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Comparative Evaluation of the Effect of Methyl Bromide Fumigation and Phytosanitary Irradiation on the Quality of Fresh Strawberries

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ABSTRACT

Comparative Evaluation of the Effect of Methyl Bromide Fumigation and Phytosanitary Irradiation on the Quality of Fresh Strawberries

Fresh strawberries are highly perishable and have a short shelf-life especially when the cold chain is not maintained. Strawberries exported to Asia are currently fumigated with methyl bromide for phytosanitary purposes, which exposes strawberries to warm temperatures for several hours and air freight without temperature control, resulting in a shelf life of just a few days in the destination country. Irradiation offers an efficacious alternative to fumigation and can be performed on cold fruit. This study was conducted to compare the quality of strawberries subject to methyl bromide fumigation or irradiation followed by simulated commercial air freight shipment of strawberries to Asian markets and ambient temperature retail display. 'Amado' and 'Marquee' strawberries were treated with methyl bromide fumigation or gamma irradiation at 400 Gy. The strawberries were wrapped with insulated foil and ice packs for 24 h to mimic commercial air freight conditions then maintained at ambient temperature for two days to simulate retail display. The strawberries lasted only 2 d at ambient temperature, however berries treated with methyl bromide had the highest severity of decay. Irradiated berries were an average of 20% softer than fumigated strawberries and 23% softer than control fruit, however, consumer sensory panels showed no difference in liking for irradiated, fumigated, or control strawberries. Titratable acidity, soluble solids content, color values, and ascorbic acid content were unchanged due to treatments. The marketability of irradiated strawberries was similar to the control and

better than the fumigated berries, thus, irradiation at 400 Gy could serve as a viable alternative to methyl bromide fumigation for export of air freighted strawberries.

Keywords: Sensory, shelf life, decay, postharvest, marketability

1. Introduction

The U.S. is the largest strawberry (*fragaria x ananassa*) producer in the world accounting for 29% of the global production (Boriss et al., 2014). In 2013, 121,880 metric tons were exported, about 12% of the total production (CSC 2014). Import permits for certain countries specify phytosanitary treatments for strawberries to mitigate the threat of insects such as two spotted spider mite (*Tetranychus urticae*) and western flower thrip (*Frankliniella occidentalis*) which commonly infest strawberries. Australia, for example, specifies that strawberries from the U.S. be fumigated with methyl bromide (MeBr) at the rate of 48 g/m^3 for 3 h at a pulp temperature of no less than 18 °C (DAFF 2015). MeBr is the most common phytosanitary treatment used on strawberries, however, it depletes the ozone layer and is scheduled to be phased out under the Montreal Protocol (EPA 2011).

One promising alternative to MeBr fumigation is irradiation. Low dose irradiation is highly effective in sterilizing insect pests and is increasingly being used worldwide to treat fruit for export (Hallman 2013). The efficacy of treatment at low doses and lack of heat make irradiation particularly suitable as a phytosanitary treatment for fresh fruit. The United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS 2015) has approved a generic dose of 400 Gy for sterilization of most insects except *Lepidoptera* pupae and adults, however doses are not to exceed 1000 Gy (USDA APHIS 2015). Strawberries have high tolerance to irradiation, however the beneficial impacts on shelf-life have been observed at dose levels far exceeding the 400 Gy generic dose for phytosanitary purposes. Hussain et al. (2007) observed that irradiation at 1500 and 2000 Gy significantly delayed mold growth and extended the storage shelf life by up to 8 d. Cheour and Mahjoub (2003) observed delays in decay with doses of 1000 and 2000 Gy, and complete inhibition of gray mold development with a dose of 4000 Gy.

Strawberries are highly perishable and should be stored at 0 ± 0.5 °C immediately following harvest to help retain marketability (UCD 2013). Maintenance of the cold chain and quick shipment is essential for optimizing the shelf life (Zegota 1988), since the fruit can shrivel, develop fruit rot, and bruising quickly if cooling is delayed (Kader 1991). During air freight to overseas destinations, however, the cold chain can be significantly compromised, particularly if the fruit is fumigated. Fumigation with MeBr involves exposing strawberries to warm temperatures for several hours (18 °C for 3 h, in the case of Australia) followed by de-gassing, which can take another 2-5 h (USDA APHIS 2015). During air freight, temperature is generally not controlled in the cargo hold and highly dependent upon the location of the fruit in the airplane, the airline, and the duration of flight (Wong 2014). To keep the temperature of the fruit as cool as possible, freight companies wrap pallets of cold fruit with insulation material such as reflective bubble insulation and cold gel packs but product temperatures can increase to 13-16 °C during the flight. Upon arrival in the destination country, the cold chain is often compromised further due to lack of refrigerated warehousing or retail. These breaks in the cold chain and subsequent retail display at ambient temperatures result in just a few days of shelf life in the destination country.

