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To Our Readers

Left photo shows sorghum field fully infested with Striga hermonthica in Africa leading to a potential high crop failure; Right photo shows newly induced mutant-lines at PBGL showing resistance to Striga (for more details see page 26).

Dear Colleagues,

The Plant Breeding and Genetics Subprogramme (PBG) had a busy and exciting first half of 2019. In addition to providing scientific coordination for five Coordinated Research Projects (CRPs), and technical support for the different Technical Cooperation Projects (TCPs) of the current cycle, we were engaged in the design of the projects for the 2020–21 cycle in collaboration with our colleagues in the IAEA Department of Technical Cooperation, and with our counterparts.

I would like to provide here a brief snapshot of our main outputs during the first half of the year (please see pages 5 and 6 for more details):

- **The successful verification and confirmation of mutant lines of sorghum that have resistance to the parasitic witchweed, *Striga*** (please see pages 5 and 26

for more details). *Striga* is a serious parasite of cereal crops and of cowpea in sub-Saharan Africa, infesting more than 50 million ha and causing yield reduction in the range of 20 to 100% in infested fields of maize, millet, rice and sorghum, resulting in enormous economic losses. It has been estimated that in rice alone there is an annual loss of USD 111 million to USD 200 million.

- **Progress on genetic mapping of the semi-dwarf/early maturing, gamma-irradiation induced mutant trait in sorghum using whole genome sequencing** (please see pages 5 and 26 for more details). A locus of approximately 5 Mb on chromosome 4 has been identified as harboring the causative genetic variant(s).
- **A new Plant Mutation Breeding Network for the Asia Pacific Region will have its first network meeting in July 2019**. This network is a pilot effort emerging from the Bali proposal of September 2017 prepared at the FAO/IAEA/BATAN Technical Meeting on Plant Mutation Breeding.
- **Approval of a new Collaboration Centre on 'Plant Mutation Breeding using Chronic Gamma Irradiation' at the Malaysian Nuclear Agency**. The objectives of the Collaboration Centre include wider utilization of chronic gamma irradiation from a gamma garden for crop improvement, technical capacity building in the region, and collaborative R&D for molecular breeding.
- **Approval of a new CRP on 'Enhanced biotic-stress tolerance of pulses towards sustainable intensification of cropping systems for climate-change adaptation'**. The research focus is on enhancing the tolerance of chickpea to the pod borer, *Helicoverpa armigera*; cowpea to the bod borer, *Maruca vitrata*, and lentil to the disease, *Stemphylium* blight.
- **Release of the improved mutant groundnut variety, Tafra-1, for the marginal rainfed areas of the North Kordofan State of Sudan was recognized by an IFAD award of excellent performance to the Elobeid Research Station**. Sudan ranks fourth in acreage under groundnut and is among the leading exporting countries.
- **The Director of the Joint FAO/IAEA Division met with stakeholders, including seed breeders and representatives of the Ministry of Agriculture in Indonesia, to discuss upscaling of seed production and access of improved, quality seed to farmers.** Three of the 23 new mutant rice varieties (Bestari, Impari Sidenuk and Mustaban) in Indonesia are now being widely cultivated in different regions across the country.

Mr Qu Liang (Director, Joint FAO/IAEA Division) met with BATAN's researchers and potential stakeholders in Jakarta, Indonesia.

In addition to the new CRP, PBG currently coordinates four CRPs: (1) Efficient Screening Techniques to Identify Mutants with Disease Resistance in Coffee and Banana – D22005; (2) Improving Resilience to Drought in Rice and Sorghum through Mutation Breeding – D23031; (3) Disease Resistance in Rice and Wheat for Better Adaptation to Climate Change – D23032; and (4) Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security – D25005. Plant Breeding and Genetics also supports 69 TCPs through partnership between IAEA and FAO.

I thank you for all your support, input and efforts, and look forward to continuing strong collaborations towards the development and dissemination of improved crop varieties through plant mutation breeding and associated innovative biotechnologies.

Sobhana Sivasankar
Head
Plant Breeding and Genetics Section

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[1] Joined in December 2018
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[4] Joined in May 2019
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[6] Separated in May 2019

Staff News

Isaac Kofi Bimpong joined the PBGL in December 2018. He started his career with Ghana National Council for Agricultural Research after his BSc. Degree. He obtained both his MSc and PhD in Plant Breeding and Molecular Biology at the University of the Philippines Los Baños (UPLB) in collaboration with International Rice Research Institutes (IRRI) in the Philippines.

Kofi worked at Africa Rice Centre (CGIAR organization) for 10 years as a Molecular Plant Breeder where he was instrumental in transforming AfricaRice breeding program with emphasis on Genetic Gain. He was also the coordinator for Africa-wide Mangrove & Lowland Swamp Breeding Taskforce - a platform for 25 NARES-Member Countries in Africa to plan rice breeding programmes by facilitating the development of product profiles for members, introduction of germplasms from AfricaRice for evaluation and release. He also coordinated a project 'High-throughput genotyping (HTPG)' to support 'forward breeding' in Africa for marker assisted selection and quality assurance processes. Kofi was also the objective leader for rice improvement under problem soils (salinity and sodicity) for STRASA project (Stress Tolerant Rice for Poor Farmers in Africa and South Asia) funded by Bill and Melinda Gates foundation.

Kofi's research work has led to the release of 15 rice cultivars with NARS members and has also nominated over 100 rice breeding lines for testing. He has more than two–dozen peer reviewed publications including one in *Nature Genetics.* He has trained nine PhD, eight MSc and more than 15 BSc students in sub-Saharan Africa

Andrew Gennet joined the PBGL in January 2019 as a Junior Professional Officer (JPO). In 2016 he graduated from the University of Kentucky, Lexington USA, with a BSc in Agricultural Biotechnology. His undergraduate work quantified Sorghum resistance against anthracnose, caused by *Colletotrichum fungi*, using digital photography and leaf damage area. Following he worked for iPiPE, an information sharing platform that connect extension plant pathologist with local farmers. Early warning of disease occurrence was shared through Twitter, @corndisease, and iPiPE informing farmers and protecting crop yield.

The above experiences combined with his study of rhizosphere interactions between host roots and symbiotic fungi, as a lab technician for Mycorrhizal Applications, provided the underlaying knowledge to join ongoing CRPs and grow with the IAEA.

Currently, he is working to determine resistance mechanisms in sorghum mutants against the parasitic plant *Striga* as well as screening banana mutants for resistance to *Fusarium oxysporum* f. sp. cubense (Foc) that causes Fusarium wilt.

Laura Morales was a laboratory technician in the PBGL from February to May 2019. Laura is a quantitative geneticist with over 10 years of experience in statistics, genomics, plant pathology, and food systems. She received a BSc in Biology/Biotechnology from the University of Florida, USA in 2011. In December 2017, Laura received a PhD in Plant Breeding and Genetics from Cornell University, USA. Her PhD research was focused on the genetics and mechanisms conferring resistance to *Fusarium verticillioides* infection and fumonisin contamination in maize. During her PhD, Laura also contributed to the fine-mapping of a foliar disease resistance locus, spatiotemporal analysis of aflatoxin contamination in maize across Kenya, and assessment of the association between mycotoxin accumulation and nitrogen fertilization. Before joining the PBGL, Laura was a research consultant for phenotypic and genomic analysis of disease resistance and morpho-physiology in maize at the Max Planck Institute for Developmental Biology in Tübingen, Germany.

Interns

Yuling Yue joined the PBGL in May 2019. She graduated from the Hebrew University of Jerusalem, Israel, and conducted her Master thesis on the microscopic and transcriptomic characterization of flowers and their volatiles in petunia. This work revealed key genes involved in regulating scent production in flowers. She has experience with *in vitro* tissue culture and Agrobacterium-mediated transgenic breeding of Chrysanthemum applying Ac-Ds transposon insertion mutagenesis. Her current research work at the PBGL is focused on breeding for resistance to drought and the parasitic weed *Striga* in cereals. She will assist in the development of screening protocols and mapping populations, phenotyping experiments, data analysis and marker development. Yuling's commitment and pleasant personality will make her a natural fit as an intern to the PBGL.

Zhu Li joined the PBGL in June 2019. She graduated from the Fujian Agriculture and Forestry University with the major in plant genetics and breeding. During her master's programme, she contributed to the research of sugarcane DREB transcription factor genes via cloning and stress resistance functional analysis. The objective of Zhu's work in the lab is mutation breeding for resistance to drought and parasitic weed *Striga spp.* in sorghum and rice.

Farewell

We are sad to bid farewell to Laura Morales who has been on a mobility reassignment and to two interns Edwin Thekkinen and Samira Tajedini. During her time in the PBGL, Laura optimized a protocol for high molecular weight DNA extraction for next-generation sequencing (NGS) applications, developed an R package for visualizing NGS variants, and compiled a reference list of gene-editing in crop species and genes involved in coffee leaf rust disease. Samira and Edwin greatly contributed to PBGL's research on *in vitro* haploidy in cereals (rice and sorghum) and barley marker development, respectively. We wish them all the best and hope to meet them again in the future!

Highlights

Plant Breeding and Genetics started the year 2019 with the successful verification and confirmation of mutant lines of sorghum that have resistance to the parasitic witchweed, *Striga*. This is a significant step towards improving sorghum to withstand this devastating pathogen and towards understanding the underlying molecular mechanisms of host-plant resistance. *Striga* is a serious parasite of cereal crops and of cowpea in sub-Saharan Africa, infesting more than 300 million ha and causing crop losses in the range of 20–100% in infested fields of maize, millet, rice and sorghum causing enormous economic losses. It has been estimated that in rice alone there is an annual loss of USD 111 million to USD 200 million. With the confirmed resistance of several mutant sorghum lines to *Striga*, earnest efforts are in progress within Plant Breeding and Genetics (PBG) to understand the molecular basis to support eventual marker-based screening. These results are part of the ongoing Coordinated Research Project (CRP), **Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security** (D25005). A total of seven mutant sorghum lines resistant to *Striga hermonthica* have been validated of which five originated from collaborative R&D with Burkina Faso, and two were developed at the Plant Breeding and Genetics Laboratory (PBGL). In continuing the development of speed-breeding technologies, the PBGL also made progress on fast forward genetic mapping of the semi-dwarf/early maturing, gamma-irradiation induced mutant trait in sorghum using whole genome sequencing. A locus of approximately 5 Mb on chromosome 4 has been identified as harboring the causative genetic variant(s). This will pave the way for fine mapping and development of molecular marker(s) for the trait. These efforts closely follow the first molecular marker from the PBGL, a marker for grain digestibility in barley that was identified on the basis of polymorphism in a gene in the lignin biosynthetic pathway.

