Predicting the impact of irradiation on mango quality

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Photo caption from report cover: Dan Moore and James Johnstone (Steritech) and Scott Ledger (Manbulloo) inserting dosimetry loggers and labelling tray positions in mango pallet to be irradiated.

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Summary

Predicting the impact of irradiation on mango quality is important to enable exporters to gauge the potential for and to manage the risk associated with using irradiation as a treatment protocol. There are a suite of variables affecting the likelihood of damage from irradiation including where and how the fruit are grown, the environmental conditions leading up to and at harvest, the post treatment storage conditions as well as the mango variety itself. The trial undertook detailed dose mapping of a commercial sized pallet using Mod12 trays suitable for cost effective export, to better understand the likely variation in dose anticipated in pallets of fruit exposed to irradiation. This trial also examined the effect of irradiating pre-ripening Kensington Pride mangoes using two post irradiation storage regimes, three irradiation level treatments (plus a control). Combined this was designed to give an exporter a reasonable expectation of what potential damage will occur, when and where in the pallet of commercially pre-ripened Kensington Pride mangoes.

Dosimetry illustrated that the irradiation service provider's process of using pallet density to define the length of exposure to reach a desired minimum irradiation dose, worked well. However it also reinforced the risk that the dose required to ensure the minimum dose (400Gy) to all fruit can result in some fruit receiving more than 850Gy. This equates to a Dose Uniformity Ratio (DUR) of well over 2.0. This can pose risk of the fruit being damaged, depending on the variables mentioned above. The dose mapping and quality assessment suggests that the fruit at greatest risk of quality loss are those in trays at the front or back (rather than in the middle) of the pallet. These trays should be targeted during export market quality inspections at arrival.

Not surprisingly, the use of 12°C storage for the first seven days (then 20°C for the remaining 11 days of assessment) post irradiation held back the ripening of the fruit by 2 and 5 days as indicated by fruit firmness and skin colour, respectively when compared with fruit held at 20°C for the entire 18 day assessment period. The cooler storage condition also delayed the expression of lenticel spotting and skin browning by about 3 days.

The irradiation dose did not have a significant effect on fruit ripening for this pre-ripened fruit, but all three irradiation doses (440Gy, 640Gy and 840Gy) resulted in higher (but similar) lenticel spotting than the control treatment (0Gy). Fruit receiving 640Gy and 840Gy did show a greater level of skin browning than those receiving 440Gy or 0Gy. Cool storage delayed the start of visible skin browning by 3 days (from 7 to 10 days after irradiation) for the 640Gy and 840Gy treatments, while skin browning in the 440Gy treatment did not start to express until day 14 after irradiation.

Keywords

Kensington pride, mango, irradiation, quality, lenticel, skin browning, ripeness, maturity

Introduction

Australian Mango Industry Strategic Investment Plan (2014/15 – 2018/19) aims to double mango exports over three years. It will drive profits for growers and identify market access opportunities so efforts can be directed to the most profitable markets. This includes a work plan that will facilitate exports of Australian mangoes to the USA. This report focuses specifically on improving supply chain effectiveness through better management of the risk factors associated with the irradiation process. This will improve out-turn of fruit quality to increase consumer confidence in Australian mangoes. While the New Zealand market has been somewhat willing to accept more lenticel spotting and skin browning than would otherwise be acceptable as grade one fruit, this does put the long term prospects for market growth at risk in this as well as emerging markets such as the USA.

Irradiation is a treatment protocol required for consignments of mangoes exported to New Zealand and the USA. Supply chain monitoring of consignments of mangoes to New Zealand and USA for this season and the one just gone revealed fruit quality issues of concern at in-store retail displays. Fruit quality concerns included skin browning, lenticel spotting and slow degreening during ripening. It is possible that some of these quality concerns were caused by the irradiation treatment protocol required to gain export access to these countries.

