Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Plant Breeding & Genetics Newsletter

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To Our Readers

Animated InfoGraphics on plant mutation breeding.

The year 2015 has started and many things have happened in the first biennium. I want to highlight some facts about Plant Breeding and Genetics (PBG) subprogramme.

If there is one thing that really characterises the planet on which we live, it is undoubtedly the diversity of the living organisms that populate it.

Over the past seventy years mutation breeding has generated thousands of novel crop varieties in hundreds of crop species, and billions of dollars in additional revenue, delivering higher yields, increased nutritional value and resilience to the effects of climate change, such as resistance to diseases and tolerance to drought.

I want to draw your attention to an informative and educative series of animated InfoGraphics that the Joint FAO/IAEA Division has generated on a number of nuclear technologies used in food and agriculture (see http://www-naweb.iaea.org/nafa/resources-nafa/multimedia.html). One of these animated InfoGraphics is on plant mutation breeding, explaining the nature and scope of mutation breeding and how it is used for crop improvement.

Mutation breeding is today a fundamental and highly successful tool in the global efforts of agriculture to feed an ever increasing and nutritiously demanding human population.

The PBG team is happy to announce the release of the new Mutant Variety Database (MVD), which went online in May 2015 (http://mvd.iaea.org). This release is the latest step in a process that started more than 50 years ago when the Plant Breeding and Genetics Section was established. The former Section Head and later Director of the Joint FAO/IAEA Division, Dr B. Sigurbjörnsson, began collecting data on mutant varieties already in 1963, and in 1969 the first classified list of mutant varieties was published. Today, the mutant variety database contains information on mutagens used and characters improved in 3222 officially released mutant varieties worldwide in more than 200 crop species.

During the 151st Session of the FAO Council in Rome, 23–27 March 2015, a side event on The FAO/IAEA Partnership for Food Security: High-Impact Nuclear Applications on the Ground was organized, highlighting impacts generated through the FAO/IAEA partnership in addressing national and regional priorities of Member States. Uniquely, this side event offered a field-level view from and by member countries on what the Joint FAO/IAEA Division's expertise, technical support and technology transfer means to them, including small-scale and often poor farming communities. Dr Huy Ham Le, Director of Agronomical Genetics Institute at the Ministry of Agricultural and Rural Development in Viet Nam, discussed the success and socio-economic impact of released mutant varieties in Viet Nam and highlighted the importance of FAO/IAEA partnership in improving efficiency, sustainability and impact in the field. He referred to Viet Nam as an exemplar of excellence in plant mutation breeding and noted that support from FAO/IAEA has led to a renaissance in the scientific appreciation for mutation breeding in his country.

To highlight, in Vietnam, 52% of the total soybean area are cultivated by soybean mutant varieties, and valuable impact of mutant rice varieties contributes to Vietnam's economy.

Cultivated mutant varieties in Vietnam increased socio-economic impact and income in agriculture and its benefit is ~3 billion USD since introducing crop mutant varieties.

This year, on 18 May 2015, the third international 'Fascination of Plants Day' took place under the umbrella of the European Plant Science Organisation (EPSO) and, in Austria, under the auspices of the First Lady of Austria, Ms Margit Fischer. Upon invitation of the Austrian National coordinator, Prof Margit Laimer of the University of Natural Resources and Life Sciences (BOKU), the Plant Breeding and Genetics Laboratory had the opportunity to present its activities on plant mutation breeding at the BOKU University. The visitors were particularly interested in learning about the comparative advantages of mutation breeding in crop improvement programmes, the broad usage of mutant crops in our daily food and the high socioeconomic impacts of many mutant varieties. The new animated Plant Mutation Breeding InfoGraphics was presented here for the first time to the general public and received a very favourable response.

The mission of the Joint FAO/IAEA Division is continually evolving to address novel challenges in MSs and nuclear applications continue to provide added value to conventional approaches in addressing a range of agricultural problems and issues. Member States are increasingly concerned with climate change and have expressed support to respond to emerging challenges related to transboundary plant diseases. The FAO/IAEA's Plant Breeding and Genetics Section is working with Member States in developing and introducing mutant crop varieties that respond to climate change and food security and has successfully supported the development of disease resistant mutant varieties, such as Ug99 wheat resistant varieties in Kenya. Future support is expected on developing resistant mutant varieties to TR4 (*Fusarium wilt*, known as Panama disease) in banana and to leaf rust in coffee.

International collaboration is one of the priorities of the Joint FAO/IAEA Division. We are pleased to announce our collaboration with Hernan Ceballos and his group at the International Center for Tropical Agriculture (CIAT) for the genotyping of cassava accessions held at CIAT in the context of which we will be developing Ecotilling and next generation sequencing approaches to characterize cassava germplasm for nucleotide variation in genes involved in traits such as starch quality and herbicide tolerance.

Ljupcho Jankuloski
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Forthcoming Events

Regional Training Course on Nutrient Management and Farm Management Strategies to Improve Crop-Water Productivity using AquaCrop Model, RAS/5/065, Los Baños, the Philippines, 6–24 July 2015

Technical Officers: P.J.L. Lagoda and L. Jankuloski

Despite the advances in increasing yields, several abiotic factors (such as drought and flood) continue to limit rice productivity. New rice varieties should be bred with higher and more stable and sustainable yield potentials, with higher adaptability to climate change and variability. The use of mutation induction for creating useful new germplasm and developing new cultivars is a profitable approach to improvement. One key to successful utilization of mutant materials is the accurate and rapid evaluation and selection of promising germplasm for continued propagation.

The purpose of this training course is to introduce the participants of TC project RAS/5/065 on Supporting Climate-Proofing Rice Production Systems (CRiPS) Based on Nuclear Applications to modern techniques in rice mutation breeding and in the use of integrated technology packages based on best fit soil and water management practices and mutation induction combined with efficiency enhancing biotechnologies.

The training course will include lectures on:

- Mutation breeding for rice improvement (concept and use of mutation induction in plant breeding, screening techniques for selecting mutant lines, techniques for detection of mutated genes);
- Plant biotechnologies applied in rice breeding;
- Rice breeding and screening methodologies for abiotic stress tolerance;
- AquaCrop model for predicting crop production under different water-management conditions (rain fed and irrigated) under present and future climate change conditions and under different management strategies;
- The use of nitrogen-15 technique for determining fertilizer use efficiency under flooded rice conditions;
- Nitrous oxide emission under flooded rice conditions.

The training course is organized by the International Atomic Energy Agency (IAEA) in collaboration with the International Rice Research Institute (IRRI), and the Government of the Philippines through the Philippines Nuclear Research Institute (PNRI).

The participants will be from participating MSs involved in project RAS/5/065 at the MSc/PhD level or equivalent by professional experience.

IAEA/RCA Training Course on Application of Mutation Breeding and Screening of Target Traits in Bioenergy Crops, RAS/5/070, Beijing, China, 24–28 August 2015

Technical Officer: F. Sarsu
Course Director: L. Liu

This training course will be organized by the International Atomic Energy Agency in cooperation with the Government of China, Space Breeding Research Center, Department of Mutational Genetics and Crop Breeding, Institute of Crop Sciences (ICS) and Chinese Academy of Agricultural Sciences (CAAS). It is open to project partners/candidates from the TC project RAS/5/070 (RCA) on Developing Bioenergy Crops to Optimize Marginal Land Productivity through Mutation Breeding and Related Techniques.

The purpose of this course is to provide participants with theoretical as well as practical information on mutation induction, mutation breeding and related biotechnologies and screening of target traits for bioenergy crops.

The one-week training course consists of lectures, demonstrations (laboratory and greenhouse and field) and exercises on:

- Scientific background of mutation induction and its application to crop breeding;
- Handling of subsequent mutated populations and identification, evaluation and selection of breeding lines;
- Utilization of appropriate technologies for mutation screening for target traits in bioenergy crops;
- Screening of mutant lines for desired traits of bioenergy crops in the field;

Participants will be also able to discuss their specific breeding problems and learn about the most suitable mutagenesis approach for their target bioenergy crops.

The participants should be from all participating MSs involved in project RAF/5/070. Additionally, they should be currently and actively working on mutation breeding in

particular bioenergy crops and should be scientists with at least a M.Sc. degree involved in plant breeding/genetics. Participants should also 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.

ARASIA Regional Training Course on Phenotyping and Genotyping of Mutants for Abiotic Stresses in Cereals, RAS/5/058, Seibersdorf, Austria, 5–16 October 2015

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

The purpose of this course is to provide participants with theoretical as well as practical information on mutation induction, mutation screening and breeding and related biotechnologies for abiotic stress tolerance in crop breeding.

The two-week training course consists of lectures, demonstrations (laboratory and greenhouse), and laboratory exercises on:

- Mutation breeding procedures/methodologies and handling of mutated populations and related techniques;
- Genetics and physiology of abiotic stress resistance/tolerance;
- Methodologies for screening of mutant population, identification and detection of mutants for abiotic stress tolerance;
- Utilization of appropriate technologies for mutant phenotyping and genotyping.

ARASIA State Parties started a mutation breeding programme under the TC project RAS/5/048 in 2007 with the assistance of the International Atomic Energy Agency. This initiative has been sustained with the project RAS/5/058 to build on the progress made under the previous TC project. Capacity has to be developed in order to use mutation induction and breeding to their most efficient level. Previous and current projects already produced some segregating mutant lines for targeted agronomic characters. These mutant genetic stocks need to be further developed using accelerated techniques in their mutation breeding programmes.

The training course will include lectures, practical sessions, roundtable discussions and consultation on methodology and their application in various field situations. The course is open to 16 participants and the participants should be from all participating Members States involved in project RAS/5/058.

AFRA Training Course on Induced Mutation in Seed Propagated Crops for Crop Improvement, RAF/5/066, Accra, Ghana, 12–16 October 2015

Technical Officer: F. Sarsu
Course Director: K. Danso

This training course will be organized by the International Atomic Energy Agency in cooperation with the Government of Ghana and Ghana Atomic Energy Commissions (GAEC). The course is open to project partners and candidates from TC project RAF/5/066 on Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach (AFRA).