Equally exciting to report is the formation of a **Plant Mutation Breeding Network for the Asia Pacific Region**, which will have a Consultants' Meeting in June 2019 sponsored by Indonesia, followed by the full network meeting in July 2019 sponsored by China. This network is a pilot effort emerging from the Bali proposal of September 2017, which in turn originated from the FAO/IAEA/BATAN Technical Meeting on Plant Mutation Breeding. At this meeting, representatives of the national agricultural research systems in Asia recommended the formation of such a network to improve the efficiency of crop mutation breeding in the region. The pilot network will focus on encouraging and facilitating the exchange of mutant germplasm for breeding purposes and on accelerating mutant trait discovery and marker development for agronomically important traits. It is very apt that such a network pilots in the Asia Pacific, a region which has the largest recorded number of improved crop varieties released through mutation breeding (close to 2000 out of a global recorded total of 3300 varieties). The region released 15 recorded new varieties in just the 2017–18 time-frame. Africa has also made rapid strides in 2017–18 in the development of new mutant crop varieties, with the release of four new varieties and the pre-release of 11 new varieties, most of which were developed to combat drought and/or heat stress.

The first half of 2019 also saw the approval of a new **Collaboration Centre on 'Plant Mutation Breeding using Chronic Gamma Irradiation'** at the Agrotechnology and Biosciences Division of the Malaysian Nuclear Agency (Nuclear Malaysia), a government research institution under the Ministry of Energy, Science, Technology, Environment and Climate Change. The Agrotechnology and Biosciences Division operates a gamma greenhouse that was built in 2005 and has been operational since 2009, and that is used

for low-dose gamma irradiation for trait improvement, genetic variation and biodiversity. The Division has R&D expertise in plant mutation breeding and molecular biology/biotechnology. The objectives of the Collaboration Centre include wider utilization of chronic gamma irradiation for crop improvement, technical capacity building in the region, and collaborative R&D for molecular breeding.

PBG also saw the approval of a new CRP on **'Enhanced biotic-stress tolerance of pulses towards sustainable intensification of cropping systems for climate-change adaptation'** during the first half of 2019. Pulses, or grain legumes, are important components of intercropping systems and crop rotations and play a key role in the sustainable intensification of crop production systems. As mixed crops or in rotation, they provide the necessary diversity for resilience against shocks and crop failures. The more than a dozen pulse crops which are grown globally are mostly cultivated by smallholders for food and fodder. Their protein- and micronutrient-rich grain is a low-cost alternative to animal protein for low-income populations. The important contributions of pulses in sustainable agriculture and food systems were recognized in the declaration of the year 2016 as the International Year of Pulses by the United Nations Food and Agriculture Organization. The new CRP aims to use mutation induction and associated genomics technologies for productivity improvement of three pulses, namely, chickpea, cowpea and lentil, which together account for 40% of the global pulses production. The research focus is on enhancing the tolerance of chickpea to the pod borer, *Helicoverpa armigera*; cowpea to the bod borer, *Maruca vitrata*, and lentil to the disease, *Stemphylium* blight.

In addition to this new CRP, and the one on resistance of sorghum and rice to *Striga* mentioned earlier, three other CRPs currently operate in PBG: (1) Efficient Screening Techniques to Identify Mutants with Disease Resistance in Coffee and Banana – D22005; (2) Improving Resilience to Drought in Rice and Sorghum through Mutation Breeding – D23031; and (3) Disease Resistance in Rice and Wheat for Better Adaptation to Climate Change – D23032.

Plant Breeding and Genetics also supports 69 Technical Cooperation Projects (TCPs) through partnership between IAEA and FAO and are engaged in the design of 32 new TCPs for the 2020–21 biennium. An important recent achievement through technical support from the Joint FAO/IAEA Division, namely, release of the improved mutant groundnut variety, Tafra-1, for the marginal rainfed areas of the North Kordofan State of Sudan, was recognized by an IFAD award of excellent performance to the Elobeid Research Station. Sudan ranks fourth in acreage under groundnut and is among the leading exporting countries. In Namibia, more than 10 new crop varieties of cowpea and sorghum that have exhibited tolerance to drought and pests are in the process of facilitated seed multiplication for the 2019 cropping season. In Sierra Leone, PBG is supporting the development of new cassava and rice varieties with improved nutritional quality. Across Africa, a total of four new varieties and 11 pre-release varieties were developed just during the 2017–18 timeframe.

Upscaling of seed production and access of improved, quality seed to farmers remains a stumbling block for impact in the progress towards SDG2 and food security, and the Joint FAO/IAEA Division continues to explore options and implementation modalities to address this. Towards this, the Director of the Joint Division met with stakeholders including seed breeders and representatives of the Ministry of Agriculture in Indonesia, where three of the 23 new rice varieties (Bestari, Impari Sidenuk and Mustaban) are now being widely cultivated in different regions across the country. The Asia Pacific region continues to be an exemplar for mutation breeding and the development and use of new genetic diversity in crop plants. China alone has released over 1,000 mutant crop varieties in the last 60 years and continues to use various mutagenic sources including space mutagenesis for creating novel genetic diversity and developing new varieties. Technical support provided by PBG for the regional Asia Pacific TCP, RAS5077, led to the release of 15 new crop varieties just within the 2017–18 timeframe.

In all, Plant Breeding and Genetics continues its momentum in supporting the delivery of outputs in the form of improved mutant varieties across participating Member States and building technical and infrastructure capacities. Alongside, efforts in fundamental research and development forge ahead to address speed-breeding technologies that will eventually enable shortened breeding times. It is an exciting time for plant mutation breeding, a technology that not only enables the creation of novel genetic diversity for crop improvement, but also serves as a platform for the discovery of candidate genes for other approaches to crop improvement.

Forthcoming Events

Regional Training Course on Application of Marker Assisted Mutation Breeding and Basic Bioinformatics for Improvement of African Food Crops, RAF5076, Dakar, Senegal, 5–16 August 2019

Project Officer: F. Sarsu
Course Director: D. Diouf

This training course will be organized in collaboration with the Government of Senegal through Université Cheikh Anta Diop de Dakar (UCAD), Faculté des Sciences et Techniques, Département de biologie végétale; Laboratoire de biotechnologies végétale. It is open to candidates and project partners in the project RAF5076 on Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach.

The purpose of the training course is to provide participants with theoretical and practical knowledge on the application of molecular techniques and bioinformatics for the identification of agricultural crops with characteristics of tolerance and/or resistance to various types of biotic and abiotic stress.

The course will include lectures and practical sessions on:

- Induced mutation for crop improvement;
- Molecular techniques (extraction, quantification, and visualization of RNA, electrophoresis, RT-PCR in real time);
- Marker assisted breeding: MASB/MASR;
- Characterization of mutagenised populations using molecular tools;
- Bioinformatics (design of oligonucleotides, gene expression profiles of interest, basic concepts of transcriptomics);
- Identification of agricultural crops with characteristics of tolerance and/or resistance to various types of biotic and abiotic stress.
- Practical sessions on application of given techniques

The participants should be from all participating Members States involved in the project RAF5076, actively working in mutation breeding and have a basic knowledge in crop breeding and molecular techniques – preferably with laboratory experience on molecular breeding. The course will enhance the capacities of scientists with at least a B.Sc. degree in or related to plant breeding and genetics. Participants should have a strong affinity and interest in modern plant breeding methods involving induced mutation, mutation screening (high-throughput phenotyping and genotyping) and techniques that can facilitate the breeding process. Participants must bring their own laptops to the training.

Regional AFRA Training Course on Field Experimental Design and Data Analysis in Mutation Breeding, RAF5076, Quatre Bornes, Mauritius, 9–20 September 2019

Project Officer: F. Sarsu
Course Director: M. Gungodaurdoss

This regional training course will be organized in cooperation with the Government of Mauritius through the Food and Agricultural Research and Extension Institute (FAREI). It is open to candidates and project partners in the project RAF5076 on Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach.

The purpose of the training course is to provide participants with theoretical as well as practical knowledge on: (1) Learning the statistical methods used for designing field and laboratory trials and robust data analysis; (2) Improving breeding efficiency through the application of appropriate experimental design and analysis models; (3) Application of mutation breeding methods for crop improvement; and (4) Consulting with experts in using efficient statistical methods and experimental designs relevant to Member States.

The course will include lectures and practical sessions on:

A. Importance of Statistical Tests and Designs in Research

- Planning of experiments and considerations in running experiments;
- Importance of experimental designs;
- Correlations and regression and their use;
- Experimental designs:
  - Randomized Plots Design
  - Randomized Block Design
  - Latin Square Design
  - Experiments with two or more factors
- Combined Analysis of data over years and locations;
- Genetic similarities and cluster analysis.

B. Application of Mutation Breeding

- Application of mutation breeding for crop improvement;
- Sampling in experimental plots;
- Interpretation of statistical data for crop improvement;
- Computer applications to agricultural experiments using statistical packages;
- Analysis of variance for plant breeding:
  - Analysis of multi-locational, multi-year data
  - Stability and its importance in plant breeding

C. Using Molecular Markers

- Using molecular analysis to detect mutations and use of molecular markers in breeding;
- Marker assisted breeding: MASB/MASR;
- Characterization of mutagenized populations using molecular tools.

Participants should be from all participating Member States involved in the project RAF5076, actively working in mutation breeding and have basic knowledge of crop breeding. The course will enhance the capacities of scientists with at least a M.Sc. degree in plant breeding and genetics. Participants should have a strong affinity and interest in modern plant breeding methods involving induced mutation, mutation screening (high-throughput phenotyping and genotyping) and techniques that can facilitate the breeding process.

Third Research Coordination Meeting (RCM) on Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security, D25005, Nairobi, Kenya, 30 September–4 October 2019

Project Officer: A.M.A. Ghanim

The third RCM will be organized at Biotechnology east and Central Africa (BecA), Nairobi, Kenya from 30 September to 4 October 2019. The meeting objectives are to present progress made in the activities of the project after the second meeting and to review and consolidate the work plan for the next cycle. The team is expected to report on the developed/adapted and validated screening protocols for resistance to *Striga asiatica* and *hermonthica* in sorghum and upland rice and efficiency enhancing technologies. In addition, reports are expected on the verification of the identified putative mutants and the development of the mapping populations of the best three mutant per crop (rice, sorghum) in each of the participanting countries (Burkina Faso, Madgascar and Sudan). Twelve participants including agreement, technical and research contract holders from Africa, Asia, Europe and USA are expected to attend the meeting.

