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Phytosanitary irradiation and fresh fruit quality: cultivar and maturity effects

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Purpose of the review: Irradiation is an effective quarantine treatment for global trade of fresh produce. The focus of this review is to examine the impact of various crop cultivars and maturity stages on the tolerance of fresh fruits to irradiation for the purposes of quarantine security.
Main findings: Tolerance thresholds for irradiated fruit are lacking for a large number of modern cultivars. Cultivar differences in radiation sensitivity are most apparent for bananas, citrus, peaches and mangoes. Some of the variation attributed to cultivars may be maturity effects. For climacteric fruit, maturity stage at the time of treatment impacts the quality and shelf-life of irradiated product. Irradiation applied at the preclimacteric stage may delay ripening, but higher doses can injure less mature fruit. Overall, many fruit types tolerate doses below 500-600 Gy.
Directions for future research: The major cultivars in current production should be evaluated at varying stages of maturity following irradiation at the range of doses (> 1000 Gy) approved for quarantine treatment. Respiration and ethylene production rates should be monitored for individual varieties of climacteric fruits, before and after irradiation, to properly gauge the physiological maturity of the fruits and the impact of radiation on fruit ripening. Simulated shipping and ripening conditions following treatment at commercial radiation facilities would provide a clear assessment of the potential for successful export of irradiated fresh fruit.

Keywords: irradiation; fruits; maturity; postharvest; quality; quarantine treatment

Introduction

Many horticultural commodities must receive an approved quarantine treatment before export to reduce the risk of introducing insect pests to new areas. Irradiation is an effective quarantine treatment for fresh produce traded internationally. The United States Animal and Plant Health Inspection Service (APHIS) regulates the use of irradiation to meet quarantine requirements of commodities entering the U.S., as well as interstate movement of crops from Hawaii, Puerto Rico and the U.S. Virgin Islands into the mainland. APHIS has approved the use of generic radiation treatments for quarantine disinfestation of fresh fruits and vegetables. The regulation is a minimum 150 Gy dose for tephritid fruit flies and 400 Gy for all insects except pupa and adult Lepidoptera [1].

In practice, fresh produce treated with a minimum absorbed dose of 400 Gy may receive maximum doses of 600-800 Gy irradiation, because dose uniformity ratios at commercial facilities are typically 1.5-2.0. Quality may be reduced for many horticultural crops at 600-800 Gy radiation. Also, maximum doses must remain below 1000 Gy, to meet regulations by the United States Food and Drug Administration (FDA) for the preservation and disinfestation of fresh fruits and vegetables with irradiation [2]. Within these dosage boundaries, crop sensitivities to radiation need to be determined to ensure quality while providing quarantine security. Several fresh commodities tolerate the doses required for quarantine treatment, but variations in crop quality at harvest can lead to visible injury from irradiation. Surface browning, pitting, or scalding are typical external symptoms of irradiation injury. Internal damage manifests as advanced softening or discoloration [3].

Multiple preharvest factors (cultivar, maturity, temperature, disease pressure) and postharvest conditions can alter a commodity's tolerance to irradiation stress. For some crops, these factors may interact with dose to decrease the physical and sensory qualities of fresh produce [3**, 4*, 5*, 6]. In particular, cultivar, maturity, and dose must be carefully managed to achieve a beneficial effect from radiation as a quarantine treatment. This may be difficult to achieve for climacteric fruit, where the impact of cultivar on radiation tolerance may be related to slight differences in physiological maturity before treatment. Climacteric fruit (apple, banana, papaya, mango, peach) exhibit a large increase in respiration and ethylene rates coincident with ripening. For many of these fruit, preclimacteric respiration and ethylene rates may increase shortly after irradiation stress, followed by a later decrease in climacteric peaks. Irradiation often delays ripening and extends shelf-life if the treatment is applied during the preclimacteric stage [7**, 8], but these fruit can develop radiation injury as dose increases. In contrast, fruit already in the climacteric stage typically tolerate higher doses than less mature fruit, but with shorter shelf-life [7**].

Distinguishing a true cultivar effect from a maturity effect for radiation tolerance would require multiple trials comparing cultivars at similar stages of maturity to a range of doses. Reports for these experiments are limited. Also, variability among and within cultivars can be high at the time of fruit harvest, between growing seasons, and among production regions. Nevertheless, the importance of cultivar and maturity on irradiated fruit quality needs clarification for consistent, successful use of the technology, and some generalities exist in the litera-

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ture, within constraints. The focus of this review is to examine the impact of various crop cultivars and maturity stages on the tolerance of fresh fruits to irradiation for the purposes of quarantine security.