The purpose of this course is to provide participants with theoretical as well as practical information on mutation induction, application in seed propagated crops, accelerated breeding techniques (such as doubled haploid, anther/embryo culture etc.) and mutant line screening for biotic and abiotic stress tolerance in crop breeding.

The course will include lectures and practical sessions on:

- Induced mutation in seed propagated crops;
- Establishment of the proper starting material for specific project objectives;
- Handling of mutated populations to develop new varieties;
- Basics of plant bio techniques;
- Doubled haploid, anther/embryo culture techniques to support mutation breeding;
- Theoretical and practical application of biotechniques in mutation breeding for crop improvement;
- Phenotyping and genotyping screening for mutants in the laboratory and in the field.

The participants should be from all participating MSs involved in project RAF/5/066. Additionally, they should be currently and actively working on mutation breeding and have basic knowledge in crop breeding. The course will surely enrich scientists with at least a M.Sc. degree involved in plant breeding/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.

Regional Training Course on Mutation Detection Methods Applied to Floods, RAS/5/069, Putrajaya, Malaysia, 2–6 November 2015

Technical Officers: L. Jankukoski and P.J.L. Lagoda

Floods are the most frequent disaster amongst all natural disasters and East Asia and the Pacific region, along with South Asia are particularly vulnerable. Climate change and variability are expected to bring about increased typhoon activity, rising sea levels and out-of-phase monsoon seasons in South East Asia and other regions. Mitigating this situation requires an integrated approach to develop technology packages of mutant lines (broader adaptability to warrant sustainable high yield under variable climatic conditions) with proper water and nutrient utilization practices. In this context, mutation induction techniques have shown potential as a valuable tool in developing improved crop cultivars tolerant to flood/submergence.

The purpose of this training course is to introduce participants of TC project RAS/5/069 on Complementing Conventional Approaches with Nuclear Techniques towards Flood Risk Mitigation and Post-Flood Rehabilitation Efforts in Asia to modern techniques in mutation breeding combined with efficiency enhancing biotechnologies in theoretical as well as practical information to improve the capacity to develop resilience/adaptation of agricultural production systems to flooding events in generating flood/submergence tolerant crops using nuclear techniques.

The training course will include lectures on:

- Modern techniques in mutation breeding and detection methods for submergence tolerance;
- Marker Assisted Selection (MAS) for submergence target traits;
- Collaborative networks for advanced mutation breeding, agronomic evaluation and molecular screening.

Participants will be able to discuss specific breeding issues and learn about the most suitable mutagenesis approach for their target towards flood risk mitigation and post-flood rehabilitation.

The training course is organized by the International Atomic Energy Agency (IAEA) in collaboration with the Malaysian Nuclear Agency and the Government of Malaysia.

Participants will be plant breeders and geneticists from participating MSs involved in project RAS/5/069.

Past Events

National Training Course on Induced Mutation Techniques for Biotic and Abiotic Stresses in Potato Breeding, RAF/5/066, Tangier, Morocco, 26–30 January 2015

Technical Officer: F. Sarsu

The national training course is part of the TC project RAF/5/066 on Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach (AFRA). The training course was implemented in the National Institute of Agriculture Research (INRA), Tangier, Morocco. Prof Mehmet Emin Caliskan from the Department of Agricultural Genetic Engineering, Faculty of Agricultural Sciences and Technologies, Nigde, Turkey, was invited as the lecturer. The training course focused on the planting and handling of mutated *in vitro* potato plants in the field, in selection of resistant/tolerant potato mutant lines to major biotic and abiotic (especially for potato common scab, *Streptomyces scabies*) stresses in the field as well as under controlled conditions (greenhouse, *in vitro*), and identification of the best mutant lines for release.

The training course included lectures on:

- Breeding methods in potato (main focus on induced mutation techniques);
- Selection scheme in potato breeding programme;
- Biotechnological tools in potato breeding;
- *In vitro* techniques for breeding and seed potato production;
- Meristem culture and micro-propagation;
- Mechanism and genetics of biotic/abiotic stress resistance/tolerance.

Practical sessions included:

- Evaluation of mutant lines in the field/greenhouse/growth chamber and laboratories;
- Screening protocols for biotic/abiotic stresses (mostly heat and drought for abiotic and on common scab as a biotic stress);
- Handling of breeding materials, harvest and selection process after the harvest.

The participants gained experience in the application of the breeding methods, especially mutation breeding to be selected for desired traits. They also emphasized that this training course will assist them to establish 'seed potato production' system that is quite different from other crops due to vegetative propagation and easy transmission of diseases and pests. Therefore, establishment of a seed production system is essential for the commercialization of potato cultivars.

Participants are evaluating mutant potato lines in the field.

Mutant potato in the field.

National Training Course on Screening of Mutant Lines for Biotic and Abiotic Stresses in the Field, ZIM/5/015, Harare, Zimbabwe, 23–27 February 2015

Technical Officer: F. Sarsu

The national training course is part of the TC project ZIM/5/015 on Developing Drought Tolerant and Disease/Pest Resistant Grain Legume Varieties with Enhanced Nutritional Content Using Mutation Breeding and Novel Techniques. The course was organized jointly by the IAEA and the Zimbabwe Ministry of Agriculture, Mechanization and Irrigation Development, Division of Crop Research. Twenty five participants from national stakeholders attended the course, which provided lectures and practical sessions on screening and breeding methodologies for biotic/abiotic stress resistance and tolerance. The training included field demonstration/screening of cowpea, Bambara nut and ground nut. Prof Hussein Shimelis from the African Centre for Crop Improvement (ACCI), University of KwaZulu Natal was invited as the lecturer of the course. Prof Shimelis is a plant breeder/molecular geneticist and has nearly 20 years of research in plant breeding. He also has experience on crop improvement through mutation breeding.

The training course included lectures on:

- Mutation induction in crop improvement;
- Handling mutated populations/lines;
- Supportive biotechnologies for crop improvement;
- Screening of mutant lines for targeted traits.

Practical Sessions included:

- Evaluation of mutant lines in field/rainout shelter/greenhouse/growth chamber, laboratories;
- Screening protocols for biotic/abiotic stresses mostly focused on drought tolerance and aphids and thrips.

The participants gained experience in the establishment of the proper screening protocols adapted to the selective traits. Participants emphasized that these practical protocols will be very useful in their research.

Participants evaluating mutant cowpea lines in the field.

IAEA/RCA Workshop on Mutation Breeding and Supportive Techniques for Development of Bioenergy Crops, RAS/5/070, Vienna, Austria, 23–27 March 2015

Technical Officer: F. Sarsu

Workshop participants.

The workshop was held under the TC project RAS/5/070 on Developing Bioenergy Crops to Optimize Marginal Land Productivity through Mutation Breeding and Related Techniques (RCA). Project coordinators from sixteen countries (Bangladesh, Cambodia, China, India, Indonesia, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, the Philippines, South Korea, Sri Lanka, Thailand and Viet Nam) attended this workshop.

The Technical Officer, Fatma Sarsu, performed a presentation on Mutation Breeding and Supportive Biotechnologies for Crop Improvement. Discussions were then made on the applications of mutation induction for crop improvement for effective implementation of national breeding programmes. All participants presented their country status of bioenergy crops and their work plans for the project. Crops of interest in the participating member countries i.e. jatropha, sweet sorghum, sugarcane, kenaf, etc., are decided according to country conditions. It was also decided that marginal areas will be defined according to country conditions; the NPC will consult a soil scientist and also include a soil scientist in the project to work together and test mutant lines in these marginal areas.

The workshop was successful in regard to the following achievements:

- The current status of bioenergy crops and its development in the region was discussed and reported, especially in the application of nuclear techniques for increasing marginal land productivity;
- Some participating countries with knowledge in bioenergy crop research shared their experience and latest developments with other participants;
- Common and specific needs of the countries were identified and could be addressed through this new project; including promising bioenergy crops which need to be further tested and validated;
- New project workplan developed to upgrade the national capability, skills and infrastructure; and strengthening of cooperation among the participating countries;
- Plans for future project activities for national level under the project RAS/5/070 were completed;
- National level workplans reviewed and activities to be implemented were agreed on;
- Collaboration in research and development of bioenergy crops among participating countries initiated; and agreement to facilitate and strengthen this collaboration through common agreements such as germplasm exchange (SMTA) and/or training courses/expert missions in regional framework.

Nuclear techniques such as gamma rays and chemicals will be used for mutation induction in the selected crop species. In addition, new techniques for mutation induction, such as space-induced mutation ‘space breeding’ and ion-beam irradiation will be used. In order to accelerate the breeding process doubled haploid techniques and the use of molecular markers is encouraged wherever applicable. Mutant resources will also be generated for gene isolation, and for reverse genetics or functional genomic approaches, which will involve the application of high throughput techniques such as TILLING.

The participants visited the Plant Breeding and Genetics and the Soil and Water Management and Crop Nutrition Laboratories in Seibersdorf, Austria. Mr Stephan Nielen (Plant Breeding and Genetics Laboratory) and Mr Ammar Wahbi (Soil and Water Management and Crop Nutrition Laboratory) gave detailed information on the current researches in these Laboratories.

Workshop participants and Joint FAO/IAEA staff in Seibersdorf.

National Training Course on Selection and Evaluation of Mutant Lines for Drought Tolerance, NAM/5/012, Ondangwa, Windhoek, Namibia, 23–27 March 2015

Technical Officer: F. Sarsu

This national training course is part of the TC project NAM/5/012 on Developing High Yielding Drought Tolerant Pearl Millet (*Pennisetum glaucum* L), Sorghum Bicolor (L) Moench, Bambara Groundnut (*Vigna subterranea*) and Cowpea (*Vigna unguiculata* (L) Walp). The IAEA in cooperation with Namibia Ministry of Agriculture, Water and Forestry organized this training course. Eighteen participants from national stakeholders attended the course, which provided lectures and practical sessions on screening and breeding methodologies for drought tolerance and field demonstration/screening of cowpea, sorghum, pearl millet and Bambara ground nut.

