science, technology and innovation, partnerships and international collaboration and investment in mainstreaming these climate-resilient and nutrient-dense crops in the agrifood systems.

The webinar featured six international experts who delved into key plant breeding and seed systems advancements. The first session highlighted innovative plant breeding techniques, such as mutation induction and biotechnologies, to develop crops resilient to climate variations while packing crucial nutrients. The second session focused on cutting-edge seed production, value addition, and distribution methods and models essential for widespread adoption and agricultural resilience.

The event served as a crucial platform for advocacy, sparking dialogue and collaboration among a diverse audience. The insights shared by experts and participants alike underscored the imperative of mainstreaming climate-resilient and nutrient-dense crops to combat food insecurity and malnutrition and bolster agrifood systems.

Panel on Plant Breeding Techniques to Improve Food Security

Online Event, 9 May 2024

The Sustained Dialogue on Peaceful Uses (SDPU) initiative, facilitated by Civilian Research and Development Foundation (CRDF) Global, recently hosted a webinar titled "Plant Breeding Techniques for Underutilized Crops in Africa". Dr Fatma Sarsu was among the panellists. The webinar centred on exploring the diverse applications of plant breeding techniques, including nuclear and isotopic methods, to develop more resilient crops and enhance food security in the region.

During the panel discussion, participants delved into how these techniques are tailored to suit both smallholder farmers and large-scale agriculture. They also examined ongoing initiatives aimed at providing training and educational opportunities to bolster capacity in plant breeding, alongside highlighting successful collaborative endeavours. This comprehensive dialogue underscored the importance of interdisciplinary engagement, a core objective of the SDPU program.

The panel conveyed to the audience the pivotal moment we inhabit, characterized by remarkable technological advancements and tools that hold promise for enhancing regional food security. However, it was emphasized that concerted efforts from the broader food security community are imperative to extend access to these technologies and training opportunities, ensuring their widespread utilization for the benefit of all.

Global Conference of the World Banana Forum

Rome, Italy, 11-14 March 2024

Ms Pooja Mathur, PBG Laboratory Head, attended FAO's Global Conference of the World Banana Forum (WBF) which was held from 11 to14 March 2024 in Rome. The event brought together more than 300 researchers, producers, industry players, policy makers, regional and sub-regional organizations, labor organizations and Representatives of Permanent Missions to discuss the collective actions for sustainable global banana production under changing climate, issues around trade, gender equity and safety of workers. Ms Mathur had the privilege to interact with an esteemed panel of colleagues from the IPPC Secretariat, Subregional Office for Mesoamerica (SLM) and Transboundary Plant Pests and Diseases, discussing the role of FAO in addressing these challenges and models for successful cross sector collaborations. Ms Mathur presented the work of the PBG Laboratory towards building Fusarium TR4 resistance in Cavendish and cooking type bananas, disease prevention and preparedness. She also showcased the efforts being made under the ongoing Coordinated Research Project on "Integrative Approach to Enhance Disease Resistance Against Fusarium Wilt (*Foc* TR4) in Banana", as well as the Peaceful use Initiative (PUI) project on "Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems in East Africa".

Coordinated Research Projects (CRPs)

Project Number	Ongoing CRPs	Project Officers
D22006	Enhanced Biotic-stress Tolerance of Pulses Towards Sustainable Intensification of Cropping Systems for Climate-change Adaptation (2019–2024)	A. Hingane F. Sarsu
D24014	Development of Integrated Techniques for Induced Genetic Diversity and Improvement of Vegetatively Propagated and Horticultural Tree Crops (2021–2025)	I.K. Bimpong F. Sarsu
D24015	Radiation-induced Crop Diversity and Genetic Associations for Accelerating Variety Development (2022-2027)	P.Mathur F. Sarsu
D23033	An Integrative Approach to Enhance Disease Resistance Against Fusarium Wilt (Foc TR4) in Banana – Phase II	C. Zorrilla P.Mathur
E43041	Application of Nuclear Techniques to Improve and Evaluate Nutritional and Health Benefits of Underutilised Crops	K. Bimpong V. Owino
D24016	Accelerated Genetic Improvement of Key Dryland Millets for Climate Change Adaptation	F. Sarsu A. Hingane

CRP D22006: Enhanced Biotic-stress Tolerance of Pulses Towards Sustainable Intensification of Cropping Systems for Climate-change Adaptation

Project Officers: A. Hingane, F. Sarsu

This CRP's objective is to increase the productivity of three key pulse crops: chickpea, cowpea, and lentil, which together constitute 40% of global pulse production. Mutation induction and genomics technologies are deployed to enhance the resistance of chickpea to the pod borer *Helicoverpa armigera*, cowpea to the pod borer *Maruca vitrata*, and lentil to combat *Stemphylium blight*.

Specific research objectives are: (1) to generate genetic diversity in chickpea, cowpea and lentil through mutagenesis for resistance to *Helicoverpa armigera, Maruca vitrata* and *Stemphylium botryosum*, respectively; (2) to develop and/or refine phenotyping tools to facilitate precise and efficient selection of biotic-stress resistance in selected pulse crops; and (3) to develop genomic tools for accelerated variety development for the selected pulse crops and associated traits of interest.

The CRP which started in 2019 had its first RCM in September 2019 in Vienna, Austria. The second RCM took place virtually from 6 to 10 September 2021, third RCM also took place virtually from 17-19 October 2022 and the fourth RCM was held in December 2023 in Vienna, Austria.

In the ongoing CRP D22006, researchers from ICRISAT, India, are focusing on the "Identification of superior lines and candidate genes for pod borer *(Helicoverpa armigera)* resistance in chickpea".

Over a period of four years, this mutant population (M1-M4) was evaluated in field conditions along with check for natural pod damage, number of pods per plant, laboratory bioassays (artificial feeding on pods/leaves), and biochemical parameters. Following thorough evaluation across seasons, 31 putative mutants were identified. These M4 mutants were further tested at four hotspot locations (Uttarakhand & Punjab-Northern Zone; Andhra Pradesh & Telangana-Southern Zone) in India for pod borer resistance and other diseases.

Based on preliminary results from two locations (M4) - Nandyal, Andhra Pradesh, and ICRISAT, Telangana - they have identified two promising mutant lines: ICCL86111-B-638-8 with erect type and ICCL 86111-B-8-4 series mutant line with spreading type morphology, exhibiting resistance to pod borer and major diseases compared to the wild/non-mutant line (ICCL 86111, with short stature and less spreading type).

CRP D24014: Development of Integrated Techniques for Mutation Breeding in Vegetatively Propagated and Horticultural Tree Crops

Project Officer: I.K. Bimpong, F. Sarsu

This CRP aims to develop new genetic resources and technologies for accelerated breeding in vegetatively propagated crops (VPCs) and horticultural tree crops (HTCs) by means of induced genetic diversity, chimera-free regeneration, and functional genomics.

The CRP is spearheading the production of stable mutant clones free of chimeras for traits of interest, as well as publication of protocols for phenotyping and genomic analyses for Member States.

Since the beginning of the project in 2021, participating research teams have made significant progress. At the University of Ghent in Belgium, researchers have standardized protocols for growing large-scale *in vitro* shoots as olive crop explants for large-scale mutagenesis programs, which has improved success rates. The CRP is exploring slow-release nanoparticles of plant growth regulators and auxin beads to induce adventitious shoot or root meristems *in vitro* and regenerate roots. At Centro IFAPA "Alameda del Obispo" in Spain, twelve early olive cultivars were found and given mutation induction. Potato micro-tuber induction for proton beam irradiation has been established at India's Bhabha Atomic Research Centre. Advanced mutant creole potato clones with excellent shelf life and dormancy have been developed at Colombia's Universidad Distrital Francisco José de Caldas. These are being tested for genetic correlations and physiological traits using GWAS and GBS. The team is also undertaking semi-commercial experiments at three locations before releasing variants.

Through the CRP, cassava's low *in vitro* success rates are addressed. For large-scale *in vitro* plantlet development, Uganda and Ghana project participants have standardized single-cell regeneration techniques. These protocols can be distributed to interested Member States to accelerate cassava variety breeding and fundamental research by VPCs. The CRP has helped four MSc students graduate, as well as two MSc and two PhD students in various phases of their studies.

CRP D24015: Radiation-Induced Crop Diversity and Genetic Associations for Accelerating Variety Development

Project Officers: P. Mathur, F. Sarsu

CRP D24015 was approved in October 2021 and was launched in April 2022 with its first Research Coordination Meeting in virtual mode. The overall objective of this CRP is to strengthen the ability of the IAEA and its Member States to develop and test emerging technologies in mutation induction, genomics, and big data to facilitate the accelerated development of crop varieties for food security and climate-change adaptation. At the end of the first year, a virtual meeting was held in March 2023, and important results from the first year were discussed of which a few are captured here.

On the use of different radiation sources as mutagens, the CRP participant from South China Agricultural University reported on genetic imprints and germplasm enhancement in rice after the circumlunar space flight in Chang'e 5. Mutation frequency in the M1 ranged from 7.97×10-6 to 1.9×10-3 with mutations distributed across all chromosomes, and GC content decreased as did methylation rate, relative to earth-based control. A variety of phenotypes including increased tillering, dwarf stature, long grains, wide grains, and salt tolerance were observed in the M2 generation. Results from the Institut de biologie moléculaire des plantes of CNRS, France, reported similar structural variants in wild type Arabidopsis plants with ionizing (proton beam) and non-ionizing (UV-A and UV-B) radiations, but higher DNA methylation changes with proton beam. The National Center of Space Mutagenesis for Crop Improvement at the Chinese Academy of Agricultural Sciences reported characterization and gene mapping for plant height and early heading in wheat mutant lines induced by space flight, as well as transcriptome variation and phenotypes resulting from C-ion beam irradiation in wheat. At Kongju National University in the Republic of Korea, irradiation dosage for proton beam on Brassica rapa subsp trilocularis were standardized and a new mutant population was developed.

On the determination of genetic associations in critical mutants, the Bhabha Atomic Research Centre of India reported the characterization of the large-seeded groundnut mutant induced by high energy pulsed electron beam, and mapping of the large-seed trait. At the Agricultural Genetics Institute of Vietnam, population development is in progress for mapping the black seed color trait in soybean, and at the University Dan Dicko Dankoulodo of Maradi, Niger, sesame populations to map low seed shattering is in progress.

On genomic selection and bioinformatic workflow development, Scotland's Rural College in the UK completed simulations for genomic prediction in mutant populations and will apply to rice mutant populations at the National Agri-food Biotechnology Institute, India.

CRP D23033: An Integrative Approach to Enhance Disease Resistance Against Fusarium Wilt (Foc TR4) in Banana – Phase II

Project Officer: C. Zorrilla, P. Mathur

This CRP is aimed at improving disease resistance in banana and developing microbes with enhanced beneficial activities through induced mutagenesis for the management of Fusarium wilt (*Foc* TR4) disease. Specific research objectives are (1) to generate induced genetic diversity in bananas using physical mutagenesis for developing resistance; (2) to generate functional genomics tools and methodologies for understanding the mechanisms of disease resistance using available resistant germplasm that will contribute to markers' development and gene editing; (3) to develop rapid and reliable diagnostic protocols for field detection of the pathogen; and (4) to develop protocols for physical mutagenesis of microbes for enhanced biocontrol and plant growth promotion activities, and evaluation against the disease.

This project had a first Research Coordination Meeting (RCM) in May 2023 and the second one in April 2024. Participants have established collaborations to enhance the results of the project. This CRP intends to expand results obtained by a previous CRP that focused on screening methods by including new aspects.

CRP D23033 participants are working collaboratively to develop knowledge and technologies that will be published and disseminated. The outputs of this project will include validated protocols field detection of the pathogen, protocols for cell and tissue culture of different banana and plantain varieties, mutant lines of banana and plantain with resistance to banana Fusarium wilt (*Foc* TR4), and microbial strains for biocontrol as part of an integrative approach to contribute to the management of this disease.