Subtropical and tropical fruits

Banana

Most banana irradiation research has focused on extending the shelf-life of 'Cavendish' fruit (*Musa* sp. group AAA) and plantains (*Musa* sp. group AAB), for which the optimum dose was 150-300 Gy [8, 9]. When radiation injury occurs it generally appears as skin browning or a grayish scald, and has been attributed to an increase in polyphenol oxidase activity in the peel [10]. Irradiation at 500 Gy caused tissue damage, peel discoloration and softening of plantain cultivars, Agbagba, Obino L'ewai, and Cardaba when treated at the full three-quarter maturity stage [9]. Preclimacteric 'Cavendish' and 'Dwarf Cavendish' bananas also developed skin browning at doses greater than 400 to 500 Gy, although flavor was not impacted with treatment at 600 Gy [8, 11, 12].

Early studies with 'Brazilian' bananas found little or no differences in the organoleptic qualities of fruit when treated with 1000 Gy at three ripening stages (mature-green, half-color and full-color) [13]. However for 'Dwarf Brazilian' bananas (*Musa* sp. group AAB), fruit maturity at harvest impacted tolerance to quarantine irradiation treatment. The proximal and distal hands from winter- and summer-harvested banana bunches responded differently to 600-800 Gy treatment. Bananas from distal hands (less mature) treated with 800 Gy irradiation developed peel injury when harvested in either the winter or summer months. Distal hands from summer-harvested bunches also were damaged at 600 Gy. Peel injury was not observed for more mature fruit from proximal hands [14]. Differences in fruit maturity may impact the ability to repair oxidative damage from irradiation stress. For proximal fruit, respiration and ethylene rates increased during the preclimacteric stage after treatment, indicating a metabolic increase in energy demand to repair radiation-damaged cells [14]. For less mature distal fruit, the physiological response may not be sufficient to avoid membrane damage after irradiation.

Citrus

Among subtropical fruit, citrus is relatively sensitive to irradiation and the response to treatment is highly variable and dependent on species, hybrid, and cultivar. Radiation injury can occur at low doses used for quarantine treatment and typically manifests as peel pitting and softening. For example, oranges (*Citrus sinensis*, cv. Mosambi) had peel injury, softening, and less vitamin C content after exposure to doses ≥ 250 Gy, whereas mandarins (*Citrus reticulata*, cv. Nagpur) tolerated doses up to 1000 Gy [4*]. 'Lane Late' navel oranges had increased surface pitting, weight loss and visual damage after treatment with 400 and 600 Gy radiation, but color, phenolics, and vitamin C contents were unaffected [15]. Other orange cultivars ('Ambersweet' and 'Valencia') tolerated 500-600 Gy irradiation, but 'Hamlin', 'Navel', and 'Pineapple' cultivars were injured at 150 Gy [5*]. Likewise, mandarin hybrids 'Minneola' and 'Murcott' showed tolerance at 500-600 Gy, but peel pitting occurred for 'Fallglo', 'Sunburst' and 'Temple' cultivars at 150 Gy [5*]. The popular 'Clementine' mandarins generally retained visual, sensory and nutritional quality when treated with 300 Gy radiation, although concentrations of ethanol and acetaldehyde increased with doses ≥ 400 Gy [16, 17, 18]. For grapefruit, maturity influenced radiation tolerance and phytochemical contents. Doses from 400 to 700 Gy reduced the quality of early-season stored 'Rio Red' grapefruit, but not late-season fruit [19]. Also, a higher dose (200 Gy) was needed to enhance grapefruit phytochemicals for early-season fruit compared to late-season fruit (70 Gy) [19].

Lychee, longan, rambutan

The exotic tropical fruit of the Sapindaceae family (lychee, longan and rambutan) require a minimum absorbed dose of 400 Gy for quarantine treatment of insects other than fruit flies. Lychee (*Litchi chinensis*, cv. Kaimana) and longan (*Dimocarpus longan*, 'Chompoo' and 'Biew Kiew') generally tolerate this dose without loss of fruit quality, and irradiation at 400 Gy is superior to hot-water immersion as a quarantine treatment for these fruit [20, 21]. Rambutan (*Nephelium lappaceum*) cultivars R134 and R167 tolerated 250 Gy radiation and exhibited better quality than fruit treated with hot-forced air [22]. At higher doses (750 Gy), 'R167' rambutans were softer and had off-flavors when compared to non-irradiated fruit [23].