Prof Hussein Shimelis from the African Centre for Crop Improvement (ACCI), University of KwaZulu Natal attended as the lecturer of the course in both, practical and theoretical sessions. The purpose of the training course was to provide participants with knowledge and experience on mutation induction for crop improvement, selection and evaluation of mutant lines, supportive techniques for mutation breeding and selection process with extension team and screening protocols for drought tolerance.

Participants evaluating mutant cowpea lines at Crop Breeding Institute.

The lecturer gave talk on:

- Mutation breeding for crop improvement;
- Handling mutated populations/lines in the field/lab/greenhouse conditions;
- Supportive biotechnologies for crop improvement;
- Selection and evaluation of mutant lines for drought tolerance.

Practical sessions were on:

- Evaluation of mutant lines in field/rainout shelter/greenhouse/growth chamber, laboratories and screening protocols for drought tolerance;
- Selection process with extension team.

The training course included lectures, roundtable discussions and consultations on breeding and screening for drought tolerance and their application on field conditions. They also gained experience in the establishment of the proper screening protocols adapted to the traits in breeding cycle to be selected for in the field conditions.

Cowpea Mutant lines.

Regional Training Course on Mutation Induction on Vegetatively Propagated Crops, RAF/5/066, Tangier, Morocco, 18–22 May 2015

Technical Officer: F. Sarsu

This training course was implemented at the National Institute of Agriculture Research (INRA), Tangier, Morocco under the TC project RAF/5/066 on Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach (AFRA). The training course was attended by 22 participants from 17 African countries (Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Egypt, Ghana, Kenya, Lesotho, Madagascar, Mauritius, Morocco (4), Namibia, Nigeria, Senegal, Sudan and United Republic of Tanzania).

The purpose of this course was to provide participants with theoretical as well as practical information on mutation induction on vegetatively propagated crops, and application of *in vitro* techniques and *in vitro* screening for biotic and abiotic stress tolerance in crop breeding.

The course included lectures and practical sessions on:

- Induced mutation for crop improvement;
- Application of mutagenesis in vegetatively propagated crops;
- Screening mutant plants/lines in lab/greenhouse and field conditions in vegetatively propagated crops for biotic/abiotic stresses;
- Micropropagation and *in vitro* techniques;
- Security and safety in the laboratory.

Training course participants.

The training course included lectures, roundtable discussions and consultations on breeding and screening for biotic/abiotic stress. The participants showed great interest in the training course and they asked many questions about the application of induced mutation in breeding vegetativey propagated crops. Discussions were made with the participants on the applications on mutation induction for crop improvement for effective implementation of national breeding programmes, particularly with young staff from the research institutes and universities. They expressed interest in improving their knowledge in plant mutation breeding and genetics.

Mr K. Danso giving lectures to the course participants.

Third RCM on Climate Proofing of Food Crops: Genetic Improvement for Adaptation to High Temperatures in Drought Prone Areas and Beyond, D2.39.29, Vienna, Austria, 22–26 June 2015

Technical Officer: F. Sarsu

Climate change is now largely accepted as a real and pressing global problem. The main impacts of climate change on agriculture will most probably be experienced through temperatures extremes (increase in minima and maxima), altered changes in rainfall patterns (in amount, spatial and temporal distribution), increased rates of evaporation, increased intensity and frequency of extreme events (floods and droughts), and raise of sea level affecting coastal areas where large quota of cultivated land are located (intrusion of salty water).

This CRP was focused on an important effects of global warming 'heat stress' and on improving the grain yields of a major cereal (rice) and a major grain legume (common bean) in the face of climate change. The aim was to develop new high yielding mutant varieties with improved quality under low input cultivation in a range of agro-ecologies, through broadening adaptability. The third and final RCM was held to review the progress made under this CRP and evaluate data including advanced mutant lines with improved heat stress tolerance. Additionally, screening protocols which have been produced under the project were evaluated. The results will be disseminated and accessible to all MSs. Detailed information on this RCM will be given in the next issue of the Plant Breeding and Genetics Newsletter (January 2016) (For more information, see CRPs on page 11).

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Coordinated Research Projects

Project Number	Ongoing CRPs	Scientific Secretary
D2.30.29	Climate Proofing of Food Crops: Genetic Improvement for Adaptation to High Temperatures in Drought Prone Areas and Beyond	F. Sarsu
D2.30.30	Integrated Utilization of Cereal Mutant Varieties in Crop/Livestock Production System	L. Jankuloski
D1.50.13	Approaches to Improvement of Crop Genotypes to High Water and Nutrient Use Efficiency for Water Scarce Environment	K. Sakadevan and P.J.L. Lagoda

	New CRPs	Scientific Secretaries
	Efficient Screening Techniques for Mutants with Disease Resistance	B. Till and S. Nielen

Efficient Screening Techniques for Mutants with Disease Resistance (Working Title)

Scientific Secretaries: B. Till and S. Nielen

Plant diseases pose a major threat to global food security. It is strongly predicted that the compounding factors of climate change and variability, newly emerging races of pathogens, and reliance on monocultures will increase the severity of the problem. The ability for MSs to maintain farmer's livelihoods and to adequately feed their population with nutritious food is at risk. Diseases affect all crops and result in massive yield losses. Traditional breeding methods are limited by narrow gene pools, and by the long time required to develop new varieties. Induced mutations offer a safe, proven and acceptable alternative route to increase the efficiency of producing crops with enhanced resistance to biotic stress. For example a search of the Mutant Variety Database (mvgs.iaea.org) shows 696 varieties when 'disease' is used as a search term, and 132 varieties when 'rust' is used as a keyword. Most are cereals. While progress is being made in mutation breeding of cereals owing to their ease of fertilization, excellent genetic resources and large network of researchers, less has been achieved with vegetatively propagated and perennial crops. In large part this is due to bottlenecks in mutation induction and screening. This CRP will focus on the development of technology packages to enhance the efficiency of generation and screening mutant populations in non-cereal crop species for the improved resistance to plant diseases. Vegetatively propagated banana and the polyploid tetraploid perennial arabica coffee are examples of target species where major improvements are needed to overcome existing bottlenecks. Activities will also include methods of mutant characterization to facilitate breeding and transfer of adapted varieties to farmers.

Detailed announcement on the project and how to participate will be published in due course.

Climate Proofing of Food Crops: Genetic Improvement for Adaptation to High Temperatures in Drought Prone Areas and Beyond, D2.30.29

Scientific Secretary: F. Sarsu

This CRP has 11 research contract holders from Colombia, China, Cuba, India, Mexico, Pakistan, the Philippines, Senegal, the United Republic of Tanzania and Zimbabwe and three agreement holders from Spain, the United Kingdom and International Center for Tropical Agriculture (CIAT).

The overall objective of this CRP is to identify high yielding food crop germplasm contributing to sustainable food security (with a focus on a major cereal; rice and a grain legume; common bean) with improved resource use efficiency (water and nitrogen) and adaptation to temperature extremes (increased minima and maxima) as anticipated by climate change and variability for the next 20 to 40 years. The aim is to develop tools that allow plant breeders to use mutation programs together with efficiency enhancing plant biotechnologies to develop improved crop varieties with higher and wider adaptability to temperature variations.

All participating countries generated new mutant populations in rice and beans. Also, some countries used characterized mutant lines from previous projects. All of

them have mutant lines at least at the M_4 generation, which tested tolerant for their responses to increased temperatures. Cuba released a new variety 'LP 20' which has good yield under heat stress conditions and low water supplies. Some participants have advanced/pre released mutant lines in rice and beans which is planned to be released to farmers by 2018.

Efficient screening techniques for identifying the positive mutants and shortening the screening procedures have been developed in order to attain the objectives more quickly and develop advanced mutant lines for multi-location trails. Each participating country has been establishing at least one or two protocols for whole plant, physiological, genetic and molecular studies. Mutant line screening protocols for rice and common beans have been developed under growth chamber and field conditions for confirmation of heat tolerance. In the particular case of beans, responses to nodulation and nitrogen fixation are closely monitored in order to identify the best symbiosis: plant/rhizobium is performing satisfactorily under heat conditions.

Significant progress has been achieved so far in major areas of research on rice and common beans to accomplish the objectives of the CRP. It is expected that the identification of high yielding rice and bean germplasm, and the establishment of experimental protocols for physiological, genetic and molecular characterization, will be completed and prepared for dissemination during the next months.

The third RCM took place in Vienna, Austria, 22–26 June 2015. The purpose of this meeting was to evaluate the progress made so far and evaluate data including advanced mutant lines with improved heat stress tolerance. Screening protocols and dissemination of the results will be published and accessible to all MSs.

Integrated Utilization of Cereal Mutant Varieties in Crop/Livestock Production Systems, D2.30.30

Scientific Secretary: L. Jankuloski

This CRP began in the third quarter of 2012 and will be concluded in the third quarter of 2017. In December 2012, we held our first RCM in Vienna, Austria and the second RCM was held in August 2014 in Bogor, Indonesia.

The objectives of this CRP are:

1. To identify mutant varieties or advanced mutant lines for food and feed;
2. To evaluate mutant cereal varieties/lines for agronomic performance and feed quality;
3. To develop crop management systems for cereal mutant varieties with respect to improved yield and quality;
4. To determine biomass, harvest index and nitrogen use efficiency of mutant varieties and advanced lines;
5. To validate and publish protocols and guidelines for speeding up the establishment of useful mutants in desirable genetic backgrounds;
6. To perform pilot tests of superior mutant varieties/lines on-farm through participatory farmer approaches.

The crops chosen are those that can be used for both human food and animal fodder. The project involves nine participating countries and four major crops, namely wheat (the Former Yugoslav Republic of Macedonia, Mongolia), rice (China, Malaysia), barley (Austria, China, Kuwait and Peru) and sorghum (Indonesia). The project aims to improve the agronomy of the crop especially in respect to soil and water management, improve nutritional value and improve the knowledge and skills base of participating MSs.