Use of irradiation as a phytosanitary treatment would allow the fruit to be kept cold during the treatment as compared to fumigation which requires exposure of the fruit to warm temperatures for several hours. Thus, the hypothesis of this study is phytosanitary irradiation treatment would be a better treatment than MeBr fumigation in preserving the quality of fresh strawberries. The objective of this study was to determine the effect of phytosanitary irradiation and MeBr fumigation on the shelf-life of strawberries under conditions simulating air transport to Asia followed by retail display.

2. Materials and Methods

2.1 Sample Procurement

The entire experiment was conducted on two varieties of strawberries at two different times each, for a total of four separate trials. Marquee strawberries were harvested on June 13^{th} and June 27^{th}, 2014 in Santa Maria, CA. Amado strawberries were harvested in October 24^{th} and November 7^{th} 2014 in Oxnard, CA. The strawberries were harvested at 70% ripeness and transported to the packinghouse where they were placed into 454 or 907 g (1 or 2 lb) clamshells and held at ambient temperature for pickup within 2 h.

Strawberries were transported directly to the fumigation facility (Raymond Express, Los Angeles, Ca.) (257 km from Santa Maria or 97 km from Oxnard) where they were assigned to one of four treatments, refrigerated control (RC), air freight control (AC), irradiation plus air freight (AI), and methyl bromide fumigation plus air freight (AM). A fourth of the berries were fumigated with methyl bromide (AM). The remaining berries were cooled to 1°C in a forced air cooler. The next day, another fourth of the untreated strawberries were taken to Sterigenics, Inc., a contract irradiation facility in Tustin, CA (~ 66 km), for irradiation treatment. All the strawberries were then transported to Chapman University (Orange, CA) (~11 km) for air freight and retail display simulation.

2.2 Methyl Bromide Fumigation of Strawberries

The strawberries were allowed to reach a temperature of 21 °C prior to being fumigated with MeBr. The boxes were fumigated using MeBr for 2 h at a concentration of 32 g/m^3 at a temperature of 21 °C as is the procedure for export to South Korea (USDA APHIS 2015) and left to degas in the fumigation chamber for 4-5 h, and subsequently cooled to 1 C in a forced air cooler.

2.3 Irradiation of Strawberries

Dose mapping was conducted by placing twelve alanine pellet dosimeters (FarWest Technology, Inc., Goleta, Calif.) at various locations on six strawberry cases arranged vertically at precise distance from a Co^{60} source (~37PBq). Six cases of strawberries were placed in exactly the same configuration as the dummy cases at ambient temperature (~20 °C) to receive treatment at a dose rate of 0.24 Gy s^{-1} and 0.16 Gy s^{-1} for Marquee and Amado strawberries respectively. The fruit was treated at a target dose of 400 Gy (4.6-5.5% uncertainty). Midway through the treatment, the boxes were rotated 180° to ensure uniform treatment. After treatment, the strawberries were transported to Chapman University and placed in cold storage at 1 °C.

2.4 Air freight and retail simulation

To simulate air freight, the strawberries were stacked four cases high and four cold packs (Cryopak Ice-Pak, Edison, NJ) were placed on top of the upper most case. The four cases with the gel packs were then wrapped with insulated foil wrap (Fig. 1) (Reflectix Bubble Pak Insulation, Markleville, IN). The insulated packs were stored in a room at ambient conditions for 24 h to simulate air shipment to Asia in a cargo hold (Orlando Wong, Able Freight, personal communication). To mimic subsequent distribution and retail display the strawberries were unwrapped and stored at ambient temperatures. The refrigerated controls were kept in cold storage at 0-1 °C for the duration of the experiment. The strawberries were analyzed for indicators of quality following simulation of air shipment, and after 2 d at ambient temperature. LogTag® (Auckland, New Zealand) temperature and humidity data loggers were used to record the temperature and relative humidity.

2.5 Analytical Measurements

2.5.1 Firmness

Firmness was determined using a Stable Micro Systems Texture Analyzer (Model TA-XT2, Texture Technology Corp. Scarsdale, N.Y., U.S.A., and Stable Microsystems, Godalming, Surrey, U.K.) with a Kramer Shear Press. Strawberries (150 g) were placed within the holding cell, and the Kramer Shear blades positioned 100 mm above the bottom of the platform. The strawberries were pierced at a speed of 4 mm/s with a post-test speed of 10 mm/s. The maximum force in N required to pierce the sample of strawberries was recorded. Data from five replicates were averaged for each data point.

2.5.2 Consumer Affective Testing

Sensory analysis was conducted by 50-100 volunteers at Chapman University (Orange, CA). Samples were prepared on the day of evaluation by placing two intact strawberries from each treatment into plastic soufflé cups labeled with 3-digit random codes. Each individual was then given a soufflé cup from each treatment, unsalted crackers, and a cup of water. One clam shell of strawberries from each of the treatments was randomly chosen and placed in the testing area for panelist to evaluate appearance. The individuals were asked to first observe the appearance of the strawberries in the clam shell. Then, the panelist were instructed to taste a sample of each strawberry and rate the flavor, texture, and overall liking of each sample using a nine-point hedonic scale (1=extremely bad to 9=extremely good) (Lawless and Heymann 1998; Peryam and Pilgrim 1957). Volunteers were then instructed to cleanse their palette with a bite of cracker and sip of water before proceeding to the next sample. The SIMS 2000 Sensory Evaluation software program (Berkeley Heights, NJ) was used to code the samples and record data from each individual evaluation.

