

**Summary of Progress Reports on Biofertilizer and Polymer Modification
FNCA Workshop on Radiation Processing and Polymer Modification
for Agricultural, Environmental and Medical Applications**

January 23rd - 26th 2024

Manila, the Philippines

Session 1: Progress Report on Biofertilizer

1. Degraded Chitosan for Animal Feed, 2. Hydrogel for Medical Application, 3. Environmental Remediation, 4. Synergistic Effect among Plant Growth Promoter (PGP), Super Water Absorbent (SWA) and Biofertilizer, 5. PGP and SWA, inclusive Process development, 6. Mutation Breeding of Microbe Using Radiation, 7. Sterilization and Sanitization Using Radiation, 8. Recycle Plastic

1) Bangladesh (Dr. Abudullah-Al-Mahin (on behalf of Dr. Kamruzzaman Pramanik), Bangladesh Atomic Energy Commission)

Subject: 2

Short summary

To increase antimicrobial activity of chitosan, chitosan–Ag nanoparticles were prepared. The antimicrobial activity of nanoparticles was determined against Gram +ve and Gram -ve bacteria. Strong antimicrobial activity was observed against *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 35150 strains. With increased concentration of chitosan–Ag nanoparticles, antimicrobial activity also increased.

Results

Chitosan–Ag nanoparticles were prepared, and their formation was confirmed by a sharp peak occurring in the range of 410–417 nm in the UV–visible spectrum. To assess their antimicrobial activity for application in the hydrogel, the chitosan–Ag nanoparticles were tested using the agar well diffusion method. *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 35150 strains were used as representatives of Gram-positive and Gram-negative bacteria, respectively. Strong antimicrobial activity was observed against both strains. The antimicrobial activity was solely attributed to chitosan–Ag nanoparticles, as increasing the concentration resulted in a larger clear zone of inhibition.

Future plan

- i) Incorporation of chitosan–Ag nanoparticles into PVA-hydrogel and assessment of antimicrobial activity of the gel.
- ii) Animal trial to check the compatibility of bioactive properties of the composite hydrogel in the animal model.
- iii) Application of different radiation doses on this preparation to further increase antimicrobial activity.

Subject: 7

Short summary

The sterilization and sanitation of medical and pharmaceutical products using ionizing radiation are

crucial aspects to ensure the safety and efficacy of healthcare interventions. Due to the increasing importance of sterilization and sanitization in the post-COVID-19 era, coupled with the demand for commercial services from various medical and pharmaceutical companies, we are focusing on launching commercial services in this sector. As part of our initiative, we initially collected samples and optimized the gamma radiation dose required for their sterilization. Additionally, we have already commenced commercial services for some products.

Results

Initially, we assessed the total viable count, total coliform, total salmonella, and total staphylococcal count in some samples after exposure to different gamma radiation levels (0-25 kGy). However, no growth, other than TB, was detected. Subsequently, we focused on the total bacterial count (TBC) of the supplied samples. For the sterility test, we incubated the samples after radiation exposure for 14 days in nutrient broth. No total bacterial count was observed after exposure to 6 kGy for Spirulina and 5 kGy for the Eye drop container, Plastic sample container, Gown, and Mask. Other samples did not show any count even without radiation exposure. Following the 14-day sterility test, the suggested minimum dose for sterilization for the Eye drop container, Plastic sample container, Personal protective equipment, Spirulina, and Camo cream was 10, 5, 5, 9, and 15 kGy, respectively.

Future plan

Due to the growing demand for commercial services, we plan to scale up our facilities. Additionally, we intend to expand our services to include sanitation using our gamma radiation facilities.

2) China (Dr. Ruifu ZHANG, Nanjing Agricultural University)

Subject: 4, 6

Short summary

Identification of *Trichoderma guizhouenase* NJAU4742 secreted cedrene to promote root development, solid fermentation production of *Trichoderma guizhouenase* NJAU4742 conidia as biofertilizer, field application of *Trichoderma guizhouenase* NJAU4742-based biofertilizer in several crops. Preparation of SWA using Cassava starch and wheat straw, effect of SWA on the spore germination of Bacillus biofertilizer.

Results

To get enhanced *Trichoderma guizhouenase* 4742 strains for different characters, breeding of this strain with X-ray radiation was carried out, Irradiation dose was: 84Gy, 84Gy and 82Gy for three times, and the total was 250Gy, After irradiation, the spores of *Trichoderma guizhouenase* NJAU4742 was coated on different screening media. About 3500 different mutants were isolated and screened, a mutant with strong ability to promote plant root development and plant growth was obtained, a volatile chemical cedrene was identified from this mutant, cedrene can promote lateral root development through the auxin signal pathway dependent manner. Different straws were compared for the solid fermentation of *Trichoderma guizhouenase* NJAU4742, and the *Trichoderma guizhouenase* NJAU4742-based

biofertilizer was developed cooperated with the company. These biofertilizers were applied in field for several crops, demonstrated the efficiency of the product. SWA was successfully prepared by radiation-induced graft polymerization of acrylic acid onto cassava starch, at room temperature and normal atmospheric pressure. The influence factors, such as the size of radiation dose, neutralization degree of AA, weight ratio of AA to cassava starch were investigated. Moreover, the optimized conditions of irradiation polymerization process were determined by single factor. The optimum condition was determined as the neutralization degree of AA was 80% and the irradiation dose was 5 kGy. The degree of swelling of SWA is 305 g/g. 0.5% SWA in soil increases spore germination ratio of *Bacillus* biofertilizer.

