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Full Length Research Paper

Phytosanitary irradiation in South Asia

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Irradiation has the potential to solve phytosanitary problems related to trade in South Asia. In general, it is the phytosanitary treatment most tolerated by fresh agricultural commodities. Irradiation technology is available in some countries of the region but is only used for phytosanitary purposes for mangoes in India exported to the United States of America since 2007. In this review, we analyze the literature on phytosanitary irradiation, present the protocol for exporting irradiated Indian mangoes, suggest possibilities for the technology in South Asia and discuss further research needs.

Key words: Radiation disinfestation, quarantine treatment, commodity quality, mango export.

INTRODUCTION

A phytosanitary treatment is an "official procedure for the killing, inactivation or removal of pests or for rendering pests infertile or for devitalization" (IPPC, 2009a). The terms quarantine or disinfestation is also often used in place of phytosanitary. The reason for using phytosanitary treatments is to prevent entry of invasive species while permitting trade, a key component of most economies. Commodities that have significant risk of carrying pests that cannot be managed as part of the pre-harvest production system may be acceptable to a market if they are subjected post-harvest to an approved phytosanitary treatment that ensures a level of quarantine security identified as necessary in a pest risk analysis. Methods available to disinfest a commodity of quarantine pests include cold storage, heating, ionizing radiation, modified atmosphere storage, fumigation, pesticide applications or a combination of these (Heather and Hallman, 2008).

Irradiation is different from all other commercially used treatments in one major way; it is the only technology that does not cause acute mortality at doses which confer quarantine security (IPPC, 2003). Radiation doses necessary to kill pests within a day are usually too high for most agricultural produce to tolerate. However, much lower doses (50 to 350 Gy) can prevent successful development or reproduction of the pest, which is equivalent to mortality in preventing an infestation. The objective of an irradiation phytosanitary treatment is usually to prevent adult development of egg and larval stages of holometabolous insects or where adults and pupae are present, to prevent reproduction. The dose required to prevent late pupae from emerging as adults is usually prohibitively high relative to the tolerance of most fresh agricultural commodities. Therefore, prevention of reproduction by emerging adults is the most reasonable objective of an irradiation treatment against insects that pupate in the commodity.

South Asia is a recognized geographical region that includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan and Sri Lanka. These countries are producers and exporters of large amounts of vegetables and fruits with a greater potential for expansion. For example, Bangladesh exports many fruits (mango, banana, lychee, pineapple, guava) and vegetables (egg plant, snake gourd, bottle gourd, yard long bean, French bean, cabbage, cauliflower, tomato, okra, green papaya) to diverse areas of the world. Cut flowers (marigold, tube rose) have considerable potential for export. Methyl bromide fumigation is the only phytosanitary measure used in many countries of the region. Because the fumigant is a significant strato-spheric ozone-depleting substance regulated by the Montreal protocol, alternatives are sought. Food irradiation technology is available in some countries of South Asia but is not used for phytosanitary purposes,

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except for mangoes from India exported to the United States of America (USA).

It makes economic sense for developing countries to export high unit-value produce to generate income when it does not interfere with the production and availability of food and other necessities required by the populace, equitable social development and environmental protection. Fair remuneration for the products and just payment to producers, pickers and packers is expected.

HISTORY OF PHYTOSANITARY IRRADIATION

Irradiation as a phytosanitary treatment was first studied against fruit flies by Koidsumi (1930) in Taiwan in the late 1920s. Twenty five years later, irradiation was further investigated as a quarantine treatment against fruit flies in Hawaii (Balock et al., 1956). However, irradiation was not tried commercially until 1986, when one load of mangoes was irradiated in Puerto Rico and shipped to Florida, USA, for sale (Hallman, 2001a). This was in response to the loss of ethylene dibromide as a phytosanitary fumigant for fruit flies. The next year, one load of papayas was shipped from Hawaii to California and in 1989, the first phytosanitary irradiation (PI) treatment (150 Gy against tephritidae in Hawaiian papayas) was published (Glosser, 1989), although, it was never commercially used. In 1996, the doses were raised to 210 to 250 Gy depending on the tephritid species because of uncertainties in the research supporting a dose of 150 Gy (Hallman, 1994). The first commercial irradiation facility exclusively for phytosanitary purposes was built in 1992 near Mulberry, Florida with the idea that, PI would replace ethylene dibromide fumigation as a phytosanitary treatment for grapefruit, although, in practice other alternatives were used (Heather and Hallman, 2008). The European and Mediterranean Plant Protection Organization (EPPO) approved irradiation doses for several species of arthropods on cut flowers in 1993 based on results from one study, yet the treatment has never been used (EPPO, 2010).

