MBTOC Update

Control of Dried Fruit Pests by Irradiation

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Method of Control: Ionizing radiation

This method uses electromagnetic radiation of energy levels sufficient to cause ionization of treated product without causing induced radioactivity. Sources of ionizing radiation for food irradiation are primarily the radioactive isotopes cobalt^{60} . While cesium^{137} and x-rays could be used, treatment by electron accelerators seems more likely. Irradiation is rapid, effective and leaves no product residue.

Crop/Commodity: Dried fruit: raisins, prunes, figs etc. Approximately 1.2 million metric tons of raisins and prunes are produced world-wide (UNEP, 1995). The United States produces the largest crop (USDA, 1994); significant quantities are also produced in Middle East and Mediterranean countries and China.

Target Pest(s):

- Indianmeal moth (*Plodia interpunctella*)
- Almond moth (*Cadra cautella*)
- Driedfruit beetle (*Carpophilus hemipterus*)
- Sawtoothed grain beetle (*Oryzaephilus surinamensis*)

Summary of Viability:

Ionizing radiation, either from isotope or machine generated sources, has been suggested as an alternative to chemical fumigation for various dried fruit and nut commodities. Both domestic applications to disinfest harvested product or control storage insects and quarantine treatments have been considered. Irradiation is technically efficacious and does not cause food quality problems.

There are, however, implementation issues. Some treated insects may survive for some time after treatment. To disinfest incoming raw product, the method must handle large amounts of product over a short harvest period. This problem could be resolved more economically through the use of accelerators, or with gamma contract irradiation facilities where sufficient other commodities are available to the facility during the off season. The possibility of having to retreat stored product, reinfested under current storage procedures, also poses logistical problems, and a significant barrier if the product has to be transported to the irradiator. Regulations in the United States do not allow reirradiation. Improvements in storage facilities or combining irradiation with preventative treatments may be necessary.

The current US-FDA approved maximum dose for disinfestation may be too low given current storage container size and product density. This problem is not an issue in other countries, or if the product is removed from bins and treated on a conveyor by electron beam accelerators. Major changes to existing processing facilities and product handling procedures, and the high initial capital cost of irradiators, make the treatment more costly than fumigation.

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Pest Efficacy and Consistency:

General mode of action and efficacy: Much work has been done on the general effects of ionizing radiation on insects (Tilton and Brower, 1983; Nation and Burditt, 1994). Because the high dosages necessary to cause immediate mortality in mature larvae, surviving pupae or adults may reduce product quality, since the criteria used for evaluation of efficacy is often based on reduction of product damage and preventing pest population growth. Relatively low doses (less than 100 Gy) have been found to be effective in preventing emergence of viable adults and preventing damage by feeding stages, although irradiated insects may survive for some time after treatment. Eggs are normally the least tolerant stage because undifferentiated, mitotically active tissues are most sensitive to ionizing radiation. The insect midgut includes undifferentiated epithelium and so is quite sensitive to radiation. For this reason, irradiated insects often stop feeding soon after treatment. Gonadal tissue is also sensitive, thus insects surviving radiation treatments at recommended treatment doses should be sterile. Efficacy of radiation for control of the major postharvest dried fruit pests was summarized in Rhodes (1986).

Viability Evaluation Factors:

a. Tested under full laboratory and field conditions including field tests in Article 5 countries

1. Additional research and field development needed (time and resources) for full evaluation of the control method.

Several developing countries market significant amounts of dried fruits. While statistics indicate the United States produces the largest share of the world's dried fruit, other countries, particularly Middle Eastern and Mediterranean countries produce several thousand tonnes of dried fruit, particularly figs (USDA, 1994). Much has been done on use of irradiation for food preservation in developing countries, including for dried fruit (Khan, 1993, Al-Bachir et al, 1993; Mahlous, 1993; Nketsia-Tabiri et al, 1993). Basic work on irradiation of dried fruit has been done, but for developing countries considering this method, pilot scale studies would be necessary to determine the cost and efficacy for their specific situation.