Future plan

- 1) Continued application of *Trichoderma guizhouense* NJAU4742-based biofertilizer.
- 2) Synergistic of SWA and Biofertilizer in greenhouse and field plot.

3) Japan (Prof. TAWARAYA Keitaro, Yamagata University)

Subject: 4

Short summary

Inoculation of arbuscular mycorrhizal (AM) fungi reduced phosphate fertilizer application to *Allium fistulosum* and achieved marketable yield under filed condition. The response of *A. fistulosum* to AM fungal inoculation under low-P and fumigated conditions were similar to those observed in sterilized pot culture condition. The colonization of roots by introduced AM fungi was affected by the abundance of indigenous AM fungi and this interaction determines growth response of host plants under filed conditions.

Results

Yield (shoot dry weight) of inoculated *A. fistulosum* grown in soil containing 300 mg P₂O₅ kg⁻¹ soil was similar to that of non-inoculated plants grown in soil containing 1,000 mg P₂O₅ kg⁻¹ soil. AM fungal colonization was observed both in the uninoculated and inoculated plants in the non-fumigated field irrespective of P treatment, and there was no difference in shoot P content and shoot dry weight between the inoculated and uninoculated plants. AM fungal colonization in the fumigated field was higher in the inoculated than uninoculated plants, irrespective of P treatment. Shoot P content and shoot dry weight were both higher in the inoculated plants than in the uninoculated plants with P₀. *Rhizophagus* spp. strain R-10 was tracked by OTU read abundance of indigenous and introduced AM fungi. Though neither inoculation nor P level affected shoot fresh weight and shoot P content in the non-fumigated main plant at 131 days after transplanting, significantly higher shoot fresh weight was obtained by the inoculation with no P fertilizer in the fumigated main plant.

Future plan

Yield response of host plant to inoculation of AM fungi is affected soil P availability and different among cultivar of host plant.

Selection of an appropriate cultivar and soil P availability needs to be studied in determining possible mutualistic, commensalistic and parasitic relationship between the AM fungus and the host plant under

filed condition.

4) Kazakhstan (Mr. Kassymzhanov Murat, JSC “Park of Nuclear Technologies”)

Subject: 3

Short summary

Studies have begun on changes in the electrical properties of insulating materials under the influence of high electric field strength and external influencing factors. Experimental work has been carried out to evaluate the physico-mechanical and electrophysical properties of end terminals.

Results

Materials and designs of 110 kV cable terminals have been obtained that are resistant to long term operation in conditions of high electric field strength and external factors.

There is a private partner of Sigma Corporation LLP, who is ready to invest co-financing in the implementation of the project.

Future plan

It is planned to modify the materials to stabilize the electrical parameters. It is also planned to evaluate the effects of ionizing radiation on the electrophysical properties of the material.

It is planned to create a production of 110 kV end terminal and connecting branching sleeve.

5) Malaysia (Dr. Phua Choo Kwai Hoe, Malaysian Nuclear Agency)

Subject: 6, 7

Short summary

A new biofertilizer formulation, as “Microbe Beads” was scheduled to be commercialized in the year 2023 and will complement the commercialization of four earlier biofertilizer products. Three potential isolates will be utilized to develop a biofertilizer products based on inoculated sterilized solid carrier. An E-book entitled “Guideline on mutagenesis of biofertilizer bacteria using gamma irradiation” is in the process of publication. Investigation of gamma mutagenesis of phosphate solubilizing microbe will be analyzed to determine any DNA changes in pqq genes.

Results

To date, Malaysian Nuclear Agency has commercialized four biofertilizer products, namely, Bioliquifert, GoGrow BioNPK Biofertilizer, M99 Biofertilizer and Bioliquifert M100. By using these biofertilizers, farmers can reduce the use of chemical fertilizers, increase by 8-12% of crop yields, and increase by 20-35% of their incomes. A new biofertilizer formulation, the “Microbe Beads” was scheduled to be commercialised in 2023. “Microbes Beads” as biofertilizers can be released slowly into the soil and help to improve soil fertility by fixing atmospheric nitrogen, solubilizing soil-fixed phosphate and potassium. Biofertilizer treated seeds (mustard) have been developed. Different concentrations of treated seeds coated with mustard seeds were evaluated on their germination rate and growth performance. Gamma irradiation is central in the development of a new sterile biofertilizer carrier in Malaysia. A digestate is produced by fermenting domestic organic waste (e.g. food waste) anaerobically in a biodigester. Gamma irradiation at a dose of 50 kGy resulted in microbe free medium. Three isolates from vegetables farm

will use to develop biofertilizer products. Mutagenesis and determination of LD₅₀ of Gram-negative and Gram-positive bacteria was conducted. The LD₅₀ for Gram-negative bacteria is in range of 400 to 500 Gy, while those of Gram-positive is the range of 800 to 1100 Gy. Screening method of dinitrogen fixation, phosphate and potassium solubilization were developed. An E-book of standard guidelines is in the process of publication. Molecular analysis on phosphate solubilizing genes (pqq) in mutated and wild type of *Acinetobacter* sp. (M100) are in progress. Five publications and an award have been achieved. The Government of Malaysia, through the Ministry of Agriculture and Food Industry (MAFI) and the Ministry of Science, Technology and Innovation (MOSTI), encourage the use of biofertilizers as part of plan for food safety and security with the purpose of reducing the use of synthetic or chemical fertilizers, and to increase yields and incomes. For human resource development, training related to biofertilizer for industry, staff and expert mission in the Seychelles have been conducted. In conclusion, the biofertilizer project has successfully delivered R&D products into the market and has been gaining acceptance in the country's agroindustry. New R&D activities such as mutagenesis and carrier developments are in progress.