All participants have identified mutant varieties and/or advanced mutant lines that are now subject to farming management practices to maximize yields in challenging conditions. Success in tailoring agronomy for mutant varieties will be judged by take up by farmers but there are already impressive outcomes, particularly in Indonesia where a mutant line is now grown in several regions on an increasing area.

All project participants have submitted project progress report and all contracts have been renewed for 2014–2015.

The Third RCM is planned to be held in July 2016 in Darkhan, Mongolia.

Approaches to Improvement of Crop Genotypes with High Water and Nutrient Use Efficiency for Water Scarce Environments, D1.50.13

Scientific Secretaries: K. Sakadevan and P.J.L. Lagoda

The CRP was started in 2011 with the objective of increasing yield, and water and nutrient use efficiencies of crops based on best fit soil and water management practices and adapted mutant varieties by small holder farmers through field demonstration and capacity development, in order to increase sustainable crop productivity in water scarce environments. The specific objectives are to: (1) increase the productivity of improved mutant varieties of crops tolerant to environmental stresses

under existing soil and climatic conditions, and (2) enhance nitrogen and water use efficiencies of crops tolerant to environmental stresses through best practice soil, water, crop and fertilizer management. Ten research contract holders (Bangladesh, China, Kenya, Malaysia (2), Mexico, Pakistan, Peru, Uganda and Viet Nam), one technical contract holder from (Peru) and one agreement holder (South Africa) are currently participating in the CRP.

Staff sampling improved wheat varieties from experimental fields for yield measurements.

All project participants have submitted project progress report and all contracts have been renewed for 2014–2015. The third RCM was held in Mexico City, Mexico, 9–13 March 2015 and twelve participants attended the meeting. During the third RCM the participants presented their field activities on soil, water and crop management and results obtained. The outputs from the CRP since 2011 include:

Fertilizer and water management practices for ratooning rice cultivar Jiafuzhan was evaluated for yield and fertilizer use efficiency and has been extended to more than 40 000 ha. Results showed that nitrogen application rate 180 kg N/ha, Jiafuzhan had a high yield of 7 650 kg/ha in the first crop and 6 900 kg/ha in the second crop, with a total yield of 14 550 kg/ha;

Three sorghum mutant varieties namely Pahat (ZH-30 mutant line), Samurai 1 (Patir-1 mutant line) and Samurai 2 (Patir-4 mutant line) were evaluated for water and nutrient use efficiency under the existing soil and climatic conditions in Indonesia under rainfed conditions. Results showed that average grain yield increased by approximately 7% when nitrogen fertilizer application increased from 30 to 60 kg N/ha. However, when fertilizer application increased to 90 kg N/ha there was no further yield increase;

Three successive field trials were carried out to evaluate elite potato varieties in the yield at (a) three levels of manure (3, 6 and 10 tons/ha), (b) 10 tons/ha manure in combinations with 30 kg N/ha, and (c) 10 tons of manure in combination with 50 kg P2O5/ha. The evaluations were carried out in four locations across Kenya (Molo, Kabianga, Njoro and Marigat). Results showed that application of manure at 10 tons/ha produced the highest yield of potato at 37 tons/ha compared with lower manure application rates. Further, nitrogen fertilizer application at 30 kg N/ha along with 10 tons/ha manure increased yield by 20–30% across the varieties and locations;

Information on yield, water and nutrient use efficiencies of three varieties and one advanced mutant line of barley, and five improved genotypes of quinoa suitable for high altitude which were evaluated in three different locations was provided for Peru. Among the five mutant varieties of barley, the Centenario showed yield stability and good adaptability to different climate conditions. For quinoa, grain yield increased with increased water application (2 300 to 3 200 kg/ha for water application from 138 to 275 mm);

A series of field studies have been carried out to evaluate and select two improved rice varieties MR219–4 and MR219–9 which are tolerant to aerobic conditions. Results showed that the improved varietyMR219–9 increased grain N uptake by 10% compared to the parent variety (28 vs 25.5 kg N/ha).

Genotypes of quinoa, Huauzontle and Chia were evaluated for yield performance for drought and salinity tolerance in Mexico. Preliminary results showed that these dry land crops performed better under water stress conditions and salinity affected yield of these gains differently. The results are currently being analyzed to understand yield response and nutrient uptake of these dry land crops.

Three gynotypes of wheat were evaluated for water and nutrient use efficiencies in two agro-ecological zones in Pakistan using four different levels of nitrogen fertilizer application labelled with N-15 stable isotope under dry land conditions. Yield performance showed that the gynotypes produced greater yield at the agro-ecozones with clay loam soils compared to the zone with sandy loam soil. Increasing fertilizer application increased yield. However, the optimum yield at both locations responded to 45 kg N/ha.

Two improved varieties of wheat tolerant to Ug99 were evaluated for grain yield and nutrient uptake in three locations in Eastern Uganda at four levels of nitrogen and three levels of phosphorus fertilizer application. Results showed that the application of 60 kg N/ha and 15 kg P/ha are recommended for maximum yield in eastern Uganda. Water and nutrient use efficiencies are currently being assessed for these improved varieties.

Three mutant soybean varieties have been evaluated for water and nutrient use efficiencies at Vân Phú precinct, Phú Thọ province during both spring (February to May) and summer (June to August). The elite variety DT2008 has produced the highest yield which is more than one ton/ha compared to domestic check variety. The yield was replicated in expanded field studies with an area of two ha.

The project will be completed in 2016. The final RCM will be held in Vienna.

General information applicable to all coordinated research projects

Submission of Proposals
Research contract proposal forms can be obtained from the IAEA, the National Atomic Energy Commissions, UNDP offices or by contacting the Technical Officer. The form can also be downloaded from the URL: http://www-crp.iaea.org/html/forms.html.

Complementary FAO/IAEA Support
IAEA has a programme of support through national Technical Cooperation (TC) projects. Such support is available to IAEA Member States and can include additional support such as equipment, specialized training through IAEA training fellowships and the provision of technical assistance through visits by IAEA experts for periods of up to one month. Full details of the TC Programme and information on how to prepare a project proposal are available at the URL: http://pcmf.iaea.org/.

Technical Cooperation Field Projects

Project Number	Country/Region	Title	Technical Officer(s)
ALB/5/007	Albania	Supporting the Improvement of Plant Productivity Using Radiation Techniques	L. Jankuloski/F. Sarsu
ALG/5/026	Algeria	Increasing the Genetic Variability for the Improvement of Strategic Crops (Wheat, Barley, Chickpeas and Dates) for Enhanced Tolerance to Biotic and Abiotic Stresses and the Development of Biotechnology Capacities	P.J.L. Lagoda/A.M.A. Ghanim
ANG/5/008	Angola	Using Nuclear Technology to Select Mutants of Cassava Resistant to the African Cassava Mosaic Virus and Various Diseases Affecting this Crop	S. Nielen/A.M.A. Ghanim
BGD/5/028	Bangladesh	Assessing Crop Mutant Varieties in Saline and Drought Prone Areas Using Nuclear Techniques	L. Jankuloski
BGD/5/029	Bangladesh	Evaluating Promising Abiotic Stress Tolerant Crop Mutants/Varieties and Measuring the Suitable Management Practices for the Promotion of Sustainable Production at Saline, Submergence and Drought Prone Areas	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section
BOT/5/009	Botswana	Using Radiation Technology and Biotechnology to Develop Mutant Lines of Important Crops with Increased Yield and Improved Nutritional and Hygienic Qualities	A.M.A. Ghanim/S. Nielen
BOT/5/012	Botswana	Improving Soil and Water Management Options to Optimize Yields of Selected Crops	P.J.L. Lagoda in collaboration with Soil and Water Management and Crop Nutrition Section
BUL/5/013	Bulgaria	Supporting Laboratory Upgrade for Improved Food Crops through Nuclear and Molecular Techniques	F. Sarsu/L. Jankuloski
BKF/5/009	Burkina Faso	Improving Voandzou and Sesame Based Cropping Systems Through the Use of Integrated Isotopic and Nuclear Techniques for Food Security and Poverty Alleviation	P.J.L. Lagoda/L. Jankuloski
BKF/5/013	Burkina Faso	Enhancing Sorghum Productivity by Breeding Resistant Varieties to Striga Hermonthica Strains in Agro-Ecological Zones	L. Jankuloski/P.J.L. Lagoda
BDI/0/001	Burundi	Supporting Human Resource Development and Nuclear Technology Support Including Radiation Safety	F. Sarsu
CAF/5/006	Central African Republic	Improving Cassava Production through High-Yielding Varieties and Sustainable Soil Fertility Management by Using Isotopic and Nuclear Techniques to Ensure Sustainable Farming	P.J.L. Lagoda/F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section
COL/5/024	Colombia	Supporting Mutagenesis and Functional Genomics Applied to the Improvement of Rice	S. Nielen/B. Till
ZAI/5/019	Congo, Democratic Rep. of the	Developing Mutations, *In Vitro* and Molecular Techniques for Further Dissemination to Breeders and Pharmaceutical Plant Producers to Enhance the Livelihood of Target Populations	L. Jankuloski/B. Till