Regional Training Course on Mutation Breeding and Efficiency Enhancing Techniques for Crop Improvement, RAS5079, Seibersdorf, Austria, 14–24 October 2019

Project Officer: F. Sarsu
Course Director: I. Ingelbrecht

This training course will be organized by Plant Breeding and Genetics Laboratory in Seibersdorf, Austria. It is open to candidates and project partners involved in the project RAS5079 on Improving Crop Resilience to Climate Change Through Mutation Breeding in Pacific Islands.

The purpose of the training course is to provide participants with opportunities to familiarize themselves with basic and more advanced aspects of crop mutation breeding through lectures and practical sessions on the following topics: i) Mutation induction; ii) Mutant population development and phenotyping methods; and iii) Application of more advanced *in vitro* tissue culture and Next Generation Sequencing (NGS) & genotyping methods.

Participants should be from all participating Members States involved in the project RAS5079, actively working in plant breeding and have basic knowledge of crop breeding. The course will enhance the capacities of scientists with university degrees related to plant breeding and/or genetics. Participants should have a strong affinity and interest in modern plant breeding methods involving induced mutation, mutation screening (high-throughput phenotyping and genotyping) and techniques that can facilitate the breeding process. Participants should have enough command in English to follow the lectures and freely engage in interactive training.

Mid-term Project Coordination Meeting on Improving Yield and Commercial Potential of Crops of Economic Importance, RLA5068, Quito, Ecuador, 2–4 December 2019

Project Officer: F. Sarsu

Many countries in Latin America and the Caribbean have a deficit in food production, leading to serious problems of poverty and malnutrition, especially in rural areas. This situation is further worsened by the effects of climate change and population growth. The productivity of small farmers is also affected by adverse weather conditions (drought, floods, extreme temperatures), soil impoverishment caused

by inappropriate agricultural practices (salinization, acidification, loss of nutrients), inadequate technology and use of underperforming cultivars often susceptible to pests and diseases. The project focusses on the use of mutation induction, mutation detection and pre-breeding technologies to develop new crop varieties with improved characteristics.

The purpose of this coordination meeting is to:

1. Review and discuss the details of the activities stated in the work plan to be implemented under the project RLA5068;
2. Report on the progress made at national level by participating countries since the last RLA5068 meeting;
3. Review the work plan of the project and agree on national plans for the activities to be implemented at the national level;
4. Identify and discuss measures to ensure sustainable continuation of work after completion of the project including exchange of material and information.

The meeting is open to participating Member States through their designated national project coordinators.

Past Events

Regional Coordination Meeting on Promoting the application of Mutation Techniques and Related Biotechnologies for the Development of Green Crop Varieties (RCA), RAS5077, Kathmandu, Nepal, 3–7 December 2018

Project Officers: L. Jankuloski and K. Bimpong

The mid-term coordination meeting of the regional TC project RAS5077, was organized in collaboration with the Nepal Agriculture Research Council, Nepal, at the Hotel Manaslu in Kathmandu.

Sixteen national project coordinators (NPCs) from 16 Asian countries (Australia, Bangladesh, China, India, Indonesia, Japan, Republic of Korea, Lao P.D.R., Malaysia, Mongolia, Myanmar, Nepal, the Philippines, Sri Lanka, Thailand, Viet Nam) as well as the national observers from Nepal participated in the meeting.

The objectives of the meeting were:

- To review the progress made regarding the implementation of the individual country work plans and the expected outputs formulated in the first coordination meeting;
- To identify and address gaps and needs for advanced mutation breeding approaches and techniques to develop new crop varieties targeted for improved and environmentally friendly crop productivity;
- To discuss and amend the national work plans to be implemented under the project RAS5077;
- To discuss and finalize the work plan for 2019 and 2020 to be implemented under RAS5077.

The current national activities as well as achievements obtained in 2017 and 2018 were presented. The national project work plans to contribute to the overall objective of the project were discussed and amended. In addition, the regional work plan was adapted to the needs of the counterparts and the activities regarding the objectives were specified.

The presented reports revealed that since the start of the project, many mutant varieties and lines with improved green traits were developed. Seventeen mutant varieties in different crops (mungbean-1, maize-3, rice-4, wheat-6 and barley-3) were officially released in 2017 and 2018. In addition, advanced mutant lines and mutant populations have been developed for further evaluation of desired green traits with some in trials to be released as new varieties. Counterparts were strongly encouraged to collaborate with farmers and seed extension companies to disseminate the released mutant varieties to the farmers.

Meeting participants.

The meeting participants had an opportunity to visit the Agronomy Division of NARC, National Agricultural Genetic Resource Centre (Nepal Genebank) of NARC. Participants were introduced to the ongoing breeding programmes of the Agronomy Division and were briefed on the genetic plant resources stored in the short-term, mid-

term and long-term storage chambers of the genebank. Participants also visited the tissue culture laboratory, molecular laboratory and field facilities of the Biotechnology Division of NARC where Mr Binesh Man Sakha (NPC) briefed them on the ongoing laboratories and field activities of the Division.

Based on request and needs of counterparts, it was agreed to strengthened human resources in Member States by organizing two regional training courses on Methodologies and Mechanisms for Screening of Photosynthetic Efficiency in Crops and Molecular Approaches for Selection of Desired Green Traits in Crops in 2019. In addition, it was agreed to organize a technical meeting in China on Improvement of Nutrient Use Efficiency Traits for Development of Green Crop Varieties. NPCs were highly encouraged to provide updated information on existing and new mutant varieties to the FAO/IAEA Mutant Variety Database (MVD) by using the MVD submission form from the MVD website (https://mvd.iaea.org).

The NPCs have prepared national reports including background information, the objective of their projects, information on the national project team and facilities at their institutes, partnerships and details on existing mutant varieties and on mutant lines that will be subject of the new project and the achievements attained since the project started.

Regional Training Course on Applications of *In Vitro* Mutagenesis to the Pacific Crops, RAS5079, Suva, Fiji, 3–7 December 2018

Project Officer: F. Sarsu
Course Director: M. Ghanem

Under the regional TC project RAS5079 on Improving Crop Resilience to Climate Change Through Mutation Breeding in Pacific Islands, the training course was organized in collaboration with the Pacific Community (SPC). Eleven trainees from Fiji, Papua New Guinea and Vanuatu attended the training course.

The purpose of this training course was to provide participants with theoretical as well as practical knowledge using mutation induction on pacific crops to improve their resilience to climate change, specifically to biotic and abiotic stress. The one-week training course consisted of lectures and practical sessions on:

- Mutation induction and application to pacific crops such as taro, sweet potato, banana, yam and breadfruit;
- Application of *in vitro* mutagenesis techniques to pacific crops;
- Handling mutant plant populations/lines in the laboratory and field conditions;
- *In vitro* mutation screening methods;
- Application of advanced tissue culture techniques in crop improvement (such as somatic embryogenesis);
- Practical examples of *in vitro* mutagenesis;
- Security and safety in the laboratory;

Practical sessions: a: Participants preparing culture medium for banana shoot tips. b: Preparation of shoot tip explants for *in vitro* culture. c-e: Inoculation of shoot tip explants. f: Participants during *in vitro* culture experiment.

During the practical sessions, participants were shown initiating cultures for mutagenesis using banana shoot tips cultures and sweet-potato nodal explants from *in vitro* cultures. They were trained the process of *in vitro* culture for mutagenesis and how to look for embryogenic callus (and cells), high frequency plant regeneration from shoot tip explants, and the parameters for radio sensitivity and mutation breeding in crop improvement. For *in vitro* selection, they were taught how to prepare infusion method with polyethylene glycol in MS media and to prepare media for selection for drought and salt tolerance using polyethylene glycol (PEG) and NaCl.

First Research Coordination Meeting (RCM) on Disease Resistance in Rice and Wheat for Better Adaptation to Climate Change, D23032, Vienna, Austria, 10–14 December 2018

Project Officer: L. Jankuloski

Cereals are the main staple crops of food security for the population of the world, supplying around 42,5% of the global food calorie supply. Almost 50% of cereals consumed

are rice and wheat and the predictions for 2017/18 being 703 and 503 million tonnes, respectively, to be consumed (FAO, 2017 http://www.fao.org/3/ai8278e.pdf). Rice is grown all over the world and is the main staple food of about 50% of the world population (IRRI, 2015; AfricaRice, 2015). The world today still has a high concentration of poverty and most of these concentrations are where rice is grown. Wheat is the staple food for hundreds of millions of poor people in developing countries while its production is mostly confined to temperate climate. Wheat provides around one-fifth of all calories and protein for people globally and in developing countries, wheat feeds around 1.2 billion people.

Diseases are among the major obstacles hindering yield improvements both in rice and wheat. Changing climatic conditions increase the spread of diseases to new destinations and exacerbate their impact. In addition to the already widely spread diseases of rice such as blast, sheath blight, false and bacterial leaf blight, threats of emerging diseases are becoming more serious such as in the case of false smut of rice and blast of wheat.

The objectives of this Coordinated Research Project (CRP) are to improve disease resistance in rice and wheat through induced mutation/mutation breeding, to develop protocols for screening rice resistant mutants to diseases, to develop molecular markers for disease resistance using available mutant germplasm.

Twelve participants from Bangladesh, Brazil, China, India, Indonesia, Malaysia, Pakistan, USA, CIAT-Columbia, and FAO participated the first RCM.

RCM participants planning activities for the next four years.

The meeting objectives were to review the work plan and consolidate the activities among participating contract holders.

Each participant presented highlights on his/her related areas of expertise as well as a work plan for the project activities during the four years of the CRP. This meeting focused on a detailed review of the CRP objectives, activities, outputs and the work plans of the individual participants. Coordination of activities, sharing of materials and short- and long-term objectives were also discussed.

Three groups were formed among participants:

1. Wheat group (with the objective of developing wheat blast resistant lines);
2. Rice blast group (with the objective of developing molecular marker/s for blast resistance);
3. Rice BLB group (with the objective of developing molecular marker/s for BLB resistance).

The major activities in the wheat group will be to develop and screen large number of (M_2) population in order to identify resistant mutants. The hot spot area in Bangladesh will be used for screening mutant populations.

The rice groups will focus on development of mapping population in order to map and develop molecular marker/s for rice blast and BLB.