Future plan

In the year 2024, the project will continue with commercialization of five biofertilizer products. Three isolates will be utilized in the development of a gamma sterilized carrier-based biofertilizer products. Mutagenesis by gamma irradiation will be incorporated in two projects. The first project is screening potential gamma irradiated mutants from culture collection. The second project is the development of allele-specific markers for detection of mutation in phosphate solubilizing bacteria. Another two new projects are mutagenesis of silica solubilization bacteria and the determination effect of biofertilizer application on greenhouse gas production.

6) Mongolia (Ms. Oyundalai Nyamdorj, Institute of Plant and Agricultural Science)

Subject: 4

Short summary

According to the average results of the 2-year study, the versions with a mixture of Humate and Biofertilizer at a ratio of 1:7 and 1:10 and 10 liters of liquid biofertilizer had a significant effect on the field germination and were 9.0-9.7% higher than the control. The application of humic preparation and biofertilizer combinations contributes to higher grain yields in comparison with the control variant. In average yield in 2022-2023, fertilizing plots were 2.0-9.3 cent/ha higher than control.

Results

1. We fertilized in 3 stages: seed, tillering stage and heading stage. Fertilizers are more suitable for seed application and application during the seed and tillering stage.
2. In terms of fertilizer types and dosages, it is suitable to fertilize with a 1:7 ratio mixture of Darkhan humate and Darkhan Rhizo biofertilizers, and to fertilize with only Humate at the rate of 1.5 l/ha.
3. Treating plants with humate and biofertilizers increases the length and number of branches of roots and forms strong roots.
4. At the stem elongation stage of wheat, all the fertilized variants had significantly higher chlorophyll

content than the unfertilized or control variant, ranging from 54.0 to 55.5.

Future plan

- a. To study impact of super water absorbent /SWA/ on greenhouse plants
- b. Isolation and determination of rhizobium bacterial culture from legumes
- c. Effects of Rhizobium bacteria on green manure legumes

7) The Philippines (Ms. Julieta A. Anarna, University of the Philippines Los Banos)

Subject: 4

Short summary

Bio N is a microbial-based-fertilizer for rice and corn that promises very significant impact on the country's farmers in terms of increasing farm productivity and income as well saving the country's dollar reserve due to decreased importation of fertilizers. It is mainly composed of microorganisms (*Azospirillum*) that can convert the nitrogen from the air into ammonia, and provide some of the nitrogen requirement of plants. For this year report the following experiments were conducted: 1. Interaction effects of Bio N inoculant with Mykovam 2. Efficacy Evaluation of **Bio N Using Bentonite Carrier** as Biofertilizer for Rice variety 216. And 3. Development of the Liquid Formulation of Bio N Biofertilizer.

Results

Two experiments were conducted for tomato and corn inoculated with two biofertilizer and 50% inorganic fertilizer which gave the highest yield of 25.85 ton per hectare while the combined inoculation for corn yielded a 66.55% over the control. Data revealed that biofertilizer influenced the yield of the tests crop. Search for another carrier of Bio N was conducted using bentonite as a substitute carrier. This was prepared and inoculated with the same procedure as the process done with the conventional Bio N using mixture of soil and charcoal. Screening of its effectiveness was tested in the field using rice variety 216. The effect of the Bio N using bentonite is similar with the effect of Bio N using soil and charcoal as carrier that is combined with 50% inorganic fertilizer. Formulation of Bio N liquid was conducted to make it easier for the end users to apply. In this study microorganism was grown in different media namely BTB medium, Soya broth and Dobereiners media. Microbial count for each media was determined for the survival of the microorganisms in each media. The highest viable count was recorded in soya broth with 7.63×10^9 but form a rancid odor followed with Dobereiners media 1.99×10^8 and the lowest was 3.20×10^7 BTB media.

Future plan

1. Conduct field trials for new formulation of Bio N and assist in the promotion and marketing.
2. Assists the new project leader
3. Since the technology has been proven effective and accepted by the end user a new technology from BIOTECH will be promoted and commercialize.

8) Thailand (Dr. Chatprawee Dechjiraratthanasiri, Kasetsart University)

Subject: 4

Short summary

At this present, Biofertilizer (BF) is one of the products for reducing chemical-fertilizer and enhancing yield and quality in Thailand. Not only the research from many studies that confirmed the efficiency of BF could increase crop productivity but also improve soil quality. Soil pH and organic matter were found as develop values since 2013 after applying BF both in northern and central site stations. Macro elements like phosphorus and potassium in soil were boosted as available forms by BF. Advocating BF is necessary to get the goal of SDGs with sustainability environment.

Results

Both soil acidity and calculus soil are the problem of economy crop productions with soil pH and the limit available elements like phosphorus and potassium. To increase soil properties could add the amendment or improve by biofertilizer. The project was set by choosing many types of effective microorganism from native areas for producing biofertilizers. Such as bacteria-producing indole-3-acetic acid (IAA) gave the highest of nitrogen phosphorus potassium uptake in shoot and root of chili (*Capsium annuum* L.) and tomato (*Lycopersicon esculentum* Mill.). Phosphate solubilizer bacteria and mycorrhiza were proved to use for increasing available P in both top and sub soil. Inoculating rhizobium (*Bradyrhizobium* sp. (SB1), *Bradyrhizobium elkanii* (SB2) and *Rhizobium* sp. (SB3) of mung bean (*Vigna radiata* (L.) R. Wilczek) production could provide high yield even soil pH still high at Saraburi province. Cellulose-solubilizing bacteria was applied for producing organic fertilizer in Chiang rai area. Organic matter was step-up from low to high levels in top and subsoil. Recently activity of research ascertain that BF could escalate to protect soil quality for long term agricultural land.

