

Nuclear Techniques Application in Food and Agriculture

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ABSTRACT

In agricultural research, isotopes and radiation play a part in so many fields and in so many ways that it is difficult to obtain a proper picture of their enormous importance. In laboratories of developed countries, isotopes are used routinely with an ever increasing assortment of modern research aids. In emerging biotechnologies, which are used increasingly by agricultural scientists, isotopes are a basic tool to achieve the goal in molecular biology intensively.

Key words : isotopes, radiation, fertilizer, induced mutation, radiation sterilized

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Introduction

The main agricultural problems, isotopes and radiation has played and contributed in solving practical problems in,

- Determine conditions necessary for optimizing fertilizer and water use efficiency, as well as biological nitrogen fixation;
- Breed high performance, well adapted and disease resistant agricultural and horticultural crop varieties using radiation induced mutations;
- Eradicate or control insect pests using insects that have been radiation sterilized or genetically altered;
- Improve reproductive performance, nutritional status and health of animals using radioimmunoassay and related techniques, as well as isotopic tracers;
- Reduce post-harvest losses by suppressing sprouting

and contamination using radiation treatment;

- Reduce food borne diseases and extend shelf-life using radiation; and
- Study ways to reduce pollution from pesticides and agrochemicals.

Crop production

A good crop needs soil with adequate amounts of nutrients and moisture. Nuclear techniques are ideal tools for measuring the efficiency of fertilizer use by crops and for keeping a watch on the moisture content.

In modern agriculture, the use of fertilizers is essential to maximize crop yields; for example, a 50 percent increase in grain yield of cereals is common in many soils through efficient fertilization. In order to provide food for the constantly increasing world population, the projected fertilizers consumption in 20 years' time is estimated to be 4 to 5 times greater than today's. To reduce the fertilizer requirement to an absolute minimum and thereby save production costs to the

farmer and reduce damage to the environment, studies to obtain information on the relative merits of different fertilization practices such as methods of fertilizer placement, time of application, and types of fertilizers are needed. The method used to solve these problems requires the introduction of known quantizer labelled with isotopes to the soil at various times and in different positions. Since the plant does not discriminate between elements from the labelled fertilizer and those from native soil, the exact amount of fertilizer nutrients taken up by the plant can be measured.

Results of this research have been incorporated in agricultural practices for cereals and have increased crop productivity significantly, reduced fertilizer use and thereby costs and helped the environment by reducing markedly residual fertilizer in soils. Recommendations based on the results of experiments in this area have been adopted in FAO organized fertilizer programmes in many countries and great savings have been reported; one country using these techniques claims

to have saved as much as US\$ 36 million per year on maize crops alone.

Similar natural methods have been adapted to evaluate deposits of cheap rock phosphates as an alternative to expensive, often imported, phosphate fertilizers, and to find the most efficient way to use these fertilizer deposits for maximum plant growth.

Although nitrogen constitutes 80 percent of gases in the atmosphere, few plants can directly make use of it. However, through a process called biological nitrogen fixation, plants are able to use the nitrogen in the air. The most important results from a symbiosis between a plant and a bacterium, and has gained great attention during recent years.

Legumes that fix nitrogen can provide high protein for human and animal consumption and also increase nitrogen in soils, The water plant *Azolla*, for example, can derive 80-90 percent of its nitrogen by fixation, and is valuable in providing nitrogen to paddy rice crops. In order to obtain maximum benefits from this unique biological process, isotopes are used to find the

amount of nitrogen that a plant can fix and how this can be improved. Isotope techniques are an ideal tool to distinguish nitrogen derived from the atmosphere, soil, and applied fertilizer.

Water is the most important limiting factor for crop production in many areas of the world. The efficient use of water in irrigation systems requires continuous monitoring of the moisture content of soil. Neutron moisture gauges are ideal instruments for this purpose and help soil physicists to make the best use of limited water resources. Through these methods, traditional irrigation methods are improved and in some cases up to 40 percent of the water can be saved.