Irradiation as a treatment protocol requires a minimum dose of 400Gy to ensure the sterilisation of Queensland Fruit Fly as well as any live detections (hitchhiker insects such as ants) that may have accessed the fruit carton during the packing process. Commercial irradiation treatment of mangoes is done on a pallet basis and to ensure a minimum dose of 400Gy is received by every tray, up to 900Gy is received by some trays in the pallet dependent of the position of that tray in the pallet and the size and packing configuration of trays on the pallet.

It has been known for some time (McLauchlan, et al, 1990) that irradiating mature green mangoes with levels greater than 75Gy causes delayed ripening and external injury (lenticel damage). Interactions between cultivar, maturity, pre-harvest conditions, storage temperature and irradiation dose may provide avenues for reducing irradiation damage. As indicated, cultivar and dose are significant factors in fruit responses to irradiation. Johnson et al. (1990) suggests that if irradiation at 300Gy is to be a disinfestation treatment for mangoes, cultivars with a higher damage threshold than 'Kensington Pride' will need to be grown. Recent results indicate that 'B74' is more susceptible to irradiation than 'Honey Gold' due to skin lenticel density, with 'Kensington Pride' and 'R2E2' intermediate in response. In fact, preliminary results indicate that 'Honey Gold' suffers no damage at 750Gy (Hofman 2009, unpublished results).

Commercial harvesting of mangoes using picking aide machines reduce the risk of damage from sap-burn, but the combination of water, chemical soaps and sap in the water do expose the fruit skin and in particular the lenticels to a low level of damage or sensitivity to subsequent damage. This can become apparent when exposed to other skin stressors such as irradiation. Poor handling at harvest will increase the risk of damage emerging after irradiation. Fruit hand harvested and desapped without water and mango wash, then irradiated show very little damage from irradiation.

Treating more mature fruit may reduce damage (Boag et al. 1990; Hofman et al. 2014), possibly mediated through decreasing lenticel sensitivity and more rapid ripening in more mature fruit. Irradiating partly ripened fruit may also help reduce skin damage and delayed de-greening (Boag et al. 1990; Hofman et al. 2014). A number of mango exporters have adopted this finding by adjusting the level of ripeness to reduce the level of irradiation damage. They are also in the process of fine tuning that ripening process with each variety to reduce the level of damage that they have become accustomed to in the New Zealand market. Fruit treated at colour stage 2-3 often incur less irradiation damage in the form of lenticel spotting and skin browning and are less prone to retaining the green skin colour for longer than fruit treated at the green mature stage (Hofman et al. 2014). The challenge then remains of getting the fruit to market and sold quickly so that the fruit are not overripe at point of sale.

In 2014 several configurations of irradiated pallets were assessed to find the lowest maximum dose in the pallet (Dmax) and the lowest ratio of the difference between the smallest and greatest dose (Dose Uniformity Ratio or DUR) in an attempt to reduce the risk of high irradiation doses causing fruit damage in the emerging

USA market. While the short (eight trays high) hollow stacked pallet reduced the DUR to around 1.8 it also increased the cost of treatment and restacking for fruit being exported using air pallets. This trial includes detailed dose mapping to not only take samples at a variety of irradiation doses for the trial, but also to identify the hot-spots in pallets where sampling can be targeted to look for the effects of high irradiation dose damage in trays arriving into USA markets. While this trial investigated the effect of irradiation dose it also focused on the risk factors including pre-irradiation ripening and post irradiation storage conditions.

Growers, pack-houses, exporters and freight forwarders currently use the irradiation treatment protocol for exporting mangoes to New Zealand and USA. Given that fruit will incur the least damage when fruit are pre-ripened, air freight remains the main option to get that pre-ripened quickly to retail. Estimated times to get fruit through the supply chain are critical and usually include the following steps;

- road transported from landing overseas to the distribution centre (4 days)
- road transport to retail store (1-2 days)
- time in store to consumer (up to 5 days)

Hence having a firm idea of what damage may emerge on the fruit for the 14 days post irradiation treatment is critical for ensuring the fruit maintain their maximum sale value.