Future plan

Long term effect of BF will be checked as parameter to stock carbon in soil and kept soil health in an environmental agriculture field. Developing the technology of sterilization carriers on BF by comparing gamma radiation and ozone fumigation.

9) Vietnam (Dr. Tran Minh Quynh, Vietnam Atomic Energy Institute)

Subject: 4, 6

Short summary

In 2023, a new biofertilizer based on brown seaweed (*Sargassum*) extract was developed for crop production, and the application of Rapol V biofertilizer was registered for vegetable and other plants. In parallel, *Trichoderma* strains with antagonism against phytopathogens were gamma irradiated to screen the mutants for control the rice blast and rice sheath blight diseases replacing for chemical pesticides.

Results

Rapol-V biofertilizer, a microbial fertilizer composed of *A. chroococcum* and *B. megaterium* has been approved by national Plant Protection for vegetable production in Vietnam. This biofertilizer can be prepared in pilot scale with relatively high cost, therefore, further studies should be performed to reduce the production cost and improve its properties for practice.

Brown seaweed, nutrient-rich algae commonly found in the Central Vietnam coastal, is a valuable resource that can be utilized as a natural fertilizer. The extracts of brown seaweed contain significant amounts of microelements and alginate, which can be degraded into oligoalginate having Mw of 3.5

kDa by gamma irradiation at 25 kGy. The irradiated extract was studied as the PGP for plant growth and our results suggested that the irradiated brown extract increased the yield of some vegetable and fruit plants, and it can be used as a potential resource to develop new biofertilizer for sustainable agriculture. 02 strains with high antagonism against phytopathogenic fungi (*Pyricularia oryzae* and *Rhizoctonia solani*) were selected from Collection, then treated by gamma irradiation as mutagenesis to screen the *Trichoderma* mutants. The preliminary results indicated that the mutants with advanced antagonistic effect can be obtained to prepare the microbial pesticides to combat rice blast and rice sheath blight diseases caused by *Pyricularia oryzae* and *Rhizoctonia solani* in Northern Vietnam.

Future plan

1. Promote the application of Rapol-V for other crop production by production in large scale and reduce the cost.
2. Develop new biofertilizers composed of the brown seaweed extracts by radiation processing,
3. Identify gamma radiation mutagenesis *Trichoderma* mutants for further application in production of microbial pesticides to control the rice blast and rice sheath blight diseases.

Session 2: Progress Report on Polymer Modification

1) Bangladesh (Dr. Salma Sultana, Bangladesh Atomic Energy Commission)

Subject: 3

Short summary

Textile dyeing industries generate a large amount of effluents containing dyes which are directly discharged into the surrounding channel, agricultural fields, irrigation channels, and surface water. These effluents may cause changes in the physical, chemical, and biological properties of the aquatic environment leading to changes injurious to public health, livestock, wildlife, fish, and other biota. Thus, environmental degradation through textile dyeing effluents is a big problem in Bangladesh. Considering above those facts many researchers use techniques like precipitation, ion exchange, activated carbon adsorption, and electrolytic method to remove dye and metal from waste water. But all these methods have some limitations like high cost, low removal rate, difficulty for regeneration, and reuse. Therefore, many researchers focused on the alternative low cost effective hydrogel as adsorbent. Here we developed gamma radiation induced hydrogels as adsorbent to adsorb dye and metal from aqueous solutions.

Results

Alginate/Polyvinyl pyrrolidone/N, N-dimethylacrylamide (NaPD) hydrogel were prepared by applying gamma radiation from Co-60 source for the removal of dyes i.e., methylene blue (MB) and Congo red (CR) from aqueous solutions. It was observed that the Langmuir isotherm model was top fit with a high correlation ($R^2 > 0.99$) for methylene blue adsorption and the Freundlich isotherm model was top fit ($R^2 > 0.97$) for Congo Red. NaPD hydrogels adsorption behavior followed pseudo second order kinetic model with maximum removal efficiency ~ 91% for MB whereas they followed pseudo first order kinetic model with maximum removal efficiency 41 % for CR. The positive values of ΔH (for both MB and CR) from the thermodynamics study, confirmed that the adsorption process was endothermic.

In response to the harmful impacts of heavy metals and cationic dyes of modern civilization, another series of superabsorbent hydrogels were prepared via γ -ray-induced crosslinking among Polyethylene Oxide (PEO), Starch, and 4-styrene sulfonic acid sodium salt (SSA). The irradiation dose and the composition of starch and SSA were optimized in terms of gel fraction, degree of swelling, porosity, and crosslink density. The pH dependent, thermodynamically spontaneous and feasible adsorptions of the cationic dyes: Basic Fuchsin (BF), Methylene Blue (MB), and Crystal Violet (CV) were governed by film-diffusion at maximum adsorption capacities of 625, 569, and 498 mg/g, with the isotherms being best characterized by Modified Langmuir, Redlich-Peterson, and Aranovich-Donohue models, respectively. After four adsorption/desorption cycles the hydrogel could still remove 77-82% of the dyes from aqueous solutions. Adsorption kinetics followed pseudo 1st order for MB (98% removal) and CV (91% removal) but pseudo 2nd order for BF (92% removal). The pH-dependent slower adsorption of the metal ion Cr^{3+} (61% removal) was best described by Freundlich isotherm, intraparticle diffusion, and pseudo 2nd order kinetic models with three adsorption sites per adsorbate.