Agrochemicals

Agricultural production relies heavily on chemical inputs-fertilizers to boost production and pesticides to suppress weeds and control insects. Excessive use of these chemical harms the environment as well as the food products.

Isotopes as ideal tools for studying the behavior, breakdown, and

residues of agrochemicals in soil, water, plants, animals and their products.

As a result of their use, it has been possible to devise safer ways to apply agrochemicals and safer formulations which are more effective in controlling pests or promoting growth, as well as less harmful to health and the environment.

Mutation

For centuries, mankind tried every possible way to improve quantity and quality of crops. Natural evolution results from spontaneous mutation and selection of the fittest mutants. The rate of mutation occurrence can be multiplied by radiation treatment thereby accelerating evolution and the selection of superior crops.

Over the last 50 years, a number of plant breeding programmes have included mutation induction with radiation or chemicals to breed improved crops.

Physical mutagens like X-rays, gamma rays or fast neutrons are most frequently applied and their use has resulted in the highest number of im-

proved, mutant crops. The number of induced mutant derived crop varieties now exceeds 1500 worldwide with billions of dollars added to farmers' incomes annually.

Important desirable properties which one may achieve by radiation include:

- Improved lodging resistance : The desired properties are a reduction in plant height and a stiffer stem, which can withstand rain and storm.
- Changed maturing times : Early maturing is important to escape frost pests, etc., or simply to make room in the field for other crops, in order to make more incomes for farmers.
- Increased disease resistance: Becoming very important in attempts to decrease the use of chemicals which are used against pests to protect the environment.
- Increased yields : The yield of many crop varieties has been increased manyfold

after mutation breeding using nuclear techniques.

- Improved agronomic characters : For example, more winter hardiness, greater tolerance against heat, or generally better adaptability to available soil conditions.
- Improved seed characteristics : Improvement of nutritional value (protein or oil content), baking and melting qualities, or reduction in cooking time.

Many countries have released crop varieties developed through induced mutations.

There are more than 40 countries with over 1500 released mutants of which less than 10 percent are chemically induced and more than 90 percent are induced by radiation.

Animal production

Many animals give us meat and milk. They also give us wool and leather to make clothes and other products. In many countries they also provide fuel for cooking and power to cultivate the land

and harvest the crops. In some countries, the economy and the wellbeing of the people depend on this and radioisotopes are helping to improved results;

- Increasing animals' body weight and milk yields through better feeds;
- Improving breeding of livestock by determining the correct stage of the reproductive cycle through hormone measurements with isotopic methods; and
- Eliminating disease by producing vaccines by radiation through X-rays which are safe and cost effective.

Radioisotopes are used to find the best way of feeding animals so that they make the optimum use of available pastures and the by-products of various agricultural industries which are normally used to feed them. This is done by labelling feed and certain body metabolites with isotopes, such as carbon-14, and then following their activity within the animal's digestive system and other parts of the body to

determine where and how quickly they are broken down and how efficiently they are converted into body tissues or milk. In effect, isotopes are used to determine the nutritional value of feeds for livestock so that the best combination of materials which are potentially available to feed them can be chosen. By the same token, if a particular feed is found not to be particularly nutritious, isotopes can be used to examine ways of improving it, such as by treating it with chemicals or supplementing it with another material so that the animal's ability to digest it is increased.

Isotopic methods have been at the centre of many of the major advances which have taken place in the past 15 years, such as how to feed animals and increase their ability to produce useful products.

By using isotopes to study how efficiently the feeding materials were digested, scientists were able to develop the feeding materials appropriate for their animals.

Another major use of isotopes in animal husbandry is in breeding.

Female animals can be bred only when their ovaries are functioning properly and they are at the correct stage of their reproductive cycles. These points can be checked by measuring the levels of the reproductive hormones which control the activity of the ovaries (in particular a hormone called progesterone), using radioimmunoassay (RIA).