CRP E43041: Application of Nuclear Techniques to Improve and Evaluate Nutritional and Health Benefits of Underutilized Crops

Project Officers: K. Bimpong, V. Owino

Malnutrition as a result of nutrient deficiencies, especially for micronutrients (e.g., iron, zinc, calcium, vitamin A, thiamine, riboflavin) and essential amino acids, is associated with almost 50% of mortality among children under five years of age, especially in Low- and Middle-Income Countries.

For example, iron deficiency affects at least 30% (2 billion) of the world's population; it is associated with anemia, decreased work capacity, impaired immune and endocrine function, and impaired physical and cognitive development in children. Underutilized crops can be used to enhance nutrition security as they have higher concentration of nutrients, including protein, vitamins, and minerals.

Mutation breeding is a routine method in plant breeding and has contributed to the development of new varieties with desired traits. However, nutritional benefits of most nutrient-enhanced underutilized crop varieties have not been evaluated adequately since the focus of mutation induction has been on enhancing crop yield. This CRP aims to fill this gap by generating robust evidence on the nutritional value and health efficacy of underutilized crops among vulnerable groups in Asia and Pacific, Africa, Latin America, and Europe. This approved CRP is an innovative cross-disciplinary approach to improving and evaluating the nutritional benefits of underutilized crops between NAFA-Plant Breeding and Genetics (PBG) and NAHU-Nutritional and Health-Related Environmental Studies (NAHRES).

CRP D24016: Accelerated Genetic Improvement of Key Dryland Millets for Climate Change Adaptation

Project Officers: F. Sarsu, A. Hingane

This CRP is aimed to develop novel genetic stocks of key dryland millets using mutation breeding and biotechnologies to accelerate the development of new varieties for food and nutrition security and climate-change adaptation. Specific objectives are (1) to generate genetic diversity in selected millets with improved nutrition and quality traits, and improved resilience to biotic/abiotic stress through induced mutation for better adaptation to climate change; (2) to develop/adapt phenotyping tools for precise screening/selection of mutant lines with the desired traits in selected millet crops; (3) to develop genomic tools for delivery of novel induced variation to accelerate genetic gain in millet improvement.

Forthcoming Events

First Research Coordination Meeting (RCM)

Accelerated Genetic Improvement of Key Dryland Millets for Climate Change Adaptation (D24016)

7-11 October 2024

Project Officers: F. Sarsu, A. Hingane

The first RCM of CRP D24016 is scheduled to be held virtually during the week of 7-11 October 2024. The meeting objectives are to establish individual project activities and consolidate the workplan for the next cycle. Project participants are expected to present on the establishment of mutant germplasm, the development and adaptation of phenotyping tools for precise screening and selection of mutant lines with desired traits in selected millet crops, and the development of genomic tools for delivering novel induced variations to accelerate genetic gain in millet improvement.

Past Events

Third Research Coordination Meeting (RCM)

Radiation-induced Crop Diversity and Genetic Associations for Accelerating Variety Development (D24015)

Vienna, Austria, 5-9 August 2024

Project Officers: P. Mathur, F. Sarsu

The Third Research Coordination Meeting of the FAO/IAEA Coordinated Research Project on "Radiation-induced crop diversity and genetic associations for accelerating variety development", was held from 5 to 9 August 2024. This CRP aims to address three important emerging trends and needs in the field of mutation breeding: (1) newer mutagen sources; (2) establishment of genetic associations for marker-assisted breeding, gene editing, and potentially, genomic selection; and (3) bioinformatic platforms and computational tools for trait analysis.

The main objective of the RCM meeting was to review progress made in the activities of the project after the second meeting, to summarize the outputs, assess the outcome, and to identify areas to be further investigated and recommend further actions to be taken by both the FAO/IAEA and participating countries. The meeting was attended by fifteen project participants (research contract and agreement holders) across Asia, Africa, Europe and North America. The CRP participants shared the progress on the planned activities during 2022-2023 and their on-going work in 2024. These were followed by discussions to assess progress made and challenges faced, and review of workplans.

Second Research Coordination Meeting (RCM)

Integrative Approach to Enhance Disease Resistance Against Fusarium Wilt (Foc TR4) in Banana – Phase II (D23033)

Vienna, Austria, 22-26 April 2024

Project Officer: C. Zorrilla, P. Mathur

CRP D23033 integrates banana breeding using induced genetic variation with identification of candidate genes using functional genomic tools, improvement of molecular detection methods and the identification of microbes with enhanced antagonistic and growth promoting activity.

CRP D23033 started in March 2023 and had its second Research Coordination Meeting (RCM) from 22 to 26 April 2024. The progress of the first year, workplans for 2024 and collaboration between the participating institutions was discussed. A total of 14 institutions from Asia, Africa and Latin America were selected to participate through research contracts and agreements.

CRP D23033 participants shared their progress during the first year of the project that includes the mutation induction in Cavendish and local varieties, development of simple molecular detection methods that can be used in the field such as mini-PCR and LAMP, and isolation of beneficial microbe strains for evaluation of their biological control activity against *Foc* TR4.

Technical Cooperation Field Projects

Project Number	Country/Region	Title	Technical Officer(s)
BDI5005	Bangladesh	Enhancing Productivity of Staple Crops Using Nuclear-derived Technologies	P. Mathur with SWMCN
BKF5024	Burkina Faso	Improving Food Crops through Mutation Breeding and Best Soil and Nutrient Management to Ensure Food Security	F. Sarsu with SWMCN
BOT5025	Botswana	Improving Selected Vegetable Crops and Cereals through the Use of Mutation by Speed Breeding Techniques	I.K. Bimpong
BUL5020	Bulgaria	Increasing the Yield and Quality of Main Vegetable Crops through Nuclear Technology to Withstand the Impacts of Climate Change	C. Zorrilla
CAF5015	Central African Republic	Improving Productivity of Maize and Developing Resistance to Fall Armyworm Using Radiation-Induced Novel Genetic Diversity - Phase II	F. Sarsu
CHI5055	Chile	Strengthening the National Cooperation Network in the Use of Nuclear Techniques in Plant Breeding Programmes	C. Zorrilla
COD5031	Democratic Republic of Congo	Using Nuclear Techniques to Improve Crop Productivity for Maize, Soybeans and Beans, as well as Food Safety Testing Capabilities	I.K. Bimpong with FSC
COL5026	Colombia	Enhancing Crop Productivity of Creole Potato Using Nuclear and Related Techniques	I.K. Bimpong with SWMCN
COL5027	Colombia	Strengthening the Detection and Management of Quarantine Pathogens by Implementing Molecular Methods and Mutation Breeding Techniques	C. Zorrilla
COS5038	Costa Rica	Developing Resistance to Fusarium Wilt in Bananas and Contributing to the Integrated Management of the Disease through the Application of Mutation Breeding Techniques	C. Zorrilla
ECU5034	Ecuador	Improving the Resilience of Bananas to their Major Diseases through Mutation Breeding Techniques	C. Zorrilla
ERI5013	Eritrea	Improving Food Crop Varieties through Mutation Breeding and Related Technologies	I.K. Bimpong
ERI5017	Eritrea	Enhancing Productivity by Improving Seed Crops Relevant for Food Security and Income through Mutation Induction and Related Breeding Technologies	C. Zorrilla
HON5010	Honduras	Application of Mutation Breeding in Agriculture for Adaptation to Climate Change in Honduras	C. Zorrilla
INT5158	Interregional	Strengthening Member State Capacities to Combat Banana Fusarium Wilt (TR4) through Early Detection, New Resistant Varieties, and Integrated Management	C. Zorrilla
IRA5015	Iran, Islamic Republic of	Enhancing Capacity of National Producers to Achieve Higher Levels of Self-Sufficiency in Key Staple Crops	F. Sarsu with FSC *and* SWMCN
IRQ5023	Iraq	Utilizing Nuclear Technology to Improve Key Legume Crops for Climate Change Adaptation	I.K. Bimpong
JAM5015	Jamaica	Strengthening National Capacities for the Introduction of the Sterile Insect Technique for Pest Control, Mutation Breeding of Crops and Post-Harvest Treatment of Agricultural Produce Using a Self-Contained Gamma Irradiation Facility	I.K. Bimpong
KAM5007	Cambodia	Improving Cotton for Enhanced Resilience to Climate Change	I.K. Bimpong
KUW5006	Kuwait	Improving Barley and Sorghum Production Under Harsh Environmental Conditions Using Mutation Breeding Techniques	F. Sarsu

Project Number	Country/Region	Title	Technical Officer(s)
LAO5006	Lao PDR	Enhancing Crop Production with Climate Smart Agricultural Practices and Improved Crop Varieties	F. Sarsu with SWMCN
LES5012	Lesotho	Improving Productivity of Potato and Sorghum through Mutation Breeding and Best Soil, Nutrient and Water Management Practices	I.K. Bimpong
LIR5004	Liberia	Enhancing Rice and Vegetable Crops' Productivity through the Use of Mutation by Speed Breeding for Food Self-Sufficiency and Income Generation	I.K. Bimpong
MAG5026	Madagascar	Enhancing Rice and Maize Productivity through the Use of Improved Lines and Agricultural Practices to Ensure Food Security and Increase Rural Livelihoods	F. Sarsu with SWMCN *and* IHS
MAK5010	North Macedonia	Improving Dry Bean Productivity and Tolerance to Diseases and Drought by Use of Nuclear Techniques	F. Sarsu
MAR5029	Mauritius	Improving Landraces of Crucifers (Cauliflower and Cabbage) and Carrot through Mutation Breeding and Biotechnology - Phase II	F. Sarsu
MAU5029	Mauritania	Improving Rice and Sorghum through the Application of Nuclear Techniques	I.K. Bimpong
MHL5003	Marshall Islands	Enhancing Food Productivity by Promoting New Mutant Varieties and Traditional Varieties	C. Zorrilla
MLI5031	Mali	Improving Rice Productivity through Mutation Breeding and Better Soil, Nutrient and Water Management Practices	I.K. Bimpong with SWMCN
MLW5006	Malawi	Developing Drought Tolerant, High Yielding and Nutritious Crops to Combat the Adverse Effects of Climate Change	C. Zorrilla
NAM5020	Namibia	Enhancing Staple Crop Yields, Quality, and Drought Tolerance through Broadening Genetic Variation and Better Soil and Water Management Technologies	F. Sarsu with SWMCN
NEP5009	Nepal	Enhancing Climate Resilient Field Crops Production Systems for Food Security by using Nuclear and Molecular Techniques	I.K. Bimpong
NER5025	Niger	Improving Food and Biological Hazard Detection, Food Preservation and Mutation Breeding	I.K. Bimpong with FSC
PAK5023	Pakistan	Strengthening and Enhancing National Capabilities for the Development of Climate Smart Crops, Improvement in Animal Productivity and Management of Soil, Water, and Nutrient Resources Using Nuclear and Related Techniques	F. Sarsu with SWMCN
PAL5011	Palestine	Enhancing Food Security via Nuclear Based Approaches	I.K. Bimpong with SWMCN
PAR5012	Paraguay	Evaluation of Varieties and Advanced Mutant Lines against Biotic and Abiotic Stress Conditions to Mitigate the Effects of Climate Change in Crops	C. Zorrilla
PER5034	Peru	Improving Yellow Potato and Coffee Crops through Mutation Breeding Techniques	F. Sarsu
PHI5036	Philippines	Providing an Innovative Platform for Germplasm Utilization for Rainfed and Irrigated Lowland Rice Ecosystems - Phase I	A. Hingane
QAT5008	Qatar	Developing Best Soil, Nutrient, Water and Plant Practices for Increased Production of Forages under Saline Conditions and Vegetables under Glasshouse Using Nuclear and Related Techniques	F. Sarsu with SWMCN
RAS5088	Regional Asia	Enhancing Crop Productivity and Quality through Mutation by Speed Breeding (RCA)	F. Sarsu
RAS5094	Regional Asia	Promoting Sustainable Agricultural and Food Productivity in the Association of Southeast Asian Nations Region	C. Zorrilla with FSC *and* SWMCN