Methodology

The approach to assessing irradiated fruit utilised industry-recognised for fruit quality assessment (Holmes et al. 2009) together with recognised fruit assessment rating scales used and published in Australia, and storage conditions during the assessment period that simulate storage conditions in transport to and in retail outlets.

Fruit sourcing

Small Kensington Pride mango fruit (13 fruit per Mod12 carton with an average fruit weight of 290g) were used in this trial as they should have a greater pallet density and hence at greater risk of higher irradiation maximum dose. The fruit were commercially picked, packed, transported and ripened at the Brisbane markets before being irradiated and stored to simulate conditions typical of fruit consigned from one of Queensland’s main production regions to export markets in either New Zealand or the USA.

Kensington Pride fruit were commercially picked and packed at Manbulloo’s property (Ayr) on 5/11/2015. The pallet consignment was transported using a refrigerated Aurizon rail container to Fresh Produce Group at Rocklea over the 6-8/11/2015 period. The pallet consignment was ripened at Fresh Produce Group at Rocklea between the 10-13/11/2015. The mangoes were exposed to the usual supply chain conditions which can include temperature fluctuation, possible disruption to the cool chain, and trans-shipping.

The pallet was then transported using a refrigerated truck to Steritech at Narangba on 16/11/2015. The pallet was stacked from the standard wooden pallet (12 x Mod12 trays per layer) onto a skip pallet for irradiation treatment (10 x Mod12 trays per layer). Tray position on the pallet was recorded and dosimetry loggers inserted into selected layers in the pallet. The dosimetry loggers were placed amongst the fruit trays in nine positions per pallet layer, eight of which were 100mm in from the pallet edge with one logger in the centre of each pallet layer. This accommodated the interlocking nature of the Mod12 trays up the pallet. Eight trays (4 reps x 2 storage treatments) were set aside during this repacking process in the 12°C cool room for allocation to the trial control treatments.

Fruit irradiation

On 16/11/2015 the pallet was irradiated to achieve a minimum dose of 400Gy based on the pallet volume and weight. Following irradiation, the pallet was repacked separating class 1 and class 2 trays and removing dosimetery loggers. The control and treated fruit were then stored overnight at 12°C in a cool room, but separately wrapped in gauze cloth. This was done so that control fruit wouldn’t jeopardise the post treatment (irradiated) status of other product in the storeroom.

On 17/11/2015 the dosimetry data was analysed and mapped for the treated pallet. Eight trays were selected in the pallet that each received 440Gy, 640Gy and 840Gy and these removed for quality assessments under two storage treatments. Tray labelling was updated with the dose received. Trays were loaded into an air conditioned car and immediately transported to the Ecosciences Precinct (Dutton Park, Brisbane) cool rooms for assessment and storage.

Fruit storage

The trial fruit were divided into two storage treatments. Half the fruit were held at 12°C for the first seven days post irradiation and then moved to 20°C with 75% relative humidity for the remaining 11 days. The other half of the fruit were held for the entire 18 day assessment period at 20°C with 75% relative humidity.

Fruit assessment

Fruit quality assessments were conducted at days 1, 4, 7, 10, 14 and 18 days post irradiation treatment. Each fruit was assessed for firmness, skin colour, lenticel spotting and skin browning according to the rating scales in the Mango Quality Assessment Manual (Holmes et al, 2009). Kensington Pride mangoes are considered eating ripe at firmness 5.

Table 1: Firmness rating scale (comparable with the rating of Holmes et al., 2009).

Rating	Description
1	Hard (no ‘give’ in the fruit)
2	Rubbery (slight ‘give’ in the fruit with strong thumb pressure)
3	Sprung (flesh deforms by 2-3 mm with moderate thumb pressure)
4	Firm soft (whole fruit deforms with moderate hand pressure)
5	Soft (whole fruit deforms with slight hand pressure)

Table 2: Skin colour rating scale (Holmes et al., 2009).