Project Number	Country/Region	Title	Technical Officer(s)
ZAI/5/022	Congo, Democratic Rep. of the	Using Nuclear and Biotechnology Techniques for Genetic Adaptation and Improvement of Staple Crops for High Temperatures and Water Stress	L. Jankuloski/B. Till
IVC/5/031	Cote d'Ivoire	Improving Plantain and Cassava Yields through the Use of Legume Cover Crops	P.J.L. Lagoda/F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section
IVC/5/035	Cote d'Ivoire	Improving Maize Crops Subject to Severe Soil and Climate Degradation through Induced Mutants Adapted to these Areas	P.J.L. Lagoda/F. Sarsu
ERI/5/008	Eritrea	Supporting the Livelihood of Barley Farmers through Mutation Techniques and N15 Technology to Improve Malting, Food and Feed Barley Production	A.M.A. Ghanim
GHA/5/034	Ghana	Screening of M2 Population for Useful Mutants for Oil Palm Mutation Breeding	L. Jankuloski/S. Nielen
INS/5/039	Indonesia	Enhancing Food Crop Production Using Induced Mutation, Improved Soil and Water Management and Climate Change Adaptation	L. Jankuloski/B. Till
KAZ/5/003	Kazakhstan	Increasing Micronutrient Content and Bioavailability in Wheat Germplasm by Means of an Integrated Approach	F. Sarsu/S. Nielen in collaboration with Soil and Water Management and Crop Nutrition Section
KEN/5/032	Kenya	Characterizing and Improving Germplasm of Selected Crops at the Molecular Level Using Nuclear and Biotechnology Techniques	F. Sarsu/S. Nielen
KEN/5/034	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	S. Nielen/F. Sarsu
LAO/5/001	Lao, P.D.R.	Enhancing Food Security through Best Fit Soil-Water Nutrient Management Practices with Mutation Induction for Drought Resistant Rice	L. Jankuloski
LES/5/004	Lesotho	Using Nuclear Techniques for Improvement of Crop Yield, Quality and Stress Tolerance for Sustainable Crop Production (Continuation of the on-going project)	S. Nielen/A.M.A. Ghanim
MAK/5/008	Macedonia, The Former Yug. Rep. of	Using Nuclear and Molecular Techniques for Improved Feed and Malt Quality and Safety in Barley	P.J.L. Lagoda
MAG/5/023	Madagascar	Promoting Climate Smart Agriculture to Face Food Insecurity and Climate Change with Regard to Basic National Foods (Rice and Maize)	L. Jankuloski/F. Sarsu
MAL/5/029	Malaysia	Applying Mutation Breeding and Optimized Soil, Nutrient and Water Management for Enhanced and Sustainable Rice Production	S. Nielen
MAR/5/020	Mauritius	Developing Stress Tolerant Banana and Tomato Varieties by Enhancing the National Capacity in Mutation Induction and Biotechnology	B. Till/S. Nielen

Project Number	Country/Region	Title	Technical Officer(s)
MON/5/021	Mongolia	Improving the Productivity and Sustainability of Farms Using Nuclear Techniques in Combination with Molecular Marker Technology	L. Jankuloski/S. Nielen in collaboration with Animal Production and Health Section
MOR/5/033	Morocco	Using Nuclear Techniques to Support the National Programme for the Genetic Improvement of Annual and Perennial Plants and to Develop Agricultural Production	P.J.L. Lagoda/A.M.A. Ghanim
MYA/5/020	Myanmar	Strengthening Food Security through Yield Improvement of Local Rice Varieties with Induced Mutation (Phase II)	S. Nielen/P.J.L. Lagoda
MYA/5/023	Myanmar	Evaluating Nitrogen Use Efficiency Using Low Nitrogen Tolerant Rice Varieties	P.J.L. Lagoda
NAM/5/010	Namibia	Developing High Yielding and Drought Resistant Pearl Millet (*Pennisetum glaucum* L), Sorghum Bicolor (L) Moench, Bambara Groundnut (*Vigna subterranean*) and Cowpea (*Vigna unguiculata* (L) Walp) Following Up a Previous Project (PHASE II)	F. Sarsu/S. Nielen
NAM/5/012	Namibia	Developing High Yielding and Drought Tolerant Crops through Mutation Breeding	F. Sarsu/S. Nielen
NEP/5/003	Nepal	Improving Crop Yield for Food Security and Economic Growth by Using Nuclear and Molecular Techniques	S. Nielen/L. Jankuloski
NER/5/015	Niger	Improving Productivity of the Millet-Cowpea Cropping System through Development and Dissemination of Improved Varieties and New Water and Fertilizer Management Techniques	P.J.L. Lagoda/S. Nielen in collaboration with Soil and Water Management and Crop Nutrition Section
OMA/5/002	Oman	Assessing the Suitability of Sterile Insect Technique (SIT) and Related Techniques for Combating Date Palm Insect Pests	A.M.A. Ghanim/P.J.L. Lagoda in collaboration with Insect Pest Control Section
PAK/5/047	Pakistan	Developing Germplasm through TILLING in Crop Plants Using Mutation and Genomic Approaches	B. Till/S. Nielen
PAL/5/006	Palestine	Enhancing the Performance of Durum Wheat Landraces by Induced Mutation	L. Jankuloski
PER/0/025	Peru	Developing Human Resources and Supporting Nuclear Technology for Addressing Key Priority Areas including Improvement of Cereals, Production of Hydrogels, and Cancer Management	S. Nielen
RAF/5/066	Regional Africa	Improving Crops Using Mutation Induction and Biotechnology through a Farmer Participation Approach (AFRA)	F. Sarsu/A.M.A. Ghanim
RAF/6/042	Regional Africa	Applying Nuclear Techniques to Design and Evaluate Interventions to Reduce Obesity and Related Health Risks	F. Sarsu/A.M.A. Ghanim
RAS/5/056	Regional Asia	Supporting Mutation Breeding Approaches to Develop New Crop Varieties Adaptable to Climate Change	S. Nielen/P.J.L. Lagoda
RAS/5/058	Regional Asia	Supporting Mutation Breeding Approaches to Develop New Crop Varieties Adaptable to Climate Change	F. Sarsu/P.J.L. Lagoda

Project Number	Country/Region	Title	Technical Officer(s)
RAS/5/064	Regional Asia	Enhancing Productivity of Locally-underused Crops through Dissemination of Mutated Germplasm and Evaluation of Soil, Nutrient and Water Management Practices	L. Jankuloski in collaboration with Soil and Water Management and Crop Nutrition Section
RAS/5/065	Regional Asia	Supporting Climate-Proofing Rice Production Systems (CRiPS) Based on Nuclear Applications	P.J.L. Lagoda/S. Nielen in collaboration with Soil and Water Management and Crop Nutrition Section
RAS/5/069	Regional Asia	Complementing Conventional Approaches with Nuclear Techniques towards Food Risk Mitigation and Post-Flood Rehabilitation Efforts in Asia	P.J.L. Lagoda/L. Jankuloski
RAS/5/070	Regional Asia	Developing Bioenergy Crops to Optimize Marginal Land Productivity through Mutation Breeding and Related Techniques (RCA)	F. Sarsu/P.J.L. Lagoda
RLA/5/056	Regional Latin America	Improving Food Crops in Latin America Through Induced Mutation (ARCAL CV)	S. Nielen/L. Jankuloski
RLA/5/063	Regional Latin America	Supporting Genetic Improvement of Underutilized and Other Important Crops for Sustainable Agricultural Development in Rural Communities (ARCAL CXXVI)	S. Nielen/L. Jankuloski
SEN/5/034	Senegal	Using an Integrated Approach to Develop Sustainable Agriculture in a Context of Degrading Soil Fertility, Climate Change and Crop Diversification	F. Sarsu/P.J.L. Lagoda
SEN/5/035	Senegal	Developing High-Performance Plant Varieties through Induced Mutagenesis to Improve the Productivity of *Jatropha curacas* L. Plantations and Contributing to Combating Rural Poverty	F. Sarsu
SIL/5/014	Sierra Leone	Enhancing Nutritional and Other End-User Postharvest Qualities of Rice and Cassava through Mutation Breeding	S. Nielen/L. Jankuloski
SRL/5/045	Sri Lanka	Establishing a National Centre for Nuclear Agriculture	F. Sarsu
SUD/5/033	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/A.M.A. Ghanim in collaboration with Soil and Water Management and Crop Nutrition Section
URT/5/029	Tanzania, United Rep. of	Improving Rice and Barley Production through the Application of Mutation Breeding with Marker Assisted Selection	L. Jankuloski/S. Nielen
THA/0/014	Thailand	Developing Applications of Ion Beam and Plasma Technology for the Induction of Crop Mutation, Gene Transfection and Biomedical/Biochemical Material Modification	S. Nielen/B. Till
THA/5/054	Thailand	Increasing Adaptability for Adverse Environment Tolerance in Rice Germplasm Using Nuclear Techniques	F. Sarsu/S. Nielen
UZB/5/005	Uzbekistan	Developing Mutant Cotton Breeding Lines Tolerant to Diseases, Drought and Salinity (Phase II)	F. Sarsu/S. Nielen

Project Number	Country/Region	Title	Technical Officer(s)
VIE/5/018	Viet Nam	Adapting Rice-Based Cropping Systems to the Impact of Climate Change by Nuclear Mutation Breeding and Improving Nitrogen Use Efficiency Using Nitrogen-15 for Vegetables in Main Growing Areas	L. Jankuloski/P.J.L. Lagoda
YEM/5/008	Yemen	Introduction of Gamma Ray Irradiation Techniques for Agriculture Purposes	S. Nielen/F. Sarsu
YEM/5/010	Yemen	Using Induced Mutations and Efficiency Enhancing Bio-Molecular Techniques for Sustainable Crop Production	S. Nielen/F. Sarsu
ZAM/5/029	Zambia	Evaluating the Impact of Nitrogen and Water Use Efficiency in Upland Rice	L. Jankuloski/F. Sarsu in collaboration with Soil and Water Management and Crop Nutrition Section
ZIM/5/015	Zimbabwe	Developing Drought Tolerant and Disease/Pest Resistant Grain Legume Varieties with Enhanced Nutritional Content Using Mutation Breeding and Novel Techniques, Phase II	F. Sarsu/L. Jankuloski

Announcements

New Mutant Variety Database (MVD) Released

The PBG team is happy to announce release of the new Mutant Variety Database (MVD), which went online in May 2015 (http://mvd.iaea.org). This release is the latest step in a process that started more than 50 years ago when the Plant Breeding and Genetics Section was established. The former Section Head, Dr B. Sigurbjörnsson already began collecting data on mutant varieties in 1963, and in 1969 the first classified list of mutant varieties was published by Sigurbjörnsson and Micke. The list was continuously updated in the following decades and published in the Mutation Breeding Newsletters (MBNL). A breakthrough was initiated in 1987 by the successive Section Head, Dr M. Maluszynski, who organized a database on an IBM PC using 'dBaseIII+' software. In November 2000, when MVD had as many as 2252 entries, the database was transferred to a web based system (4D). This system was replaced in 2008 by a new version, written in ASP.NET. This version, however, could no longer be updated due to IT security reasons. The actual new MVD, written in ASP.NET MVC, is a completely new development and is running on the IAEA Nucleus platform thus meeting the Agency's standards for IT security. The necessary migration was used for a comprehensive renewal in order to correct errors in the previous database structure, to introduce new features that make the database more user-friendly and to make it fit for future enhancements. Among the new features is the ability to sort search results and to export them to Excel, enabling the user to prepare his own statistics and analysis of data. Thumbnails are also supported on the variety sites, making the site more attractive and informative. The new MVD allows the inclusion of miscellaneous information, especially on the impact of the variety. The data has been transferred from the previous database to the new one, and users are encouraged to check their varieties in the MVD and report errors and comments to the MVD contact Point (MVD.Contact-Point@iaea.org). This is particularly important for cases where a mutant variety was developed indirectly using cross breeding. Also, any updated information on an existing variety, especially on its use and impact is very welcome in order to make MVD a useful information instrument for all our stakeholders. For registration of new varieties, please download and complete the related form from MVD and send to the Contact Point.