A shipment of 240 boxes of Hawaiian papayas to a cobalt 60 irradiation facility near Chicago, Illinois on April 5, 1995 marked a new era in PI (Moy and Wong, 2002). Since then, commercial use of PI has been continuous and increasing throughout the world. The use of PI to disinfest sweetpotato of *Cylas formicarius* in Florida in 2000, was the first time it was used specifically against an adult quarantine pest, which marked a significant regulatory advancement because live adults of a quarantine pest were accepted post-treatment (Hallman, 2001b). Commercial PI treatments until then were all against tephritids which failed to reach the adult stage after irradiation.

In late 2004, the first international shipment of fruit using PI was undertaken when Australian mangoes irradiated with 250 Gy dose of radiation were exported to New Zealand. In 2007, Indian mangoes were irradiated with a minimum of dose of 400 Gy and exported to the USA. Later, fruits irradiated in Vietnam, Thailand and Mexico (150 or 400 Gy) were exported to the USA. Other countries, like Pakistan (Arshad, 2010) are expressing interest in the use of this technology and further expansion is expected. Phytosanitary protocols for irradiation of wood with moderately high doses (1 to 10 kGy) have been developed (EPPO, 2009). Eight PI treatments were the first to be included in the IPPC treatment standard (IPPC, 2009b).

PHYTOSANITARY IRRADIATION RESEARCH IN SOUTH ASIA

Agriculture is one of the main economical endeavours of the countries in South Asia and the climate is dominated by the South Asian Monsoon. All countries of South Asia are potential areas for growing a wide variety of horticultural produce. These countries are already significant exporters of fruits such as mangoes, oranges, guavas and apples.

Irradiation technology is available in some of the countries of South Asia. Treatment of horticultural products with ionizing radiation is starting to become an accepted processing option for counties in the region wishing to meet phytosanitary requirements in international trade, and the objective of this review is to familiarize the region with this technology and summarize the literature on PI published in this area. The following are analyses of research done in South Asia regarding efficacy, commodity quality and effect of radiation on phytonutrients.

Efficacy of irradiation on pests

Studies have been done with three species of the important genus of tephritidae, *Bactrocera* (Reddy et al., 2010) and an assortment of other quarantine pests in the region. Other studies determined doses required to kill tephritid immatures in fruit (Hossain et al., 2006a,b; 2007). Usually, prevention of the emergence of normal-looking adults and not larval mortality is the objective of PI treatments of tephritids (IPPC, 2009b).

Haque and Ahmad (1967) demonstrated that, the dose required to prevent further development of *Bactrocera zonata* (Saunders) increased with increased development. The dose required to prevent pupariation of the egg and 1st, 2nd and 3rd instars in guava fruit was 0.185, 0.55, 0.77 and 1.25 kGy, respectively. Adult emergence of the most tolerant stage found in fruit, 3rd instar, was prevented with 55 Gy, the lowest dose attempted when a total of 776 larvae were irradiated. Bughio et al. (1972) studied *B. zonata* in glass vials with the open end covered by paper and found that, higher doses were required to prevent pupariation compared with the study of Haque and Ahmad (1967) in guava. Normally, fruit fly larvae irradiated *in vitro* are controlled with lower doses than those in fruit (Hallman and Thomas, 2010).

Thomas and Rahalkar (1975) found that, 150 Gy (the lowest dose used) prevented adult emergence when 3 to 4 day-old larvae of *Bactrocera cucurbitae* and *Bactrocera dorsalis* in slices of fruit were irradiated. Prasad and Sethi (1980) report very high rates of adult emergence (31.5 to 42.5%) of *B. dorsalis* from 3rd instar larvae irradiated *in vitro* at 100 to 200 Gy. Other studies do not support such high radiotolerance of any tephritid (Hallman, 1999). Akter et al. (2006) found that, 50 Gy applied to eggs and 1st instar *B. cucurbitae* and *B*. *dorsalis* infesting tomato, completely prevented adult emergence. Adult emergence of *B*. *dorsalis* 3rd instars inserted into banana was prevented with 150 but not 100 Gy (Akhter et al., 2008).

Shukla and Tandon (1985) irradiated mango seed weevils, *Sternochetus mangiferae,* in harvest-mature 'Alphonso' mangoes at 0.1, 0.2, 0.3, 0.4 and 0.5 kGy. Fruit were cut open after an unspecified period to examine the presence of dead or live insects. The 0.5 kGy dose killed immature stages but not adults. Again, mortality is generally not the goal of PI.