Rating	Description
1	0-10% yellow
2	10-30% yellow
3	30-50% yellow
4	50-70% yellow
5	70-90% yellow
6	90-100% yellow

Table 3: Lenticel spotting rating scale (Holmes et al., 2009).

Rating scale	Rating %*
0	Nil
1	Dense, pronounced spots on not more than 5% of the surface
2	Dense, pronounced spots on not more than 10% of the surface or scattered, pronounced spots on not more than 25% of the surface
3	Dense, pronounced spots on not more than 25% of the surface or scattered, pronounced spots on not more than 50% of the surface
4	Dense, pronounced spots on not more than 50% of the surface or scattered, pronounced spots on not more than 50% of the surface
5	Dense, pronounced spots on more than 50% of the surface

*The rating refers to the percentage of the overall area of skin affected by lenticel spotting. Dense = spots no more than 2mm apart.

Table 4: Skin browning rating scale (Holmes et al., 2009).

Rating	Description
0	Nil
1	Less than 1cm2
2	1 - 3cm2 (approx. 3%, 5 cent coin)
3	3 - 12cm2 (approx. 10%)
4	12cm2 (approx. 10% - 25%)
5	More than 25%

During the scheduled fruit assessments, fruit suspected of showing signs of stem end rot infection (probably due to *Dothiorella dominicana* but not identified) were removed due to the likelihood of interference with the fruit quality assessment parameters as well as the likelihood of accelerating fruit to fruit infection within the trays.

Following the day 18 fruit assessment, two samples of fruit were selected from the 840Gy treatment. Twenty fruit were selected with significant damage (skin browning) and twenty fruit without damage and then all fruit were tested for fruit Brix levels using an Atago PAL-1 Digital Hand-held Refractometer. This was done as it was suspected that the fruit with skin browning were either less mature or had not ripened as much as the undamaged fruit due to their firmer, greener and sometimes thinner fruit appearance under the skin browning (Image 1). This assessment was only an opportunistic look because if a rigorous assessment of Brix at ripe was undertaken, all fruit would have to be in a similar ripe condition.

Image 1: A photograph of the fruit selected for Brix assessment at the conclusion to the exterior fruit quality assessment at day 18. Twenty fruit with and without skin browning damage were selected from the highest irradiation dose treatment (840Gy).

Statistical analysis

Statistical analysis was performed using GenStat (2015). The effect of irradiation dose and storage conditions on fruit firmness, skin colour, lenticel discolouration, skin colour and skin browning was tested. Analyses were performed (using a significance level of 5%) to determine if differences between factor levels were significant. The time-series nature of the data was taken into account by an analysis of variance of repeated measures (Rowell and Walters 1976), via the AREPMEASURES procedure of GenStat (2015). This forms an approximate split-plot analysis of variance (split for time). The Greenhouse-Geisser epsilon estimates the degree of temporal autocorrelation, and adjusts the probability levels for this. Individual trays of fruit were considered as the ‘experimental units’ or replicates, while individual fruit were regarded as sub-samples. Hence taking the average of thirteen fruit per tray gave continuous measurements, as assumed in the ANOVAs. The residual plots were all approximately normal, so no transformations were considered.

Outputs

Data collected during the trial are presented in the following sections on dosimetry and fruit assessment characteristics.

Dosimetry

Data from the nine dosimetry loggers placed per layer on layers one, two, five, six, nine, 10 and 13 from the base of the pallet are presented in the following tables. The irradiation dose recorded by each logger was recorded and averaged in the following figures with the detailed data presented in Appendix 1. The data is colour-coded to assist in interpretation where blue shading indicates the lowest irradiation dose recorded, yellow the mid-level figures and red the highest dose of irradiation recorded. The data suggests that the irradiation is lowest towards the bottom of the pallet in the middle depth of the pallet whereas the highest level is at the top of the pallet on the front and back of the pallet in relation to exposure to the irradiation source. This would infer that the fruit at greatest risk of irradiation damage are those on the front or back of the pallet at least five layers up from the base of the pallet.