Future plan

We will try to increase the dye and metal adsorbing properties of prepared hydrogels.

Subject: 8**Short summary**

The enormous amount of waste Terephthalate polymers, or PET, cause major environmental problems. One frequent way to recycle it is use of it as a filler material in concrete technology. However, the adhesive strength between waste polymers and the cement paste weakens with waste polymer introduction, which causes loss of some mechanical properties. One other way to deal with it is to use radiation. Accordingly, research is under progress on how waste polyethylene terephthalate (PET) and gamma radiation affects the compressive strengths (CS) of cement-based concrete.

Results

We are preparing concrete blocks using gravel, sand, cement and PET powder and we are using universal testing machine for mechanical strength testing. Initially the manufacturing process involved the preset ratio of 2:3:5 for cement to sand to gravel and irradiated and non-irradiated PET weighing 0.5, 1 and 1.5 g was used in place of the sand. Next, 0.5, 0.25, and less than 0.25 mm of gravel mess size were used to optimize gravel mess size. When the gravel size was less than 0.25 mm, the control, irradiated, and non-irradiated concretes showed increased compressive strengths compared to other gravel sizes. Following the selection of the gravel mess size (pan size which was less than 0.25mm) the sand was again replaced by 0.5, 1 and 1.5 g of irradiated and non-irradiated PET using three different ratios of cement, sand and gravel of 1.8:3:5, 2.2:3:5 and 2.4:3:5. Cement, sand and gravel ratio of 2.2:3:5 showed good result. Additionally in this case, the irradiated concrete's compressive strength was higher than that of the non-irradiated concrete block. Highest compressive strength obtained was 18 MPa. 50 kGy of radiation dose was utilized in all these experiments.

Future plan

We will investigate the compressive strength of concrete blocks at varying radiation doses (30 kGy, 50 kGy, 70 kGy, and 100 kGy). We will replace cement instead of sand with equal amount of irradiated and non-irradiated PET. Irradiated and non- irradiated PET will be investigated by SEM, XRD, and FTIR.

2) China (Dr. Hongjuan MA, Shanghai University)**Subject: 2****Short summary**

Research projects of polymer modification with irradiation technology and their applications in uranium extraction, solar-driven desalination, degradation of persistent organic pollutants and efficient treatment of microplastics were ongoing investigated. Irradiation technology with EB and ⁶⁰Co holds a huge market and demand in China and will maintain continuous growth. In addition to traditional radiation processing applications, radiation curing is particularly concerned. New materials based on radiation technology have broad application space in the future.

Results

1. An ultrafast strategy to prepare AO based nanofibers with polyvinyl alcohol super hydrophilic slit nanopore structure via radiation crosslinking and grafting polymerization was designed. Combined

- with hydrophilic 2D MXene nanosheets for excellent photothermal and photoelectric synergistic assistance, further improved the adsorption performance.
2. Poly(ethylene)-poly(amidoxime) membranes with a two-in-one bifunctional structure of synergistic adsorption and in-situ reduction were designed to enhance uranium extraction from seawater. Adsorption capacity of the hydrazide-functionalized materials in uranyl solution and simulated seawater increased by 22% compared with AO functional membranes.
 3. A novel Janus photothermal hydrogel-fabric was developed by firmly formatting surface hydrophobized porous photothermal hydrogel on a commercial cotton fabric in large area. 6.3 kg m⁻² of freshwater was produced from 3.5 wt% NaCl solution in 9 h under natural sunlight.
 4. An efficient advanced oxidation process was used to degrade cardiovascular drug salbutamol by EB irradiation. Toxicity evaluation suggested that the toxicity of SAL aqueous solution reduced after EB irradiation, indicating that it is an effective method to degrade SAL.
 5. EB irradiation was employed to effectively decompose Cu-ethylenediaminetetraacetic acid. Heavy metal complexes with high stability and poor biodegradability were almost completely eliminated at 5 kGy.
 6. EB irradiation is used to age and degrade microplastics. EB irradiation can effectively promote the aging and degradation of microplastics.

Future plan

Research and development of new materials with higher capacity, pilot scale of materials (100 kg), uranium extraction (1 kg)

Assemble seawater desalination devices to solve drinking water problems for individual soldiers or fishermen.

Seeking suitable hospitals and pharmaceutical companies to conduct pilot-scale verification of electron beam irradiation for the degradation of medical wastewater.

3) Indonesia (Dr. Tita Puspitasari, Research Organization for Nuclear Energy)

Subject: 1, 8

Short summary

R&D for Polymer Modification using radiation processing technology is currently overseen by the Research Organization for Nuclear Energy, BRIN. There is still a need to make adjustments to certain aspects such as human resources, facilities, financial support, research topics, and administration procedures. The research of oligochitosan for animal feed supplements was conducted through collaboration with the university. Furthermore, the research of recycling plastics was implemented with the collaboration among BRIN, the university, the Indonesia Recycler Plastics Association (ADUPI), and the industry namely PT Viro.

Results

1. Application of oligochitosan on native quail was conducted. As the results of the study, it can be affirmed that the addition of oligochitosan with early glutathione induction affects the growth of quail ileal villi. The growth of quail ileal villi remains optimal with the lowest adverse histology impact,

namely the administration of 100 ppm irradiated chitosan induced by 150 ppm glutathione.