Majumder et al. (1996) found that, the mite *Oligonychus biharensis* laid eggs when irradiated at the highest dose tested, 0.5 kGy, although, eggs from females irradiated with ≥0.3 kGy did not hatch. A dose of 0.15 kGy prevented reproduction of pupae and adults of the thrips *Retithrips syriacus* (Bhuiya et al., 1999). Reproduction in eggs and larvae was stopped with 0.1 kGy. F_1 adult emergence was prevented with 50 Gy applied to parent generation adults (Majumder, 2001).

Qureshi et al. (1995) studied the effects of gamma radiation on one-day old adults of pink bollworm, *Pectinophora gossypiella* and their F_1 progeny and reported that, the fecundity, fertility and longevity were dose-dependent. Females were more susceptible to gamma radiation than males. A dose of 150 Gy is considered to induce sterility in F_1 adults.

A dose of 0.15 kGy absorbed by 6 day-old pupae of *Spilosoma obliqua* resulted in 22 to 27% hatch of F_1 eggs (Rahman et al., 2002). Higher doses were not tried. Mortality of the J2 stage of the nematode *Meloidogyne* spp. irradiated with 4 kGy was 34.2 ± 1.4% after 14 d compared with 6.5 ± 0.7% for the non-irradiated control (Bhuiya et al., 1999). The nematodes were not observed after 14 d to determine if they would survive to reproduce.

Because irradiation does not provide acute mortality of organisms at the doses used for phytosanitary treatments, to determine if an organism has been irradiated would be useful to inspectors finding live regulated pests in commodities that have been ostensibly irradiated. A distinct reduction in size of about 72 to 76% in the supraoesophageal ganglion along with the non-responsive proventriculus was observed when third instar *B. cucurbitae* and *B. dorsalis* larvae were treated with gamma radiation (Rahman et al., 1992). It was suggested that, the reduction in size of the ganglion could be used as a direct method for determining if larvae found in imported fruits or vegetables were irradiated. Although, techniques to identify irradiated organism are useful, commercial use of PI should not be dependent on the availability of these techniques because they usually require some time at ambient temperature before their effect becomes evident and they may not be consistent or totally reliable (Heather and Hallman, 2008).

General tolerance of fresh produce to irradiation.

The primary concern with PI is prevention of the distribution of invasive species. However, it is necessary that the host commodities tolerate the treatment. This research need not be strictly regulated as is efficacy research and should be observed if not done by commercial interests who know what is marketable.

Heather and Hallman (2008) note that, irradiation is the most broadly tolerated of the commercially applied phytosanitary treatments. Some fruits that have not been shipped before for lack of a treatment that they tolerated are being shipped using irradiation. Thomas (2001) reviewed the literature on irradiation of fruits and vegetables (much of it done in South Asia) regarding detrimental effects as well as beneficial effects on shelf life and pathogen control in fruits and vegetables. He concluded that, maturity at harvest, time delay between harvest and irradiation and physiological state of climacteric fruit can influence delay of ripening and increase shelf life. As a generalization with exceptions, fruits that are ready to eat when picked may tolerate irradiation, while those that must ripen after harvest (climacteric) may show some problems if picked too early. Control of fungal post-harvest pathogens via irradiation alone is not feasible, because the doses required to slow pathogens significantly are not tolerated by fruits and vegetables. However, combined with other techniques, such as low-oxygen storage or fungicides, irradiation has a role in slowing disease progression.

Much of the research on tolerance of fruits to irradiation done in South Asia was with the important fruit mango, although, studies on papaya, tomato, banana, orange, apple, pear and eggplant have also been done. Mangoes have been found to tolerate doses of several hundred gray, which is exemplified by the commercial shipment of mangoes from India irradiated with a minimum absorbed dose of 0.4 Gy. The maximum dose absorbed by some of these mangoes is at least 0.6 kGy demonstrating that, the fruit's tolerance of the treatment is quite acceptable. Several researchers found that, irradiation could prolong the shelf life of mangoes that were mature green when picked (Dharkar et al., 1966; Mumtaz et al., 1969; Dharkar and Sreenivasan 1972; Akhter et al., 2005).

Ahmad (1983) noted that, anthracnose rot in mangoes could be partially controlled by post-harvest irradiation.

Other fruits in the region that responded positively to shelf life extension via irradiation were eggplants (Akter et al., 2005), tomato (Huque and Khaleque, 1970; Dar et al., 2003) and pear (Sattar et al., 1971). The optimum doses for shelf life extension may be somewhat lower than those required for phytosanitary purposes.