RCM participants visiting experiments at Plant Breeding and Genetics Laboratory, Seibersdorf, Austria.

The second RCM will be held in February 2020 in Bangladesh where the progress will be reviewed, and future activities will be discussed among participants.

Regional Coordination Meeting on Improving Sustainable Cotton Production Through Enhanced Resilience to Climate Change, RAS5075, Bangkok, Thailand, 1–5 April 2019

Technical Officer: L. Jankuloski

Cotton has a special significance and plays an important role in the economies of the participating countries, as well as in other countries in Asia, Australia.

The negative effects of climate variability and change such as flood, drought, heat, salinity and diseases are constraints affecting sustainable agricultural productivity globally. With increasing climate change and variability, it is important to develop improved cotton varieties with enhanced adaptability to harsh conditions of high temperatures, drought, soil salinity, acidity or low nutrient availability, as well as resistant to diseases and pests.

Meeting participants.

This leading fibre crop is grown on 20.5 million hectares in the three-main cotton producing countries of the Asia and Pacific region i.e. China, India and Pakistan, with an annual contribution of about 60–65% of the total world cotton production. Emerging demands from Viet Nam and Bangladesh for their cotton mill use signifies the increased role of cotton production in the economy of the countries in the region.

The regional coordination meeting was organized in collaboration with the Government of Thailand, Nakhonsawan Field Crop Center, Department of Agriculture. It was attended by the main counterparts participating in RAS5075 (Bangladesh, Cambodia, Indonesia, Islamic Republic of Iran, Malaysia, Myanmar, Pakistan, Syrian Arab Republic and Thailand).

The purpose of the meeting was to review progress, results and achievements, and to provide future direction and recommendation for cotton mutation breeding in the participating countries.

After reviewing national cotton breeding programmes and discussion with counterparts, it was concluded that the regional project was progressing as planned.

As a leading country in cotton mutation breeding, Pakistan has released four cotton varieties, and disseminated to the farmers. Cotton mutation breeding programmes were established in participating countries (Bangladesh, Cambodia, Islamic Republic of Iran, Malaysia, Myanmar, Pakistan, Syrian Arab Republic and Thailand) and successfully developed M_4/M_5 generation and identified number of mutant lines with improved yield and fibre quality. Cambodia, Indonesia and Thailand joined the regional project in 2017 and are in the initial phase of cotton mutation breeding, irradiation of seed material and generation of M_1 and M_2.

Cotton germplasm from NIAB, Pakistan, was shared among participating countries. In Bangladesh and Myanmar two lines from Pakistan showed excellent performance and after signing bilateral agreement between countries, they will be registered and officially released to the farmers.

Participating countries agreed to continue networking and exchanging material for breeding purposes and they strongly recommended the continuation of the regional project.

Regional Training Course on Improving Crop Resilience to Drought and Heat Stress, RAS5079, Jakarta, Indonesia, 22–26 April 2019

Technical Officer: F. Sarsu
Course Director: S. Human

This training course was organized in collaboration with the Indonesia Center of Isotopes & Radiation Application, National Nuclear Energy Agency. Besides local participants, 13 scientists from Fiji, Micronesia, New Guinea, Palau, Papua and Vanuatu attended the training course. Scientists from the host country and Dr Penna Suprasanna (an expert from India) gave lectures on:

- Mutation breeding procedures/methodologies and handling of mutated population; crops specifically taro, sweet potato, banana, yam and breadfruit;
- Identification, evaluation and selection of breeding lines in laboratory and field conditions;
- Genetics of drought stress tolerance;
- Physiology of drought and heat stress tolerance;
- Pre-field screening methodologies for heat and drought stress tolerance;
- Breeding for abiotic stress specifically drought heat stress through mutation breeding, conventional breeding and utilization of appropriate biotechnologies;
- Field demonstration and practical sessions

Practical sessions included interactive deliberations with participants and laboratory experiments. Participants were quite enthusiastic and showed interest in getting acquainted with the theory and practical aspects. During the practical sessions, participants were shown how to set up experimental design for screening *in vivo* and *in vitro* protocols for heat and drought tolerance using banana shoot-tip cultures and rice seedlings. Participants were asked to prepare *in vitro*, and *in vivo* screening media, sterilization and culture of seedlings/banana shoot cultures. They were trained the process of *in vitro* culture for mutagenesis and *in vitro* selection, and the parameters for screening using polyethylene glycol (PEG) and heat stress.

Practical sessions at BATAN: a-d: Training course participants preparing banana culture medium for in vitro selection; culturing in vitro banana shoots for drought tolerance and discussing about the selection method. e-f: Participants in the session on seedling-based screening for head and drought tolerance in rice.

Workshop on Farmers Field Days to Support the End Users and disseminate Technology Packages on Improved Varieties as well as Nutrient and Water Saving Technologies, RAS5073, Kuantan and Rompin, Malaysia, 29 April–3 May 2019

Technical Officer: L. Jankuloski

Workshop participants discussing case studies of successful dissemination of rice varieties to farmers.

Rice is the most important food crop contributing to food security in Asia and worldwide. The negative effects of climate change such as flood, drought, heat and salinity are major constraints affecting sustainable agricultural productivity globally. Most cultivated areas depend on rainfall. Despite the advances in increasing yields, abiotic and biotic factors continue to limit productivity.

The contribution of plant breeding to improve rice is remarkable. The use of mutation induction for creating useful new germplasm and developing new cultivars is a profitable approach towards improvement. If desired traits are to be enhanced and mutant varieties with high yield, short duration, shatter resistance, and stress tolerance are to be developed, it is important that various valuable mutant germplasm are generated, identified, and utilized efficiently.

This workshop is part of the regional TC project RAS5073 on Supporting Climate-Proofing Rice Production Systems (CRiPS) Based on Nuclear Applications. It was organized in cooperation with the Government of the Malaysia through the Malaysian Nuclear Agency (Nuclear Malaysia). The workshop was attended by 39 participants from Bangladesh, Cambodia, China, Indonesia, Lao P.D.R., Malaysia, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, Thailand and Viet Nam.

The purpose of the workshop was to discuss a regional approach and strategy and the role of plant mutation breeding and improved nutrient and water management on socio-economic impacts for national and regional development.

The workshop objectives were:

- Case studies of successful dissemination of rice varieties and nutrient and water management practices to farmers;
- Discussion to promote and strengthen collaboration in plant mutation breeding among the regional Asia and Pacific countries, including capacity building;
- Technical/field visit to rice mutant varieties with best nutrient management;
- Site-specific nutrient management (SSNM) approach and its application;
- Dissemination and partnership in developing crop mutant varieties and best water, nutrient management practices to stakeholders including academia, company/industry and farmer cooperatives.

Participants from Bangladesh, China, Indonesia, Malaysia, Pakistan and Viet Nam presented their rice mutation breeding programme and socio-economic impact of released mutant varieties in their respective countries.

During the workshop, Memorandum of Understanding (MoU) was signed between Malaysian Nuclear Agency, AgroMinda and Bayer for seed multiplication and production of certified seed.

The host organizer arranged a field day in Rompin, Pahang, where representatives from the Ministry of Agriculture, farmers, seed extension centers and private companies (AgroMinda, Bayer, Pessl, etc.) attended the event. Malaysian Nuclear Agency presented advanced mutant lines

NMR 151 and NMR 152, that are in the process of official registration. These mutant lines, with improved tolerance to drought and higher yield, will be registered as certified rice varieties and released to the farmers in the near future in collaboration with seed production company AgroMinda and Bayer.

Workshop participants and farmers visiting rice fields at Rompin, Malaysia.

Participants showed strong interest in networking and sharing mutant varieties amongst countries in the region for research and breeding purposes. The final meeting of RAS5073 will be held in March 2020 in Indonesia.

Coordinated Research Projects

Project Number	Ongoing CRPs	Project Officers
D22005	Efficient Screening Techniques to Identify Mutants with Disease Resistance for Coffee and Banana	I. Ingelbrecht
D25005	Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security	A.M.A. Ghanim
D23031	Improving Resilience to Drought in Rice and Sorghum through Mutation Breeding	F. Sarsu
D23032	Disease Resistance in Rice and Wheat for Better Adaptation to Climate Change	L. Jankuloski
D22006	Enhanced Biotic-stress Tolerance of Pulses Towards Sustainable Intensification of Cropping Systems for Climate-change Adaptation	S. Sivasankar

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

Project Officer: S. Sivasankar

Pulses are important food crops in smallholder agriculture in Africa and Asia, and in several instances, they are also grown for fodder. Because of their vital role in human and soil health, farmers grow these crops with cereals to not only meet the diversified food needs but also for maintaining soil health. Leguminous crops are known to add nitrogen to the soil through biological nitrogen fixation and can be grown without added nitrogen fertilizers thus contributing to reduced carbon footprint. Among the pulse crops, chickpea, cowpea, and lentil are popular choices for the smallholder farmers in South Asia and sub-Saharan Africa as they thrive well even under limited external inputs. These crops are the mainstay of dryland farming systems.

The productivity of pulses is generally low in most developing countries, average yields ranging from about 0.5 to a little over one tonne per ha. Yields are reduced further by the incidence of several biotic and abiotic stresses. The fact that pulses are self-pollinated has led to a narrow genetic diversity in many of these crops.

In this CRP, mutation induction and associated genomics technologies will be used for productivity improvement of three pulses, namely, chickpea, cowpea and lentil, which together account for 40% of global pulses' production. The research focus is on enhancing the tolerances of: (1) chickpea to the pod borer, *Helicoverpa armigera*; (2) cowpea to the bod borer, *Maruca vitrata*, and (3) lentil to the disease, *Stemphylium* blight. Towards this end, the CRP, with the expected participation of the National Agricultural Research System of countries where the crops are grown extensively, shall over a period of four to five years, generate mutant populations, including advanced lines, and develop, validate and publish genotyping and phenotyping protocols.

Mutation induction is an established means to generate heritable variation in crops and therefore holds great promise to diversify further the genetic base of pulses, enhancing their adaptation to the pressures induced by the effects of climate change, especially the frequent emergence of new biotypes and strains of pests and diseases. The Mutant Variety Database of the IAEA identifies 23, 18 and 13 varieties, respectively, of chickpea, lentil and cowpea, released from past efforts in mutation breeding using irradiation (gamma rays) and chemical (EMS) mutations.

CRP Overall Objective

This CRP aims to develop genetic resources through induced mutations and associated genomic tools for accelerated adaptation of pulses-based cropping systems to climate change.