2. Tested in developing countries (identify countries)

Work has been done on irradiation of dates in Iraq (Ahmed, 1981) and Tunesia (Mahjoub, 1993). Dried apricots, dates, figs, and raisins have been irradiated in Pakistan (Khan 1993). Irradiation of dried fruits has been given clearance in China (Ahmed, 1993).

b. Efficacy with respect to crops and targeted pests

1. Pest efficacy and variability

Indianmeal moth: A major pest of postharvest dried fruit, this insect infests the product while it is in storage. Much work on the effect of radiation on this insect has been done, both as a possible disinfestation technique and in developing a sterile insect release program. Because Indianmeal moth has a wide host range and is cosmopolitan in distribution, this work includes a number of commodities. Generally, minimal dosages of 200 to 250 Gy have been suggested to prevent continued development of populations (Brower and Tilton, 1970, 1971, 1972), although to reduce female longevity a dose of 300 Gy may be more practical (Johnson and Vail, 1987). Such a dose will not prevent feeding of late instar larvae (Johnson and Vail, 1988) but does reduce product damage considerably (Johnson and Vail, 1989).

Of dried fruit commodities, raisins often undergo multiple fumigations due to the ability of Indianmeal moth to reinfest. Currently, US regulations regarding food irradiation do not allow for multiple treatments; this may not be an issue in other countries. Without a regulatory change in the United States, irradiation disinfestation of California dried fruit must be combined with other measures to prevent reinfestation. Temperatures $\leq 10°C$ prevent Indianmeal moth populations from developing (Johnson et al, 1995), but cold storage of dried fruit, particularly raisins, is not very common. Another method that may prevent reinfestation is modified atmosphere (Soderstrom et al 1984).

Almond moth: This moth is closely related to Indianmeal moth and is similar in its habits. Much of the work done on irradiation of dried fruits in developing countries targets this insect, where it is a major pest of dates and figs. Ahmed (1981) recommended 200 Gy as a dose for disinfesting dates, but because of prolonged survival after treatment suggested

300 Gy as more practical. Wahid et al (1987) found that a dose of 250 Gy was insufficient to prevent development of *C. cautella* populations in figs, but, when coupled with post-treatment storage at 20°C, population growth was prevented.

Driedfruit beetle: Little radiation work has been done on *Carpophilus* species. Papadopoulou (1964) used relatively high doses (1.0-1.5 kGy) to obtain immediate mortality in larvae and adult *C. hemipterus.* Brower et al (1973) prevented adult development from eggs and larvae of *C. dimidiatus* with doses as low as 50 Gy. Johnson (1987) found that *C. hemipterus* was controlled readily with radiation doses of 300 Gy.

Sawtoothed grain beetle: Early work identified *Oryzaephilus surinamensis* as more tolerant to irradiation than other stored product beetles, but Brower and Tilton (1970, 1972) disagreed, finding that a dose of 0.2 Gy prevented production of a second generation. Papadopoulou (1964) obtained quick control of both larvae and adults of *Oryzaephilus surinamensis* with 1.5 kGy.

2. Crop impact (yield/quality/storage life) and consistency

Radiation doses required for insect disinfestation of most dried fruits generally cause little or no quality damage. Taste panel studies on irradiated raisins and prunes conducted by Rhodes (1986) found that radiation doses of up to 900 Gy did not cause deterioration in quality, but, some results were inconsistent using accelerated storage techniques. Wahid et al (1987) found that a dose of 250 Gy had no significant effect on taste of various dried fruits even after 12 months of storage. They also found that radiation significantly reduced ascorbic acid levels in dried fruits, but noted that these changes were not necessarily of any nutritive significance. Auda and Al-Wandawi (1980) noted that very high radiation doses (1 to 10 kGy) caused some significant amino acid loses in dates, but also found that the loses were greatly reduced when the dates were stored at 0°C. On the other hand, dates are not usually a valuable source of ascorbic acid to most diets. Khan et al (1985) found that radiation generally had little effect on total acidity, color or sugar levels for several dried fruits, but noted that higher doses (0.5 and 1.0 kGy) adversely affected ascorbic acid levels.

3. Potential for methyl bromide emission reductions

If radiation were to be applied as an alternative for all methyl bromide uses throughout the handling and storage period, emissions from this application would be eliminated. Current practice in the United States indicates that much of the dried fruit industry already uses phosphine for many of its fumigations, therefore the use of irradiation would actually have a lesser impact on decreased methyl bromide use in the United States. Should radiation be used only for certain specific applications, such as packaged product or quarantine treatments, then methyl bromide emissions would be reduced proportionately.

c. Ease of application

1. Type and ease of application (logistics)

When a commodity is irradiated, it passes through an irradiator producing ionizing radiation either from an isotope source or machine generated (x-rays or electron beam). These types of irradiation equipment are quite different; the selection of which equipment should be used depends on how the fruit would be presented to the irradiator, in this case, in bulk or packaged.