Nutritional qualities of irradiated produce

The carbohydrates in fruits and vegetables are a good source of energy. However, the main importance of fruits and vegetables in human diet is as good sources of vitamin C (Ascorbic acid), pro-vitamin A caratenoids, flavonoids and anthocianins having antoxidant properties and minerals. The effect of irradiation on vitamin C and caratenoids in fruits has been studied in India (Thomas, 1986a, b; 1988). It should be emphasized that, the changes occurring as a consequence of irradiation can be due to either the direct effect of radiation on fruit chemical constituents or an indirect effect resulting from irradiation induced changes in the physiology and ripening of the fruits.

Most of the studies found in the literature from South Asia were on the effect of irradiation on ascorbic acid which is normally present in reduced form. Most of the results reported in the literature seem to suggest that, significant loss of phytonutrients do not occur in fruits irradiated at doses optimal for quarantine security (Ali et al., 1968; Thomas, 2001; Akhter et al., 2005; Akhter et al., 2008). For different cultivars of banana grown in south Asia, irradiation at levels optimal for delaying ripening (0.30 kGy) did not significantly affect ascorbic acid (Thomas et al., 1971; Akhter et al., 2008). Irradiation up to 250 Gy had no negative impact on the vitamin C content of banana, tomato or mango (Akter et al., 2005). The radiation doses up to 600 to 800 Gy did not affect sugar content (Akhter, 2003), vitamin C and protein content of banana (Ali et al., 1968).

The yellow and orange colors of fruits such as apricots, bananas, mangoes, papayas, peaches and plums are due to carotenoids. Because irradiation slows down the rate of ripening, a corresponding delay in the formation of carotenoids associated with ripening may occur in irradiated food (Thomas, 2001). Irradiation (0.25 kGy) of green preclimacteric 'Alphonso' mangoes had no significant effect on total carotenoids and vitamin C (Thomas, 1986b; Thomas, 2001). No significant changes in initial content of carotenoids or their formation during ripening have been observed as a result of irradiation of papayas (Thomas, 2001). In general, treating green mature fruits with relatively low doses (up to 0.75 kGy) has been found to delay the rate of ripening, but these fruits often fail to develop a uniform red coloration, thus, impairing their consumer appeal. Fruits irradiated in the breaker, pink or red ripe stages can tolerate higher radiation doses and these fruits develop the normal red coloration on ripening.

DOSIMETRY

Dosimetry is the basis for assurance that the quantification of the source and the treatment process have been done in accordance with phytosanitary requirements (Heather and Hallman, 2008). Dosimetry should document that, the required minimum dose was delivered to all parts of the consignment and the range of dosimeter response should cover the entire range of doses likely to be received by the product. To ensure absorbance of the minimum dose to the entire load, doses in excess of twice the minimum may be absorbed by some parts of the load.

Absorbed dose can be measured by a number of techniques and standards that are available (IAEA, 2001; ISO, 2009). Methods and results of routine dosimetry including range of absorbed doses compared with standard reference dosimetry should be reported in all PI research. Usually, the highest dose recorded in research confirming the efficacy of a treatment should be the lowest dose recommended for commercial application of the treatment.

EXPORT PROTOCOL FOR IRRADIATED INDIAN MANGOES

The mango is indigenous to India, which accounts for half of global production. The total mango growing area in India is 1.3 million hectares with an annual production of 12 million tonnes. India exports about 80 thousand tonnes. Approximately 30 mango cultivars, the main commercial ones being Alphonso, Kesar, Banganapally, Chausa, Dashehari and Totapuri, are grown throughout the tropical and subtropical regions of the country to an altitude of 1500 m. Nearly 30% of the mangoes grown in India are grown in the state of Andhra Pradesh (Biosecurity Australia, 2008).

India exports mangoes to the United Arab Emirates, Bangladesh, United Kingdom, Nepal, Canada, South Africa, the European Union and Saudi Arabia without a phytosanitary treatment. In 2007, India began exporting mangoes to the USA using irradiation at 400 Gy as a phytosanitary treatment and 157 MT of mangoes were shipped that year. In 2008, the volume nearly doubled to 275 MT while 130 MT were exported in 2009 (Das, 2010). In 2009, 14.5 MT were successfully exported by boat to the USA, using cold temperature and low oxygen conditions to prolong the shelf life of the irradiated fruit. In 2010 95 MT of irradiated mangoes were exported. The lower volume of export registered during the last couple of years is attributed to mango crop failures in the region

Table 1. Pest risk analysis of mangoes from India for export to the USA (USDA, 2006).