This technique is very simple and is also sufficiently sensitive to measure the extremely small concentrations of hormones which are present in the animal's blood or milk from the animal, adding it to a tube which already has been coated with antibody to the hormone, and then adding a radioactively-labelled hormone. The tube is then centrifuged, the liquid contents removed, and the radioactivity left in the tube counted. The concentration of the hormone then can be determined by reference to the radioactivity counts in samples containing known amounts of the hormone.

RIA's of reproductive hormones are used for many different purposes today. In artificial insemination programmes, they are used to check

whether animals are being inseminated at the correct time in their reproductive cycles, whether the inseminator is conducting the insemination properly, and to determine at a very early stage whether the animals has become pregnant after insemination. This can save the farmer a great deal of money because if the animal is found not to be pregnant, she has to be bred again at the appropriate time of the next reproductive cycle, otherwise, there will be a long delay between the birth of successive offspring. RIA's are also used in embryo transfer programmes to check that the recipient of the embryo is at the same stage of the reproductive cycle as the donor, and they are used to develop and check ways of treating reproductive problems in animals using hormones and other drugs.

All these applications are important in the "high-tech" animal breeding programmes currently used in the industrialized world, but hormone RIA's also are very important in developing countries. Here, their main use is in research to monitor the reproductive efficiency of animals and to identify and

eliminate animal husbandry practices which are responsible for the poor breeding performance of animals often observed in these countries.

For example, in some countries, allowing the calf to suckle its mother shuts off the activity of the mother's ovaries for long periods of time after she has calved. Therefore, she cannot become pregnant again for many months and cannot produce another calf or have another lactation to produce milk. TIA has been used to examine this phenomenon and to develop calf-sucking regimes which will allow the cow's ovaries to resume activity quickly after calving while at the same time not adversely affecting the health of the calf.

In the same vein, RIA can be used to develop feeding strategies which allow animals to breed more effectively in areas where the amount or quality of the feed available is low, and even to identify animal breeds and types which reproduce better than others in harsh environments. There are many ways, therefore, in which radioisotopes, in this case in the form of RIA, are applied to the improvement of

animal breeding and husbandry methods the world over,

Finally, there is the widespread use of radiation and radioisotopes in animal health. By eliminating the disease-causing potential of some parasites, ionising radiation from cobalt 60 or X-ray sources is used to produce vaccines through the attenuation technique, which is both safe and cost effective.

The other major area in the animal health field where the use of radioisotopes has a major impact is in the development of serological tests to diagnose diseases. It is extremely important to be able to diagnose disease properly to determine with which drug or vaccine the animal should be treated. This in turn improves the cost effectiveness of programmes aimed at diseases control or eradication. To obtain the high specificity, and in some cases the high sensitivity, needed to differentiate one disease from another, requires refined biochemical and immunological methods to produce the reagents which form the components of the diagnostic test.

These methods rely heavily on radioisotopes to label either the organism itself or antibodies which will attach to the organism. In this way, the part of the organism or the particular antibodies needed for diagnostic purposes can be identified and purified.

Having identified these materials, the presence of the disease-causing organism in the animal's blood then can be detected by adding blood serum to a tube which has been coated with one of these materials. An immunoassay test similar to that described earlier for the measurement of hormones is then conducted, either using a radioisotope (RIA) test, or alternatively an enzyme (ELISA) test to measure the binding of the disease agent to the antibody and hence diagnosing the disease.

The successes achieved by nuclear techniques in animal production are many:

- In Asia an improvement in the production of buffaloes was made possible by

adding a few kilos of cheap waste material to their feed. This resulted in nearly 6 times less grass being needed to produce 1 tonne of bodyweight gain per animal.

- In Africa, nuclear methods are helping to fight two devastating diseases rinderpest and trypanosomiasis—thereby increasing food production and incomes for small farmers.

- In South America, isotopic methods helped to preserve the alpaca and vicuna populations in the Andes, which helped to improve the economy and wellbeing of low income farmers in the Highlands.