Project Number	Country/Region	Title	Technical Officer(s)
RAS5098	Regional Asia	Improving the Resilience of Crops to Climate Change through Mutation Breeding - Phase II (SAPI)	C. Zorrilla
RAS5099	Regional Asia	Developing Climate Smart Crop Production including Improvement and Enhancement of Crop Productivity, Soil and Irrigation Management, and Food Safety Using Nuclear Techniques (ARASIA)	I.K. Bimpong with SWMCN
RLA7027	Regional Latin America	Applying Nuclear Technology in Agriculture, Water Resource Management and the Environment in Caribbean Member States (CARICOM)	I.K. Bimpong
RER5024	Regional Europe	Enhancing Productivity and Resilience to Climate Change of Major Food Crops in Europe and Central Asia	F. Sarsu
SAF5016	South Africa	Promoting Mutation Breeding of Vegetables to Improve Rural Livelihoods - Phase I	N. Warthmann
SIL5024	Sierra Leone	Improving Rice and Cassava Production Using Nuclear Related Techniques	I.K. Bimpong with SWMCN
SRL5050	Sri Lanka	Supporting Genetic Improvement of Tea	F. Sarsu
STK7001	Saint Kitts and Nevis	Building National Capacity for the Application of Nuclear Science and Technology	I.K. Bimpong
SUD5041	Sudan	Enhancing Productivity and Quality of High Value Crops through Improved Varieties and Best Soil, Nutrient and Water Management Practices	F. Sarsu with SWMCN
SWA5002	Eswatini, Kingdom of	Improving Adaptability of Cowpea to Climate Change through Mutation Breeding	I.K. Bimpong
SWA5003	Eswatini, Kingdom of	Improving Cowpea for Enhanced Resilience to Climate Change	I.K. Bimpong
TOG5004	Togo	Improving Crop Productivity and Agricultural Practices through Radiation Induced Mutation Techniques	I.K. Bimpong with SWMCN
TUN5031	Tunisia	Developing Cereal and Legume Mutants for Improving Food Security and Farmers' Resilience to Climate Change	F. Sarsu
UGA5043	Uganda	Improving Cassava and Rice Disease Resistance through Mutation Breeding Techniques	I.K. Bimpong
URT5037	Tanzania, United Republic of	Developing Rice Varieties with Resistance to Rice Blast and Salinity Tolerant Using Mutation Breeding and Biotechnology Techniques	F. Sarsu
URT5039	Tanzania, United Republic of	Mutation Breeding for Improved Productivity, Nutritional Quality, and Pest and Disease Resistance in Cotton and Common Beans - Phase I	C. Zorrilla
VEN5023	Venezuela	Improving Banana Productivity through Mutation Breeding Techniques for Enhanced Disease Resistance	C. Zorrilla
YEM5016	Yemen	Enhancing Sorghum and Legume Crop Productivity through Induced Mutations with Supportive Breeding and Biotechnologies - Phase II	F. Sarsu
ZAM5035	Zambia	Enhancing Resilient AgriFood Systems through Improved Crop Varieties and Soil Management Practices	I.K. Bimpong
ZIM5027	Zimbabwe	Enhancing Food Security by Developing and Disseminating High Yielding Climate Resilient Mutant Crop Varieties	A.J. Hingane

APH: Animal Production and Health, NAFA; FSC: Food and Environmental Protection, NAFA; IPC: Insect Pest Control, NAFA; SWMCN: Soil and Water Management and Crop Nutrition, NAFA; RPRT: Radioisotope Products and Radiation Technology, NAPC; ARBR: Applied Radiation Biology and Radiotherapy, NAHU; PHY: Physics, NAPC; PCG: Programme Coordinator, NA; IHS: Isotope Hydrology Section, NAPC

Forthcoming Events

National Training Course

Mutation by speed breeding techniques (MbyS) in cereals - LIB5004

Monrovia, Liberia, 5-16 August 2024

Project Officer: I.K. Bimpong

Project Objective: Develop improved rice varieties that are high-yielding and salinity-tolerant contributing to food security in the country.

Course Objective: As this is the first mutation breeding programme for Liberia, the goal is to continue to raise awareness of the importance of nuclear techniques in food and agriculture. Topics for the training will include mutation induction, breeding schemes, early and late generation selection methods for targeted stresses, introduction to protocols in the laboratory, greenhouse, and field conditions for successful implementation of mutation breeding programmes, informal and formal seed systems for the multiplication and dissemination of seeds for upscaling and cultivation. The course will include lectures, demonstrations, and practical sessions on various protocols on mutation breeding and selection methods. This event is a follow-up to a previously held virtual training.

Fifteen participants (five women and ten men researchers) are expected to attend the training.

Regional Training Course

Regional Training Course on Banana breeding for resistance to Fusarium wilt (*Foc* TR4) using tissue culture and nuclear techniques.

Strengthening Member State Capacities to Combat Banana Fusarium Wilt (TR4) through Early Detection, New Resistant Varieties, and Integrated Management – INT5158

Bahia, Brazil, 12-16 August 2024

Project Officer: Cinthya Zorrilla

Project Objective: Develop capacities for disease management against *Foc* TR4 and the development of new resistant banana varieties using mutation breeding and combined biotechnologies to contribute to prevent the spread of this disease and reduce farmers' losses.

Course Objective: Develop capacities on breeding methods used to develop resistance to *Fusarium oxysporum* f.sp *cubense*, Tropical Race 4 (*Foc* TR4) with special emphasis on breeding using nuclear-induced mutations to generate new genetic diversity, as well as *in vitro* techniques used for multiplication of banana and plantains.

This training is the second edition of another training organized last year at the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Cassava and Fruits Research Station. Participants will share experiences and be trained on the implementation of mutation breeding as part of a banana and plantains breeding programme.

This event is focused on the thematic area of the project related to Mutation Breeding. A maximum of sixteen participants are expected. In this edition participants from Asia and Africa will also join in addition to the ones from Latin America.

Regional Training Course

Application of Tissue Culture (DH) in Crop Improvement and on Molecular Breeding and Marker-Assisted Selection" - RAS5099

Jakarta, Indonesia, 19-30 August 2024

Project Officer: I.K. Bimpong

Project Objective: Support the transfer of knowledge and expertise among ARASIA participating countries and collaborate to enhance the production of major food crops with improved performance and better resilience to climate change through mutation breeding and combined biotechnologies, in order to contribute to food security in ARASIA participating countries.

Course Objective: Foster capacity development in the application of tissue culture techniques, specifically Doubled Haploidy (DH), in crop improvement. Participants will learn how to utilize DH for rapid crop breeding and genetic improvement. Additionally, the course will cover the principles and methodologies of molecular breeding and marker-assisted selection, empowering participants to integrate cutting-edge biotechnological tools in crop improvement programs.

Twenty participants (six women and fourteen men researchers) are expected to attend the course.

National Training Course

Experimental designs, multilocation trials, seed multiplication and data analysis - MAU5029

Rosso, Mauritania, 26-30 August 2024

Project Officer: I.K. Bimpong

Project Objective: Address the development and deployment of seeds of improved rice varieties that are high-yielding and tolerant to saline conditions contributing to food security in the country.

Course Objective: Equip participants with comprehensive knowledge and practical skills in experimental designs, multi-location trials, seed multiplication, and data analysis techniques. Participants will learn to design robust experiments, conduct trials across multiple locations, manage seed multiplication effectively, and analyze data to draw meaningful conclusions. By mastering these essential components, participants will enhance their capacity for conducting rigorous research and making informed decisions in agricultural settings.

Twenty participants (five women and fifteen men researchers) are expected to attend the training.

National Training Course

Experimental designs, multi-location trials, seed multiplication and data analysis - LAO5006

Vientiane, LAO PDR, 26-30 August 2024

Project Officer: F. Sarsu

Project Objective: Bolster crop production through the implementation of climate-smart agricultural practices and the adoption of improved crop varieties within the country.

Course Objective: The training course will comprise a diverse range of activities, including lectures, presentations, practical sessions, and discussions. Key components of the program include:

- A comprehensive blend of theoretical lectures, case studies, and practical demonstrations, focusing on experimental design for both early and advanced generation testing.
- Instruction on data recording, statistical analysis of field experiments for mutant population advancement, multi-location trials, GxE interactions, and stability analysis, all utilizing open-source software.
- Practical applications of statistical methodologies covered in mutation breeding will be integrated, along with hands-on training in the use of open-source software for field experimental data analysis in both single and multi-location trials.
- Opportunities for active discussions between participants and the trainer throughout the course.

National Training Course

Farmer training on the participatory approach of handling and producing mutant seeds in their respective farms - SL5024

Rokupr, Sierra Leone, 2-6 September 2024

Project Officer: I.K. Bimpong

Project Objective: Support the production of major food crops with higher yields, improved quality, and better resilience to climate change through mutation breeding and combined biotechnologies, in order to contribute to food security in the country.

Course Objective: Enhance capacity of farmers in the participatory approach on handling and producing mutant seeds in their farms, fostering sustainable agricultural practices, enhancing crop resilience to climate change, and promoting community engagement in seed production. Through hands-on training sessions, farmers will learn techniques for seed selection, handling, and cultivation, empowering them to improve crop yields and promote genetic diversity in their farming practices.

Twenty participants (ten women and ten men researchers) are expected to attend the training.

Regional Training Course

Bioinformatics and Genetic Improvement of Crops and Methodologies for Screening Biotic Stress - RAS5099

Doha, Qatar, 14-27 September 2024

Project Officer: I.K. Bimpong

Project Objective: Support the transfer of knowledge and expertise among ARASIA participating countries and collaborate to enhance the production of major food crops with improved performance and better resilience to climate change through mutation breeding and combined biotechnologies, in order to contribute to food security in ARASIA participating countries.

Course Objective: Equip participants with skills in bioinformatics tools and techniques for genetic improvement of crops. Participants will learn how to utilize bioinformatics in analyzing genetic data, identifying target genes, and accelerating crop breeding programs. Additionally, the course will cover methodologies for screening biotic stress resistance traits in crops, empowering participants to develop resilient crop varieties through informed genetic interventions.

Twenty participants (six women and fourteen men researchers) are expected to attend the course.

Regional Meeting

Applying Nuclear Technology in Agriculture, Water Resource Management, and the Environment in Caribbean Member States (CARICOM) - RLA 7027

Roseau, Dominica, 16-20 September 2024

Project Officer: I.K. Bimpong

Project Objective: Support the transfer of knowledge and expertise among CARICOM countries through meetings, workshops, and trainings with the participation of scientists and experts in the region. CARICOM countries will collaborate in the regional project to enhance crop production through national crop improvement programmes by using mutation breeding and related technologies.

Meeting Objective: This event will focus on the planning of a technical workplan, technical visits, discussion of proposed training activities according to the needs of the region, exchange of knowledge and progress on mutation breeding among participants, and future actions to be taken to increase the impact of the project in the availability of improved varieties for sustainable food production and strengthening or establishing collaborations among participating Member States.

National Training Course

Cotton breeding for drought/heat tolerance - KAM5007

Phnom Penh, Cambodia, 16-20 September 2024

Project Officer: I.K. Bimpong

Project Objective: Support the development of improved cotton varieties that are high-yielding and drought-tolerant contributing to food security in the country.

Course Objective: Provide participants with specialized training in mutation breeding techniques for cotton, focusing on enhancing drought and heat tolerance in cotton varieties. Participants will learn how to induce mutations, conduct selection for desired traits, and implement field testing protocols to develop cotton varieties resilient to drought and heat stress. By acquiring these skills, participants will contribute to sustainable cotton production in challenging environments.

Twenty-five participants (ten women and fifteen men researchers) are expected to attend the training.

National Training Course

Plant Mutation Breeding for Developing Stress Tolerant Mutants in Seed/Vegetative Propagated Crops - NEP5009

Kathmandu, Nepal, 26-30 October 2024

Project Officer: I.K. Bimpong

Project Objective: Enhance crop resilience by developing stress-tolerant mutants in both seed and vegetative propagated crops through mutation breeding, contributing to sustainable agriculture and food security.

Course Objective: Enhance capacity participants with the knowledge and skills needed to implement mutation breeding techniques effectively for developing stress-tolerant mutants in both seed and vegetative propagated crops. Participants will learn about mutation induction, selection methods, and field-testing protocols to enhance crop resilience to environmental stressors. The course will empower participants to contribute to sustainable agriculture through the development of improved crop varieties.

Twenty participants (five women and fifteen men researchers) are expected to attend the training.