Specific Research Objectives

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 (confident) and efficient selection of biotic-stress resistance in selected pulse crops.

3. To develop genomic tools for accelerated variety development for the selected pulse crops and associated traits of interest.

Outputs

1. Mutant population(s) generated for chickpea, cowpea and lentil.
2. Phenotyping tools developed for the identification of resistant germplasm.
3. Improved lines identified for traits of interest.
4. Molecular markers and associated protocols developed for variety development/improvement.
5. Scientific publications produced.
6. Protocols and training manuals developed and disseminated.

The first Research Coordination Meeting (RCM) of this CRP is planned to take place in September in Vienna, Austria.

Disease Resistance in Rice and Wheat for Better Adaptation to Climate Change, D23032

Project Officer: L. Jankuloski

A range of diseases are responsible for hindering yield improvements in both rice and wheat. Changing climatic conditions are helping diseases spread to new localities and exacerbating their impact. In addition to the already widespread diseases of rice, such as blast, sheath blight, false smut and bacterial leaf blight, emerging diseases like wheat blast are increasingly becoming serious threats.

To minimize the impact of such diseases, environment-friendly and cost-effective technologies are needed to help prevent and manage them. The use of mutation breeding techniques to develop disease resistant varieties is a viable tool in the development of appropriate germplasms and varieties.

Mutations are a primary source of genetic variation in any organism, including plants. The use of mutation induction in generating new germplasm and developing new disease resistant varieties in rice and wheat is an efficient and valuable approach in crop improvement and has been very successful in rice and wheat breeding. More than 820 rice varieties and 255 wheat varieties have been developed by mutation breeding using mostly physical mutagens (https://mvd.iaea.org/#!Home).

CRP Overall Objective

This CRP aims to improve disease resistance in rice and wheat through induced mutation/mutation breeding and development of screening techniques for sustainable food security.

Specific Research Objectives

1. To generate genetic diversity and develop rice lines resistant to important diseases (blast, sheath blight, bacterial blight, and false smut).
2. To develop protocols for the screening of rice mutants resistant to diseases.
3. To develop molecular markers for disease resistance using available mutant germplasm.
4. To generate mutant wheat populations and develop screening methods for resistance to wheat blast.

Outputs

1. Improved rice and wheat mutant germplasm as novel sources of disease resistance generated.
2. Efficient laboratory, screen-house or field-based screening protocols and techniques for identification of mutants with improved resistance to diseases developed.
3. Molecular marker(s) developed.
4. Publications from the findings of the research activities generated.

This CRP officially started in September 2018 and had its first RCM from 10 to14 December 2018 in Vienna, Austria. The second RCM is planned to take place in Bangladesh in 2020.

Improving Resilience to Drought in Rice and Sorghum through Mutation Breeding, D23031

Project Officer: F. Sarsu

Drought is the most devastating abiotic stress factor affecting crop production worldwide and is projected to worsen with anticipated climate change. It severely limits plant growth and development as well as agronomic characteristics, resulting in a reduction of crop yields. Improving drought tolerance in crops to increase the efficiency of water use and to enhance agricultural water productivity under rain-fed conditions is a top priority for most countries. Among various agro-ecologies, Africa and South Asia are considered to be the most vulnerable to climate change and both have large numbers of poor populations constrained with meagre access to basic resources of water and productive land.

The breeding of hardy, input-use efficient, 'climate-smart varieties' that are inter alia drought tolerant, which produce greater yields with fewer inputs, would constitute part of the solution to the predicted abiotic stresses arising from climate change.

The main objective of this CRP is to adapt and develop robust protocols for efficient screening of mutant populations for drought tolerance. The target crops are improved rice and sorghum tolerant to drought for current and future climate change scenarios. These two crops are essential staples in the diets of millions of impoverished and vulnerable populations and, therefore, any attempt in increasing their yields under drought stress could have a major and positive impact in terms of food security and improved health and income generation. The results from the first year of the CRP were reviewed and the second RCM was held Beijing, China, from 10 to 14 June 2019.

Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security, D25005

Project Officers: A.M.A. Ghanim and L. Jankuloski

The parasitic weeds *Striga* are major biological constraints to cereal production in most of sub-Saharan Africa and semi-arid tropical regions of Asia. The mean objective of CRP (D25005) is to develop laboratory, screen-house and field screening protocols of mutant populations of sorghum and upland rice for resistance to *Striga asiatica* and *S. hermonthica*. In addition, the CRP focuses on technologies such as rapid cycling of generation of crop plants, doubled haploidy techniques, and molecular markers to enhance efficiency of mutant identification and accelerate delivery of resistant varieties.

The second RCM was organized from 15 to 19 October 2018 at the Vienna International Centre (VIC), Vienna, Austria. During the meeting it was shown that a significant progress is made on the planned activities by the participating research and technical contract holders. Field and glass-house screening protocols of mutant populations for resistance to *Striga* were optimized by Burkina Faso, Madagascar and Sudan; laboratory screening protocols using gel-assay, rhizotron and others were optimized by Kenya, United States of America (USA) and Japan. Contract holders planned to submit draft of these protocols during 2018/19 cycle. The Plant Breeding and Genetics Laboratory (PBGL) has optimized protocols for rapid crop cycling and screening for *Striga* resistance in glass-house. The PBGL validated the screening protocol on M_2 population of sorghum and used it to verify putative mutants identified by participating Member States. Encouraging progress is made on the optimization of doubled haploidy for upland rice in Iran and Turkey, while progress on sorghum was limited. During the second RCM, work plans were revised to timely deliver the targeted outputs of the CRP. The third RCM will take place in Nairobi, Kenya, from 30 September to 4 October 2019.

Efficient Screening Techniques to Identify Mutants with Disease Resistance for Coffee and Banana, D22005

Project Officers: I. Ingelbrecht

The CRP officially started in November 2015 and had its first RCM from 7–11 December 2015 in Vienna, Austria. The second RCM was held from 29 May–2 June 2017 in Lisbon, Portugal and the third RCM was held in Guangzhou, China (26–30 November 2018). The project started with 12 participating institutes from ten countries (Austria, China, Islamic Republic of Iran, Malaysia, Nigeria, Peru, the Philippines, Portugal, South Africa and UK) and one International Organization (Bioversity International). Within the first year, two more research contract holders from Costa Rica and Mauritius joined the project and two research agreements (Austria and Portugal) were transferred to Technical Contracts.

The main objective of this CRP is to adapt and develop mutation induction and screening protocols that are suitable for mass screening of mutant lines to identify rare plants showing enhanced resistance to disease in banana and coffee. Cavendish bananas are clones and susceptible to diseases, including Fusarium wilt caused by *Fusarium oxysporum* f.sp. *cubense* (Foc) tropical race four (TR4). In recent years TR4 has caused epidemics in nine countries and is spreading from where it originated in Asia towards Africa (Mozambique) and Australia. Foc TR4 threatens especially the desert bananas which are important for small scale farmers and also agro-industries.

Coffee is the second most traded commodity behind crude oil and derivatives. Coffee leaf rust (CLR) caused by *Hemileia vastatrix* is devastating the affected plantations in countries in Central and Southern America. Global climate change has been directly implicated in the prevalence and spread of coffee leaf rust.

At the end of the third year of this project, considerable progress has been achieved in the development of screening techniques as well as in mutation induction techniques in both crops. In banana, a fast *in vitro* bioassay for TR4 resistance has been established and applied for screening of 6000 *in vitro* rooted plants derived from mutation induction experiments. Also, a technique has been optimized for greenhouse screening of small plants, as well as a hydroponic system for lab-based screening of Fusarium wilt. In line with the defined expected project outputs, new methods for low cost tissue culture of banana have been developed. As for coffee, very little work on mutation breeding has been done before this CRP. Hence, the CRP is

focused on developing and validating mutation induction techniques, specifically in *Coffea arabica*. Effective methods for seed irradiation were developed and the optimum dosages determined. As an alternative to seed irradiation, methods for callus induction, formation and regeneration of embryogenic callus, germination of embryo and development of seedlings were established, and different types of explants were irradiated with various dosages of gamma rays. Results from these experiments have emerged in the third year of the project.

Technical Cooperation Field Projects

Project Number	Country/Region	Title	Technical Officer(s)
ANG5015	Angola	Achieving Drought Tolerant Plants by Inducing Mutation with Gamma Rays	K. Bimpong
AZB5002	Azerbaijan	Developing Mutant Cotton Breeding Lines Tolerant to Diseases, Drought and Salinity through Mutation Breeding	F. Sarsu
BUL5014	Bulgaria	Screening of Cereal Germplasm Stress Response and Adaptation Potential by Advanced Nuclear, Omics and Physiological Approaches	L. Jankuloski
BUL5015	Bulgaria	Increasing Productivity and Quality of Basic Food Crops	F. Sarsu
BKF5019	Burkina Faso	Improving Food Crop Genotypes for Enhancing Yield and Adaptation to Climate Change Using Mutation Breeding and Isotopic Techniques	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
BDI5001	Burundi	Improving Cassava Productivity through Mutation Breeding and Better Water and Nutrient Management Practices Using Nuclear Techniques	K. Bimpong in collaboration with Soil and Water Management and Crop Nutrition Section *(Leading)*
CAF5008	Central African Republic	Improving Cassava Yield through Improved Crop Variety and Best Soil Management Practices Using Nuclear Techniques	I. Ingelbrecht
CPR5024	China, People's Republic of	Enhancing the Accelerated Application of Mutant Germplasm and High-Efficiency Breeding in Crops	N. Warthmann
ZAI5022	Congo, Democratic Republic of the	Improving Productivity and Quality of Crops (Soybean and Maize) Using Induced Mutation and Biotechnology	L. Jankuloski
ZAI5025	Congo, Democratic Republic of the	Increasing Genetic Variability in Cassava and Maize for Enhanced Tolerance to Biotic and Nitrogen Stresses	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
ZAI5026	Congo, Democratic Republic of the	Improving Productivity and Quality of Crops (Soybean and Maize) Using Induced Mutation and Biotechnology	K. Bimpong
PRC5002	Congo, Republic of the	Developing Disease Resistant Varieties of Cassava and Banana	K. Bimpong