Mango

In general, mangoes (*Mangifera indica*) are fairly tolerant of radiation treatment, although the diversity of cultivars exhibit varying degrees of sensitivity. Some cultivars ripen abnormally after irradiation (> 1000 Gy), so that the peel and flesh lack full color. This is most likely to occur in less mature fruits. Irradiation (250 to 750 Gy) tends to delay fruit ripening when fully mature-green, preclimacteric mangoes are treated [24]. Riper fruit can tolerate higher doses. 'Tommy Atkins' mangoes retained physical and sensory quality when exposed to ≤ 1000 Gy radiation and stored 21 days at 12 °C [25], but higher doses (≥ 1500) produced fruit softening, peel scald, and flesh pitting of 'Tommy Atkins' fruit [25, 26].

The nutritional compositions of 'Kent', 'Zill', 'Haden', and 'Peach' mangoes were similar for non-irradiated and irradiated (750 Gy) fruit treated at the mature-green stage [27]. 'Haden' mangoes treated at the preclimacteric stage with 1500 Gy radiation also retained organoleptic qualities [13].'Tommy Atkins' mangoes treated with ≤ 1500 Gy had greater sugars, antioxidant activity and phenolic concentrations, but lower ascorbic acid content than non-radiated fruit [28].

Papaya

Papayas (*Carica papaya*) have been successfully exported following quarantine irradiation treatment for over 15 years. However as a climacteric fruit, tolerance to radiation is mediated by maturity stage at treatment. A limited number of papaya cultivars had been evaluated for radiation tolerance, and almost all are of the 'Solo' lineage. Therefore, cultivar effects are secondary to maturity factors for irradiated papayas. Irradiated 'Solo' papayas at the mature-green to quarter-ripe stage retained nutritional and sensory quality and tolerated 1000 Gy before surface scald appeared [29]. Fruit at more advanced stages of ripeness tolerated doses between 1000 and 1500 Gy, depending on variety.

Radiation can also slow papaya ripening and softening. When 'Rainbow' papayas were treated at 750 Gy they had similar ascorbic acid, carotenoid, and soluble solids content as control fruit, but were slightly firmer with a less intense aroma, flavor and color indicative of delayed ripening [23]. 'Sunset' papayas treated at the 25-30% yellow stage with 500 to 1500 Gy radiation remained firmer at full-ripeness than untreated fruit [30]. Papayas treated at the 30% yellow stage with 250 Gy irradiation also ripened and softened at a slower rate than control fruit [31*]. However, fruit at 10-20% yellow stage softened immediately after irradiation as dose increased to 1500 Gy [30]. Papayas with < 25% yellow color developed skin scald when stored at 10 °C immediately after radiation (250 Gy), but injury was prevented by delaying storage by 12 hours [31*].

Temperate fruits

Apple

Apples (*Malus domestica*) are one of the largest fresh fruit crops traded internationally. As such, the potential for irradiation as a quarantine treatment is considerable. Apples are moderately tolerant to irradiation stress relative to other fruit crops, but cultivars have varying dose responses. In general, radiation advances apple fruit softening, lowers acidity and impacts volatile production, but does not affect sugar content [32*, 33, 34, 35]. 'Gala' and 'Red Delicious' apples decreased in firmness and acidity as dose increased to 800-1000 Gy [32*, 34, 36]. 'Gala' fruit also developed internal browning at doses ≥ 880 Gy, but these effects were minimal in apples stored at 0 °C after irradiation [32*]. 'Red Delicious' apples lost firmness at 200 to 400 Gy when late harvest, mature fruit (> 90% starch degradation) were treated [36]. 'Fuji' apples softened at doses > 600 Gy and 'Granny Smith' fruit at doses > 150 Gy [37]. For 'Fuji' apples, the volatile yield and major flavor compounds of irradiated (≤ 1000 Gy) fruit were similar to control fruit [38]. In contrast, volatile ester production was irreversibly impaired in 'Red Delicious' apples radiated with ≥ 880 Gy, although fruit treated with 440 Gy recovered the capacity to generate volatiles during storage [33]. Overall, most of the main cultivars ('Red Delicious', 'Gala', 'Fuji') met quality and export standards after irradiation at doses < 800 Gy and storage at 0-1 °C [32*, 34, 36].