Regional Training Course

Regional Training Course on Genomics; Genotyping; Phenotyping; Genetics, Handling of mutants to speed up - RAS5088

Islamabad, Pakistan, 28 October-8 November 2024

Project Officer: F. Sarsu

Project Objective: Enhancing crop productivity and quality is the eternal subject in the Asia Pacific Region to satisfy the demand of population growth and climate change. Plant mutation breeding has played an important role in the past 60 years to breed new mutant varieties, elite lines, and mutant germplasm. The current project is combining mutation induction with speed breeding methods to develop a new approach, named mutation by speed breeding (MbyS), and the approach is extended to other Government Parties (GPs) through regional training courses, expert missions, or technical meetings.

Course Objective: Strengthen Member States' capacities on application of mutation breeding, rapidly advancing genomic technologies, genomic predictions of mutant populations/lines to be used for increased efficiency of the breeding process, acceleration of crop improvement and enabling long-term increases in the "genetic gain" of breeding programs working on staple food crops in Africa; provide techniques/technologies to young scientists in Africa to expedite the breeding process and developing and disseminating new and improved mutant crop varieties with improved yield, quality, and tolerance to biotic and abiotic stresses; release mutant varieties to applied to mutation breeding for increased precision and breeding efficiency.

Regional Training Course

Farmer Participatory Variety Selection Approach in Plant Mutation Breeding - RAS5099

Muscat, Oman, 17-30 November 2024

Project Officer: I.K. Bimpong

Project Objective: Support the transfer of knowledge and expertise among ARASIA participating countries and collaborate to enhance the production of major food crops with improved performance and better resilience to climate change through mutation breeding and combined biotechnologies, in order to contribute to food security in ARASIA participating countries.

Course Objective: Enhance capacities on the principles and practices of farmer participatory varietal selection in plant breeding. Participants will learn how to engage farmers in the selection and evaluation of crop varieties based on local preferences and needs. Through this approach, farmers will be empowered to actively participate in the breeding process, fostering the development of crop varieties that are well-suited to local conditions and preferences.

Twenty participants (six women and fourteen men researchers) are expected to attend the course.

Past Events

Regional Training Course

Improving the Resilience of Crops to Climate Change through Mutation Breeding — Phase II (SAPI) - RAS5098

Suva, Fiji, 29 July-2 August 2024

Project Officer: Cinthya Zorrilla

Project Objective: Develop capacities and establish mutation breeding programmes in the Pacific Island countries. The main objective of this project is to contribute to food security in the region by building capacities in mutation breeding and generating new mutant varieties with increased productivity and better adaptation to biotic/abiotic stress.

Course Objective: This training included tissue culture technique for germplasm conservation: generalities and facilities, data and inventories management, and barcoding labelling, introduction to *in vitro* culture, micropropagation and *in vitro* conservation of sweet potato, acquisition and distribution of sweet potato germplasm, virus elimination: thermotherapy and meristem culture, bacteria elimination, and good practices and quality control.

Twelve participants from Pacific countries, representing institutions that are initiating or in process to initiate mutation breeding, attended the training course.

Network Meeting

Mutation Breeding Network Meeting

Vienna, Austria, 22-26 July 2024

Project Officer: F. Sarsu

The Mutation Breeding Network was established in the Asia Pacific region, with the first meeting held in Jingzhou, Hubei, China, from 22 to 25 July 2019. However, due to the Covid-19 outbreak, many planned activities were postponed. This meeting presents an opportunity to broaden the network's reach into other regions, providing support to Member States in Africa, Latin America, Europe and Central Asia.

The purpose of the meeting was to (i) Develop and refine the strategy for plant mutation breeding including vision, mission, strategy, operating framework, and work plans; ii) Provide technologies and capacities utilizing nuclear science and technologies, including seed system modalities, to identify or refine successful models contributing to food security and sustainable agriculture; iii) Promote applied mutation breeding and advanced biotechnologies research and fostering both regional and interregional cooperations; iv) Establish a plant health-related network to address issues concerning plant health, further enhancing the scope and impact of the mutation breeding efforts; v) Expand the network to other regions (Africa, Latin America, Europe and Central Asia) to contribute to the Sustainable Development Goals.

Twenty-five senior scientists from twenty-two countries across Asia, the Pacific, Europe, Africa, and Latin America participated in the meeting. The key outcomes of the meeting were:

i) The decision to expand the Mutation Breeding Network from Asia Pacific to include Europe, Africa, and Latin America by establishing MBN+, aimed at enhancing global capacity in mutation breeding and biotechnologies to contribute to the Sustainable Development Goals.

ii) Enhanced international cooperation in developing and mobilizing resources for joint research projects.

iii) Strengthened research networks to sustain knowledge sharing, learning, and application of plant mutation breeding techniques and biotechnologies.

iv) Establishment of the Plant Breeding Innovation (PBI) Laboratories Hub among participating countries.

National Training Course

Mutation by Speed Breeding techniques (MbyS) in Legumes - BOT5025

Gaborone, Botswana, 22-26 July 2024

Project Officer: I.K. Bimpong

Project Objective: Support the development and deployment of seeds of improved cowpea varieties that are high-yielding and drought-tolerant contributing to food security in the country.

Course Objective: Foster capacity development in mutation by speed breeding techniques (MbyS) specifically tailored for legumes. Participants learned advanced methods to accelerate the breeding process, induce mutations effectively, and select desirable traits in legume crops. By mastering MbyS techniques, participants were equipped to develop improved legume varieties with enhanced traits such as yield, nutritional content, and stress tolerance, contributing to food security and agricultural sustainability.

Twenty-five participants (ten women and fifteen men researchers) attended the training.

National Training Course

National Training Course on the Use of NIRS Methodologies for Nutritional Quality Improvement Evaluation of Varieties and Advanced Mutant Lines against Biotic and Abiotic Stress Conditions to Mitigate the Effects of Climate Change in Crops – PAR5012

Asuncion, Paraguay, 8-12 July 2024

Project Officer: Cinthya Zorrilla

Project Objective: Develop mutant lines with tolerance to biotic and abiotic stresses, as well as improve nutritional quality in several crops including soybeans, beans, and Stevia.

Course Objective: This course included demonstrations of the use of the equipment, preparation of samples for analysis, demonstration of the use of the equipment with different types of samples and large number of samples in a breeding programme, experimental design, and interpretation of results to generate calibration models.

Additionally, lectures included different non-destructive equipment for nutritional quality assessment (NIR, FT-MIR, XRF, Raman, etc.), advantages and disadvantages of the NIRS equipment, information on the type of data that is needed for calibration and modelling, the process of model development, calibration and quantification using NIRS equipment, as well as present examples of cases to showcase the complete process for the application of NIRS in nutritional evaluation.

National Training Course

Improving Crop Adaptation to Drought using Nuclear-derived Techniques, and Speed-breeding Methodologies - LES5012

Maseru, Lesotho, 24-28 June 2024

Project Officer: I.K. Bimpong

Project Objective: The project addresses the development and deployment of seeds of improved root and tubers and cereals that are high-yielding and drought-tolerant contributing to food security in the country.

Course Objective: Enhance capacities to improve crop productivity using mutation breeding and biotechnologies, as well as to develop climate-smart varieties. Participants learned how to expedite breeding processes and enhance crop resilience to water scarcity. The training program covered both phenotypic and genotypic selection of mutant lines, data collection, analysis, and interpretation, as well as the application of biotechnologies in developing crop varieties tolerant to both biotic and abiotic stresses.

Twenty-five participants (ten women and fifteen men researchers) attended the training.

Regional Training Course

Enhancing Genetic Gain through Genomic Selection in Mutation Breeding Programme for Climate Change - RER5024

Sarajevo, Bosnia and Herzegovina, 27-31 May 2024

Project Officer: F. Sarsu

Project Objective: Support the production of major food crops with higher yields, improved quality, and better resilience to climate change through mutation breeding and combined biotechnologies to contribute to food security in Europe and Central Asia. The expected outcome is the enhanced productivity and resilience to climate change of major food crops in the region.

Course Objective: The training comprised a diverse range of activities, including lectures, presentations, practical sessions, and discussions. Key components of the program included:

- Genomic predictions for enhanced breeding efficiency
- Phenotypic and genotypic linkage for mutant population/line selection
- Data collection, analysis, and interpretation
- Accelerating breeding processes and developing improved varieties enhancing yield, quality, and adaptation to climate change
- Practical sessions on genomic technologies
- Integration of genomic selection into plant mutation breeding programs

Twenty-one participants (fifteen women and six men researchers) attended the training.

First Project Coordination Meeting

Enhancing Agricultural Productivity for Improved Food Security in Africa (AFRA) - RAF5002, RAF5092

Nairobi, Kenya, 6-10 May 2024

Project Officer: F. Sarsu

Project Objective: Strengthen the capacity of agricultural systems across Africa, driving advancements in regional agricultural productivity.

The project integrates four crucial agricultural dimensions, with a comprehensive strategy that leverages nuclear science and technology to enhance food security in Africa. It focuses on addressing challenges related to improved productivity, specifically concentrating on:

(1) increasing the yield of major food crops in Africa.

(2) optimizing agricultural water and nutrient use efficiencies.

(3) mitigating the incidence of insect pests affecting fruits, crops, and livestock; and

(4) enhancing the productivity of livestock.

The First Coordination Meeting was attended by seventy participants, including Project National Coordinators from thirty-three Member States participating in the project, five designated regional experts, partner institutions and IAEA staff.

The meeting focused on both strategic and operational issues relevant for the management and implementation of the project and relevant to the role of the Project National Coordinators. It will provide a platform for learning and peer-to-peer collaboration and sensitize the project counterparts to new possibilities in the application of nuclear science in crop production, soil and water management, insect pest control, and livestock production in Africa. The meeting addressed a comprehensive overview of the AFRA project in agriculture, delineating its goals, objectives, identification of key regional priorities in food security.

National Training Course

Improving Banana Productivity through Mutation Breeding Techniques for Enhanced Disease Resistance – VEN5023

Maracay, Venezuela, 6-10 May 2024

Project Officer: Cinthya Zorrilla

Project Objective: Obtain promising mutant lines of bananas and plantains with resistance and/or tolerance to diseases; especially to *Fusarium oxysporum* f sp *cubense* Raza 4 Tropical (*Foc* TR4) and *Ralstonia solanacearum*.

Course Objective: Strengthen technical capacities in the field management and detection of the disease caused by *Foc* R4T in Venezuela and evaluation of resistance to this disease in breeding material developed.

This course will provide the necessary tools to implement screening methods appropriate to the condition of Venezuela that can be applied by the institutions that have been authorized to do research with the pathogen led by INIA and following the guidelines of INSAI.

The training was held in Maracay, Venezuela, with an expert from Colombia's National Agricultural Research Institution (AGROSAVIA).

A total of sixteen professionals (twelve women and four men researchers) from national research institutions (INIA, UCV, IDEA, UCV) participated in the training.

Regional Training Course

Regional Training Course on Plant Mutation Breeding and Molecular Techniques for Crop Improvement

Promoting Sustainable Agricultural and Food Productivity in the Association of Southeast Asian Nations Region (RAS5094) and Improving the Resilience of Crops to Climate Change through Mutation Breeding - Phase II (SAPI) (RAS5098)

Bangkok, Thailand, 22 April-3 May 2024

Project Officer: Cinthya Zorrilla

Project Objective: This training was organized for RAS5094 (Southeast Asia) and RAS5098 (Pacific) projects. They have the common objective to enhance capacities of young professionals in mutation breeding and related biotechnologies.

The training was held in Bangkok, Thailand, with the participation of local Thai experts and international experts from Malaysia and Japan. Some demonstration sessions and technical visits were prepared by the Thailand Institute of Nuclear Technology and Kasetsart University research staff.

A total of seventeen participants (nine women and eight men researchers) from Southeast Asia (Bangladesh, Cambodia, Indonesia, Lao P.D.R., Malaysia, Myanmar, Pakistan, Philippines, Thailand, and Vietnam) and six participants (three women and three men researchers) from the Pacific Islands (Marshall Islands, Palau, Papua New Guinea, Samoa, Tonga, and Vanuatu) attended the training course.