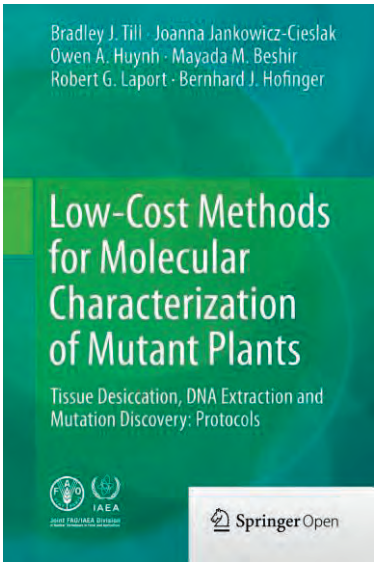
This new edition of MVD was developed through a cooperation of PBG with the Agency's Division of Information Technology (MTIT). The PBG acknowledges the efforts and high quality of work performed by MTIT/BSS (Business Solutions Section) staff in the project, especially Mr Sergio Pines and Ms Karmen Knezevic.

Developments at the Plant Breeding and Genetics Laboratory (PBGL)

Improving Methods for the Molecular Characterization of Mutant Plants

Evaluation of DNA is an especially powerful approach because nucleotide variation is the major contributor to heritable phenotypic variation, and methods to uncover nucleotide variation provide important information on plant evolution, and enable methods for efficient breeding that avoid GxE interactions. Tools for genomic DNA acquisition and evaluation have been rapidly improving to the point where re-sequencing of hundreds to thousands of plant genomes is now a reality. The risk of new technologies, however, is that they tend to be expensive and require a high level of technical expertise. New tools, therefore, are not available to all laboratories. Yet, many powerful methods can be developed that are lower-cost and suitable for laboratories with varying infrastructure. One example is the starting point of all genotyping experiments: the extraction of DNA from plant tissues. While long-term storage of plant tissues prior to DNA extraction often involves the use of liquid nitrogen and -80C freezers, these can be avoided by desiccating and storing leaf material in silica gel at room temperature. Extraction of high quality genomic DNA from leaf material is typically performed using expensive kits, or with more manual methods that require toxic organic chemicals such as the CTAB method. These can be avoided by binding genomic DNA to silica in the presence of chaotropic salts. This mirrors the chemistry used in expensive kits, but at about 1/10th of the price. Importantly, high quality genomic DNA can be made without specialized equipment for tissue grinding and without the use of any toxic organic compounds that require specialized waste disposal. Finally, nucleases used in assays to discover mutations can be self-extracted at a cost of less than 0.06 cents per reaction.

The PBGL is pleased to announce the publication of a book containing easy to follow protocols for all of the above procedures. The book titled 'Low-Cost Methods for Molecular Characterization of Mutant Plants' is published by Springer and is open access. It is free to download at http://rd.springer.com/book/10.1007%2F978-3-319-16259-1. Readers of this newsletter will know that this works represents years of efforts by the PBGL to reduce the cost and toxicity of methods for evaluation of mutant plants.

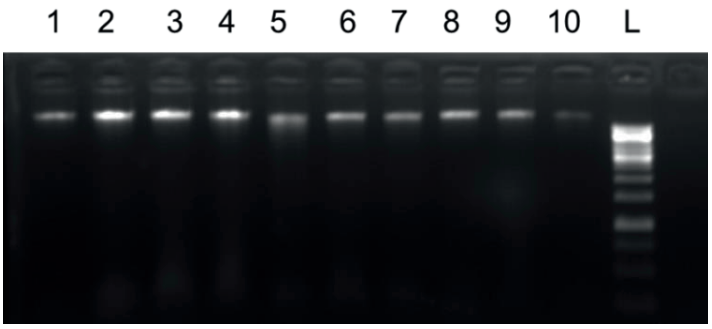


The new open access book from the PBGL provides detailed protocols for low-cost and non-toxic desiccation of plant tissues, extraction of genomic DNA, extraction of single-strand-specific nucleases and enzymatic mismatch cleavage for mutation discovery.

While the publication of the protocol book is a major accomplishment, it does not mean that methods cannot be further improved. For example, the University of Hyderabad, India, recently held its first National Workshop on TILLING in Crop Plants. Course organizer Prof Ramesh Sharma invited Mr Till from PBGL as an expert lecturer to teach the recently published low-cost methods. In addition to lectures and demonstrations on low-cost methods, Mr Till gave a lecture at the University of Hyderabad on the activities of the Joint Programme to support sustainable food security through nuclear techniques. During the course, at the suggestion of University staff, several modifications were tested. First, the efficiency of using tungsten carbide balls versus standard metal balls was evaluated in tissue grinding. While expensive, tungsten carbide balls can be washed and reused for years. However, they are not available in all countries. Steel balls such as those used in ball bearings of bicycles can be found almost anywhere and purchased in bulk for less than 0.05 cents per ball. At this price balls need not be reused, saving time and money previously used for washing. Data shows that similar results are achieved with each type of ball (see figure). The use of sodium iodide as a chaotropic salt in replace of potassium iodide was also tested and shown to have

equivalent performance (see figure). Sodium iodide is approximately half the cost of potassium iodide. The chaotropic salt is the most expensive component of DNA extraction and thus switching to sodium iodide marks a major improvement. Mr Till was also invited to ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) where he gave a lecture and met with staff.

Staff and students of the first National Workshop on TILLING in Crop Plants organized by Professor Ramesh Sharma of the University of Hyderabad.

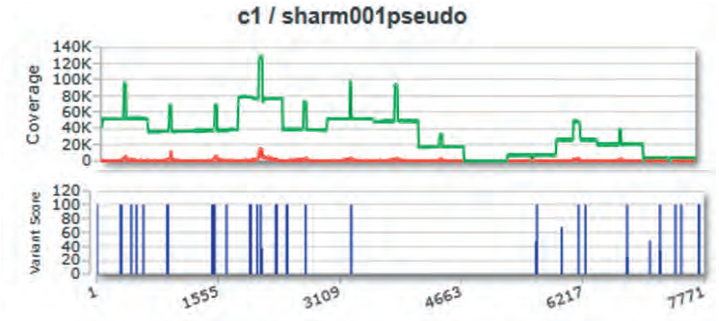


Example of genomic DNA quality produced at the first National Workshop on TILLING in Crop Plants held at the University of Hyderabad in April 2015. Odd lanes represent tissue ground with tungsten carbide balls and extracted using potassium iodide. Even lanes were prepared with steel balls and sodium iodide. Fresh tissue was used for lanes 5 and 10. Tissue desiccated with silica gel was used for all other samples.

Higher-throughput Methods to Support Reverse-genetics

The PBGL continues efforts to develop efficient methods for mutation discovery using high throughput next generation sequencing. Different approaches are appropriate for different goals. In previous newsletters we have discussed methods for recovery of large genomic insertions/deletion mutations to support forward mutation breeding, marker development and gene cloning.

We are also keen to adapt methodologies to increase the efficiency of the reverse-genetics strategy known as TILLING (for Targeting Induced Local Lesions IN Genomes). Most examples of TILLING in crops focus on point mutagenesis. Amplicon sequencing using the Illumina platform is ideally suited for gene-target based TILLING approaches. In collaboration with Prof Ramesh Sharma, Dr Yellamaraju Sreelakshmi, Mr Prateek Gupta, and Ms Sadhna Narayan of the University of Hyderabad, the PBGL has been developing strategies and optimizing methods for TILLING by Sequencing in tomato. Pooling strategies and library preparation is being carried out in the Illumina facility operated by PBGL. The University of Hyderabad is supplying amplicons from mutant populations and providing informatics support. This work has just begun and the first experiments aim to optimize multiplexing/indexing and depth of coverage needed in three dimensional pools (see figure)



Example of TILLING by sequencing optimization for tomato. Top panel shows test of different depth of coverage for mutation discovery in three dimensionally pooled samples with variant calls in blue.

Sample Name	Position	Variant Type	Call	Frequency
c5	727	SNP	T->[T/A]	0.02
d4	727	SNP	T->[T/A]	0.02
r15	727	SNP	T->[T/A]	0.01
c10	797	Indel	AT/A-	0.01
c13	1884	SNP	C->[C/T]	0.02
r9	1884	SNP	C->[C/T]	0.01
c2	2120	SNP	A->[A/G]	0.01
c2	2181	SNP	C->[C/T]	0.02
d4	2181	SNP	C->[C/T]	0.02
r8	2181	SNP	C->[C/T]	0.02

Lower panel summarizes a subset of nucleotide variation recovered in different pooling dimensions.