2.5.3 Soluble Solids Content (SSC) and Titratable Acidity (TA)

A homogeneous strawberry puree was created using an Elite Gourmet Maxi-matic Juice Extractor TS-738 (City of Industry, CA). The juice was filtered through 3 layers of cheesecloth and one drop of strawberry juice was placed on the prism of a digital pocket refractometer (Atago U.S.A. Inc., Bellevue, WA) and the SSC reading was recorded. Measurements were made in triplicate.

For determination of TA, five mL of juice was blended with 50 mL carbon dioxide free water and was titrated with 0.1N NaOH to an endpoint of 8.1 (pH200, Hannah Instruments, Woonsocket, RI). Measurements were made in triplicate. Total acidity was expressed as grams per liter of citric acid using the following formula:

% Citric Acid = [(mL base titrant x molarity of NaOH x 0.064)/ (mL of sample)] x 100

2.5.4 Color

Color was measured using a white tile calibrated spectrophotometer (model CR-700d, Minolta, Tokyo, Japan). Two measurements were taken for each strawberry, two on opposing sides halfway between the calyx and bottom of the strawberry. Twenty strawberries were analyzed per treatment to ensure uniformity of samples.

2.5.5 Ascorbic Acid

Analysis of ascorbic acid (AA) and dehydroascorbic acid (DHA) was based on Odriozola-Serrano et al. (2009). A sample of 25 g of strawberries was homogenized with 25 mL of 2.5% metaphosphoric acid (Acros Organics, Belgium) solution. The mixture was vacuum-filtered through Whatman No. 1 filter paper. Then 10 mL of the filtered sample was diluted 1:10. The diluted sample was passed through a .45µm Millipore membrane filter and was injected in the HPLC system. To quantify DHA, a solution of dithiothreitol (20 mg/mL) (ThermoScientific, Waltham, Ma) was prepared and 0.2 mL was added to 1 mL of the vacuum filtered sample. The mixture was diluted 1:10, passed through a .45µm hydrophilic PTFE membrane filter (ThermoScientific, Waltham, Ma) and injected into the HPLC system. DHAA was calculated as the difference between the AA after reduction and AA without reduction. The HPLC was equipped with a Synergi™ 4 µm Max-RP 80 Å, Reverse phase LC Column 250 x 4.6 (Phenomenex, Torrance, Ca). The mobile phase was a 0.01% solution of sulphuric acid (ThermoScientific, Waltham, Ma.), recording an absorbance at 245 nm. Standards of ascorbic acid (Sigma Aldrich, St. Louis, Mo.) were run in triplicate to make a standard curve and quantify total AA.

2.5.6 Damage Evaluation

Evidence of damage was assessed by evaluating all the strawberries in two clamshells immediately following air freight simulation and again two days after ambient temperature storage. Each strawberry was evaluated individually and classified based on the most dominant defect. The defect categories were: (1) decay: white or gray mold present (2) wet/leaky: bruised skin with a wet leaky spot the diameter of a pencil eraser top or larger, and (3) dry bruise: sunken area the diameter of a dime or larger that is healed and appears dry. The percentage of strawberries exhibiting each of these defects was recorded.

2.6 Statistical Analysis

A longitudinal randomized treatment design with repeated measurements was used to compare the differences between treatments and determine the effect of time using the R statistical software package (R Development Core Team, 2012, Vienna, Austria). Data for the two varieties were analyzed separately. Linear mixed effect models with random effects were used to determine estimated means of quality attributes and to assess the effects of significant variables (air freight shipment, treatment, and time) on strawberry quality.

3. Results and Discussion

Fig. 2 shows the change in temperature of strawberries starting from point of harvest, through treatment, air freight simulation, and 2 d of retail display at ambient temperatures.

3.1 Firmness

Firmness data from both trials within the cultivars was similar and therefore combined. The Marquee strawberries were ~25% firmer in comparison to the Amado berries (Fig. 3). Air freight of the Marquee strawberries caused a decline in firmness, but the decline was not statistically significant ($p>0.05$). For the Amado berries, firmness differences between the refrigerated and air freight control was not evident until after ambient display for two days ($p\leq0.05$). Thus, it appears that the Marquee strawberries were sensitive to the air freight but display at ambient temperatures did not cause additional softness. For the Amado, there was no effect of air freight but they softened by 14% during two days of ambient temperature display.

Irradiation treatment plus air freight caused a greater loss of firmness ($p \leq 0.05$) for the Marquee variety (32-40%) than for the Amado variety (13-15%). However, during the subsequent two day retail display under ambient conditions, the Marquee strawberries did not experience further significant loss in firmness (6-8%), while the Amado variety experienced ~15-18% decrease in firmness ($p \leq 0.05$).