Pest	**Risk level**
Coleoptera: Curculionidae	
Sternochetus frigidus (F.)	Medium
S. mangiferae (F.)	Medium
Diptera: Tephritidae	
Bactrocera caryeae (Kapoor)	High
B. correcta (Bezzi)	High
B. cucurbitae (Coquillett)	High
B. diversa (Coquillett)	High
B. dorsalis (Hendel)	High
Bactrocera tau (Walker)	High
B. zonata (Saunders)	High
Hemiptera: Coccidae	
Ceroplastes rubens Maskell	High
Coccus viridis (Green)	Medium
Hemiptera: Diaspididae	
Aulacaspis tubercularis (Newstead)	Low
Parlatoria crypta Mckenzie	Low
Pseudaonidia trilobitiformis (Green)	Low
Fungi	
M. mangiferae Higorami & Sharma	Medium
C. mangiferae Died,	Medium
Actinodochium jenkinsii Uppal, Patel & Kamat	Low
Hendersonia creberrima Syd. Syd. & Butler	Low
Phomopsis mangiferae Ahmad apud Petrak & Ahmad	Low
Bacterium	
X. campestris pv. *mangiferaeindicae* (Patel et al., 1948; Robbs et al., 1974)	Medium

in 2009 and problems in airlifting due to volcanic ash over Europe in 2010. In any case, all of these annual exports are far below the target of 1500 MT envisioned when exports of Indians mangoes to the US began a few years ago (Basu, 2009). The reasons are two-fold; (1) lack of enough irradiation facilities; (2) high cost of air shipment with difficulty in achieving effective low-cost sea shipment. Both of these obstacles may be overcome by proposals to set up new facilities in Navi Mumbai and Ahmedabad combined with improved sea shipping techniques (Das, 2010). Sea shipment should lower mango retail costs from a few dollars per mango to much closer to those of mangoes from Latin America, which may cost less than one dollar apiece.

A pest risk assessment was conducted when India requested permission to export mangoes to the USA. A list of mango pests in India was prepared from scientific publications, information submitted by the Government of India and United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) records of intercepted pests. The pest risk assessment identified 14 quarantine insect pests, five fungi and one bacterium (Table 1) likely to follow the pathway on fresh mango fruit from India under the standard post-harvest practices in Indian mango production (USDA, 2006).

India proposed to treat mangoes with the APHIS-approved generic irradiation treatment of 400 Gy for all insects except pupae and adults of Lepidoptera. This dose provides a margin of security as Heather and Hallman (2008) note that, 250 might be adequate for all insects studied so far except pupae and adults of Lepidoptera. Other measures would be used to mitigate risks posed by the fungi and bacterium.

USDA (2010a) requires that mango fruit from India be imported into the continental United States under the following conditions: (A) The mangoes must be treated in India with a minimum absorbed dose of 400 Gy for plant pests of the class Insecta, except pupae and adults of the order Lepidoptera; (B) The risks presented by *Cytosphaera mangiferae* and *Macrophoma mangiferae* must be addressed in one of the following ways; (1) The mangoes are treated with a broad-spectrum post-harvest fungicidal dip; or (2) The orchard of origin is inspected prior to the beginning of harvest as determined by the mutual agreement between APHIS and the national plant protection organization (NPPO) of India and the orchard is found free of *C. mangiferae* and *M. mangiferae;* or (3) The orchard of origin is treated with a broad-spectrum fungicide during the growing season and is inspected prior to the beginning of harvest as determined by the mutual agreement between APHIS and the NPPO of India and the fruit found free of *C. mangiferae* and *M. mangiferae.* (C) Each consignment of mangoes must be inspected jointly by APHIS and the NPPO of India as part of the required preclearance inspection activities at a time and in a manner determined by mutual agreement between APHIS and the NPPO of India; (D) The risks presented by *C. mangiferae, M. mangiferae* and *Xanthomonas campestris* pv. *mangiferaeindicae* must be addressed by inspection during preclearance activities;

(E) Each consignment of fruit must be inspected jointly by APHIS and the NPPO of India and accompanied by a phytosanitary certificate issued by the NPPO of India certifying that, the fruit received the required irradiation treatment. The phytosanitary certificate must also bear two additional declarations confirming that: (1) The mangoes were subjected to one of the pre- or post-harvest mitigation options described in (b) earlier and (2) The mangoes were inspected during preclearance activities and found free of *C. mangiferae, M. mangiferae* and *X. campestris* pv. *mangiferaeindicae.* (F) The mangoes may be imported in commercial consignments only.

The Agricultural and Processed Food Products Export Development Authority (APEDA) within the Ministry of Commerce of the Government of India provides guidance for mango growers to facilitate shipment of their fruit to the USA (APEDA, 2007). Importers must secure the USDA-Import permit at least 30 days in advance of arrival of the irradiated mangoes at the scheduled port of entry to facilitate the timely transmission of the permits to inspectors at that port. The mangoes must be dipped in a solution of prochloraz or hypochlorite (500 ppm) in 52°C water for 3 to 4 min.