Table 5: Averaged dose (Gy) of thirteen layer high trial pallet - side view (full data in Appendix 1).

	Back		Front
L13	830	611	832
L12			
L11			
L10	793	441	744
L9	784	453	729
L8			
L7			
L6	797	456	767
L5	765	430	778
L4			
L3			
L2	773	457	731
L1	704	510	639
		Left side of skid pallet	

Table 6: Averaged dose (Gy) of trial pallet - front view (full data in Appendix 1).

	Left		Right
L13	749	749	776
L12			
L11			
L10	679	601	698
L9	680	584	702
L8			
L7			
L6	701	609	711
L5	684	599	690
L4			
L3			
L2	645	619	697
L1	604	612	637
		Front of skid pallet	

Once the pallet had been mapped, the treatments were assigned to eight trays per irradiation treatment then four each randomly assigned to the two storage treatments. The resultant dose for each replicate tray for each irradiation treatment and each storage treatment is as follows;

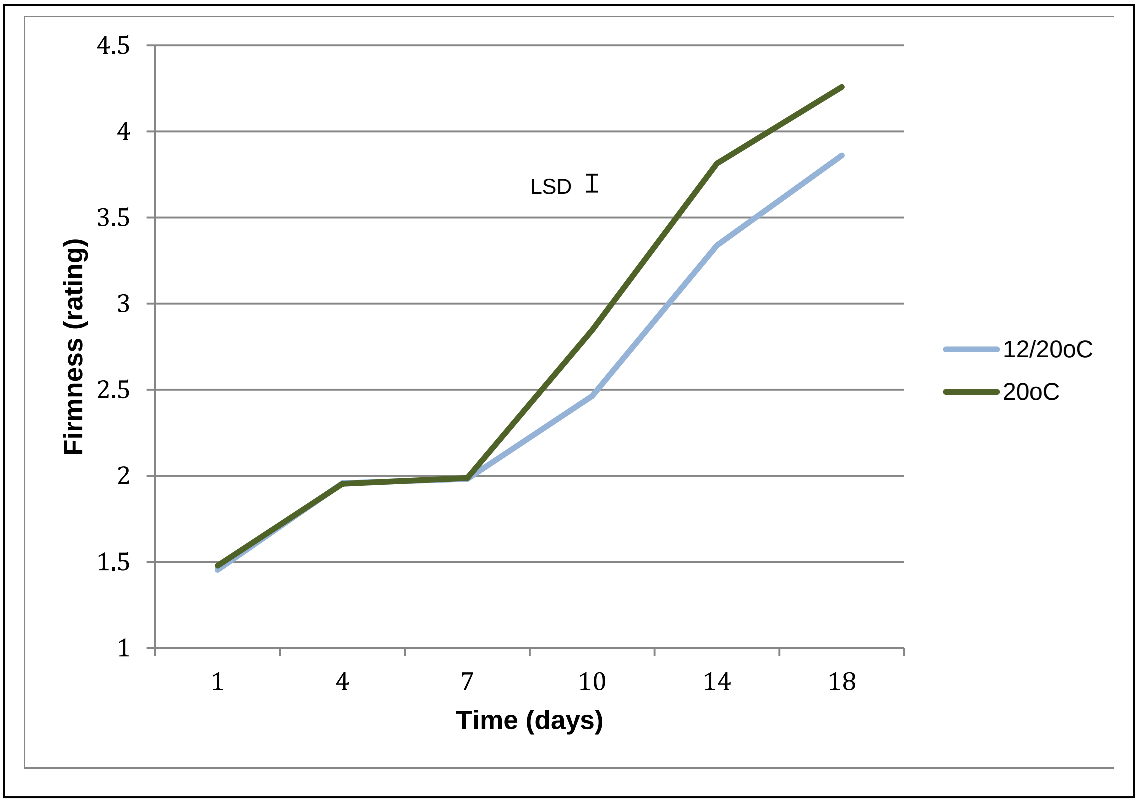
Table 7: Treatment dosage (Gy) (using closest dosimeter in or against carton edge) where s refers to the two storage treatments and i the four irradiation treatments.