In order to ensure the safety of workers, either type of equipment requires large amounts of shielding, and a way to move the commodity past the source. Irradiators require a certain level of training and understanding of technology. Given that about 180 commercial gamma irradiators and 450 electron beam accelerators currently operate in over 40 countries, including many developing countries, it should be assumed these operational and safety issues are manageable.

California processors of dried fruit normally use methyl bromide or phosphine to fumigate incoming product, with additional fumigations used at regular intervals of fruit in storage. The fruit arrives at the packing house in large bins, and most are kept in the same bins for storage. Although some of the bins are dumped out for inspection or processing before storage, most of the fruit is stored in bins until just before processing for sale. Given the minimum dose required for pest control (0.30 kGy) and the size of the storage bins normally used for dried fruit, if gamma irradiators were used the maximum dose would not fit under the current 1 kGy general maximum dose allowed for disinfestation in the United States. This situation would not be a problem in other countries. If using irradiation would require removing the fruit from its storage bins, or moving large volumes of the commodity through an irradiator at a remote location, changes in normal handling practices would be required, with the resulting impact on cost.

For this reason, electron beam accelerators might be a better irradiation equipment choice for unpackaged dried fruit. An accelerator could irradiate bulk fruit on a conveyor and keep the dose within current regulatory limits. Depending on packaging size, an accelerator might not, however, be able to effectively irradiate packaged fruit. If gamma irradiation equipment were to be used for packaged products or for quarantine treatments, or if gamma contract irradiators were used for the treatment as part of shipping proceedures, then changes in product handling practices might be minor. Depending on final package density, the dose maximum might be met within current regulatory limits for pacakged product with gamma facilities.

2. Safety (grower, worker, consumer)

The most immediate safety concern is for workers in the processing plant and/or irradiation facility. Irradiators are carefully designed to prevent accidental exposure of workers, operated by trained and licensed personnel, and inspected regularly. Medical product irradiators have been operated for years with excellent safety records.

The safety of irradiated foods has been researched for years. In 1980, the Joint Food and Agriculture Organization/International Atomic Energy /World Health Organization Expert Committee on the Wholesomeness of Irradiated Food recommended general approval of foods treated with doses of up to 10 kGy as unconditionally wholesome (Sapp, 1995). The committee based this recommendation on research involving microbiological, nutritional, and food chemistry studies, as well as long-term feeding studies. The U. S. Food and Drug Administration has determined that food irradiation is safe and has approved general use of up to 1 kGy in addition to certain applications at higher doses.

3. Special requirements and restrictions on use

Irradiators must be approved and licensed by the appropriate governmental agency, and must be inspected regularly. The Codex Alimentarius Commission General Standard for Irradiated Foods recommends that foods only be irradiated once, but allows for reirradiation under certain circumstances. Within the United States, food stuffs may not be irradiated more than once, and irradiated food must be clearly labeled. Should the method be used for quarantine purposes, the necessary clearances with the importing countries would be required.

4. Potential non-target impacts

Because any insect within packaged product is undesirable, all may be considered as target species. Since irradiation is a broad spectrum treatment, all pests infesting the product, and their natural enemies, will be controlled or killed, depending on their radiation sensitivity.

d. Relevance to climatic conditions, soil and cropping patterns

1. Geographical areas (acres and climatic conditions)

Climatic variation has no effect on efficacy or practicality. Lack of irradiation equipment in the geographic area where the product is produced continues to be a problem in many regions.

2. Soil types

Not applicable.

3. Cropping patterns, rotations, and/or land use

Not applicable.

e. Commercial availability

1. Registration potential/requirements/status

Food irradiation is a well established treatment method in many countries. Within the United States, commercial food irradiation is allowable under current regulations. On a limited basis, produce, poultry and spices have been irradiated and sold within the United States. U. S. Animal Plant Health Inspection Service has developed policies and guidelines for use of radiation as a quarantine treatment.