Blueberry

Three species of blueberries are grown in the U.S. for commercial markets: highbush (*Vaccinium corymbosum*), lowbush (*Vaccinium angustifolium*), and rabbiteye (*Vaccinium ashei*) blueberries. The highbush blueberry is the major species in commerce, and more than 50 cultivars have been developed. A limited number of irradiation studies have been conducted for highbush or rabbiteye blueberries. There are no reports with lowbush blueberries. In an early report [39], six cultivars of highbush blueberries were treated with gamma radiation at doses between 1000 Gy and 5000 Gy, with the principle goal to extend shelf-life. Berries from four of the six cultivars darkened with treatment, and berries of all varieties softened following treatment. In general, irradiation at doses exceeding 1000 Gy caused undesirable changes in color and texture. However, certain varieties ('Bluecrop' and 'Jersey') appeared more tolerant, indicating that the irradiation response is cultivar-dependent.

In a more recent study with northern highbush blueberries (unknown cultivar), e-beam irradiation at doses > 1100 Gy caused berries to soften substantially during storage at 5°C [40]. Texture, as measured by shear force, decreased significantly with dose, confirming other reports that irradiated blueberries are softer than nonirradiated berries. Irradiation at doses > 1100 Gy was not recommended for blueberries, because of the adverse effect on texture. However, blueberries exposed to 1600 Gy were acceptable to a sensory panel for overall quality, color, texture and aroma. Irradiated berries were generally darker in color than controls, with less ascorbic acid but greater total phenolics and antioxidant activity [40, 41].

There is only one report of highbush blueberries treated at doses below 1000 Gy. Blueberries of the cultivar Sharpblue (a southern highbush hybrid) were irradiated at doses ≤ 1000 Gy for potential quarantine treatment [42]. Berry flavor and texture declined linearly as dose increased, but sensory quality was still deemed acceptable. Weight loss, decay, soluble solids, acidity, skin color, and waxy bloom were not affected by irradiation at doses less than 1000 Gy. 'Sharpblue' berries tolerated doses up to 750 Gy with slight decline in sensory quality.

The majority of the blueberry radiation literature pertains to rabbiteye fruit. When rabbiteye berries (cv. Climax) were treated with gamma radiation (750 to 3000 Gy), doses above 750 Gy adversely impacted flavor within 24 hours of treatment [43]. The blueberries softened, and preference scores declined significantly. Irradiated fruit had more decay than control berries, regardless of dose or storage duration. The results indicate that 'Climax' blueberries tolerated doses less than 750 Gy irradiation. Berry quality was seriously reduced at > 1500 Gy, with increased softening and decay, loss in pulp integrity, and reduced flavor acceptability [43]. Later studies confirmed that high doses damaged rabbiteye blueberries (cv. Bonita Blue) [44]. Sensory panelists detected undesirable taste at doses greater than 1000 Gy.

When 'Climax' blueberries were treated with irradiation at low doses (250 to 1250 Gy), berry firmness, flavor and texture declined as dosage increased [45]. Fruit treated at doses higher than 750 Gy were consistently rated lowest in flavor. Weight loss, decay, skin color, soluble solids, acidity, and visual appearance (powdery bloom and shriveling) were not affected by irradiation dose [44, 45]. Doses ≥ 1000 Gy were detrimental to the quality of 'Climax' blueberries because of softening, loss of flavor and texture. For another rabbiteye variety ('Bonita Blue'), blueberries irradiated at 500 and 1000 Gy had equivalent flavor to non-irradiated fruit, but the shelf-life at 4°C was reduced by 8 days, compared to non-irradiated fruit [44].

The response of rabbiteye cultivars, Brightwell and Tifblue, to 500 and 1000 Gy radiation was generally consistent with those of 'Climax' and 'Sharpblue' [46]. Irradiation softened 'Brightwell' berries but did not affect the incidence of decay. Weight loss, soluble solids, acidity, and sensory quality were not affected by dose, similar to previous studies. For 'Tifblue', there was no difference in quality for any attribute, regardless of dose. In general, the blueberry research indicates that highbush and rabbiteye cultivars suffer quality loss following irradiation at doses ≥ 1000, but that most cultivars tolerate doses below 750 Gy.