Fumigation and air freight also caused immediate softening ($p \leq 0.05$). For the Marquee variety, the loss of firmness was less than the irradiated samples, and for the Amado variety, it was similar to irradiated berries. But unlike the air freighted control and irradiated berries, the fumigated strawberries became firmer during the four days of ambient storage.

Temperature control is critical in maintaining strawberry quality. Mitchell et al. (1964) observed a significant reduction of marketable strawberries by exposing harvested berries to a 2 h delay in the field at 29 °C before cooling to 4°C. Air freight caused the strawberries to gradually warm, so that in the 24 h that the berries were wrapped in insulated foil, the temperature had risen to 18-20°C. Warm temperatures affect strawberry respiration; a 10 °C change in temperature over the range of 0-30 °C was directly correlated to a 4-fold change is respiration rate (Hardenburg et al., 1986).

The significant softening of irradiated berries is attributed to the partial degradation of cell wall polysaccharides that occurs during irradiation and subsequent storage. Specifically cellulose and the polygalacturonic acid chains of pectic fractions experience higher degradation than neutral sugar side-chains of pectic and hemi-cellulose fractions (Amour et al., 1993). Ahmed et al. (1972) also observed an immediate effect of irradiation on textural parameters of irradiated strawberries tested with Kramer Shear and a penetrometer. Softening was apparent immediately following irradiation at 1500 and 3000 Gy and occurred to a lesser extent during storage.

The softening effect on fumigated strawberries is likely a function of exposure to high temperatures for several hours. Nunes et al. (1995) observed 14-22% decrease in tissue firmness, 50% greater water loss and increase in shriveling of strawberries exposed to 30 °C for 6h before cooling at 1 °C. However, MeBr fumigation has shown softening effects on other fruit such as cherries even when fumigated at lower temperatures. Moffitt et al. (1999) observed softening of cherries fumigated at 64 g/m^3 for 2 hours at 6 °C.

3.2 Sensory

Sensory scores for all the attributes for both varieties including overall liking generally ranged from 6-7 (Table 1). The strawberries used in this study were picked for export at 70% maturity. Maturity stage at harvest has a major impact on sensory attributes. Ripening of strawberries includes changes in the cell wall composition, metabolism of sugars and acids, and the biosynthesis of pigments (carotenoids, anthocyanins), all of which affect consumer perception of quality. Ripening of strawberries is also correlated to a decrease in total acidity and a general increase in the total sugar content (Azodanlou et al., 2004), which are directly related to flavor perception.

Air freight did not impact sensory quality ($p \leq 0.05$) as compared to the refrigerated control for both varieties. However, there was a differences between varieties in response to irradiation and fumigation, with the Marquee berries exhibiting lower sensitivity to treatments as compared to the Amado.

Irradiation only impacted texture scores for the Marquee in trial 1 and flavor for the Amado in both trials ($p \leq 0.05$). Fumigation also affected sensory attributes of Amado berries more than the Marquee variety. For Amado berries, panelists rated the texture of fumigated strawberries significantly lower ($p \leq 0.05$) in comparison to air freight berries. However, there were no significant differences between fumigated berries and irradiated berries.

Irradiation-induced softening as measured using the Kramer Shear did not negatively impact overall liking of either variety of strawberries as compared to the control. Fumigation-induced softness on the other hand, seemed to lower overall liking scores as compared to the control strawberries for the Amado berries ($p \leq 0.05$).

3.3 Titratable acidity

Air freight lowered TA, particularly for the Amado berries, which showed significantly lower TA than refrigerated controls ($p \leq 0.05$) (Table 2). This can be attributed to the higher temperature during air freight. Both irradiation and fumigation did not affect TA immediately but during the two days of retail display, the irradiated berries showed no change in TA ($p > 0.05$), whereas the MeBr fumigated Marquee berries (but not Amado) showed a decrease in TA ($p \leq 0.05$). Irradiation generally doesn't affect TA of strawberries, even up to 3000 Gy (Zegota 1988), however, since MeBr fumigation necessitates a delay in cooling of the strawberries the decrease in TA was expected. Nunes et al. (1995) observed decreases in TA in strawberries subjected to a 6 hour delay in cooling.

3.4 Soluble Solids Content

The SSC content ranged from 7.7 - 9.2% in Marquee berries and 6.75- 7.9% in Amado berries (Table 2). Air freight resulted in significantly ($p \leq 0.05$) higher SSC in the Marquee berries, but not Amado berries. An increase of temperature by 10 °C can increase respiration rate by 4-5 fold (Kader 1991), which can increase SSC due to breakdown of starch. It is not uncommon to observe an increase in SSC due to enzymatic conversion of higher polysaccharides into simple sugars during storage followed by a decrease that can be attributed to the oxidative breakdown of sugars due to respiration as well as utilization of sugars and other soluble nutrients as substrates for fungal growth (Hussain et al., 2007).