2. Commercial availability (materials/engineering)

Several companies build and maintain irradiation facilities. While both Co^{60} and Cs^{137} may be used in food irradiators, currently all facilities use Co^{60}. This material is produced by nuclear bombardment of Co^{59} in a nuclear reactor. Currently, the supply of Co^{60} meets the needs of planned irradiators.

3. Technology readily transferable

Currently there are about 450 electron beam irradiators and 180 gamma irradiators operated by industries throughout the world (Leemhorst, 1993). Used primarily for applications other than food processing, this demonstrates that the technology has already been transferred to commercial users.

4. Public/consumer acceptance

Public acceptance is possibly the most debated issue associated with this method. Within the United States, a small but vocal number of consumer advocacy and environmental groups have expressed concern over the issue of safety (Sapp, 1995). While safety concerns are unfounded, the fear of public outcry has caused the food industry to be reluctant to adopt radiation as a processing technique. Nevertheless, irradiated produce is currently sold in about 40 stores in the mid-western United States.

Besides this record of continued consumer purchases of irradiated foods consumer acceptance studies seem to indicate that the majority of consumers will eventually accept irradiated foods. Marcotte summarized work done on consumer attitudes and market studies on food irradiation. Market tests of irradiated foods worldwide have all been successful; in numerous consumer research studies, the attitudes of the majority of consumers are often positive (Marcotte, 1995). Consumers are more interested to know the price and quality of foods rather than the method of treatment. Other work indicates that acceptance increases when consumers are provided with information about specific advantages of the process (Bruhn, 1995). Thus, education of the public and legislative sectors concerning the safety of irradiated foods needs to be pursued vigorously.

f. Economic viability

1. Direct effects

Irradiation equipment capable of processing large volumes of commodities such as dried fruits is very capital intensive, with facility costs in the range of $4-7 million (Leemhorst, 1993). A recent note on the costs of treating dried fruit with accelerator equipment or X-rays indicates costs could vary between $1.40/ton if all California commodities were irradiated at one plant to $5-10/ton if 5-10 facilities were built (AECL Application Note, November 1996). Increased handling costs were not included in the analysis. Irradiation is more expensive than fumigation, but given the high value of dried fruit, irradiation costs might not be prohibitive.

An in-depth economic analysis of the use of radiation specifically for California raisins and prunes was done by Rhodes (1986). Although this report is 10 years old, and costs for irradiation have changed, the work is still relevant in that it compares costs of other alternative methods, and looks at the costs of combination treatments. Annual costs of combining radiation as a pre-shipment treatment with controlled atmosphere treatment of yard stacks of prunes and raisins, plus refrigeration during grading were estimated at $3.15-19.93 and $4.80-34.67 per ton. Costs varied with plant size, with per ton estimates being lower for larger plants. Cost for controlled atmosphere alone was $4.23-4.88 and $3.90-4.80 per ton handled annually for raisins and prunes repectively. Normal control costs using methyl bromide fumigation for both raisins and prunes was only $0.46-0.86 per ton handled annually, regardless of plant size.

Radiation processing and equipment has changed in the time since the above study. Additional analysis should be done on the basis of current commercial practices and fumigation costs, investigating options for irradiation at different stages of product storage and marketing and including scenarios for improved storage that prevents reinfestation of the product. Comparison of radiation costs with use of phosphine should be included.

2. Indirect effects

In the analysis by Rhodes (1986) for the control scenario where radiation was the sole method, the assumption was made that product could be reirradiated. US regulations do not allow retreatment, therefore without a regulatory change, dried fruit in the United States would only be irradiated one time. Because other control measures would be needed throughout storage, the cost estimates for radiation combined with modified atmosphere is more realistic. Another possible method to prevent reinfestation is refrigeration to temperatures below insect developmental thresholds (10°C). While some nuts are often stored at low temperatures to preserve product quality, this is not the case with most dried fruit.

While logistic, regulatory and economic problems, and the current use of phosphine reduce the likelihood of irradiation being used as the single substitute for methyl bromide in dried fruit, there are applications where the speed and penetration of the method may be useful. Where these applications are for limited points within the product flow, contract irradiators may be more economically acceptable (Leemhorst, 1993). These applications include quarantine treatments and disinfestation of finished packaged material.