Insect control

Insects compete with man for food and fiber and are a threat to animal and human health. In controlling insects with chemicals, we have sometimes created problems of environmental pollution and toxic residues in our food. Also, many insects have developed resistance to insecticides, often resulting in more insecticides being used. Therefore, new

approaches to insect control are needed.

One way of controlling or eradicating insects without the use of chemicals is the sterile insect technique (SIT). In this approach to insect control, insects are produced in large rearing plants, sexually sterilized using gamma radiation and released into the native population. When the sterile insects mate with the wild insects, no offspring are produced. This approach is not only environmentally sound, frequently it is the only practical means of insects eradication.

Sometimes the native population of the target insect is first reduced by cultural, biological, or attractant/chemical methods before sterile insects are released. Then, when sterile insects are released, the ratio of sterile to native insects is high and the probability of a native insect mating with another native insect is low. If the ratio is high enough in an isolated situation, the insect will be eradicated from that area. SIT is most effective when the sterile insects can be produced in large numbers and the

native population is low and isolated from other infestations.

It is an ideal way of eradicating new infestations of insects before they spread over large areas, but also it is effective in area-wide control of established populations. Further, pest-free zones of agricultural production can be maintained through the use of the SIT.

SIT must be undertaken on an area-wide basis for an effective programme. Area-wide control of key insects without heavy use of insecticides is often the most economically and ecologically sound approach to pest management. This usually involves an integration of several methods of insect control of which the SIT is often a component.

Isotopes are also commonly used to study insect movement, feeding, behavior and metabolism. They are also standard tools in biotechnology, including molecular biology,

Standard insect genetics have been used to study the compatibility of various insect strains and the hy-

bridization of related species. In the future, genetic engineering will be used to develop strains of insects designed specifically for the SIT.

Food preservation

One of the first priorities in the world is to have enough healthy food for everybody. Great trouble is being taken to fertilize the land, develop suitable mutants of basic crop plants, provide a suitable infrastructure adapted to the country and, generally, create the right circumstances for a good harvest. After that we have to do more to make sure that the preciously grown food is preserved and protected against contamination and pests, an especially important priority for the developing world.

For thousands of years this problem has been with us and preservation methods have evolved from the earliest days of sun drying to salting, smoking, canning, freezing, heating and the addition of chemicals. The latest addition to this list is irradiation, the exposure of foods to

carefully controlled amounts of ionizing radiation.

Although a relatively new commercial process, food irradiation has been studied more thoroughly than any other food technology. More than 40 years of research have shown conclusively that there are no adverse effects from the consumption of irradiated food. In fact, for many foods, the preservation of food by irradiation has proved to be by far the best method.

All necessary rules and regulations to irradiate certain foods have been adopted by the relevant international authorities, but there is still some public reluctance over the acceptance of such foods. This is surely only temporary and in the future food irradiation will certainly develop to be one of the great benefits for mankind and food preservation by irradiation will be of greatest importance to food products grown in developing countries.

What are the benefits of using irradiation? It can kill viable organisms and specific, non-spore forming, pathogenic micro-organisms such as

salmonella, or it can interfere with physiological processes, for instance it can be used for sprout inhibition of potatoes or for extending the shelf-life of fresh fruits. In short, irradiation of food is an alternative and in some cases the only method to :

- Eliminate many health risks in food;
- Enhance the quality of fresh produce;
- Improve the economy of food production and distribution;
- Reduce losses during storage or transportation; and
- Disinfest stored products such as grain, beans, dried fruit and dried fish.

Economically, one of the most important applications results in the extension of shelf-life, which is of utmost

value to countries with warm climates like so many of the developing countries. The same is true for the reduction of losses through storage which are very heavy in some areas. One can hardly believe it, but some countries report 40-50 percent post-harvest losses through infestation of staple foods like grains and yams. Most stored staple foods therefore are fumigated by chemicals when not irradiated.

Therefore, at last, all practical obstacles seem to have been removed which could hinder the fast development of this most useful application of radiation to mankind in the very near future.