Course Objective: Train participants on mutation breeding techniques and associated methodologies such as molecular/genomic techniques that allow increasing genetic diversity and selecting for improved mutant varieties.

Participants got acquainted with basic concepts on mutation induction to generate genetic diversity, radio-sensitivity testing, screening methods for different traits, as well as methods for mutant population advancement.

Regional Workshop

Workshop on Accelerating Climate-Resilient Crop Improvement - RAS5088-2

Hanoi, Vietnam, 15-19 April 2024

Project Officer: F. Sarsu, P. Mathur

In collaboration with the Vietnam Atomic Energy Institute and the Agricultural Genetics Institute, the Regional Workshop of the IAEA/RCA TC project RAS5088-2 was held in Hanoi, Vietnam, from 15 to 19 April 2024.

Workshop objectives:

- In-depth presentations showcasing the implementation and impact of mutation by speed breeding protocols in different countries.
- An exchange of valuable information and knowledge among participants to foster collaborative learning.
- Presentations highlighting the tangible impact of mutation breeding and speed breeding technologies on crop improvement, featuring concrete results from the project.
- A dedicated Field Day event to unveil newly released mutant varieties to Vietnamese farmers and stakeholders.

Fifteen participants (seven women and eight men researchers) including fourteen National Project Coordinators (NPCs) from Asian and Pacific countries, and the Technical Officer (TO) of the project (Joint FAO/IAEA Centre), participated in the workshop.
The methodologies on mutation by speed breeding in different crops towards protocol development and their applications in Member States were reported, discussed, and amended to contribute to the overall objective of the project. In addition, the updates on mutation breeding activities in Vietnam were shared through invited presentation session. Based on the results from different countries, the basic framework for the book entitled "Accelerating Plant Breeding: Advanced Techniques in Plant Mutation Breeding for Crop Improvement" was discussed and, the contribution from each MSs towards this book was invited as an output of the project, aimed to be published by 2025. The meeting also was very useful to reinforce the work of the Asia and Oceania Association of Plant Mutagenesis (AOAPM).

Regional Project Meeting

Regional Project Meeting on Field Experimental Design and Data Analysis for the Advancement of Mutant Populations

Promoting Sustainable Agricultural and Food Productivity in the Association of Southeast Asian Nations Region (RAS5094) and Improving the Resilience of Crops to Climate Change through Mutation Breeding - Phase II (SAPI) (RAS5098)

Hanoi, Vietnam, 18 - 22 March 2024

Project Officer: Cinthya Zorrilla

Project Objective: In recent years, climate change has negatively impacted crop production, plant growth, crop yield, abiotic stresses such as drought and salinity, and disease incidence and severity. Increasing genetic diversity can play an important role in addressing the problems arising from unfavorable environmental conditions.

Project RAS5094 aims to develop mutant lines/varieties and integrate climate smart agricultural practices to enhance nutrient and water use efficiencies on farms, increase crop productivity with low environmental footprints, capacity building development, prevalent seed system models, seed certification, dissemination, identification of a testable model, and explore possibilities for securing valuable mutant germplasm in the Svalbard global seed vault. Transfer of knowledge and expertise among ASEAN countries will be encouraged through meetings, workshops, and trainings with participation of scientists and experts in the region.

Project RAS5098 is addressing the improvement of main crops for the Pacific Islands with the technical support from the Joint FAO/IAEA Centre.

Meeting Objective: Evaluate research progress made by counterparts in their mutation breeding activities under projects RAS5094 and RAS5098; identify the common challenges and strategies for success; update project activities accordingly and plan activities for 2024 and 2025; and establish strategies for a closer collaboration and exchange of information, knowledge, material, etc. between Member States and the possibility of publications.

Integrating two regions in the meeting was a very successful strategy as the exchange of knowledge allowed counterparts from countries that are just starting the implementation of mutation breeding to learn from the achievements accomplished by more experienced counterparts.

A total of fifteen participants (eleven counterparts of project RAS5094 from Bangladesh, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Pakistan, Philippines, Thailand, and Viet Nam; three counterparts of project RAS5098 from Fiji, Palau, and Samoa; and one expert from CePACT – SPC) participated in the meeting and exchanged progress and ideas for future implementation of both projects.

Group photo at the Regional Meeting, projects RAS5094 and RAS5098

National Workshop

Mutation Induction and Mutation Breeding - HON5010

Tegucigalpa, Honduras, 12-13 March 2024

Project Officer: Cinthya Zorrilla

Project Objective: Improve the crop adaptation to biotic and abiotic stresses mainly in the Dry Corridor of Honduras with emphasis on drought tolerance and nutritional quality improvement in beans.

Course Objective: Make participants familiar with the basics of inducing mutations to generate genetic diversity, radiosensitivity testing, drought tolerance detection methods and nutritional quality, as well as methods for mutant population advancement. In addition, to recognize mutation breeding techniques as an important strategy that could be implemented in their own breeding programs and to discuss how a bean mutation breeding strategy for drought tolerance, disease resistance, and improved nutritional quality could be implemented in Honduras.

A total of seventeen participants, eleven women and six men researchers, were a part of the workshop. They belonged to the Ministry of Agriculture, University Zamorano and Universidad Nacional de Agricultura which will be collaborating to implement mutation breeding in seed crops.

National Workshop on Mutation Induction and Mutation Breeding

National Training Course

Molecular Detection Methods for Musaceae Diseases

Improving Banana Productivity through Mutation Breeding Techniques for Enhanced Disease Resistance – VEN5023

Maracay, Venezuela, 4-8 March 2024

Project Officer: Cinthya Zorrilla

Project Objective: Obtain promising mutant lines of bananas and plantains with resistance and/or tolerance to diseases; especially to *Fusarium oxysporum* f sp *cubense* Raza 4 Tropical (*Foc* TR4) and *Ralstonia solanacearum*.

Course Objective: This course contents included DNA extraction from banana pseudo stem and leaves, isolation of the pathogen, as well as application of main molecular methods to be implemented at the NPPO laboratories with the support of national research institutions across the country. Participants also received a training manual in Spanish developed by the IAEA with the support of AGROSAVIA.

The training was held in Maracay, Venezuela, from 4 to 8 March 2024, and it was led by an expert from Colombia's National Agricultural Research Institution (AGROSAVIA) with the support of INIA-Venezuela research staff.

A total of seventeen professionals (thirteen women and four men researchers) from national research institutions (INIA, UCV, IDEA, IVIC) and the National Phytosanitary Protection Organization (INSAI) of Venezuela participated in the training.

Group photo at the National Training Course on Molecular Detection Methods for Musaceae Diseases, project VEN5023

Regional Coordination Meeting

Applying Nuclear Technology in Agriculture, Water Resource Management, and the Environment in Caribbean Member States (CARICOM) - RLA7027

Vienna, Austria, 4-8 March 2024

Project Officer: I.K. Bimpong

Project Objective: Support the transfer of knowledge and expertise among CARICOM countries through meetings, workshops, and trainings with the participation of scientists and experts in the region. CARICOM countries will collaborate in the regional project to enhance crop production through national crop improvement programmes by using mutation breeding and related technologies.

Meeting Objective: This event focused on planning of a technical workplan, technical visits, discussion of proposed training activities according to the needs of the region, exchange of knowledge and progress on mutation breeding among participants, and future actions to be taken to increase the impact of the project in the availability of improved varieties for sustainable food production and strengthening/establishing collaborations among participating Member States.

Twenty-two participants (eight women and fourteen men researchers) attended the meeting.

Regional Project Meeting

Strengthening Member State Capacities to Combat Banana Fusarium Wilt (TR4) through Early Detection, New Resistant Varieties, and Integrated Management – INT5158

Virtual, 28-29 February 2024

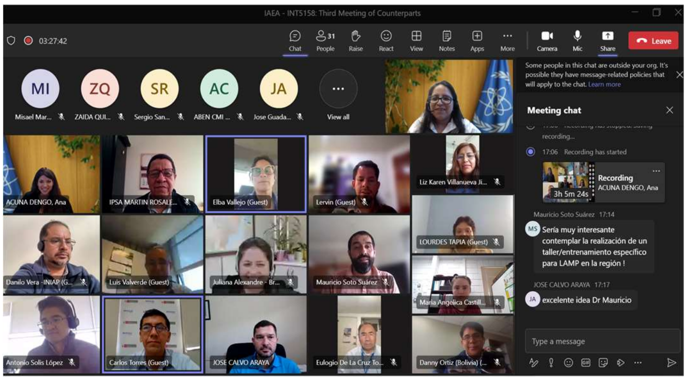
Project Officer: Cinthya Zorrilla

Project Objective: Develop capacities for disease management against *Foc* TR4 and the development of new resistant banana varieties using mutation breeding and combined biotechnologies to contribute to prevent the spread of this disease and reduce farmers' losses.

A total of thirteen countries were represented in this meeting. Two sessions were developed, the first one on prevention and detection of the disease and the second one focused on mutation breeding. A total of forty-two participants (eighteen women and twenty-four men researchers) were a part of the meeting as presenters or observers.

Meeting Objective: Review the progress and obtain inputs to plan the next activities to be carried out in the project.

The survey applied indicated that the main topics of interest of the participants were banana mutation breeding and detection and diagnosis of banana Fusarium wilt. Some tentative topics for future trainings were proposed depending on the availability of funds. Additionally, the counterpart from Brazil was designated by voting as the new DTM of the project.



Group photo at the Counterparts Meeting, project INT5158

National Coordination and Review Meeting

Enhancing Food Security via Nuclear Based Approaches - PAL5011

Vienna, Austria, 26-28 February 2024

Project Officer: I.K. Bimpong

Project Objective: (1) Provide technical advice, guidelines, and human capacity building; (2) upgrade laboratory infrastructure; and (3) support partner universities in establishing national research laboratories and providing technical staff with related training.

Meeting Objective: This event focused on planning of the workplan and proposed training activities according to the project need, and progress on mutation breeding, as well as future actions to enhance crop production by using mutation breeding and related technologies.

Three participants (all men researchers) attended the meeting.

Regional Coordination and Review Meeting

Developing Climate Smart Crop Production including Improvement and Enhancement of Crop Productivity, Soil and Irrigation Management, and Food Safety Using Nuclear Techniques (ARASIA) - RAS5099

Virtual, 23-24 January 2024

Project Officer: I.K. Bimpong

Project Objective: Incorporate advanced technologies, especially in speed breeding, to hasten the pace and precision in developing new and improved mutant varieties, through meetings, workshops, and trainings with the participation of scientists in the region. ARASIA countries will collaborate in the regional project to enhance crop production through national crop improvement programmes by using mutation breeding and related technologies.

Meeting Objective: This event focused on planning proposed training activities according to the needs of the region, individual country workplan, and progress on mutation breeding among participants, as well as future actions to be taken to increase the impact of the project in the availability of improved varieties for sustainable food production and strengthening or establishing collaborations among participating Member States.

Twelve participants (five women and seven men researchers) attended the meeting.

Developments at the Plant Breeding and Genetics Laboratory (PBGL)

Steering Committee from FAO

PBGL was thrilled to receive the members of the Steering Committee from FAO on 12 April 2024 and present our ongoing work on space breeding, drought phenotyping, disease detection and diagnostics. The lab members benefitted from the engaging discussions and were encouraged by the interests shown by our esteemed visitors.

Training course on Fusarium TR4 diagnostic to COMESA countries

During the week of 22-26 April 2024, PBGL had the privilege to collaborate with the International Plant Protection Convention (IPPC) of FAO to host the hands-on training course on Fusarium TR4 diagnostic to Common Market for Eastern and Southern Africa (COMESA) countries to strengthen the capacities of National Plant Protection Organizations (NPPOs), who play a pivotal role in mitigating its impact and safeguarding our agricultural systems. The threat of *Foc* TR4 is pressing, and the participants investigated various aspects of TR4 diagnostics, from understanding its biology and epidemiology to hands-on practical sessions on morphological identification, pathogenicity testing and advanced molecular techniques. A valuable experience was the opportunity for the trainees to meet and engage with global expert participants of the Coordinated Research Project on "Integrative Approach to Enhance Disease Resistance Against Fusarium Wilt (*Foc* TR4) in Banana" who shared insights on how to effectively address this challenge. Through collaborative and coordinated efforts and shared knowledge, plant health can be effectively safeguarded to protect agricultural systems. The participants greatly benefitted from our experts and facilitators who shared their knowledge and expertise.