2. A research-based start-up company called PT Ecomara Pandu Inovasi tried to conduct the downstream of oligochitosan as an animal feed supplement. The funding for this project was supposed to be supported by BRIN, and the proposal was submitted in mid-2023. However, the results showed that the proposal was unsuccessful. The team plans to resubmit the proposal for the next cycle after making some improvements.
3. A recent study focused on the development of new products using recycled plastics, specifically a compatibilizer that can be used for wood-plastic composites. The study revealed that the use of a compatibilizer made from irradiated PE was highly effective when added to the composite at a concentration of 2%. As a result, the prototype was able to successfully pass the TRL 3 stage supported by the Indonesia Recycler Plastics Association.

Future plan

- Continuing to complete the data sheet of the effect of oligochitosan on various parameters such as immunity, histology, and reproduction of animals.
- Trying to get funding support from BRIN, for down-streaming the oligochitosan as an animal feed supplement through a research-based start-up company called PT Ecomara Pandu Inovasi
- Continuing to reach the TRL 4 of the development of compatibilizer generated from irradiated recycled PE to be used in wood plastics composite supported by PT Viro.

4) Japan (Dr. TAGUCHI Mitsumasa, National Institutes for Quantum Science and Technology)

Subject: 2

Short summary

Our research aim is to create highly original and functional biodevices by ionizing radiations. The microtopography and physical and chemical properties of the biomaterials can be freely and three-dimensionally controlled from nm to μm by utilizing the uniqueness and superiority of radiations. We are conducting research and development of cutting-edge medical devices such as three-dimensional cell culture substrates, and nanosensors based on biocompatible polymers.

Results

1) Functional 3D cell culture sheets

The folds and protrusions found in vivo are essential for organs to function normally, but the details of how cells form these 3D structures have remained unclear. We focused on the traction force that cells exert on adhesive surfaces and conceived of the formation of folds and protrusions. Flexible thin films have been developed for cell culture that deforms with a very small traction force. Culture thin films were prepared by controlling the depth profile of chemical reactions induced in polylactic acid by a 50 keV nitrogen ion beam. The substrates consist of two layers: a surface layer (film) that is crosslinked and carbonized to enhance adhesion so that cells can exert firm traction, and a lower layer that dissolves during culture. The surface layer peels off as a thin film when external forces are applied during cell culture. By patterning the thin film, we succeeded in obtaining 3D cell sheets with folds and protrusions within only 48 hours. The 3D cell sheet is expected to be used as a biological model as well as for

transplantation therapy for organs.

2) Smart peptide nanoparticles

In the development of the nanosensors, peptides suitable for quantum beam crosslinking reactions were synthesized. These peptides were crosslinked using quantum beams to produce nanoparticles with a particle diameter of less than 50 nm. By evaluating the stability, biodegradability, production yield, and surface charge of them, as well as biological evaluation using pancreatic cancer, we succeeded in developing a nanoparticle-based sensor suitable for the diagnosis of pancreatic cancer.

Future plan

We investigate the radiation crosslinking technique to develop functional bio-devices in medical applications. Specifically, we aim to develop 3D cell culture hydrogels for drug discovery and regenerative medicine, nanosensors for PET diagnosis, and microfluidic chips for rapid and accurate drug evaluation, and implement into society.

5) Kazakhstan (Mr. Nurkassimov Azat Kanatovich, JSC “Park of Nuclear Technologies)

Subject: 3

Short summary

In the presence of oxygen, the formation of peroxide compounds is possible at the sites of formation of active radicals. It was necessary to determine the effect of radiation on the polyethylene crosslinking process. The irradiation environment, or rather the presence of oxygen, can provoke the occurrence of side processes of oxidation of polyethylene. Therefore, experiments were conducted on irradiation of polyethylene samples in an air environment, in an environment of inert gases argon and nitrogen.

Results

To create an inert environment, the samples were placed in bags, which were purged with the appropriate gas (argon or nitrogen) and sealed. The samples were kept in an inert environment until the moment of analysis. As a result, it turned out that the crosslinking process is influenced by the irradiation environment - in an inert environment there is a larger proportion of the gel fraction than in the air. This is typical for almost all samples. In EVA, P8 160, HDPE 176 samples, the gel fraction increased to 90% or more during irradiation. The crosslinking process dominated the destruction in the radiation dose range up to 125 kGy. At 175 kGy, destruction mainly occurs.

Irradiation in an inert atmosphere made it possible to increase the content of the gel fraction by at least 10% in all samples compared with the air environment.

The removal of oxygen/air during irradiation and its replacement with an inert gas made it possible to reduce the radiation dose, which leads to a reduction in the cost of the product.

Future plan

It is planned to conduct research on post-thermal processing of samples in a nitrogen atmosphere at temperatures of 70 and 95 ° C. This study will allow us to evaluate the change in the mobility of free radicals and the recombination of residual free radicals in polyethylene layers, as well as the degree of reduction in the rate of degradation reaction in polyethylene layers of irradiated samples and the degree of crosslinking.

It is also planned to develop a technology for producing a new PTC polymer with a nanodisperse graphene-like filler with subsequent modification at an electron accelerator.

6) Malaysia (Ms. Maznah Binti Mahmud, Malaysian Nuclear Agency)

Subject: 1, 4, 5

Short summary

The preparation of Kitogama (animal feed), CarraPGP (PGP) and SWA using gamma radiation technique have been established. The characterization on Kitogama, CarraPGP and SWA was carried out. The optimized formulation was selected for validation study. Kitogama consisting of LMW-chitosan (5000 Da) has proven to increase red tilapia growth and survival rate. CarraPGP, is a LMW-carrageenan-based plant growth promoter (10000Da) indicated promising results on plant growth activity and yield compared to Control. As for synergistic study of SWA-PGPs, combination treatments also show good effect on the plant growth performance and yield even in poor-irrigated soil.