Cherry

Sweet cherries (*Prunus avium*) are non-climacteric fruit that generally withstand irradiation at 600 Gy [47]. Differences among cultivars in sensitivity to radiation stress is often related to slight variations in maturity or quality at harvest. When 'Lambert' and 'Van' sweet cherries were treated with 1000 Gy radiation at two stages of maturity, 'Lambert' fruit were redder and 'Van' fruit were darker than control cherries, and both cultivars retained firmness [39]. 'Bing' and 'Rainier' cherries treated with 300 Gy radiation had similar visual quality, soluble solids content, and titratable acidity as control fruit after 2 weeks storage at 1 °C [48]. However, irradiated 'Bing' cherries had a larger number of fruit with surface pitting. In another report, 'Bing' and 'Rainier' cherries softened when exposed to 600 Gy radiation, but not to an unacceptable level [49]. The visual ratings were reduced for the fruit and stems of irradiated 'Rainier' cherries, but fruit color was not impacted for either cultivar.

Peach

Peaches (*Prunus persica*) are climacteric fruits that undergo rapid ripening. For this reason, peaches are harvested and treated at the preclimacteric stage to withstand handling. Peaches treated with high doses (1000 to 3000 Gy) of radiation for the purposes of extending shelf-life or controlling decay had increased respiration and ethylene production, accelerated fruit ripening and softening, increased red color through anthocyanin production, decreased fungal growth, and reduced flavor and aroma when compared to control fruit [50, 51, 52, 53, 54, 55, 56, 57]. Also, ascorbic acid production was delayed at doses ≥ 1500 Gy [53, 54], with a 23% decrease for peaches irradiated at 1500 Gy and stored 10 days at 5°C [58]. Several of these early studies described significant radiation effects on fruit softening. When texture was evaluated with four different methods (sensory, puncture, shear force, and compression), irradiated 'Loring' and 'Dixiland' peaches were substantially softer than control fruit immediately after treatment (1500 and 3000 Gy) [59]. 'Veteran' peaches were 40% to 50% softer than control fruit one week after treatment with 1500 to 2500 Gy irradiation [54]. Also, 'Maygold', 'Suwannee', 'Southland', and 'Loring' peach firmness was reduced at doses ≥ 1000 Gy, regardless of storage temperature [57]. Firmness values were 35% and 19% lower than control fruit when irradiated at 1000 Gy and stored at 20°C or 2°C, respectively. Softening of irradiated peaches has been attributed to a relatively high sensitivity of pectic components to treatment. Pectin solubilization appears to be a major factor in softening of irradiated peaches at doses ≥ 1000 Gy [57, 60]. For 'Red Rose' peaches, there was a marked reduction in firmness (60% of control) for fruit treated with 1000 Gy, leading the scientists to conclude that the use of doses ≥ 1000 Gy was impractical for peaches [55].

Peach cultivars vary in their response to irradiation, but at least some of this variation can be explained by differences in physiological maturity at harvest. When 'Dixiland' peaches were treated at different stages of ripeness, the sensory quality was not compromised with 2000 Gy radiation if treated at the firm-ripe stage (16 to 38 Newtons firmness) [56]. However, when irradiation was applied at the hard stage (> 38 N), the quality was lowered significantly. Panelists regarded these fruit as flat in taste and mealy in texture [56]. For 'Maygold', 'Loring' and 'Dixiland' peaches, irradiation (≥ 1000 Gy) induced softening one day after treatment. 'Southland' peaches softened considerably with a 500 Gy dose [50], and the texture, flavor and overall acceptance declined in a linear trend with increasing dose (> 1000 Gy) [56]. A similar, but more pronounced trend was observed for 'Loring' fruit. 'Elberta' peaches also exhibited a dose-dependent loss of firmness between 1000 to 2000 Gy [61]. However, doses up to 3000 Gy had no effect on the firmness of 'Suncrest', 'Fay Elberta', and 'Halloween' peaches, whereas 'Cardinal' and 'Redglobe' fruit softened with 2000 Gy irradiation [51]. For several of these reports, it is unclear whether the peaches were in the preclimacteric or climacteric stages of ripening. Therefore, the variable irradiation effects on fruit softening may actually be an outcome of the relative stages of ripening for the different cultivars.