There was little effect of treatment on SSC of both berries. Previous studies show no significant differences in soluble solids content of irradiated berries (Hussain et al., 2007; Majeed et al., 2014). In addition, our sensory panelists were unable to detect differences between treatments in regard to strawberry flavor.

3.5 Ascorbic Acid

There was no effect of treatment or air freight on AA or DHA (Table 2). Irradiation at levels above 1000 Gy can cause fluctuations in AA and DHA, however lower doses generally have no significant effect on vitamin C content of various fruits and vegetables (Lee and Kader 2000). It has also been noted that the variety of strawberry has a greater effect on vitamin C content than irradiation treatment or storage (Graham and Stevenson 1997; Young and Hong 2003).

3.6 Color

In general, color L*, a* and b* values declined in the strawberries during air freight and storage indicating darkening and decrease in redness and yellowness of the strawberries (Table 2), although the values were not significantly different ($p>0.05$). The color of irradiated and fumigated strawberries was not different from the air freighted control indicating that treatment did not impact color. These results correlate with sensory results which show that consumer perception of the appearance of the fruit was unaffected by treatment. Consumers rated appearance of treatments of berries between a 5.9 (neither like nor dislike) and 7.0 (like moderately) and the ratings were not significantly different across treatments or time.

Previous studies have shown that at low levels of irradiation, strawberry color is not affected. Brecht et al. (1992) saw no significant changes in color of refrigerated berries irradiated at 1000 Gy, but Zegota (1988) reported loss in redness of strawberries after irradiation at 2.5 kGy.

3.7 Damage/Decay

Fig. 4 shows the percentage of defective berries following treatment, air freight and ambient temperature display. The highest occurrence of damage was determined to be characterized as wet leaky or decayed. Wet leaky berries exuded liquid and later developed obvious sign of mold growth. There were differences among clam shells as seen in the photographs in Fig. 5, but overall it was clear that air freight of berries caused a noticeable increase in the occurrence of damage and decay, particularly wet leaky, as compared to the refrigerated control.

Following air freight and ambient temperature storage, irradiated berries had lower incidence of damage as compared to the air freight alone, and fumigated berries consistently exhibited the greatest amount of wet leaky and decay. The increased incidence of mold/decay in the air freighted as well as fumigated berries can be attributed to the exposure to higher temperatures and delay in cooling of the fumigated berries. Prompt cooling and low storage temperatures lower respiration and delay physiological processes such as senescence and are among the most important controllable factors in maintaining strawberry quality and occurrence of postharvest diseases (Hussain et al., 2007; Kader 1991).

While the irradiated samples had a lower incidence of damage and decay as compared to the fumigated, they were still considered unmarketable after two days at ambient temperatures. The shelf-life benefit was less than one day at most for the irradiated berries compared to the fumigated berries. These results are not surprising since previous studies show reduction or delay in mold growth such as Botrytis rot (*Botrytis cinerea)* and Rhizopus rot (*Rhizopus* *stolonifer*) on refrigerated strawberries occurring at a minimum dose of 500 Gy (Hussain et al., 2007; Barkaigo et al., 1971). Furthermore, under ambient temperatures higher doses of irradiation are required to help delay mold growth. For example, Hussain et al. (2007) observed that ‘Confitura’ strawberries treated with doses of 500-1500 Gy and stored under ambient temperatures were unmarketable after 2 d, however mold growth was delayed by 2 d when doses of 2000 Gy were utilized.

At higher doses, softening of the fruit is a concern, but some cultivars are able to sustain physical integrity following irradiation treatment at higher doses (Hussain et al., 2007). Barkaigo et al. (1971) observed ‘Lassen’ strawberries irradiated with 2000 Gy exhibit prolonged shelf life, however doses of 3000 Gy exhibited significant loss in textural integrity. The varieties used in this study, ‘Marquee’ and ‘Amado’, exhibited softening even at 400 Gy, thus higher dose levels that could control mold and decay would not be tolerated by these varieties.

4. Conclusion

There were some differences in responses to air freight and post-harvest treatments between the Amado and Marquee strawberries and also among the trials with the same variety. However, air freight had the greatest impact on quality and shelf-life, as seen by comparison with the refrigerated control. Irradiation caused softening but it did not affect consumer liking of texture. Treatment at 400 Gy did not impact development of mold indicating that irradiation at this dose did not wound the fruit to encourage mold growth, nor was it high enough to destroy mold. Fumigation, on the other hand, accelerated decay during ambient temperature display, most likely due to the higher temperature exposure during fumigation, confirming the importance of maintaining the cold chain for optimum strawberry quality. The marketability of strawberries irradiated at 400Gy was similar to the untreated control, and therefore phytosanitary irradiation could serve as a viable alternative to MeBr fumigation for export of air freighted strawberries.

Further research should explore the irradiation dose, within the 1000 Gy FDA limit, at which mold growth could be mitigated without impacting sensory quality. These studies could include combination with modified atmosphere packaging as a means to preserve quality and extend shelf life of irradiated strawberries.