Results

Kitogama was prepared by gamma-irradiation of chitosan solution at 25kGy. Kitogama has antimicrobial activity against *E.coli* indicated as a good supplement to protect fish. Brine shrimp toxicity study showed that Kitogama is safe to use at 3.14% of its original concentration. The protein digestion test of fish feed pallet revealed the performance of Kitogama is as good as protease enzyme in digesting protein molecules to amino acids, hence promoting growth rate and improving feed conversion ratio of tilapia.

CarraPGP obtained through gamma irradiation of carrageenan powder at 75kGy. As a shorter-chain of complex carbohydrate-based substance, the CarraPGP has a high tendency to deteriorate during storage. The effect of E211 and Na-EDTA at 500, 750 and 1000 ppm in CarraPGP, respectively were studied. The pH of CarraPGP after preserved with Na-EDTA insignificantly changed compared to the initial pH. Furthermore, The Na-EDTA concentrations indicated insignificantly changed the pH stability. In comparison, the stability of viscosity in E211 treatments is worse than Na-EDTA treatments. However, all Na-EDTA and E211 treatments indicated the viscosity insignificantly changed after 12 months.

The plants supplied with 0.1% SWA and PGPs indicated better results compared to PGPs only. The treatment of SWA without PGPs indicated good results on plants as well because SWA releases stored water and helps plant nutrients intake resulting in its growth performance. From the data, it can be concluded that SWA not only can absorb water but, at the same time it can release water to the soil to be taken by the plant for their growth.

Future plan

Currently, Nuclear Malaysia is ready with the established preparation procedure on Kitogama, CarraPGP and SWA. These three products have indicated great potential as animal feed supplement, plant growth promoter and water retainer agent, respectively. The next plan is to approach community, private sector, or research agency to study on the product performance in the semi-field, either with or without fund (strategic collaboration). The study approaches are to identify the factors that influence the product performance (increase or vice versa), the product limitations and the optimize application procedure.

Also, to involve for more road tour promotions, to find potential collaborators and outreach the technology to the community.

7) Mongolia (Dr. Chinzorig RADNAABAZAR, National University of Mongolia)

Subject:

Short summary

We have studied total bacterial count reduction in Mongolian air-dried beef (*Borts*) due to the effects of e-beam irradiation. Different amounts of absorbed dose were used such as 2 kGy, 4 kGy, 6 kGy, 8 kGy, and 10 kGy, and compared the effects of these doses with the negative control group. No significant changes occurred in both chemical and physical states, but the most beneficial effect was the total number of bacterial cell count in a sample. After e-beam irradiation of 4 kGy of absorbed dose, the total bacterial counts were reduced from 1.7×10^4 control group to 2.4×10^3 , and in the case of 6 kGy total counts were reduced to 6×10^2 , and for the 8 kGy, the bacterial counts were significantly reduced to 3.8×10^1 colony forming units.

Method and materials:

Air-dried beef (*Borts*) is irradiated using 2MeV and 10meV e-beam irradiation. Before and after the irradiation, we measured changes in total protein, lipid and chemical composition, and the physical state of whole samples with basic microbiological and biochemical methods.

Results

1. No changes in chemical composition were detected (FT-IR) after irradiation.
2. Protein and lipid contents were variable.
3. After e-beam irradiation of 4 kGy of absorbed dose, the total bacterial counts were reduced from 1.7×10^4 control group to 2.4×10^3 , and in the case of 6 kGy total counts were reduced to 6×10^2 . For the 8 kGy, the bacterial counts were significantly reduced to 3.8×10^1 colony forming units.
4. Ionization irradiation has beneficial effects in reducing microbial contamination in Mongolian dried beef–*Borts*.
5. In addition, our results confirmed that ionization radiation does not have significant adverse effects on the nutritional value, flavor, appearance, and texture of Aaruul.

Future plan

- a. Post-harvest treatment of basic vegetables (potato) with irradiation to reduce losses during preservation.
- b. Meat treatment to improve hygiene and sanitation.
- c. Promote and educate farmers and small businesses, provide nuclear technological information to the public as a safe.

8) The Philippines (Dr. Charito T. Aranilla, Philippine Nuclear Research Institute)

Subject: 2

Short summary

The Trial Sites for the Clinical Study of the Hemostats had been identified. The Clinical Trial Protocol

was submitted to the Institutional Ethics Review Board for evaluation. The production process for the CMC granules was demonstrated to the collaborating Toll Manufacturing Company for the Pilot Scale production. Market assessment studies for the hemostats was conducted by the Business Development Section.

Results

The trial sites for the Clinical Study of the hemostats were identified as East Avenue Medical Center (ER Dept. and Trauma Center) and the V. Luna Medical Center. The Clinical Trial Protocol has been evaluated two times by EAMC-Institutional Ethics Review Board for but no approval yet. The production process for the CMC granules was demonstrated to Lynx-nia Medica, Inc. in preparation to the Pilot Scale trials. Based on the market study, there is strong evidence that the Philippine market is ready to embrace the product. The selling points were low price point and quality. Customer cohorts identified were hospitals, the military, other health institutions and groups like the DOH and local health units. With confirmation of demand and acceptable price points, the financial feasibility confirmed the potential for a profitable business venture. Given an expected low capital needed, return on investment (ROI) can reach as high as 22%. In the financial projections, this figure was reached with a projected selling price of only Php500, on the lower end of the acceptable price point, based on the market study, and assumed a single version of the product only.