There are very few reports of peach quality following irradiation treatment at the low doses (< 1000 Gy) suitable for quarantine treatment. In general, the composition (pH, titratable acidity, organic acids, sugars) of peaches irradiated at low doses (75 and 300 Gy) does not differ from control fruit before or after storage at 1°C [62]. Also, 'Elberta' peaches irradiated with 100 Gy remained firm, ripened slower, and had higher anthocyanin contents and less postharvest decay than control fruit [63]. At ≥ 500 Gy dose, irradiated peaches were redder but softer than control fruit when ripened for 3 days, and soluble solids content increased, suggesting irradiation-induced ripening [64, 65]. Fruit treated with ≥ 500 Gy also had higher total phenolic contents and antioxidant activity than control fruit [64, 65].

The sensory quality of California peaches (cv. Autumn Gem) was evaluated after treatment at doses up to 1000 Gy [66]. Differences were detected between irradiated and control fruit for color and flavor at 300 Gy; color and aroma at 500 Gy; and texture at 1000 Gy. However, only small differences were detected in flavor at 300 Gy, and no physical, chemical, or pathological analyses were done. When Freestone peaches (cv. Regina) were treated with 650 to 750 Gy gamma radiation, strong differences were detected by a trained sensory panel for odor and components of flavor not associated with sweetness [67]. Irradiated peaches tended to have off-odors, indicating that the characteristic peach volatiles of the fruit were impacted by irradiation. In contrast, other researchers reported that sensory tests showed no differences in flavor or overall acceptability of peaches (cv. Dangeumdo) treated at doses greater than 500 Gy [64].

In a report by Drake and Neven [49], 'Regina' peaches irradiated at 300 Gy or less (as a quarantine treatment) had little quality loss. Irradiation had no effect on interior or external color, soluble solids content, or titratable acidity. However at doses above 600 Gy, internal breakdown, softening, and color changes were evident and the quality loss was unacceptable for 'Regina' peaches. When peaches were treated commercially in pallet loads (target dose of 400 Gy), consumer scores were similar for acceptability between irradiated and non-treated fruit [68**]. Also, consumers initially scored irradiated 'Blaze Prince', 'Encore', 'August Lady', and 'Flame Prince' peaches higher than control fruit for flavor, texture, and juiciness due to faster ripening.

There is general consensus in the literature that peaches do not tolerate doses above 1000 Gy, because of softening and a decline in peach flavor and aroma, but the maximum tolerable dose for peaches has not been clearly established. As with other climacteric fruit, differences in cultivars, fruit condition, and stage of ripeness can create variable responses to irradiation. A conservative estimate for the radiotolerance limit for peaches is 600 to 700 Gy [49, 68**].

Pear

'Barlett' pears (*Pyrus communis*) radiated at the target minimum dose (400 Gy) for phytosanitary treatment had delayed ripening, with less bruising and decay, under simulated commercial conditions [69]. Early- and late-harvest pears responded somewhat differently to irradiation. Late-harvest pears showed increased respiration rates, weight loss and reduced soluble solids after radiation treatment. These effects were not observed in early-season pears, but the fruit were harvested from different growing areas. Consumers rated irradiated late-harvest 'Barlett' pears lower in sensory aspects than control fruit. 'Anjou' and 'Bosc' pears also ripened normally after exposure to 300-900 Gy irradiation, but 'Anjou' fruit developed scald and 'Bosc' pears softened as dose increased [40].

Conclusions

The commercial use of irradiation is expanding with the availability of facilities and the approval of low dose phytosanitary treatments for fresh produce. Most fruit types tolerate doses below 500 to 600 Gy, except for some species of *Citrus*. Papayas and mangos are most radiotolerant, and retain quality when treated at the maximum dose (1000 Gy) approved by the FDA. Many temperate tree fruits are sensitive to these doses, depending on variety. Cultivar effects may be related to slight variations in maturity at harvest, and few carefully designed studies have differentiated these factors. Objective assessments of physiological maturity are needed to evaluate multiple cultivars for sensitivity to irradiation during quarantine treatment. As quarantine radiation treatment increases for fresh fruit, large-scale trials with cultivars of commercial interest are advised for several crops. Pilot-scale treatment and shipping studies will provide a realistic assessment of fruit quality and consumer acceptance for irradiated fruit within the context of the total postharvest chain.

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