At the orchard level, registered orchards will adopt good agricultural practices for management of mango orchards established by APEDA and maintain records of all operations. A pre-harvest orchard survey will be carried out by the registered packinghouse to assess fruit production and pest incidence. The survey will involve fruit sampling to determine the ideal stage of harvest of fruits for post-harvest processing. If any pests are noticed during the survey they will be referred to the NPPO for identification and mitigation measures, if any.

Mangoes for export by sea carrier will be harvested when the fruits are at the hard mature stage and for air shipments when fully mature. Only healthy, unblemished fruits will be harvested with sufficient length of stem with the help of specially designed knives which have a long stick horizontally fitted with a curved blade at 45°angle and smooth net pouch for holding the fruit. The harvested fruits will be kept in clean and disinfected ventilated plastic crates with clean polyurethrene foam cushions and stacked in the shade until transport to a packinghouse. Each crate of fruits will be labeled with the name of the orchard, its locality, the production unit code, variety, date and time of harvesting. Care should be taken to avoid contamination of fruits and crates with the soil by keeping them on a clean plastic or paper sheet on the ground.

Immature, overripe or damaged fruits will be placed into separate crates distinctly marked ‘not for export’ and subsequently buried at least 15 cm under soil in a pit at the orchard. The workers will adopt hygienic practices while handling the fruits during harvesting, segregating and placing fruits in the plastic crates in the orchards. The harvested fruits will be transported from the orchards to the packinghouse in clean and hygienic transport vehicles. No non-programme fruits will be transported with the programme fruits.

Packinghouses involved with the export of mangoes to the USA will be registered with APEDA. The registered packinghouses will abide by the irradiation operational work plan and its addenda established between India and USA. The registered packinghouses will have documented standard operating procedures (SPO) that are approved by the NPPO which describes in detail all the process related to de-sapping, cleaning, hot-water fungicidal dipping, grading, hygienic handling, packing and labeling of mangoes.

Prior to processing, the packinghouses will verify that fruits received at the facility are labeled from a registered orchard. Mangoes from non-registered orchards will be distinctly marked ‘not for export to the USA’ and physically separated from the registered orchard lots. No other fruits or vegetables besides mangoes will be processed while processing mangoes for export to the USA at the facility. Damaged, diseased and over-ripe fruits will be physically segregated into separate crates marked ‘rejected’ and removed for disposal by burying under 15 cm of soil.

Water for washing fruits will be of potable quality and mixed with a neutral detergent such as teepol, sandovit or indtron at 0.1% concentration. The processing lines will be physically inspected at the end of each process load to remove all debris in the conveyor belt and fruit scrubbing brushes, rinsed and washed with clean water containing mild soap or detergent such as teepol to remove any left over organic matter followed by mild scrubbing and a second rinsing with clean water. The processing lines will be cleaned before program fruit is packed and/or after non-program fruit is packed. Fruits will be dipped in a 200 ppm sodium hypo chloride solution at 52°C for 3 to 4 min to control fungi.

Each individual fruit will be wrapped in a clean, white, soft, expandable netted-type polystyrene sleeve to prevent bruising before packing in insect-proof boxes of dimensions 37 x 27.5 x 9 cm made of food-grade material. If ventilated boxes are used, the openings should be covered with screen of a minimum of 12 meshes per centimeter and the edges of the boxes should be sealed with tape to prevent entry of pests. Each box must be either preprinted or affixed with a treatment label approved by APHIS. The label should be placed on left side of the box indicating production unit code number, packinghouse code number, date of packing and lot number.

Before loading the boxes of processed mangoes in a conveyance for the irradiation facility, the conveyance must be inspected to ensure it is clean and free of contaminating (hitch-hiking) pests. At the completion of loading, the doors of the conveyance will be closed and locked and a suitable seal must be affixed to ensure the integrity of processed consignment.

The treatment facility must be approved and certified by APHIS to be authorized to apply PI treatments. The facility will abide by the irradiation operational work plan (IOWP) between India and USA and its addenda and only accept mango fruits from registered packinghouses in insect-proof boxes. Documentation ensures that the processed mangoes are only from registered orchards and can be traced back to them. The facility must develop and document SOP that address irradiation of commodities for phytosanitary purposes. The SOP will be reviewed and approved by the NPPO of India before applying for certification by APHIS. The treatment facility will enter into a compliance agreement with the Indian NPPO and APHIS in addition to a cooperative agreement and the IOWP.