Project Number	Country/Region	Title	Technical Officer(s)
IVC5035	Cote d'Ivoire	Improving Maize Crops Subject to Severe Soil and Climate Degradation through Induced Mutants Adapted to these Areas	K. Bimpong
IVC5039	Cote d'Ivoire	Improving Maize Production in Savannah Areas with Severe Pedoclimatic Degradation in the North of Cote d'Ivoire through the Cultivation of Induced Mutants Adapted to these Areas	K. Bimpong
GHA5036	Ghana	Screening Oil Palm M2 Population for Useful Mutants	L. Jankuloski
GHA5037	Ghana	Using Irradiated Pollen for the Development of Provitamin A Rich, Drought Tolerant and Cassava Mosaic Disease Resistant Cassava Mutants	I. Ingelbrecht
INS5043	Indonesia	Intensifying Quality Soybean Production to Achieve Self-Sufficiency	A.M.A. Ghanim/L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
IRA5014	Iran, Islamic Republic of	Improving Wheat Yield and Stress Tolerance for Sustainable Production	L. Jankuloski
JAM5013	Jamaica	Improving Crops by Using Experimental Mutagenesis and Diagnostic Technologies	K. Bimpong
KAZ5004	Kazakhstan	Developing Drought Tolerant and Disease Resistant Wheat Varieties with Enhanced Nutritional Content Using Mutation Breeding	F. Sarsu
KEN5034	Kenya	Using Irradiated Improved *Brachiaria* Grass and *Dolichos Lablab* Species for Increasing Quantity and Quality of Milk Production and Reproduction for Smallholder Dairy Farms in Drought Prone Areas	F. Sarsu/L. Jankuloski
KEN5038	Kenya	Using Nuclear Techniques to Evaluate and Improve the Impact of Mutated Forages on the Performance of Smallholder Dairy Cows	K. Bimpong in collaboration with Animal Production and Health Section *(Participating)*
KUW5002	Kuwait	Implementing Mutation Induction to Improve Barley Production under Harsh Environmental Conditions	L. Jankuloski
KUW5003	Kuwait	Implementing Mutation Induction to Improve Barley Production under Harsh Environmental Conditions – Phase II	L. Jankuloski

Project Number	Country/Region	Title	Technical Officer(s)
LAO5002	Lao, P.D.R.	Improving Soil Fertility and Water Use Efficiency in the Cassava-Rice-Soybean Production System under Smallholder Farming Systems	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
LES5004	Lesotho	Using Nuclear Techniques for Improvement of Crop Yield, Quality and Stress Tolerance for Sustainable Crop Production (Continuation of the on-going project)	F. Sarsu
MAG5023	Madagascar	Promoting Climate Smart Agriculture to Face Food Insecurity and Climate Change with Regard to Basic National Foods (Rice and Maize)	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
MAG5025	Madagascar	Enhancing Biocontrol of *Striga asiatica* (L.) Kuntze through the Development of Tolerant Rice and Maize Lines and its Links with Microbiological and Ecological Functioning of Soil	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
MLW5003	Malawi	Developing Drought Tolerant, High Yielding and Nutritious Crops to Combat the Adverse Effects of Climate Change	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
MAL5031	Malaysia	Establishing an Environmentally Sustainable Food and Fodder Crop Production System	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section and Animal Production and Health Section *(Participating)*
MAU5006	Mauritania	Contributing to the Improvement of Rice Crop Yields through the Application of Nuclear Techniques to Water Management and Soil Fertility	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
MAR5023	Mauritius	Improving Landraces of Crucifers (Cauliflower and Cabbage) and Carrot through the Use of Nuclear Techniques for Mutation Breeding and Biotechnology	F. Sarsu
NAM5014	Namibia	Evaluating Efficient Water and Nutrient Use, Molecular Characterization and Nutritional Composition of Mutant Germplasm Populations	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*

Project Number	Country/Region	Title	Technical Officer(s)
NAM5016	Namibia	Developing Drought Tolerant Mutant Crop Varieties with Enhanced Nutritional Content	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
NEP5003	Nepal	Improving Crop Yield for Food Security and Economic Growth by Using Nuclear and Molecular Techniques	L. Jankuloski
NEP5006	Nepal	Enhancing Productivity of Corps and Fruit Employing Nuclear and Molecular Techniques	K. Bimpong
NER5019	Niger	Improving Sesame Plant Productivity by Obtaining High-Yielding Induced Mutants Adapted to Semi-Arid Conditions	I. Ingelbrecht in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
NER5021	Niger	Using Microbial Biotechnology to Improve Productivity and Adapt Cowpea to Climate Change	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
NIC5011	Nicaragua	Broadening the Genetic Variation of Vegetative Propagated Crops Using Nuclear Techniques	K. Bimpong/L. Jankuloski
OMA5004	Oman	Building Capacity for the Improvement of Major Crops through Induced Mutation Using Nuclear and Related Techniques	A.M.A. Ghanim/I. Ingelbrecht
OMA5005	Oman	Enhancing the Application of Mutation Breeding and Supporting Biotechnology Techniques for the Improvement of Important Strategic Crops	A.M.A. Ghanim
PAL5009	Palestine	Enhancing the Performance of Durum Wheat Landraces by Induced Mutation (Phase II)	L. Jankuloski
QAT5006	Qatar	Enriching Genetic Diversity and Conserving Plant Genetic Resources Using Nuclear Techniques and Related Technologies	A.M.A. Ghanim
RAF5066	Regional Africa	Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach (AFRA)	F. Sarsu
RAF5076	Regional Africa	Improving Crops by Using Mutation Induction and Biotechnology through a Farmer Participatory Approach	F. Sarsu

Project Number	Country/Region	Title	Technical Officer(s)
RAS5069	Regional Asia	Complementing Conventional Approaches with Nuclear Techniques towards Food Risk Mitigation and Post-Flood Rehabilitation Efforts in Asia	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Leading)* and Animal Production and Health Section
RAS5070	Regional Asia	Developing Bioenergy Crops to Optimize Marginal Land Productivity through Mutation Breeding and Related Techniques (RCA)	L. Jankuloski/F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
RAS5073	Regional Asia	Supporting Climate-proofing Rice Production Systems (CRiPS) Based on Nuclear Applications-Phase II	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
RAS5074	Regional Asia	Enhancing Wheat and Barley Productivity through Induced Mutation with Supportive Breeding and Related Biotechnology Techniques (Phase III)	F. Sarsu
RAS5075	Regional Asia	Improving Sustainable Cotton Production through Enhanced Resilience to Climate Change	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
RAS5077	Regional Asia	Promoting the Application of Mutation Techniques and Related Biotechnologies for the Development of Green Crop Varieties (RCA)	K. Bimpong
RAS5079	Regional Asia	Improving Crop Resilience to Climate Change through Mutation Breeding in Pacific Islands	F. Sarsu
RLA5068	Regional Latin America	Improving Yield and Commercial Potential of Crops of Economic Importance (ARCAL CL)	F. Sarsu
SEN5034	Senegal	Using an Integrated Approach to Develop Sustainable Agriculture in a Context of Degrading Soil Fertility, Climate Change and Crop Diversification	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Leading)*
SIL5017	Sierra Leone	Selecting and Analysing Bio-Enriched and Bio-Fortified Rice and Cassava Lines and their Efficient Postharvest Transformation to Popular Food Products	K. Bimpong
SIL5020	Sierra Leone	Enhancing the Concurrent Selection and Evaluation of Biofortified and Bio-enriched Varieties Derived from Mutant Rice, Cassava and other Crops	K. Bimpong

Project Number	Country/Region	Title	Technical Officer(s)
SRL5045	Sri Lanka	Establishing a National Centre for Nuclear Agriculture	F. Sarsu in collaboration with Animal Production and Health Section and Soil and Water Management and Crop Nutrition Section *(Participating)*
SUD5033	Sudan	Enhancing Productivity of Major Food Crops (Sorghum, Wheat, Groundnut and Tomato) under Stress Environment Using Nuclear Techniques and Related Biotechnologies to Ensure Sustainable Food Security and Well-Being of Farmers	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
SUD5037	Sudan	Applying Nuclear Techniques to Improve Crop Productivity and Livelihood of Small-scale Farmers in Drought Prone Areas	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
TOG5002	Togo	Improving Crop Productivity and Agricultural Practices through Radiation Induced Mutation Techniques	K. Bimpong in collaboration with Soil and Water Management and Crop Nutrition Section *(Leading)*
URT5028	Tanzania, United Rep. of	Improving Crop Production and Productivity through the Use of Nuclear and Nuclear-Related Techniques	L. Jankuloski
URT5029	Tanzania, United Rep. of	Improving Rice and Barley Production through the Application of Mutation Breeding with Marker Assisted Selection	L. Jankuloski/F. Sarsu
URT5030	Tanzania, United Rep. of	Improving Rice and Barley Production through Application of Mutation Breeding with Marker Assisted Selection	L. Jankuloski/F. Sarsu
URT5032	Tanzania, United Rep. of	Developing Maize Cultivars for Improved Yield and Resistance to Viral Disease	F. Sarsu
TUN5029	Tunisia	Developing Barley and Durum Wheat Resilience to Drought and Heat Tolerance through Mutation Breeding	F. Sarsu
UGA5041	Uganda	Developing Disease Resistant High Yielding Farmer Preferred Cassava Varieties in Uganda through Induced Mutation Breeding	K. Bimpong
NHE5001	Vanuatu	Enhancing the Productivity and Quality of Crops through the Application of Mutation Breeding Techniques	L. Jankuloski

Project Number	Country/Region	Title	Technical Officer(s)
ZAM5031	Zambia	Improving the Yield of Selected Crops to Combat Climate Change	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Participating)*
ZIM5021	Zimbabwe	Assessing and Promoting Sustainable Agricultural Production in Communal and Newly Resettled Farms	F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section *(Leading)*

Success Stories

Sierra Leone to Tackle Hidden Hunger with Better Crops and Nuclear Technology

One successful story has been featured on IAEA's Website under News on 26 February 2019, where the threat to malnutrition – a chronic deficiency in micronutrients (minerals and vitamins) especially among children has been addressed under TC project SIL5020 entitled Enhancing the Concurrent Selection and Evaluation of Biofortified and Bio-enriched Varieties Derived from Mutant Rice, Cassava and other Crops. https://www.iaea.org/newscenter/news/sierra-leone-to-tackle-hidden-hunger-with-better-crops-through-nuclear-technology

Using nuclear techniques, Plant Breeding and Genetics Section assisted Sierra Leone to irradiate local varieties of rice and cassava, which are priority food crops in the country, at its laboratory in Seibersdorf. And so far, they have produced more than 2000 cassava and over 3000 rice mutant lines, targeting various nutritional and other beneficial traits. Further selection will be done using advanced biochemical screening techniques in the newly established analytical laboratory at the Department of Agricultural and Biosystems Engineering at Njala University. The equipment provided by the IAEA will be used to measure the amount of nutrients and minerals present in the pilot rice and cassava varieties and other food products to monitor their nutritional quality, as well as any toxicity levels.