Extra Budgetary Funding to Support Improvement of Cassava

The PBGL is happy to announce a collaboration effort with the International Center for Tropical Agriculture (CIAT) for the genotyping of cassava accessions held at CIAT. Financial support for this work is provided by the Colombian granting agency COLCIENCIAS (Grant

number 223670048777 — 'Ecotilling in cassava for identifying sources for herbicide tolerance and new types of high quality starch'). Cassava (*Manihot esculenta*) is an important staple crop for over 500 million people in the tropics. The project is scheduled to begin in the second half of 2015. Working with Prof Hernan Ceballos and his group at CIAT, the PBGL will be developing Ecotilling and next generation sequencing approaches to characterize cassava germplasm for nucleotide variation in genes involved in traits such as starch quality and herbicide tolerance.

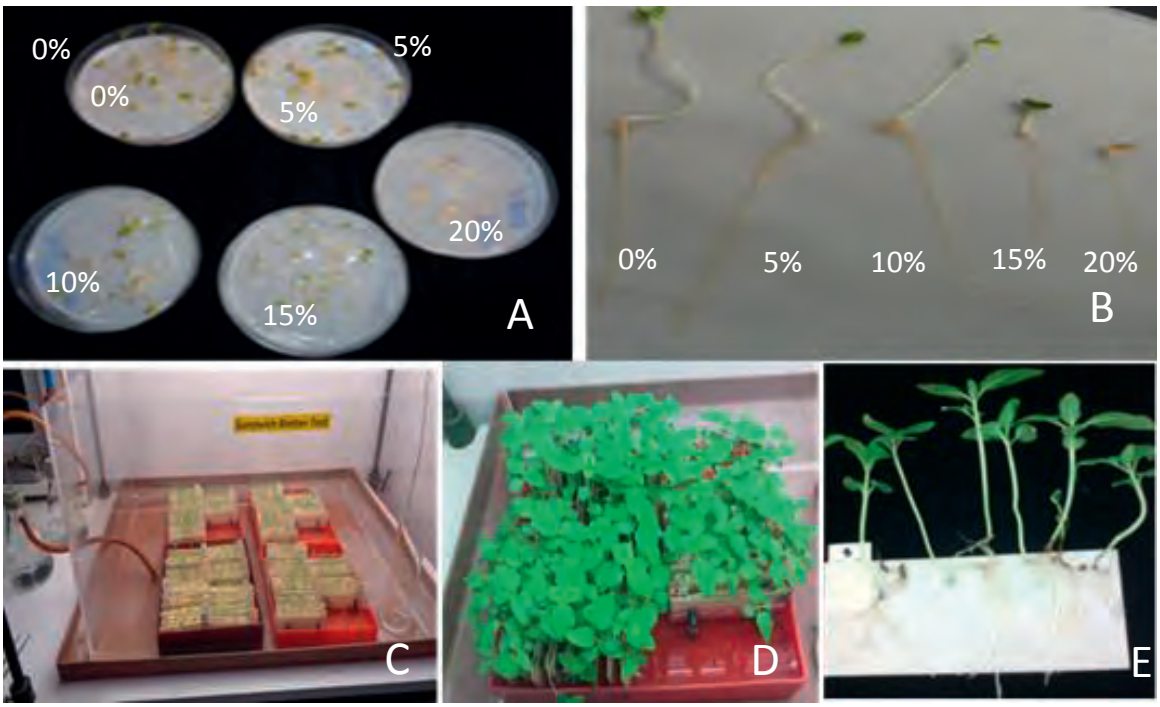
Screening for Drought Tolerance in Sesame and Cowpea

In the current context of climate change, there is great challenge to maintain sustainable food production under expanding water scarcity to feed growing world population. Mutation breeding has a great potential to induce genetic variability and generated drought tolerant varieties. The PBGL has been involved actively in developing efficient and reliable screening methods to induce and identify drought tolerant varieties. Screening packages are being designed and evaluated to suit different crops under different conditions in the laboratory, glasshouse and open field using as appropriate hydroponic system with osmotic stress generator such as Polyethylene glycol (PEG6 000) or water stress through controlled irrigation regimes in soil. During the reporting period two experiments were conducted for drought screening in cowpea and sesame varieties and advance mutant lines from Senegal. Two popular varieties along with four advance mutants (M_5) from each variety were used for drought screening by the two approaches (hydroponic vs soil). PEG6 000 was used at 0, 10, 15% concentrations for drought induction in hydroponic system with Hoagland's solution. Drought stress was imposed at two weeks after germination and continued for a week followed by removal of stress to assess potential of recovery from drought stress among genotypes. (see Figure). The same genotypes were screened for drought tolerance in pot experiment in the glasshouse. Plants were sown in pots containing 3.5Kg of soil and irrigated every two days with 200ml of water/pot. Two weeks after germination, drought treatment was applied in the form of water stoppage for 20 and 30 days followed by re-watering every two days as the control for assessing recovery potential among genotypes. Measures were taken for plant growth, biomass, stomatal conductance and chlorophyll fluorescence (see Figure). Genotypes and mutant had shown variation in sensitivity to drought stress and in potential of recovery.

Screening for drought stress using PEG6 000 in hydroponic (left) and soil (right). From top to bottom; cowpea plants in hydroponic for two weeks before stress treatment (A), after one week in PEG6000 (B), measurement of chlorophyll fluorescence using flour Pen (C) and stomatal conductance using Porometer (D).

On the other hand, sesame was screened for drought tolerance using different concentrations of PEG6 000 (0, 5, 10, 15 and 20%) at germination in Petri-dishes and at early seedling stage in Sandwich blotter (see Figure).

Measurements were taking for germination%, shoot and root length after one week. Four concentrations of PEG6000 (0, 10, 15, 20%) in nutrient solution were used for drought screening in the Sandwich blotter. Measurements were taken, after one week in stress, for biomass, leaf area and chlorophyll content. Variation in scoring of these parameters enabled classification of the genotypes into drought sensitive, moderate and drought tolerant. For both cowpea and sesame drought screening experiments further field validation for drought tolerance is planned in Senegal to evaluate how close is the classification of genotypes in screening methods in the lab and glasshouse to the field screening.



Screening for drought tolerance in sesame using different concentrations of PEG6 000 at germination in petri-dishes (A and B) or early seeding in a Sandwich blotter (C, D and E).

Irradiation Services

At the time of writing the PBGL has received since publication of the last newsletters at total of 14 requests for plant irradiation services from 13 MSs (MSs). These are listed below and included 16 crop species. The total number of irradiation requests since records began now stands at 1421. For each request (unless otherwise stated), we carry out radio-sensitivity tests to determine the optimal irradiation dose for mutation induction (some examples are given below). Therefore, we normally request that MSs send us sufficient seed for this initial test (usually 100–300 seeds). Once the optimal dose is determined, this is applied to the rest of the seed samples and the M_1 seeds will be returned to the Member State.

Request number	Country	Species
1408	Sierra Leone	Rice
1409	Nigeria	Sesame
1410	Kenya	*Brachiaria ruziziensis, Dolichos lablab*
1411	USA	Pea, common bean
1412	UK	*Rudbeckia fulgida*
1413	Germany	Aster, *Dendranthema*
1414	Madagascar	Cassava
1415	Botswana	Maize
1416	Spain	Euphorbia
1417	UK	Wheat
1418	Lao P.D.R.	Rice, soybean, mungbean, maize
1419	Nepal	Rice
1420	Mongolia	Wheat, rape
1421	Namibia	Rice

Kits

The PBGL has developed positive control kits to assist MSs in optimizing PBGL protocols in their own laboratories for their own species. Each kit contains a

detailed protocol along with the material needed to successfully complete the protocol. Kits are available upon request. The latest kit, announced in the last newsletter, is for column based purification of single-strand-specific nucleases for mutation discovery. The new protocol has now been taught at one national workshop and two *ad hoc* training courses and the kit has been distributed to six MSs.

Kits distributed since the last newsletter:

- Low cost DNA extraction kits distributed to India, Mauritius and Pakistan;
- Low cost mutation discovery kits distributed to India;
- Low cost enzyme extraction for mutation discovery distributed to Austria, India, Mauritius, Pakistan and Poland.

Professional Networking

The PBGL thanks all of you who have connected with us on LinkedIN. If you have not already linked with us, please feel free to connect (http://at.linkedin.com/pub/iaea-plant-breeding-and-genetics/31/4b6/aa3). We are now linked with 271 researchers and are happy to continue to expand our connections to the broader plant sciences and agricultural community.

PBGL Participation in the 'Fascination of Plants Day' 2015

The PBGL participated in the third international 'Fascination of Plants Day', 18 May 2015, which was launched under the umbrella of the European Plant Science Organisation (EPSO). According to the organizers, the goal of this event is to get as many people as possible around the world fascinated by plants and enthused about the importance of plant science for agriculture, in sustainability producing food, as well as for horticulture, forestry, and all of the non-food products such as paper, timber, chemicals, energy, and pharmaceuticals. The role of plants in environmental conservation will also be a key message.

Under the auspices of the First Lady of Austria, Ms Margit Fischer, our host country participated in the event with various activities, some of them in Vienna. On invitation of the National coordinator, Prof Dr Margit Laimer of the University of Natural Resources and Life Sciences (BOKU), PBGL had the opportunity to present its activities on plant mutation breeding at BOKU University. Among several informative posters and banners some of the crops of interest, such as banana, coffee, cassava, rice, and barley, along with their fruits, seeds, and tubers, were part of the exhibition, which attracted numerous students as well as visiting people from Vienna. The visitors were very interested in learning more about the comparative advantage of mutation breeding in certain crop improvement programmes and also about the broad usage of mutant crops for our daily food and the high social-economic impact that many mutant varieties have. On the occasion of this exhibition, the new animated Plant Mutation Breeding InfoGraphics was presented for the first time to the public and favourably assessed. The animation is available at http://www-naweb.iaea.org/nafa/.

PBGL stand at Fascination of Plants Day at BOKU University, Vienna, Austria. (Mr Stephan Nielen and Mr Souleymane Bado with the National Coordinator, Prof Dr Margit Laimer (red jacket) and visitors.