The NPPO of India and the inspector of APHIS will jointly carry out preclearance inspection of mangoes received at the treatment facility prior to treatment to confirm that the lot is free from non-target quarantine pests and meets the requirements for the target pests listed in Addendum 2 to the IOWP. For this purpose a systemic sampling of lots as specified in Addendum 2 of IOWP will be carried out using a random number table. The sample size shall include: Lot size of 1 to 4 cartons, inspect all cartons; cut a minimum of 10 fruit; lot size of 5 to 99 cartons, inspect 5 cartons; cut a minimum of 20 fruit; lot size of 100 to 240 cartons, inspect 7 cartons; cut a minimum of 30 fruit; lot size of 241 or more cartons, inspect 14 cartons; cut a minimum of 30 fruit.

The exterior of selected cartons and fruits will be thoroughly inspected for target and non-target quarantine pests. Thereafter, a minimum number of fruits as specified earlier will be cut and examined for internal feeders. In the event of interception of live pests during inspection the following actions will be undertaken: (1) If any targeted pests such as fruit flies (Tephritidae), one or more detected, the entire lot will be rejected for export; (2) if any target pests such as internal feeders (weevils), one or more detected, the lots will be cleared for treatment and certified under notification to APHIS IS Area Director; (3) if any target external pests are detected in one or more, the lots will be cleared for treatment and certified. However, the APHIS International Services Area Director will be notified; (4) if any non-target quarantine pests (e.g., adults or pupae of Lepidoptera, fungal or bacterial pathogens, snails or mites), one or more are detected the entire lot will be rejected.

The mangoes will be irradiated with a minimum absorbed dosage of 400 Gy at the approved and certified irradiation treatment facility. The source and equipment must be capable of safely and effectively irradiating the commodities to the specifications that are required for the target pests.

Dose mapping and routine dosimetry will be done with ceric-cerous sulphate dosimeters with a potentiometer read-out system calibrated by using Fricke reference standard dosimetry with a spectrometer read-out system. If the absorbed doses fall outside the acceptable limits, the treatment facility will enter the results in the treatment register as “failed” and mark the product “rejected” on the cartons. The particulars of rejected product will be entered in the product log book and the rejected product immediately removed to prevent their shipment to the USA. The treatment facility will notify the failure to the NPPO of India and APHIS and further investigate the cause of treatment failure and take preventive measures to prevent like failures in the future.

If the results of dosimetry reveal a successful treatment the particulars of the treatment (Treatment Facility Code, Treatment Identification Number and date of treatment) must be marked on the right-hand side of the preprinted or affixed ‘radura’ label on every box as approved by APHIS and a treatment certificate will be issued for each treated lot. The treated lots will be safeguarded in a secured holding area separated from untreated lots with an insect-proof screened partition to prevent any reinfestation of treated commodities.

After verification of treatment the NPPO of India will issue a phytosanitary certificate with two declarations that; (1) The mangoes were subjected to post-harvest mitigation options described earlier; and (2) the mangoes were inspected during pre-clearance activities and found free of *C. mangiferae, M. mangiferae* and *X. campestris* pv*. Mangiferae indicae*. The particulars of treatment will be noted on the phytosanitary certificate. The APHIS import permit and treatment certificate numbers will be marked on each phytosanitary certificate. The treated shipments of mangoes will be certified for export by the inspector of APHIS after verifying that all treatment requirements and post-treatment security requirements have been met and maintained. The PPQ Form 203 (Foreign Site Certificate of Inspection and/or Treatment) will be completed, signed and issued by the inspector of APHIS and the original copy will accompany the shipment to the USA.

For transport to the airport the empty trucks will be carefully inspected jointly by the NPPO of India and

Table 2. Pest risk analysis of mangoes from Pakistan for export to the USA (USDA, 2010b).

Pest	Risk level
Diptera:Tephritidae	
B. correcta (Bezzi)	High
B. cucurbitae (Coquillett)	High
B. dorsalis (Hendel)	High
B. zonata (Saunders)	High
Hemiptera: Coccidae	
C. discrepans (Green)	Medium
C. viridis (Green)	Medium
Hemiptera: Diaspididae	
A. tubercularis (Newstead)	Medium
P. blanchardi (Targioni-Tozzetti)	Medium
P. crypta Mckenzie	Medium
Pseudaonidia trilobitiformis (Green)	Medium
Fungus	
Phomopsis mangiferae Ahmad apud Petr. & Ahmad	Low
Bacterium	
X. campestris pv. *mangiferaeindicae* (Patel et al., 1948 ; Robbs et al., 1974)	Medium

APHIS to ensure freedom from pests and plant debris prior to loading with irradiated mangoes. If any pests are found, the empty truck should be thoroughly treated with a suitable insecticide followed by a second inspection to ensure that the pests are effectively controlled. While loading, the space between the doors of the truck and loading area of the facility will be covered by insect-proof screen to prevent entry of hitchhiking pests. At the end of the loading the doors of the truck are secured by a lock and seal.