Three national scientists have been trained on the analysis of micronutrients (minerals and vitamins) at international research centres. The project aims to further train international experts in the use of the new equipment, addressing the country's need to systematically monitor food and environmental samples for food safety. The long-term goal is to generate nutritionally enhanced varieties of rice and cassava that will lead to new nutritionally enhanced products with more carotene in cassava, increased protein in maize, and more vitamins and minerals in rice.

In related research, geneticist at both the National Research Institute (SLARI) and Njala University are using mutation breeding to develop and select rice varieties that have the capacity to tolerate high levels of iron and other heavy metals. This has become necessary due to the abandoned weapons from the time of the country's civil war, 1991 to 2002, which have increased the presence of iron in the soil. In addition, iron from mining activities accumulated naturally in inner-valley swamps is accumulating in soils where crops grow.

Developments at the Plant Breeding and Genetics Laboratory

In 2016, the Plant Breeding and Genetics Laboratory (PBGL) initiated a mutant trait discovery programme to fast track breeding using marker technologies. Two pilot projects were initiated, one on barley to improve feed digestibility and a second on a semi-dwarf/early maturing mutant trait in sorghum. We previously reported the successful development and use of a marker assay for stacking feed digestibility traits in barley. We are pleased to now report progress on NGS-based genetic mapping of the early maturing semi-dwarf trait in sorghum in this Newsletter. Further, greenhouse experiments have validated an additional seven advanced mutant sorghum lines showing resistance to the parasitic weed *Striga hermonthica*. Details on this R&D progress is presented below.

Recently, the PBGL received the good news that the Belgium Government provided support to a new Peaceful Use Initiative for climate proofing coffee and banana production in Eastern Africa. This is a joint project with colleagues from the Soil and Water Management and Crop Nutrition Laboratory (SWMCNL) and it includes a crop improvement and a soil, water and crop management component. The project envisages a holistic approach to address productivity challenges in these two important crops in two target countries, Uganda and Tanzania.

Genetic Mapping of a Semi-dwarf/Early-maturing Mutant Trait in Sorghum

As mentioned, the PBGL is currently working on a 'semi-dwarf/early-maturing' trait in a farmer-preferred sorghum from Sudan. The trait is important for escaping late-season (terminal) drought. The trait had been induced by gamma-ray irradiation and was confirmed several times in field and greenhouse experiments. During the last couple of months, we have continued our efforts towards finding the causative mutated locus to convert it into a molecular marker. PBGL also uses this as a pilot case to develop capacity for fast-forward genetic mapping by genomics approaches; i.e. to develop protocols for using the recent massive DNA sequencing capacities to support genetics studies for associating traits with causative DNA variants.

Modern DNA sequencing techniques allow us to comprehensively catalogue the DNA differences between individuals. Comparing a mutant with its wildtype progenitor in that way yields a long list of candidate mutations, and we built a catalogue for the induced sorghum semi-dwarf/early maturing trait in 2018. Now, for identifying the causal mutation, the molecular biology needs to be combined with genetics to identify mutations that are closely associated with the trait: After crossing the mutant back to the wildtype we observed that the semi-dwarf/early-maturing trait segregated in a 1:3 ratio in F2 populations; a classical mendelian, recessive trait. In these F2 populations we now need to find those mutations that are shared by individuals that are dwarf and early flowering, but not by the others that are tall and late.

To that end we sequenced the entire genomes of about 480 plants, belonging to two F2 populations, and we were able to statistically associate a region on Chromosome 4 with the trait. Only this region differentially segregates between tall/late flowering and small/early flowering individuals. Geneticists call such a genomic region a 'candidate locus' or 'mapping interval', which, depending on the resolution of the study, can vary considerably in size. The next step usually is to inspect all variants at the mapping interval and see whether any can be identified that inflict drastic changes to known or predicted genes.

In our case the interval is about five MB in size and it falls very close to the centromere. Genomic regions around centromeres are notoriously difficult to study as they are highly repetitive, gene poor but instead littered with pseudogenes and transposons. Another hallmark is their reduced recombination frequency which explains the fairly large mapping interval despite us studying more than 200 plants in each of the segregating populations. Going forward we are currently developing PCR-based screens for candidate variants in the interval. Using those we will comprehensively screen F2 plants and identify the closest linked variant. In addition, we are exploring long-read sequencing with Oxford Nanopore Technology to better resolve the repeats in our candidate interval.

Mutation Breeding for Resistance to *Striga* Parasitic Weeds in Cereals for Food Security

During the reporting period, the PBGL continued the verification experiments for putative mutants of sorghum in the context of the CRP on *Striga* (D25005). We used the established protocols at PBGL for pot-screening of mutant populations for resistance to *Striga* to verify 61 putative mutants of sorghum from PBGL, Burkina Faso and Sudan. The mutants from PBGL and Sudan were in M_3 generations while those from Burkina Faso were in advanced M_4/M_5 generation (see Table). Seeds were planted in medium-size pots filled with soil mixture containing Seibersdorf clay soil and sand in 2:1 ratio. Four pots with uniformly mixed seeds of *Striga hermonthica* and four *Striga* seed-free pots were assigned to each mutant line and wild parent. Plants were maintained in a glass-house under 25°C and natural light during January to May

2019 at PBGL facility in Seibersdorf. Seedlings were irrigated two times a week until establishment of 4–6 leaf stage and then continued with one watering per week. No fertilizer was applied and *Striga* plants started to emerge above the soil across the experiment in about two months. After three months the experiment was uniformly covered with *Striga* plants at different stage including many flowering plants (see Figures 1 and 2) and the damage became clear on the infected sorghum plants with many complete dead. The number of *Striga* plants per pot, plant height and % damage was scored, and the tolerance/resistance index was calculated based on % reduction in growth due to *Striga* infection. There were significant differences in the damage due to *Striga* infection and the mutant lines were classified into susceptible (with all plants in the four pots damaged), segregation (with some infected and healthy plants out of the four pots), resistant (no *Striga* infection and tolerance index above 90%), and tolerant lines (some *Striga* plants observed but the reduction in plant growth is relatively less than the control), as illustrated in Figure 1 and Table 1. In total, seven resistant mutants were confirmed (five from Burkina Faso and two from the PBGL putative mutants) in which no infection was scored, and the plant vigor is statically not different from the *Striga*-free control, while there were some tolerant lines and some segregating lines, especially in the M_3 mutant lines from Sudan. The lines with confirmed resistance will be advanced to study the mechanisms of resistance, the genetics of the resistance, and allelism testing. Mapping populations will be developed by intercrossing of the resistant mutant lines and their respective wild parent to identify the causative mutation and develop molecular markers for Marker-Assisted-Selection to pyramid different sources of resistance and produce varieties with combined durable resistance for the Member States.

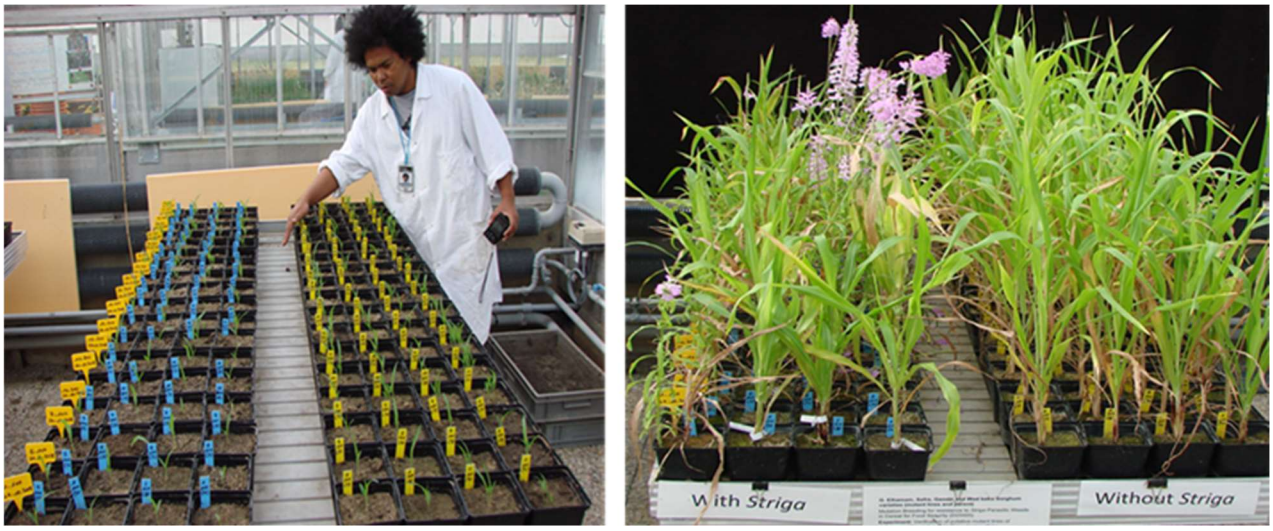


Figure 1. General view of the verification experiment for 18 putative mutant lines of sorghum each replicated four times with Striga (blue label) and without Striga seeds (yellow label) at seedling (left) and pre-flowering stage (right) using the established protocol at PBGL.