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List of Tables

Table 1. Consumer liking scores of Marquee and Amado strawberries for appearance, flavor, texture and overall liking. The four treatments include: refrigerated control (RC), air freight control (AC), irradiation plus air freight (AI), and methyl bromide fumigation plus air freight (AM). [ab] Values on the same day within each trial that are followed by the same letter are not significantly different.

		Trial 1				Trial 2			
		RC	AC	AI	AM	RC	AC	AI	AM
Appearance	Marquee	6.3 ab	6.5 ab	7.0 a	6.5 b	6.9	6.3	6.3	6.9
	Amado	6.5	6.7	6.3	6.5	6.1	6.4	5.9	5.6
Flavor	Marquee	6.9	7.1	6.8	6.2	7.3	6.7	6.7	6.4
	Amado	6.9 ab	7.1 a	6.3 b	6.6 ab	7.6 a	7.3 a	6.0 b	5.9 b
Texture	Marquee	6.0 ab	5.9 a	6.9 b	6.1 ab	7.1	6.5	6.2	6.2
	Amado	6.8 ab	7.0 a	6.5 ab	6.3 b	7.1 a	7.0 a	6.5 ab	6.0 b
Overall Liking	Marquee	6.0	6.1	6.8	6.0	7.2 a	6.5 ab	6.2 b	6.3 ab
	Amado	6.7 a	6.9 a	6.3 a	6.1 b	7.0 a	7.1 a	6.2 ab	5.8 b

Table 2. Effect of air freight shipment and treatment on estimated means of TA (% citric acid), TSS, and total AA of Marquee and Amado strawberries. The four treatments include: refrigerated control (RC), air freight control (AC), irradiation plus air freight (AI), and methyl bromide fumigation plus air freight (AM). [ab] Values on the same day within each trial that are followed by the same letter are not significantly different.

			RC		AC		AI		AM		RC		AC		AI		AM	
% Acid	Marquee	Day 2	1.0		0.9		0.9		1.0		0.8		0.8		0.8		0.8	
		Day 4	0.9	ab	0.9	ab	1.0	a	0.8	b	0.8	ab	0.7	ab	0.8	a	0.7	b
	Amado	Day 2	1.6	a	1.1	b	1.2	b	1.4	ab	1.1	a	0.6	b	0.6	b	0.9	ab
		Day 4	1.1		1.4		1.3		1.1		0.6		0.9		0.8		0.6	
% SSC	Marquee	Day 2	8.2	b	9.3	a	8.8	ab	8.7	ab	7.7	b	8.8	a	8.4	ab	8.3	ab
		Day 4	8.8	ab	8.9	a	8.8	a	8.5	a	8.4	a	8.4	a	8.3	a	8.1	a
	Amado	Day 2	7.5	ab	7.2	b	7.5	ab	7.6	a	7.9	ab	6.9	b	7.8	ab	7.9	a
		Day 4	7.2	a	7.1	a	7.1	a	6.8	b	7.5	a	7.5	a	7.5	a	7.1	b
Ascorbic Acid	Marquee	Day 2	0.6		0.7		0.6		0.7		0.5		0.6		0.5		0.6	
		Day 4	0.6	ab	0.7	a	0.6	ab	0.6	b	0.5	ab	0.6	a	0.5	ab	0.5	b
	Amado	Day 2	0.7		0.8		0.7		0.8		0.8		0.8		0.8		0.8	
		Day 4	0.6		0.7		0.7		0.6		0.7		0.8		0.7		0.7	
Color (L*)	Marquee	Day 2	39.2		36.0		36.6		35.9		39.9		36.6		37.2		36.5	
		Day 4	37.8		34.9		36.3		34.2		38.4		35.5		37.0		34.9	
	Amado	Day 2	36.4		36.6		36.9		35.7		36.3		36.5		36.8		35.7	
		Day 4	36.5		34.6		34.3		34.1		36.4		34.5		34.3		34.0	
Color (a*)	Marquee	Day 2	34.9		32.6		34.0		33.8		37.6		35.3		36.7		36.5	
		Day 4	35.4		33.2		33.9		32.1		38.1		35.8		36.6		34.8	
	Amado	Day 2	39.8		37.2		37.2		35.2		36.1		33.4		33.4		31.4	
		Day 4	36.4		34.4		35.8		34.9		32.6		30.6		32.1		31.1	
Color (b*)	Marquee	Day 2	24.9		22.0		22.9		21.2		26.5		23.5		24.4		22.8	
		Day 4	23.9		21.5		22.3		18.6		25.5		23.1		23.9		20.2	
	Amado	Day 2	27.0		23.9		23.5		21.5		25.0		21.9		21.5		19.5	
		Day 4	23.6		20.7		21.9		20.6		21.6		18.7		19.9		18.6	

LIST OF FIGURES

A.

B.

C.

D.

Figure 1. Commercially air freighted strawberry pallets A. maintained cold with ice packs B. wrapped with insulated foil. Chapman University air freight simulation C. with ice packs D. wrapped with insulated foil.