Upon arrival at the perishable air cargo complex at Mumbai Airport the irradiated product is x-rayed for security and then, loaded into LD-3 or air containers which are immediately sealed by customs and held in a secure area until loaded on the aircraft. If an air shipment is delayed or the flight cancelled the irradiated product will be safeguarded in a secure cold storage room at the airport until in can be shipped.

Research supporting the radiation processing of fruit was initiated at the Bhabha Atomic Research Centre 40 years ago (38) and has prepared the country to export good quality irradiated mangoes today (Sharma, 2008). As further research, India should determine if the risk associated with the five scale insects and two weevils (Table 2) could be adequately mitigated with doses <400 Gy. A lower dose could result in savings in treatment costs and reduce the risk of radiation damage to mangoes. Heather and Hallman (2008) noted that, doses for weevils and scales studied so far are 80 to 150 and 150 to 250 Gy, respectively. The treatment of 400 Gy or even as low as 250 Gy might control mango pulp weevil, mango seed weevil, fruit flies, red-banded caterpillar and mealybugs pests of Indian mangoes that are of quarantine concern to (Biosecurity Australia, 2008).

POSSIBILITIES FOR OTHER EXPORTS FROM THE REGION USING PHYTOSANITARY IRRADIATION

Bangladesh is working for the promotion of irradiation phytosanitary treatment to overcome trade barriers and to manage the invasive arthropod species of the country. Although, at this moment there is no provision of irradiation technology as an alternative quarantine treatment in Bangladesh the existing “Destructive Insects and Pest Rules (Plant Quarantine) -1966 amended in 1989 of the Plant Protection Wing, Department of Agricultural Extension, Ministry of Agriculture, Government of Bangladesh would allow any scientific treatment under “disinfestation or disinfection” definition of the rules. Therefore, plant quarantine would allow fresh agricultural commodity from abroad if those are irradiated for quarantine purposes. The plant quarantine authority has agreed to include irradiation as an alternative quarantine treatment method in their forthcoming amendment of the rules.

Pakistan currently produces a diversity of fruits and vegetables which are in global demand. Pakistan currently exports fruits and vegetables to Europe, the Middle East, the Far East, India and Sri Lanka. Mangoes, kinows, apples, dates, peanuts, oranges and guavas are main fruit exports, while potatoes, onions, garlic, mushrooms and chilies are the major vegetable exports. Pakistan is heavily reliant on one single market for each fresh produce item exported. For example, Sri Lanka is the only market for Pakistani apples (Anjum and Awan, 2006). Despite good quality of Pakistani mangoes, export is much less than other mango producing countries with insignificant shares of the markets in the European Union and the Americans (Sheikh and Bashir, 2003). There are many factors responsible for its limited export. Due to increased concerns on sanitary requirements in developed countries, Pakistani mango export is facing quarantine requirement particularly from USA and similarly, some European destinations could not be exported with mangoes due to short shelf life of the fruit. This is especially relevant in view of the fact that USA is the largest import market of mangoes. During the year 2005, the USA imported 37% of the total global exports of >530,000 tons of mangoes. A 5% share of this market can provide a big boost to exports of any country producing mangoes.

After increased phytosanitary issues and quarantine requirements by developed countries, all developing countries which are producing mangoes were seeking for the technology that can help them meet quarantine requirements as well as add to the existing shelf life of the fruit. To meet international quarantine requirements food irradiation provided a breakthrough. Pakistan signed an agreement with USDA in 2007 and irradiation is approved as a phytosanitary measure for export of mangoes between USDA and Ministry of Food, Agriculture and Livestock (MINFAL). The Pakistan Plant Quarantine Act has recently been reviewed and updated to meet the requirements of SPS agreements on agriculture and in 2010, the USA approved PI for Pakistani mangoes (USDA, 2010b).

RECOMMENDED FUTURE RESEARCH

South Asia has contributed to the worldwide bank of knowledge on PI and is using the technology in one instance (Indian mangoes to the US). Future research should concentrate on an international effort to develop more PI treatments and utilize the technology where feasible. India is part of a new 5-year cooperative research project funded by the IAEA to develop more generic PI treatments. The Indian group will work on mealybugs (Pseudococcidae) and together with results from other countries from outside the region (Indonesia, South Africa and Vietnam) may develop a generic treatment for that important group of quarantine pests. Other countries in the South Asian region are encouraged to contribute to the international effort by developing PI treatments for other important groups such as various families in the Lepidoptera, weevils, scale insects and mites.

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