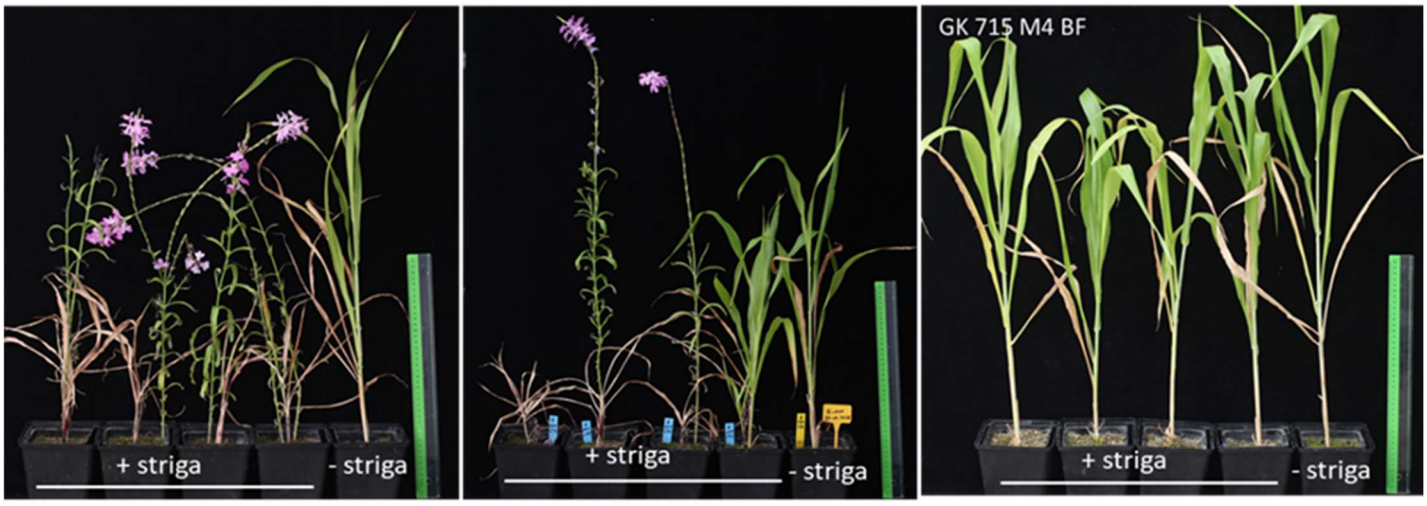


Figure 2. Representative verification experiments showing susceptible (left), segregating (middle) and resistant mutant lines three months after planting in Striga infected soils (four pots with + Striga) compared to Striga free soil (one pot – Striga).

TABLE 1. SUMMARY OF THE NUMBER OF PUTATIVE MUTANT LINES TESTED AND THEIR CLASSIFICATION BASED OF REACTION TO *STRIGA HERMONTHICA*

			Reaction to *Striga hermonthica*			
Wild parent	No of lines	Generation	Resistant	Tolerant	Susceptible	Source
Sariasso	9	M_5	2	3	4	Burkina Faso
Grinkan	3	M_4	1	1	1	"
ICSV	6	M_5	2	3	1	"
SUD1-3	18	M_3	0	12	4	Sudan
V1	17	M_3	0	14	3	PBGL
V2	8	M_3	2	6	0	PBGL
Total	61		7	39	13	

Crop Irradiation Services Provided to Member States

At the time of writing (22 May 2019), the PBGL has received 19 crop irradiation requests for 18 different plant species from 17 different Member States. Requests received in the context of Technical Cooperation (TC) projects or a Coordinated Research Projects (CRP) are indicated.

Request Number	Country	Request Type	Crop
1583	Hungary		Ornamental
1584	United Arab Emirates	TC	Quinoa
1585	Togo	TC	Maize
1586	The Netherlands		Ornamental
1587	Zimbabwe	TC	Cowpea, Sorghum
1588	Cameroon	TC	Watermelon, Ochra, Cowpea, Maize
1589	Burkina Faso	TC	Cowpea
1590	Congo, Democratic Republic of	TC	Maize
1591	The Netherlands		Ornamental, Tomato
1592	PBGL		Arabidopsis
1593	Nigeria	TC	*Dioscorea rotundata*
1594	Mongolia	CRP	Pea, Soybean
1595	Austria		Maize
1596	Mali	TC	Rice
1597	USA		*Capsicum annuum*
1598	Malawi	TC	Maize, Groundnut
1599	Fiji		*Capsicum annuum*
1600	Namibia	TC	Pearl millet, Cowpea
1601	Ghana		Taro

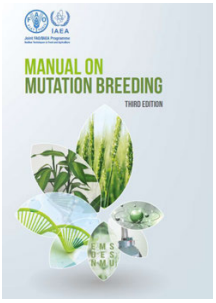
Individual Training Activities at the PBGL

The PBGL is currently hosting seven fellows and two interns for R&D support, training and technology transfer in mutation breeding and related (bio)technologies. A cost-free consultant from Indonesia and an additional fellow from Togo are expected to join the PBGL in June.

Name	Country	Status	Topic	Period
Ms Samira TAJEDINI	Iran	I	Haploid in rice and sorghum; mutant population development *Striga*	5 months
Ms Yuling YUE	China	I	Drought/*Striga* screening protocols and marker development in rice and sorghum	8 months
Mr. H. Jhonny RABEFIRAISANA	Madagascar	F	*Striga* screening protocol, marker development	3 months
Mr Sadate AMADOU	Togo	F	Mutation induction; population development and screening; efficiency enhancing technologies	3 months
Mr Modeste PALANGA	Togo	F	Mutation induction; population development and screening; efficiency enhancing technologies	3 months
Mr Phillipe NIKIEMA	Burkina Faso	F	Mutant population development *Striga; Striga* screening protocol	6 months
Mr Solomon OUT	Ghana	F	Marker-assisted selection protocol in barley; *in vitro* haploid rice	3 months
Mr Bawoumodom BODJONA	Togo	F	Marker-assisted selection protocol in barley; radio-sensitivity testing cowpea	3 months
Mr Clement ANNOR	Ghana	F	Radio-sensitivity testing taro; marker-assisted selection protocol in barley	4 months

Publications

Books



Manual on Mutation Breeding, Third Edition

Edited by Madeleine Spencer-Lopes, Brian P. Forster and Ljupcho Jankuloski. Co-published by the International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization (FAO) of the United Nations.

URL: http://www.fao.org/3/I9285EN/i9285en.pdf

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Pre-Field Screening Protocols for Heat-Tolerant Mutants in Rice

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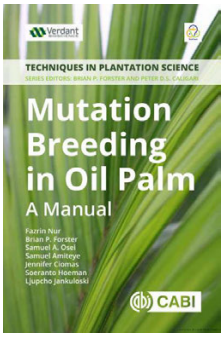

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2018

TILL, B.J., DATTA, S., JANKOWICZ-CIESLAK. J. (2018) TILLING: The Next Generation. In: Advances in Biochemical Engineering/Biotechnology. Rajeev K. Varshney et al. (eds.), Springer.
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KENZHEBAYEVA, S., ABEKOVA, A., ATABAYEVA, S., YERNAZAROVA, G., OMIRBEKOVA, N., ZHANG, G., TURASHEVA, S., ASRANDINA, S., SARSU, F., WANG, Y. (2019) Mutant Lines of Spring Wheat with Increased Iron, Zinc, and Micronutrients in Grains and Enhanced Bioavailability for Human Health. Hindawi BioMed Research International Volume 2019, Article ID 9692053, 10 pages.
https://doi.org/10.1155/2019/9692053

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AMRI, W.T., LAOUAR, M., ABDELGUERFI, A., JANKOWICZ-CIESLAK, J., TILL, B.J. (2018) Genetic Variability Induced by Gamma Rays and Preliminary Results of Low-Cost TILLING on M_2 Generation of Chickpea (*Cicer arietinum* L.). Frontiers in Plant Science-Plant Breeding 9:1568. DOI: 10.3389/fpls.2018.01568

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DOI: 10.1111/pbi.12901

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KAMAL, N.M., MOHAMMED, Y., GHANIM, A.M.A. (2018) Performance of Sorghum Stay-green Introgression Lines Under Post-Flowering Drought. April 2018. International Journal of Plant Research 7(3). DOI: 10.5923/j.plant 20170703.02

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2019

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ENAYATI SHARIATPANAHI, M., TAJEDINI, S., GHANIM, A.M.A., FAKHERI, B., OROOJLOO, M., MAHDINEJAD, N. (2018) Haploidy in Rice (*Oryza sativa* L.) Mutation Breeding for *Striga* Resistance. Poster 79 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

ENAYATI SHARIATPANAHI, M., TAJEDINI, S., GHANIM, A.M.A., FAKHERI, B., OROOJLOO, M., MAHDINEJAD, N. (2018) Enhancing Efficiency of Mutation Breeding for *Striga* resistance in Sorghum by Haploid Technology. Poster 82 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

MUNASINGHA JAYASUNDARA MUDIYANSELAGE PRIYANTHI KUMARARATHNA, GHANIM, A.M.A. (2018) Mungbean Radiosensitivity Test to Gamma Irradiation for Mutation Breeding in Mungbean. Poster 100 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

SARAYE, B., JANKOWICZ-CIESLAK, J., PEERBOCCUS, S., TILL, B.J., NOWBUTH, R.D. (2018) Induced Genetic Variability for Yield and Heat Tolerance in Tomato (*Solanum lycopersicum*). Poster 111 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

MAGHULY, F., JANKOWICZ-CIESLAK, J., GUPTA, P., TILL, B.J., LAIMER, M. (2018) Creation and Characterization of an EMS Mutant Population of *Jatropha curcas*. Abstract 184 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

SARAYE, B., JANKOWICZ-CIESLAK, J., TILL, B.J. (2018) A Pre-Screening Methodology for Identification of Heat Tolerant Mutant in Tomato (*Solanum lycopersicum* L.). Poster 254 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

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HASSAN, O., GHANIM, A.M.A., INGELBRECHT, I. (2018) Mutation Induction in Pearl Millet (*Pennisetum glaucum*) and Fingermillet (*Eleusine coracana*) for Drylands in Sudan. Poster 257 presented at the FAO/IAEA

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LAOUAR, M., TILIOUINE AMRI, W., DAHBIA, T., JANKOWICZ-CIESLAK, J., TILL, B.J. (2018) Early Assessment of Lentil and Chickpea Mutant and Evaluation of Low Cost TILLING on M_2 Chickpea. Abstract 269 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

SARSU, F., GHANIM, A.M.A., PAREEK, A. FORSTER, B.P., INGELBRECHT, I., ASHRAF, M., KUSOLWA, P.M., DAS, P., BAHUGUNA, R., SINGLA-PAREEK, S.L. (2018) Screening Protocols for Heat Tolerant Mutants in Rice. Poster 273 presented at the FAO/IAEA International Symposium on Plant Mutation Breeding and Biotechnology, 27–31 August 2018, Vienna, Austria.

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Websites and Links

- Plant Breeding and Genetics Section:
  http://www-naweb.iaea.org/nafa/pbg/index.html
- InfoGraphic on Mutation Breeding:
  http://www-naweb.iaea.org/nafa/resources-nafa/Plant-Mutation-breeding.mp4
- Mutant Variety Database:
  http://mvd.iaea.org
- Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture:
  http://www-naweb.iaea.org/nafa/index.html
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- Food and Agriculture Organization of the United Nations (FAO):
  http://www.fao.org/about/en/
- FAO Agriculture and Consumer Protection Department:
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