Diagnostic markers developed to improve Striga resistance in sorghum

Marker-assisted early generation selection (MEGS) has emerged as an effective approach for selecting desired alleles in early generations, across range of crops and traits. However, MEGS requires diagnostic markers with high selection efficiency, so that decisions can be made at very early stages of the breeding program.

At PBGL we continue with our previous report on using ddPCR based rare mutant detection assays in the available sorghum mutant lines. Upon subsequent validation of these easy-to-use allele-specific markers, we now report development of single nucleotide polymorphism (SNP)-based KASP (Kompetitive Allele Specific PCR) assays for genetic association studies for pre germination resistance to *Striga hermonthica.*

The KASP markers were validated in F1 plants to confirm their accuracy and reliability. Upon successful confirmation in F2 progenies, these KASP markers represent a significant development for marker-assisted selection (MAS) strategies in sorghum. By incorporating these markers into ongoing introgression programs, we hope to accelerate the efficiency and precision of mutation breeding efforts aimed at incorporating durable Striga resistance traits into various backgrounds.

Overall, the integration of KASP markers and assays into our research not only enhances our understanding of Striga resistance in sorghum but also provides practical tools for breeders to accelerate the development of Striga-resistant cultivars, ultimately contributing to sustainable agricultural practices and food security in Member States.

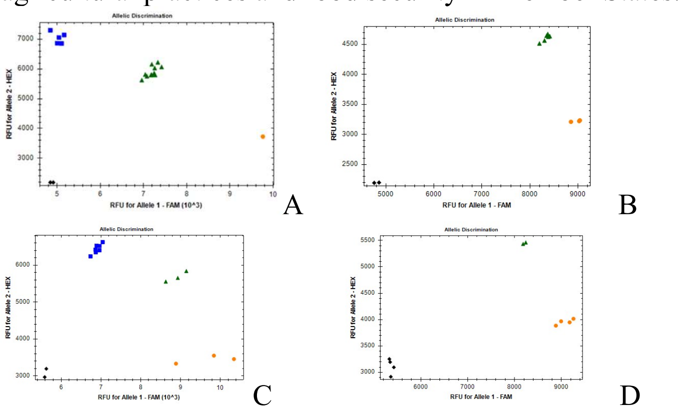


Figure: KASP assay development for Striga resistant mutants. Green: Heterozygous F1 plants, Blue: Homozygous mutant plants, Orange: Homozygous wild-type plant clusters identified based on KASP assay using four distinct mutant backgrounds

Coffee (C. arabica) mutant population screens reveal EMS- and gamma-induced resistance to coffee leaf rust.

Coffee leaf rust (CLR), a disease caused by *Hemileia vastatrix*, has tremendously impacted global coffee (*C. arabica*) production since the 18th century. To combat this disease, farmers use chemical fungicides, which in turn affect the quality of their produce and have detrimental effects on the environment. Building durable host plant resistance is a sustainable and eco-friendly approach to controlling *H. vastatrix* in *C. arabica* and mutation breeding offers potential to enhance genetic gains within preferred commercial varieties.

One of the main objectives of the ongoing PUI project “Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems in East Africa” is to identify Arabica coffee mutants with induced resistance to CLR. To achieve this, leaf discs from young leaves collected from M2 populations and wild-type lines grown in the greenhouse at PBGL were inoculated with a fungal suspension (uredospores) following a protocol developed and optimized at PBGL (Newsletter 52). The assay was monitored for 50 days after infection (DAI) to observe the emergence of lesions and sporulation.

Our results revealed a highly significant influence of mutagens on the CLR pathogen infection in *C. arabica* mutant population (Fig. 1). The mutagens induced resistance to CLR. Notably, in wild-type controls symptoms of infection manifested much earlier (latent period) compared to both EMS- and gamma-derived mutants (Fig. 1A). Moreover, the number of lesions (Fig. 1B) and sporulating lesions (Fig. 1C) exhibited a significant reduction in EMS- and gamma-derived mutants in contrast to the parental controls. Further screening of additional mutants is planned to ascertain their resistance status concerning CLR infection.

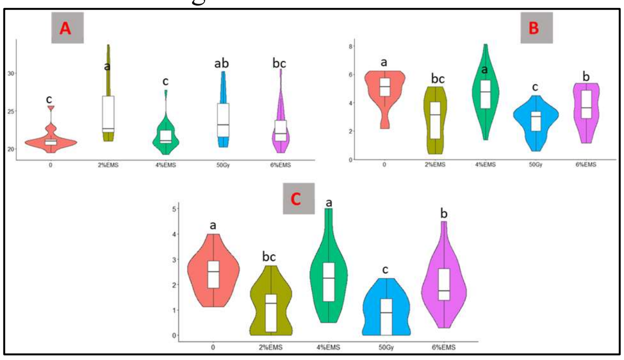


*Figure: Screening of C. arabica (M_2) mutant population for resistance to coffee leaf rust infection. Leaf discs were infected with uredospore suspension. (**A**) Time (days) to appearance of the first symptoms (latent period. (**B**) Number of lesions at 50 days after infection (DAI). (**C**) Number of sporulating lesions at 50 DAI. Bar graphs with different letter are significantly different (p≤0.05). Means were separated using least significant difference (LSD) at p≤0.05.*

Physiology Experiment

Plant aquaporins (AQP) and its responsiveness to soil moisture stress and atmospheric stress has been studied extensively in past decades both in model and crop species for their role in drought adaptation. To understand whether mutations in AQPs (aquaporins) affect nitrogen and carbon partitioning in sorghum under water stress conditions, green house studies are being conducted at Plant Breeding and Genetic laboratory, Seibersdorf using single and double AQP mutants in sorghum along with their parent.

Two experiments were conducted on plants comprised of single and double aquaporin mutants and their wild types to predict their water and nutrient use efficiency. In the first experiment, mutants and their wild type were grown under well-watered conditions and water stress was imposed at flowering. Daily water consumption, transpiration rate, leaf temperature and chlorophyll contents through SPAD meter were measured. These measurements were recorded till the pot water reached to 50% of WW levels. Furthermore, gas exchange parameters were recorded at the end of the stress period and leaves, stem and roots were collected to measure the carbon isotopes (^{13}C). Likewise, grain yield and yield traits were recorded and samples for leaves, stem, roots, and grains were taken to evaluate the role of ^{13}C in prediction of water use efficiency and drought adaptation of sorghum. Preliminary results from this experiment indicate that water consumption in mutants was significantly slower in comparison to their parent. Furthermore, the root length was observed to be higher under drought conditions in comparison to well-watered conditions with one of the mutants having the highest root length (Figure 1).

The objective of the second experiment was to predict the nitrogen use efficiency for which the genotypes were grown with two different treatments, i.e., nitrogenous fertilizers (^{14}N) and labelled fertilizer (^{15}N). Furthermore, drought stress was imposed at flowering stage by dividing the plants under each N treatment into two further treatments of well-watered and drought conditions until maturity. The daily water consumption, leaf temperature and chlorophyll contents were recorded including leaves samples after 7 weeks of stress and stored at -80°C for phytohormone analysis. Likewise, plants were harvested at maturity and different parameters recorded, samples of roots, stems, leaves, and grains were taken for ^{13}C and ^{15}N measurements.

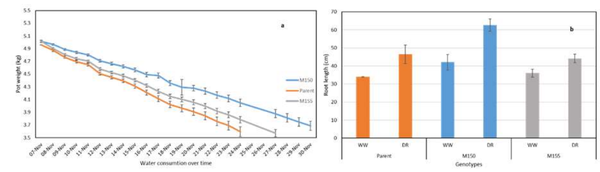


Figure: The average water consumption along with standard error over the stress period has been indicated by figure 1(a) and the average root length along with standard error is indicated by figure 1(b). Further, WW is denoting well-watered conditions, DR is indicating drought conditions.

The collected data is being analyzed in detail and potentially will throw light on nutrient use efficiency in sorghum as well as the role of aquaporins in N remobilization in grains. This study will discover the traits for nitrogen and carbon partitioning in sorghum mutants where plant ^{13}C and data of ecophysiology, phytohormones, and grain yield will help to understand the plant adaptation to drought stress and ^{15}N will identify the nutrient partitioning under drought stress conditions. Moreover, this protocol will also be useful to develop such methods for other crop species.

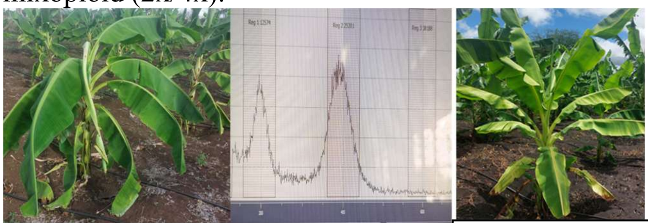
Morphological and Foc 1 response variation in gamma and EMS diploid cooking banana subgr. Mchare (Musa spp.) mutants

In vitro mutagenesis in banana can rapidly generate many genetic variations including novel traits that may not be present in the existing gene pool in a shorter period. This accelerated rate of mutation induction can significantly speed up the breeding process compared to conventional methods, which may take years to achieve.

The Mchare mutant population previously reported undergoing field trial in hot spot in Tanzania for resistance screening to *Foc* Race 1 so far (58 weeks), have not shown any external *Foc* symptoms in over 45% of the test mutants. We expect the number to drop during final evaluation when scoring for Rhizome discoloration (RDI) will be done as some varieties express internal symptoms more clearly than external symptoms.

Photo1: External (right) and Internal (left) Fusarium wilt race 1 symptoms as seen from the field in Bukoba Tanzania.

In addition, large number of phenotypic variants have been identified. These include plants with short pseudostem internodes which may be linked to dwarfism, broader leaves, elongated crenated leaves, black pseudostem, drooping leaves and green-yellow leaves plants. Few variants selected from this population analyzed for ploidy estimation showed variations ranging from diploid (2x) to mixoploid (2x/4x).



Accs code	ITC code	Name	Mutagen	Dosage	Ploid results
2595		Huti white	EMS	1%	2X+4X

Green-yellow leafed mutant

Photo 2. Variants with drooping leaves, mixoploid and Green-yellow leaves

In vitro backups for over 300 selected mutants that have so far shown field resistance against *Foc* race 1 were hardened in greenhouse conditions for screening for TR4 resistance. A comparative experiment has been set to compare and optimize the inoculation methods (solid and liquid/pouring methods) for studying the genotypic responses of Mchare to *Foc* TR4.

Photo 3. Plant material in the glasshouse prior TR4 screening

Low-cost Digital Droplet PCR based detection method developed for Foc diagnostics

Fusarium wilt, caused by *Fusarium oxysporum* f. sp. cubense (*Foc*), poses a significant threat to banana cultivation worldwide and amongst its various strains, Race 1 and Tropical Race 4 (TR4) have been particularly devastating for dessert Cavendish as well as cooking types and plantains. The disease detection mostly relies on PCR based techniques, and although these methods facilitate precise identification of infected plants, they are qualitative and require higher quantities of pathogen DNA to be isolated for conclusiveness.

More recently at PBGL *Foc* TR4-specific probe-free digital droplet PCR (ddPCR) assays have been developed to detect and quantify *Foc* TR4 from symptomatic and asymptomatic plant tissue at greater sensitivity and low costs. This probe-free ddPCR approach not only enhances cost-effectiveness but also offers exceptional sensitivity and detection levels in low abundant infected samples (the internal control, the *COX* gene was detected at $\geq$ 0.4 picograms, while TR4 was detected at genomic DNA concentrations $\geq$ 0.004 ng (4 picograms) that are difficult to detect by conventional PCR further underscoring its utility in early disease surveillance and management efforts.

In addition, this method deployed previously reported TR4-specific LAMP primers (Li et al. 2013), without the need to design newer primer set further reducing the complexities. So far, ddPCR based method relied on expensive probes, that limit the widespread adoption of this method for the early and accurate detection of *Foc* TR4 by NPPOs.