Future plan

- Conduct Pilot Scale production trial
- Secure IERB-approved Protocol and FDA Certificate of Medical Listing
- Conduct Pilot Clinical Trial
- Conduct Pivotal Clinical Trial
- Initiate Technology Transfer process

Subject: 5

Short summary

The journey to commercialization of the Cassava Starch/Polyacrylic Acid SWA has been initiated. A technology taker has already signed PNRI's Direct Licensing Term Sheet.

Results

The journey of the CS/PAA SWA from R&D to market is already within reach. The developed Cassava Starch/Polyacrylic Acid superwater absorbent has been well-characterized. The optimized SWA has been proven to be biodegradable, noncytotoxic and nongenotoxic. The shelf-life of 9 mos. stored at RT can be prolonged to 3 years if stored under refrigerated temperature. Retrogradation which affects the stability of the SWA can be controlled with the addition of calcium chloride or storing at low or freezing temperature. There was no apparent depreciation of gel properties from lab to upscaled production. The efficacy of the CS/PAA SWA was apparent in the increase in root biomass, early flowering and reduction of watering interval. Market research showed a competitive price of the SWA compared to imported biodegradable SWA products. The cost-benefit analysis revealed greater than 20% savings in production operating cost. Finally from these efforts, a deal with a Private Company or Technology adopter has

been initiated. The JC Dots Agri Trading has signed the Institute's Direct Licensing Term Sheet.

Future plan

Since this project has officially ended in June 2022, a new proposal will be submitted to obtain funding for the development of new SWA based on carboxymethyl cellulose incorporated with PGP or natural bioactive agents for plant diseases and pests.

9) Thailand (Dr. Kasinee Hemvichian, Thailand Institute of Nuclear Technology)

Subject: 5

Short summary

Previously, SWA hydrogel was successfully prepared. Results from the field tests revealed that the prepared SWA was able to increase the survival rate of young rubber trees planted in arid area by up to 40%. However, the method used for SWA hydrogel production consumes a lot of time and energy, while producing SWA hydrogel is produced in irregular sizes and shapes. This research aims to develop a novel method to fabricate SWA in uniform size and shape.

Results

A new method was developed to prepare SWA in uniform size and shape. SWA beads were successfully prepared via radiation-induced graft polymerization of AA onto alginate-cassava starch beads. Gel fraction and swelling ratio of the prepared SAP beads were dependent on pH, concentration of monomer, presence of starch as well as radiation dose. The prepared SWA beads have a high swelling ratio of 360 g/g. The results from this study have proved that this new method can prepare SWA beads in uniform shape and size, while saving both energy and time.

Future plan

Field tests of SWA beads will be performed in order to analyze their potential for agricultural applications.

10) Vietnam (Prof. Nguyen Ngoc Duy, Vietnam Atomic Energy Institute)

Subject: 3, 8

Short summary

- The Cu nano/TiO₂ photocatalysts with a size in the range of 20–30 nm were successfully synthesized by electron beam irradiation method. Cu nano/TiO₂ photocatalyst materials have high efficiency in reducing COD and BOD₅ concentrations in leachate. Cu nano/TiO₂ photocatalyst with 1.5% Cu concentration was suitable to achieve the highest organic substances degradation efficiency
- The Cu@TiO₂/PES/PAA membranes were successfully synthesized by EB irradiation method. AB260 degradation catalyzed by coated membrane was stable over five cycles. The surfaces of coated membranes were rougher than the pristine membrane. The water flux of coated membrane was lightly decreased, but acceptable. The flux recovery ratio (FRR) of the coated membrane under photocatalysis was 98%.

Results

- The Cu nano/TiO₂ photocatalysts were successfully synthesized by electron beam irradiation method.

The Cu nano/TiO₂ catalysts synthesized have a higher photocatalytic activity than the original TiO₂ because of the band gap smaller than TiO₂. The results show that Cu nano/TiO₂ photocatalyst materials have high efficiency in reducing COD and BOD₅ concentrations in leachate. The Cu nano/TiO₂ photocatalyst with 1.5 % Cu concentration was suitable to achieve the highest organic substances degradation efficiency. Under the irradiation of visible light, the photocatalytic efficiency of decomposing organic matter in leachate was 73,1 % and 51,5 % on COD and BOD₅ values, respectively after 3 hours of light.

- This study reduced the high bandgap of TiO₂ by utilizing Cu NPs, resulting in the creation of a composite photocatalyst that was subsequently coated onto the PES membrane through a plasma-grafted PAA layer. The best CuNPs molar ratio is found to be at 25%. AB260 degradation efficiency reaches 96% due to reactive free radicals such as •OH and the presence of H₂O₂. The process is also proven to be stable over 5 cycles when catalyzed by the coated membrane. Notably, the Flux Recovery Ratio (FRR) of the coated photocatalytic membrane after undergoing photocatalytic treatment was remarkably high, reaching approximately 98%. Despite the higher surface roughness of coated photocatalytic membranes when compared to pristine PES membranes, the antifouling ability may not be significantly compromised due to the high photocatalytic activity of the modified membranes. This study underscores the potential of the Cu@TiO₂/PAA/PES photocatalytic membrane for further research and practical application in wastewater treatment.

Future plan

- Study on the treatment of hospital wastewater treatment using electron beam method.
- Study on the increase of mechanical properties of plastic waste (mesh waste) using irradiation for recycle purposes.
- Study on the fabrication of nanogels by the electron beam irradiation method from natural polymers for applications in medicine.