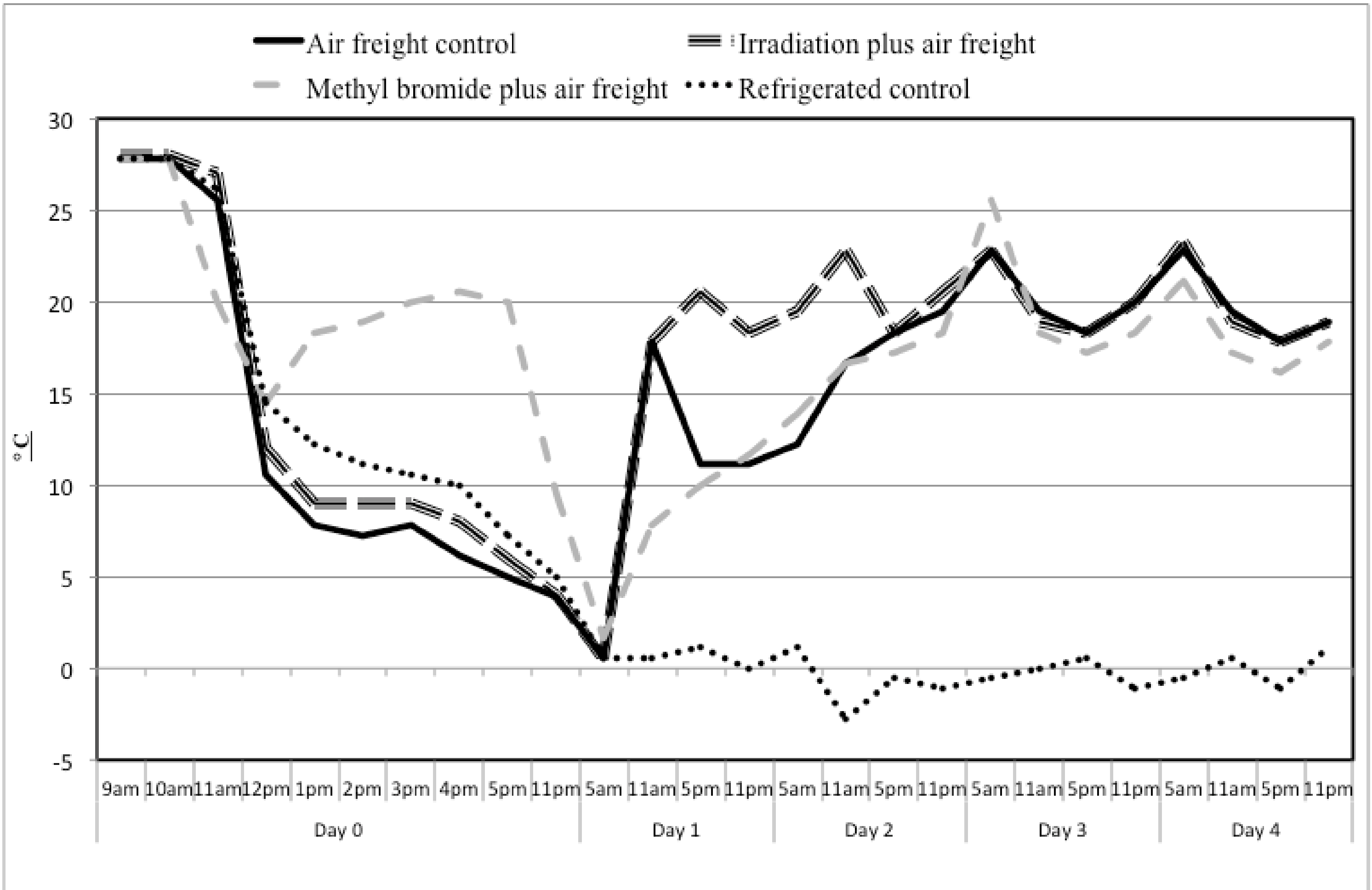
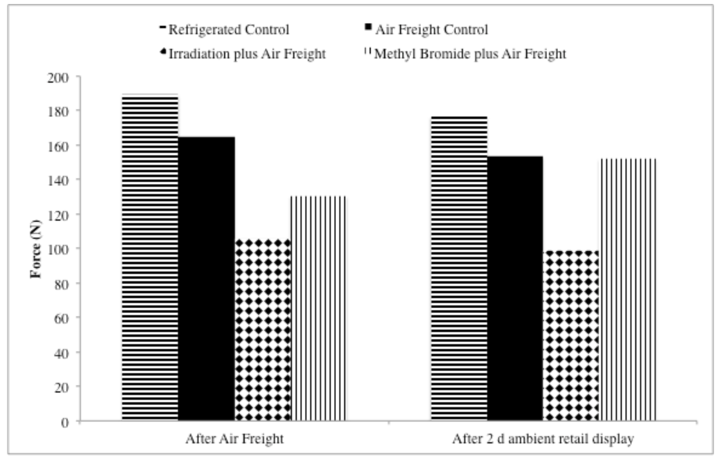


Figure 2. Change in temperature of strawberries starting from point of harvest, through treatment, air freight simulation, and 2 d of ambient temperature storage.