This low-cost molecular method offers significant advantages over conventional PCR methods and holds great promise for improving disease management strategies and safeguarding banana crops against the detrimental impacts of Fusarium wilt. Efforts are underway to further optimize it for disease complexes that pose additional challenges and require high sensitivity due to mixed samples.

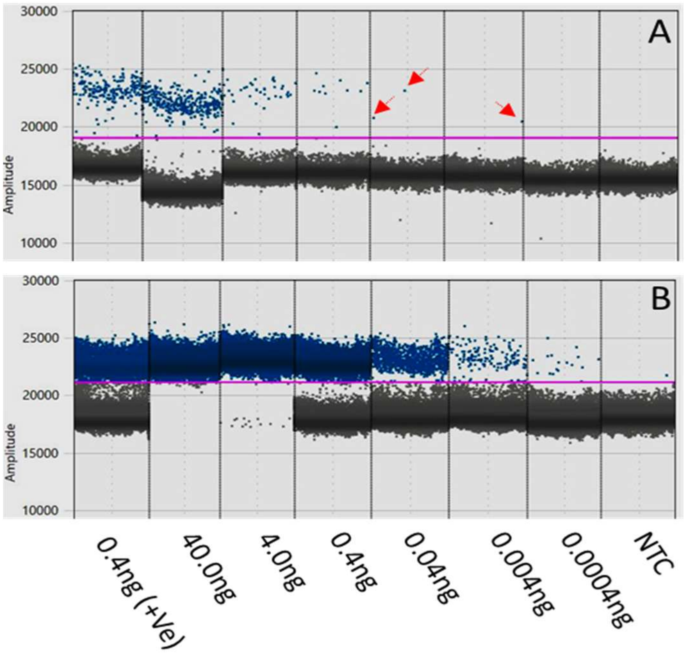


Figure: Fusarium oxysporum f. sp. cubense Tropical Race 4 (TR4) detection using ddPCR in infected banana samples. A) ddPCR detection of Foc TR4 using TR4-specific primers. B) ddPCR detection of banana internal control COX gene. NTC: No Template Control. +Ve: positive control

Project update on "Seeds-in-Space"

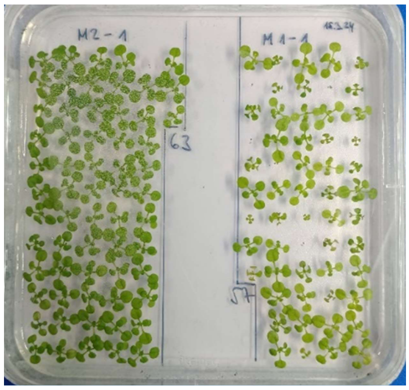
In support of the CRP Radiation-induced Crop Diversity and Genetic Associations for Accelerating Variety Development PBGL has embarked on a genomics study that aims to compare the effects of different ionizing radiations on plant genomes. The question is: does irradiation with energy from different sources induce different mutation spectra?

Highlights are certainly our plants that germinated from seeds that spent extended periods of time in outer space, experiencing cosmic radiation, extreme cold, and microgravity.

We are currently undertaking a study to compare the Arabidopsis and sorghum seeds returned from space with those irradiated with gamma and x-rays, two sources readily available on earth. This also includes assessing the gamma and x-ray irradiation dose intensities that provide a meaningful comparison.

To minimize technical artifacts, we are conducting this fundamental research study in *Arabidopsis thaliana*, the plant with the best characterized genome. We also decided to focus on heritable mutations; the ones that are transmitted to the next generation, as those are the ones relevant for mutation breeding.

Plants that emerge from irradiated seeds are chimeras. Each plant is comprised of sectors, descendants from different mutagenized cells from the mutated meristem. In addition, all those somatic mutations are in a hemizygous state. To detect the heritable ones, we are sampling complete siliques: we germinate all M2 seeds from an individual M1 silique and pool the seedling tissue into one sample. This will allow for detecting all relevant, germline mutations in the respective M1 lineage using long-read sequencing with PacBio HiFi technology.



Picture 1: Arabidopsis M2 seedlings from individual M1 siliques (lineages M1-1, M2-1)

Picture 2: Transplanting Arabidopsis seedlings from germination plates onto soil

Table 1. Crop Irradiation Services

Request Number	Country	Request Type	Crop/Species
1769	Germany		ornamental
1770	The Netherlands		ornamental
1771	Ghana		Bambara groundnut
1772	PBGL		arabidopsis
1773	Ghana		sorghum
1774	PBGL		sorghum, lentil
1775	Hungary		ornamental
1776	Germany		Brassica sp.
1777	Slovakia	TC	proso millet

Table 1 lists the irradiation requests that the PBGL received to date in the second half of 2023 (2023-09-25). A total of 22 requests were received from 18 Member States across 28 different plant species covering 92 accessions/varieties.

Individual Training

Table 2. Individual Training Activities at the PBGL

Name	Country	Status	Topic	Period
Mr Radisras NKURUNZIZA	Uganda	PHD-Consultant	Coffee mutation breeding	1 year
Mr Hassan MDUMA	United Republic of Tanzania	PHD-Consultant	Mutation breeding of African cooking banana for Fusarium Wilt resistance	1 year
Mr Maliata Athon WANGA	Republic of Namibia	Fellow	Hands on training on Molecular techniques and bioinformatics	2 months
Mr Abu Sayeed Md HASIBUZZAMAN	Bangladesh	Fellow	Molecular Breeding, including PCR, DNA extractions and QC (hands-on), Genetic/genomics/NGS, KASP marker genotyping and MAS	3 months
Ms Asma ARIS	Malaysia	Fellow	Molecular Breeding, including PCR, DNA extractions and QC (hands-on), Genetic/genomics/NGS, KASP marker genotyping and MAS	3 months
Ms Piyanuch ORPONG	Thailand	Fellow	Molecular Breeding, including PCR, DNA extractions and QC (hands-on), Genetic/genomics/NGS, KASP marker genotyping and MAS	3 months
Mr Shahzad AHMAD	Pakistan	Fellow	Molecular Breeding, including PCR, DNA extractions and QC (hands-on), Genetic/genomics/NGS, KASP marker genotyping and MAS	3 months
Ms Maikaeo LAMAI	Thailand	Fellow	Molecular Breeding, including PCR, DNA extractions and QC (hands-on), Genetic/genomics/NGS, KASP marker genotyping and MAS	3 months

Other News

Impact of Induced Genetic Variation and Biotechnologies on Rice and Soybean Productivity in Viet Nam*

Agriculture in Viet Nam: An Overview of Key Crops and Challenges

Viet Nam's economy is predominantly based on agriculture, which employed 18 million Vietnamese in 2020, making it the largest sector in the country. The estimated agricultural area is 12.4 million hectares (ha), about 40 percent of the total land area of 31.3 million ha. Over 60 percent of Viet Nam's 98.5 million population lives in rural agricultural areas. Smallholder agriculture predominates, with average land holdings below one hectare, among the smallest in the world.

Rice is the staple food in Viet Nam, with an average consumption of 145 kg per person per year, constituting 90 percent of all food consumed in the country. To ensure food security, about 3.8 million ha of cropland are dedicated to rice cultivation (Hoang et al., 2021). Major rice-producing areas include the Mekong River Delta in the south and the Red River Delta in the north, where rice is grown annually on 2 million and 1 million ha, respectively. Although the land area under rice cultivation is 3.8 million ha annually, the actual harvested area is 7.9 million ha due to the practice of cultivating two to three crops per year.

Soybean is a traditional food crop in Vietnam, increasingly demanded for livestock feed. Domestic soybean production meets only 8 to 10 percent of the crop's demand, making it the second largest imported commodity after maize. Domestic production is constrained by price competition with imported soybean and small, fragmented land holdings.

Climate change poses a significant threat to Vietnam. Drought, salinity, and increased incidences of diseases and pests due to global warming challenge both rice and soybean production, affecting smallholder farmers' livelihoods.

Induced Genetic Variation and Mutation Breeding for Crop Improvement in Viet Nam

While mutation breeding as a crop improvement strategy in Viet Nam dates back to the early 1970s, it began in earnest in 1979 with technical support from the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture for the strengthening of institutional and human capacities in the technology.

As a result, 80 improved mutant crop varieties, including 54 rice and 16 soybeans, were registered, and officially released in the country. Information on rice and soybean mutant varieties as reported to the FAO/IAEA Mutant Variety Database (http://mvd.iaea.org). The adoption and cultivation of induced mutant crop varieties, especially rice and soybean, have significantly contributed to the economic development of Viet Nam.

The Institute of Agricultural Genetics has been at the forefront in the use of mutation breeding for crop improvement in the country. Other institutions that successfully applied the technology in the country are the Institute of Agricultural Sciences for Southern Viet Nam, Soc Trang Department of Agriculture, Food Crop Research Institute, Hanoi Agriculture University and Hanoi Pedagogical University.

Rice

Rice production in Vietnam not only ensures food security but also helps increase farmers' incomes and reduce poverty. Initially, variety improvement for rice in Viet Nam emphasized productivity, while current efforts focus on adaptation to climate change and grain quality. Mutant rice varieties began to be increasingly grown in the Mekong River Delta after 1995. By the end of the first decade of the twenty-first century, these varieties occupied 10.3 percent of the area under modern rice varieties in southern Viet Nam.

One notable mutant variety, VND 95-20, released by the Southern Institute of Agricultural Science and Technology, is known for its high quality and salt tolerance. It became one of the top five export rice varieties of southern Vietnam, leading to the Institute being awarded the State Prize for Science and Technology in 2005.

Other prominent mutant varieties in the region include VND 99-3, TNDB 100, VND 95-19, OM 2717, and OM 2718. By 2008, these varieties had generated returns of USD 300 million, USD 9 million, USD 37.5 million, USD 6 million, USD 12 million, and USD 8.5 million, respectively (Do, 2009). VND 95-20 alone was cultivated on an average annual area of 280,000 to 350,000 hectares since 2000, and during its peak popularity between 2000 and 2007, provided a return equivalent to USD 300 million.

In the northern provinces, mutant varieties, including CM 1, DT 10, DT 11, and Khang Dan, occupied 40 percent of the cultivated area under rice in 2007, covering approximately 0.4 million hectares annually (Vinh et al., 2009). Among these, the rice mutant variety DT 10, developed by AGI, enjoyed a prolonged period of popularity, and was cultivated by farmers for roughly 25 years between 1990 and 2014. During this period, DT 10 recorded a cumulative area of 2.4 million hectares, benefiting 3 million farmers and contributing to an increased income of USD 450 million. This calculation is based on the farm gate value of additional income, estimated at roughly USD 188 per hectare. Notably, DT 10 exhibits an average yield of 6–8 tons per hectare, significantly higher than the average productivity of rice at the time of its release in the early 1990s, which stood at 3.3 tons per hectare.

The peak annual area under the rice mutant, Khang Dan, released in 2008, reached 200,000 hectares, establishing itself as one of the most popular varieties in north and central Viet Nam. This popularity translated into an increased income of USD 143.8 million for farmers. This calculation was based on factors such as the cumulative area during the cultivation period, yield difference relative to the parent variety, and the farm gate value of additional produce. Additionally, the saline-tolerant DT 80, identified through marker-assisted selection for the presence of the Saltol QTL, has demonstrated resilience to saline soils since its release in 2019. With a cumulative area of 15,000 hectares, it boasts a yield of 6–7 tons per hectare, providing an average yield advantage of 1–1.5 tons per hectare over its parent TL6.2. This enhancement contributes to increased earnings of USD 330 per hectare annually. It is anticipated that this variety will be cultivated on 1.2 million hectares, generating an additional income of around USD 268.8 million for approximately 1.5 million farmers.

Currently, mutant rice varieties are cultivated on 3.5 million hectares, contributing to a yearly increase in farmers' income of hundreds of millions of USD. Notably, the mutant rice variety VND-95-20 covers approximately 30% of the total cultivated area of 1 million hectares in the Mekong Delta.