Human Capacity Development

Group Training on Low-cost Purification of Single-strand-specific Nucleases for Mutation Discovery

An *ad hoc* training course was organized by Mr Bradley Till from 11 to 12 May covering low-cost protocols developed at the PBGL for bench-top enzyme purification and mutation discovery. Visitors from Austria and Poland attended this course.

Dr Miriam Szurman-Zubrzycka of the University of Silesia, Poland (centre) and Dr Stephanie Bannister of the University of Vienna (right) are taught methods for purification of single-strand-specific nucleases from plant extracts.

Training Workshop on Portable Photosynthesis System LI-6400XT

The PBGL has purchased new portable Photosynthesis System LI-6400XT to enhance its capacity for screening mutant populations under stress environment. A three-days training workshop was organized in Seibersdorf 25–27 February 2015 and the programme included:

- Introduction to plant gas exchange and fluorescence measurements;
- Instrument principles, assembly and maintenance;
- Software overview;
- Taking measurements.

The workshop was attended by 15 participants including PBG staff, fellows and interns. Beside the lectures, the workshop included practical measurements using the equipment to measure photosynthesis, stomatal conductance and chlorophyll fluorescence for narrow and broad-leaf crop plants. The photosynthesis system is expected to add value to the capacity needed for research and developments in phenotyping for stress tolerance and physiological characterization of crop plants. The equipment together with others in the PBGL are currently being used in developing protocols for screening of mutants under drought and salt stress.

Training workshop on Portable Photosynthesis System LI-6400XT at PBGL.

Individual Training Activities

Name	Country	Status	Topic / Areas of Training	Period
*Mr Zhiwei Chen	China	Cost-free Expert	Mutation detection in rice	August 2014–July 2015
Mr Mohammed Jouhar	Syrian Arab Republic	Consultant	Development of low cost method for mutant characterization	1–12 June 2015
Ms Farzaneh Taassob Shirazi	Islamic Republic of Iran	Scientific Visitor	Mutation induction in barley, screening and accelerated breeding	Until 30 April 2015
Ms Anna Sochacka	Poland	Intern	Plant mutation induction, *in vitro* propagation and screening techniques	Starting March 2015
Ms Banumaty Saraye	Mauritius	Individual Fellow	Heat stress screening of tomato mutants	Until 31 March 2015
Mr Ndiogou Gueye	Senegal	Individual Fellow	Mutation induction in sesame and cowpea, drought screening *in vivo* and *in vitro*	January–April 2015
Ms Ndeye Fatou Deme	Senegal	Individual Fellow	Mutation screening in cowpea	February–June 2015
Mr Milton Kabbia	Sierra Leone	Individual Fellow	Cassava mutation breeding	Starting February 2015
Ms Udompan Promnart	Thailand	Individual Fellow	Mutation breeding in rice, screening for abiotic stress tolerance	Starting May 2015

*Funded and supported by the Fujian Agriculture and Forestry University and the Chines Government, respectively.

Visitors to the PBGL

The PBGL continues to host a high flux of visitors. From July 2014 until the time of writing we have received over 24 visitors groups from various MSs, as well as internal groups. Visitors are keen to understand the role of the PBGL (and other NA-Laboratories), out impact and future vision.

December 2014

- Delegation from Burundi
- Visit from UNIDO

January 2015

- Kuwait University students
- Kunsan National University students, Republic of Korea
- Visit of Mr A.H.M. Razzaque, Director General of BINA, Bangladesh, , and Mr M. Mofazzal Islam (winner of FAO/IAEA Outstanding Achievement Awards in Mutation Breeding, 2014)

Director General of BINA visiting PBGL's greenhouse in Seibersdorf.

February 2015

- Delegation from Japan
- Technical University of Vienna
- Delegation of Brunei Darussalam

March 2015

- Delegation from United States of America
- High-level Delegation from Australia
- Office of Legal Affairs, IAEA
- Annual Safety review
- Meeting participants from regional TC project RAS/5/070
- Visit from Communication Specialists, NA, OPIC (IAEA)

April 2015

- National Liaison Officers TC Africa

May 2015

- Delegation from Seychelles
- Delegation from Marshall Islands
- High-level Delegation from Jordan
- Delegation from OFID (OPEC Fund for International Development)

June 2015

- National Liaison Officers TC Asia and Pacific
- High-level Delegation from China
- The Standing Advisory Group on Nuclear Applications (SAGNA)
- National Liaison Office of Panama

ReNuAL Update

January 2015 - June 2105

The ReNuAL project continues to make progress in 2015. The conceptual designs completed in November last year for the two new laboratory buildings to be constructed — the Flexible Modular Laboratory (FML), which will house the Joint FAO/IAEA Division's Food and Environmental Protection Laboratory and the Soil and Water Management & Crop Nutrition Laboratory in addition to the Terrestrial Environment Laboratory, and the new Insect Pest Control Laboratory — were reviewed by a panel of external experts in February this year. The experts concluded that the designs would successfully meet the future needs of the laboratories. The detailed design plans were accordingly initiated in March, with an expected completion date in August, so that the procurement of building construction can begin, pending the availability of funds.

Approximately €7.4 million in extrabudgetary resources have been raised to date. By September, when the IAEA's Programme and Budget for 2016–17 is expected to be approved by the General Conference with an additional €5 million in regular budget resources for ReNuAL, a total of €10.4 million in regular budget funds will have been allocated to the project. This will bring the total funds raised and allocated to nearly €18 million of the €31 million that is targeted to fund ReNuAL, with the remaining approximately €13 million to come from extrabudgetary sources. Additional extrabudgetary contributions are expected during the General Conference in September.

The funds available by September should be sufficient to construct the first of the two buildings and the new site infrastructure necessary to support these buildings. Procurement to begin construction of the infrastructure

began in June, with work on site to begin in September. Once the final cost estimates are available in late August, a decision will be made to construct either the FML or IPCL, with the construction contract to start by the end of 2015. In the meantime, fundraising will continue and construction of the second building will begin as soon as the required funds are available.

Publications

Books

HUYNH, O.A., J. JANKOWICZ-CIESLAK, B.J. HOFINGER, M.M. BESHIR, R.G. LAPORT, B.J. TILL (2015) Low-Cost Methods for Molecular Characterization of Mutant Plants: Tissue Desiccation, DNA Extraction and Mutation Discovery, A Protocol. Springer ISBN: 978-3-319-16258-4 (Print) 978-3-319-16259-1 (Online), ISBN: 978-3-319-16258-4 (Print) 978-3-319-16259-1 (Online) http://rd.springer.com/book/10.1007%2F978-3-319-16259-1.

Peer-reviewed Book Chapters

JANKOWICZ-CIESLAK, J., B.J. TILL. Forward and Reverse Genetics in crop breeding. Chapter 8 in: Advances in Plant Breeding Strategies Volume I: Breeding, Biotechnology and Molecular Tools. J.M. Al-Khayri et al. (eds.), Springer (*in press*).

BADO, S., B.P. FORSTER, B.J. TILL, S. NIELEN, P.J.L. LAGODA, M. LAIMER (2015). Plant Mutation Breeding: Current Progress and Future Assessment. J. Janick (editor), In: Plant Breeding Reviews, Volume 39, pp 23–88 *(in press, to be published in June 2015).*

Peer-reviewed Journal Articles

JHURREE-DUSSORUTH, B., J. JANKOWICZ-CIESLAK, B.J. TILL. Genetic Diversity Study of Dessert-type Banana Accessions in Mauritius using Low-Cost SNPs Detection Technology. Acta Horticulturae *(in press).*

BADO, S., P. BAZONGO, G. SON, A.M. LYKKE, T.K. MOE, B.P. FORSTER, S. NIELEN, A. OUEDRAOGO, I.H.N. BASSOLÉ (2015). Physicochemical characteristics and composition of three morphotypes of Cyperus esculentus tubers and tuber oils. Journal of Analytical Methods in Chemistry, http://www.hindawi.com/journals/jamc/aa/673547/.

MAGHULY, F., J. JANKOWICZ-CIESLAK, S. PABINGER, B.J. TILL, M. LAIMER (2015). Geographic origin is not supported by the genetic variability found in a large living collection of Jatropha curcas with accessions from three continents. Biotechnology Journal 10, pp 536–551.

FORSTER, B.P., B.J. TILL, A.M.A. GHANIM, H.O.A. HUYNH, H. BURSTMAYR, P.D.S. CALIGARI (2015). Accelerated Plant Breeding. CAB International 2015 (Online ISSN 1749-8848).

LEAL-BERTIOLI, S.C.M., S.P. SANTOS, K.M. DANTAS, P.W. INGLIS, S. NIELEN, A.C.G. ARAUJO, J.P. SILVA, U. CAVALCANTE, P. GUIMARÃES, A.C. BRASILEIRO, N. CARRASQUILLA-GARCIA, R.V. PENMETSA, D. COOK, M.C. MORETZSOHN, D. BERTIOLI (2015). Arachis batizocoi: a study of its relationship to cultivated peanut (A. hypogaea) and its potential for introgression of wild genes into the peanut crop using induced allotetraploids. Ann Bot 115, p. 237–49.

Websites and Links

- Plant Breeding and Genetics Section:

  http://www-naweb.iaea.org/nafa/pbg/index.html

- InfoGraphic for Mutation Breeding:

  http://www-naweb.iaea.org/nafa/resources-nafa/Plant-Mutation-breeding.mp4

- Mutant Variety Database:

  http://mvd.iaea.org

- IAEA Plant Breeding and Genetics LinkedIn:

  http://at.linkedin.com/pub/iaea-plant-breeding-and-genetics/31/4b6/aa3

- Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture:

  http://www-naweb.iaea.org/nafa/index.html

  http://www-naweb.iaea.org/nafa/news/index.html

- Joint FAO/IAEA Publications

  http://www-naweb.iaea.org/nafa/resources-nafa/publications.html

- Food and Agriculture Organization of the United Nations (FAO):

  http://www.fao.org/about/en/

- FAO Agriculture and Consumer Protection Department:

  http://www.fao.org/ag/portal/index_en/en/

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