3A.



3B.

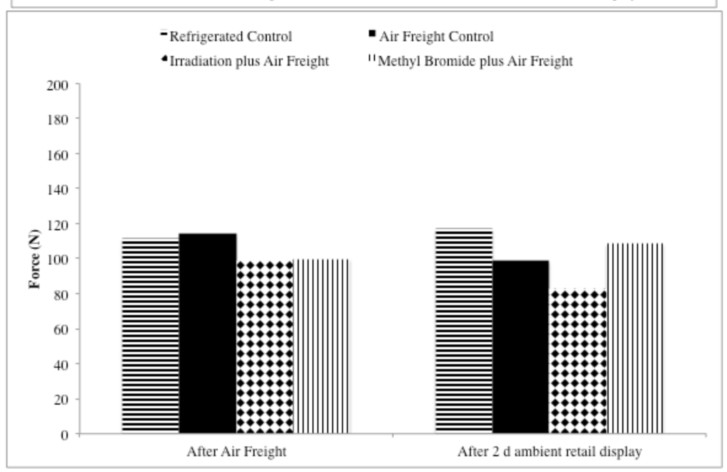
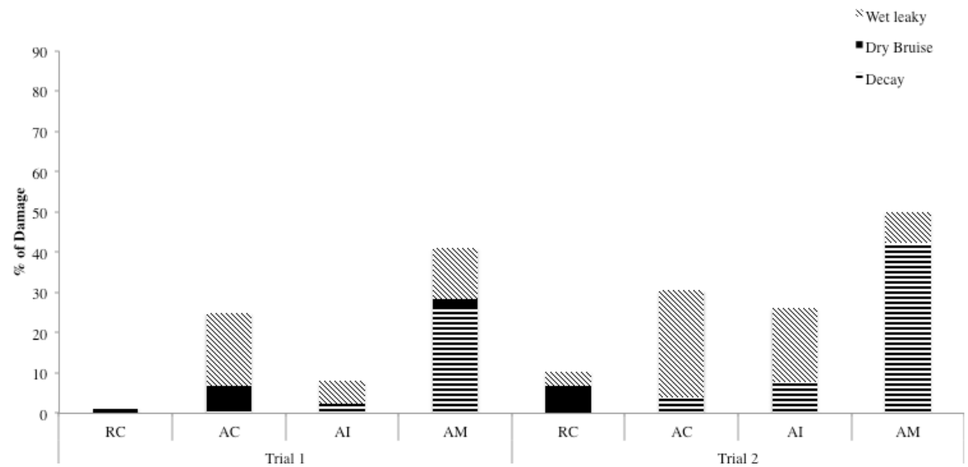


Figure 3. Effect of irradiation and fumigation on firmness of A. Marquee B. Amado strawberries following air freight and 2 d of ambient temperature storage. Values on the same day that are followed by the same letter are not significantly different.

4A.



4B.

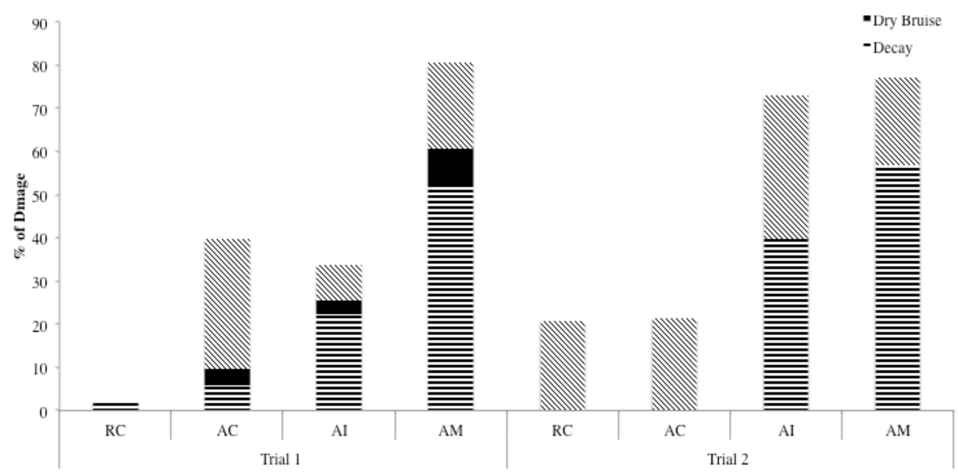


Figure 4. Damage and decay of A. Marquee B. Amado strawberries after air freight and 2d of ambient temperature storage. The treatments include: refrigerated control (RC), air freight control (AC), irradiation plus air freight (AI), and methyl bromide fumigation plus air freight (AM).

Figure 5. Appearance of strawberries following air freight simulation and 2 days of ambient temperature storage. The treatments include: air freight control (AC), irradiation plus air freight (AI), methyl bromide fumigation plus air freight (AM).