Soybean

Sixteen mutant soybean varieties have been released for cultivation, with thirteen developed by AGI. These include seven national varieties: M 103, DT 83, DT 84, DT 55 (AK 06), DT 96, and DT 2008; three regional varieties: S 31, DT 95, and DT 99; as well as a few outstanding lines or varieties, including DT215 DB. These improved soybean mutant varieties are characterized by wide adaptability, high yield, and short duration. Their average yield ranges from 1.8 to 3.6 tons per hectare, which is 0.8 to 1.5 tons per hectare higher than earlier local varieties. With a growth duration of 70–100 days, they enable three crops per year. Additionally, these varieties generally have a high protein content of 40 to 47 percent.

The black seed coating is crucial for soybean, and the black-seeded mutant developed from DT 2008, named DT 215, stands as the sole, black-seeded variety in the country. With an average yield of 3.5 tons per hectare, DT 215 holds significance within the soybean cultivation landscape. However, the extended duration of this variety has posed challenges in its integration into various cropping systems across the country.

Another notable variety, DT 84, released in 1994 and one of the earliest soybean varieties developed in the country, covered 40 percent of the total soybean area in Viet Nam in 2017. During the period from 2000 to 2019, the cumulative area under mutant varieties DT 99, DT 2001, DT 96, and DT 2010 was estimated at 156,000 hectares. The yield advantage of these varieties over their parents ranged from 0.2 to 0.8 tons per hectare, providing a total yield advantage of 76,600 tons cumulatively over their years of cultivation. This translates to an estimated value of USD 58.6 million. Among these varieties, DT 2008 had the highest yield advantage at 0.8 tons per hectare and was cultivated over a cumulative area of 30,000 hectares from 2011 to 2019. Another popular variety, DT 96, with a yield advantage of 0.6 tons per hectare, was cultivated over 60,000 hectares from 2004 to 2019.

For soybean, it is currently estimated that 60 to 70 percent of the total cultivated area in the country is planted with mutant varieties. There's a preference for high-yielding, short-duration varieties, with the mutant variety DT 2008 being cultivated by approximately 1.5 million farmers.

*Published by FAO in 2023 as Case Studies of the Use of Agricultural Biotechnologies to Meet the Needs of Smallholders in Developing Countries.

Picture 1. Farmers field Day showcasing the rice variety of CNC11
Photo captured by Ms Dong Thi Kim Cuc

Picture 2. Farmers field Day showcasing the soybean variety of DT2010
Photo captured by Ms Nguyen Van Manh

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Editors: Abdelbagi M. A. Ghanim, Shoba Sivasankar, Patrick J. Rich
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ISBN 978-3-662-68181-7 (eBook)
[Mutation Breeding and Efficiency Enhancing Technologies for Resistance to Striga in Cereals | SpringerLink]

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Editors: Ivan L.W. Ingelbrecht, Maria do Céu Lavado da Silva, Joanna Jankowicz-Cieslak
Springer, 2023
ISBN 978-3-662-67273-0 (eBook)
[Mutation Breeding in Coffee with Special Reference to Leaf Rust: Protocols | SpringerLink]

Efficient Screening Techniques to Identify Mutants with TR4 Resistance in Banana
Editors: Joanna Jankowicz-Cieslak, Ivan L. Ingelbrech
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[ePDF 9781789249101]

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Guest Editors: F. Sarsu, B.P. Forster, S. Sivasankar
Australian Journal of Crop Science, Southern Cross Publishing, Volume 14, Number 8, 2021
DOI: 10.21475/ajcs.21.15.09.sp
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Manual de mejoramiento por mutaciones, Tercera edición
Editado por M.M. Spencer-Lopes, Forster, B.P., Jankuloski, L., Sub Programma de Mejoramiento de Plantas y Genética, División Conjunta FAO/OIEA de Técnicas Nucleares en Alimentación y Agricultura.Manu
ISBN 978-92-5-133741-7 © FAO, 2021
[Manual de mejoramiento por mutaciones (fao.org)]

Manuel d'amélioration des plantes par mutation, Troisième édition

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Division mixte FAO/IAEA des Techniques Nucléaires appliquées à l'Alimentation et à l'Agriculture.
ISBN 978-92-5-132932-0 © FAO, 2020
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DAS P., BAHUGUNA R.N., RATHORE R.S., ABBAT S., NONGPIUR R.C., SARSU F., SINGLA-PAREEK S.L., PAREEK A. (2021) Rice mutants with tolerance to multiple abiotic stresses show high constitutive abundance of 11 stress-related transcripts and proteins. In Sarsu et al (eds) 2021. Crop Adaptation to Climate Change: High-Temperature Stress in Drought-Prone Areas. Southern Cross Publishing, Australia, pp 12-21.

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MUNOZ L.C., RIVERA M., MUNOZ J.E., SARSU F., RAO I.M. (2021) Heat stress-induced changes in shoot and root characteristics of genotypes of tepary bean (*Phaseolus acutifolius* A. Gray), common bean (*Phaseolus vulgaris* L.) and their interspecific lines. In Sarsu et al (eds) 2021. Crop Adaptation to Climate Change: High-Temperature Stress in Drought-Prone Areas. Southern Cross Publishing, Australia, pp 50-58.

MUNOZ L.C., DEBOUCK D.G., RIVERA M., MUNOZ J.E., ALPALA D., SARSU F., RAO I.M. (2021) Mutation breeding for heat and drought tolerance in tepary bean (*Phaseolus acutifolius* A. Gray). In Sarsu et al (eds) 2021. Crop Adaptation to Climate Change: High-Temperature

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KUSOLWA P.M., NEEMA Y., RAJAB M., LUZI-KINUPI A., SARSU F. (2021) Field performance of heat tolerant mutant rice lines generated from *Oryza sativa* and *Oryza glaberrima.* In Sarsu et al (eds) 2021. Crop Adaptation to Climate Change: High-Temperature Stress in Drought-Prone Areas. Southern Cross Publishing, Australia, pp 68-77.

ASHRAF M., HAMEED A., ZIAL-UL-QAMAR, SARSU F. (2021) Correlation of yield with early seedling performance and physio-biochemical traits in Basmati rice 78 mutants subjected to heat stress. In Sarsu et al (eds) 2021. Crop Adaptation to Climate Change: High-Temperature Stress in Drought-Prone Areas. Southern Cross Publishing, Australia, pp 79-90.

Conference Abstracts and Posters

2023

SUBRAMANIAN N, PILLAI S, ROONEY W, BAGAVATHIANNAN M, SIVASANKAR S (2023) Utilization of electron-beam mutagenesis for sorghum crop improvement. Global Sorghum Conference 2023, June 5-9, Montpellier, France

SIVASANKAR S (2023) Innovative plant breeding for climate-resilient crops. Invited plenary lecture at the 5th Mindanao Summit of the Philippine Phytopathological Society, Inc. - Southern Mindanao Division (PPS-SMD), June 9, 2023, Davao City, Philippines.

DHANASEKAR P, SOUFRAMANIEN J, DHOLE VJ, HINGANE AJ, SIVASANKAR S (2023) Physical mutagenesis for induction of resistance against *Maruca* pod borer in cowpea [*Vigna unguiculata* (L.) Walp]. Submitted to the International Conference on Pulses: "Smart Crops for Agricultural Sustainability and Nutritional Security" February 10-12, 2023, New Delhi, India.

SIVASANKAR S (2023) Induced genetic variation and mutation breeding for crop improvement at the Joint FAO/IAEA Centre. Invited talk at the 2nd International & 12th Biennial Conference of the Plant Breeding and Genetics Society of Bangladesh 2023, February 18-19, 2023, Dhaka, Bangladesh.

SIVASANKAR S (2023) The role of induced genetic variation in crop improvement towards food and nutrition security – a global context. Invited Keynote Lecture at the International Conference on Food and Nutrition Security (iFANS-2023) January 6-9, 2023, Mohali, India.

JAWDAT D., MOSTAFA O., JANKULOSKI L., SARSU F., MALEK M., MIR A.N. (2023) Mutation breeding, an affordable crop improvement strategy in challenging times: Barley mutation breeding projects in Syria and the urge for acceleration. The 3rd International Barley Mutant Conference- 8-10 October 2023, - Kurashiki, Japan

KIRYAKOV I., PETKOVA M., AZIZ S., MASHEVA V., SARSU F., TOMLEKOVA N. (2023) Phytopathology and molecular investigation of resistances to bacterial and fungal patogens in common bean mutant and breeding lines. 2-4 November 2023, Antalya, Türkiye.

AZIZ S., MLADENOV P., GULER U., ONAT B., PLANCHON S., TOPALOVA E., MASHEVA V., KIRYAKOV I., RENAUT J., SALIH B., SARSU F., TOMLEKOVA N. (2023) Drought stress tolerance in common bean mutant and breeding lines: Physiology and proteomics response. 2-4 November 2023, Antalya, Türkiye

JANKOWICZ-CIESLAK, J., WARTHMANN, N., ENRIQUE MORALES ZAMBRANA, A., VILJOEN, A., INGELBRECHT, I. (2023) Induced Mutagenesis of Banana for Resistance to Fusarium Wilt Tropical Race 4. The Plant & Animal Genome Conference (PAG), January 13 - January 18, San Diego, CA, USA.

WARTHMANN, N., MURRAY, K.D., MORALES ZAMBRANA, A.E., CONDE M.V., MORALES., L., ALI, A., GHANIM, A.M., BOREVITZ, J.O., INGELBRECHT, I. (2023) Mainstreaming Genomics: Protocols for Genome Re-Sequencing at the Population Scale. The Plant & Animal Genome Conference (PAG), January 13 - January 18, San Diego, CA, USA.

NKURUNZIZA, R., JANKOWICZ-CIESLAK, J., INGELBRECHT, I.L.W., WERBROUCK, S. (2023) In vitro tissue culture and genotyping innovations to accelerate mutation-assisted breeding of Coffea arabica. COPYTREE (European Network for Innovative Woody Plant Cloning - Cost Action 21157), Faculty of Chemistry, Universidad de Santiago de Compostela, 17 - 18 April 2023, Spain.

2022

TAHERI S., BIMPONG I.K., SIVASANKAR S., WERBROUCK, P.O. (2023) Meta-topolin riboside and dikegulac for improved micropropagation of olive (Olea europea L.), Angers, France.

News Highlights

- Can the harsh conditions of space breed more resistant crops for Earth? | Grist **(14 May)**
- COMESA countries upgrade laboratory diagnostic capacity to manage Fusarium TR4 - International Plant Protection Convention (ippc.int) **(13 May)**
- Improving Resilience to Drought in Rice and Sorghum through Mutation Breeding | IAEA**(1 February)**
- NEW CRP: Accelerated Genetic Improvement of Key Dryland Millets for Climate Change Adaptation (D24016) | IAEA **(31 October)**
- Africa's First IAEA Collaborating Centre for Plant Breeding and Genetics **(23 October)**
- IAEA and FAO Announce Winners of Seeds in Space Comic Book Contest | IAEA **(11 August)**
- Crop Seeds Return from Space in IAEA/FAO Project to Help Feed a Warming World (**15 April**)
- IAEA and FAO Engage Youth in STEM with First-of-a-Kind Space-Themed Event (**28 March**)
- Seeds in Space: 'Cosmic crops' for food security and climate change adaptation (**27 March**)
- Cosmic crops poised for harvest on Earth (**27 March**)

Websites and Links

- Plant Breeding and Genetics Section: https://www.iaea.org/topics/plant-breeding
- Infographic on Mutation Breeding: https://www.iaea.org/newscenter/multimedia/videos/using-nuclear-science-to-boost-plant-biodiversity
- Mutant Variety Database: http://mvd.iaea.org
- Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture: https://www.iaea.org/about/organizational-structure/department-of-nuclear-sciences-and-applications/joint-fao/iaea-centre-of-nuclear-techniques-in-food-and-agriculture
- Plant Breeding Publications: Plant breeding publications | IAEA
- Food and Agriculture Organization of the United Nations (FAO): Home | Food and Agriculture Organization of the United Nations (fao.org)

Impressum

Plant Breeding and Genetics Newsletter No. 53

The Plant Breeding and Genetics Newsletter is prepared twice per year by the Plant Breeding and Genetics Section, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture

International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Printed by the IAEA in Austria, July 2024

24-03311