	Intended	Treatment replicates				Treatment	Treatment
	Average	Rep 1	Rep 2	Rep 3	Rep 4	Average	Range
s1i1	0	0	0	0	0	0	0
s1i2	440	416	452	423	452	435.8	416-452
s1i3	640	674	626	603	675	644.5	603-683
s1i4	840	839	839	848	840	841.5	831-848
s2i1	0	0	0	0	0	0	0
s2i2	440	452	452	440	430	443.5	416-452
s2i3	640	683	648	684	674	672.3	603-683
s2i4	840	848	833	836	831	837	831-848

Fruit firmness

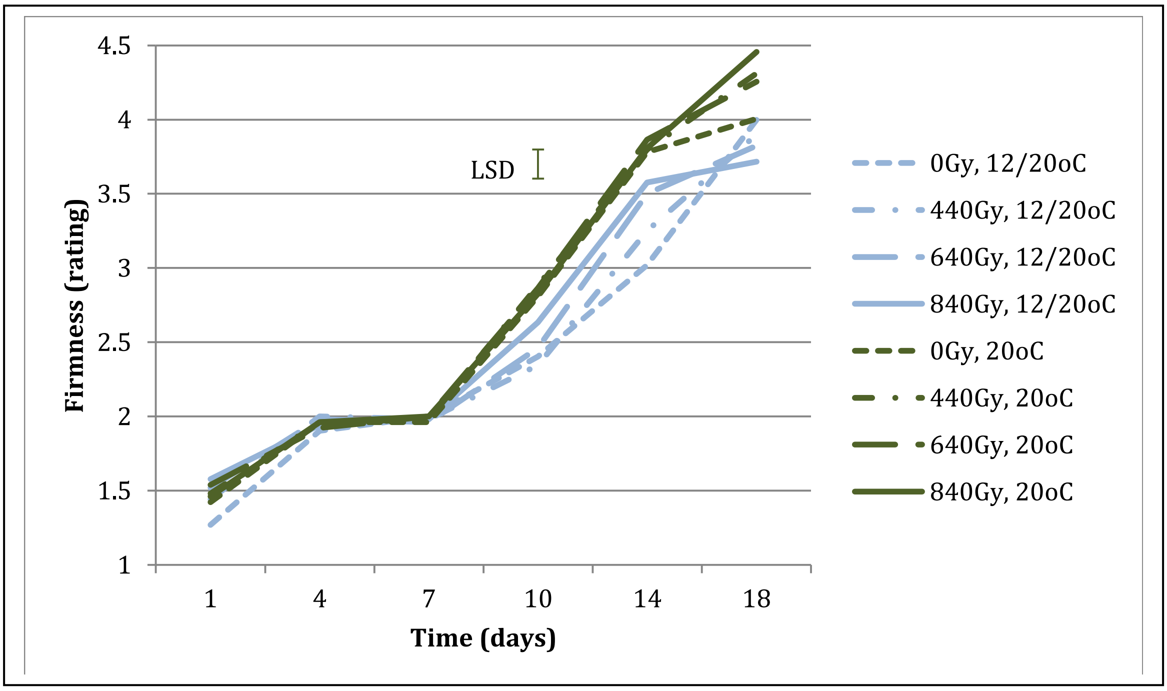
The storage treatment that held the fruit at 12°C for the first seven days significantly (P<0.001) delayed the onset of fruit softening, where rating 1 is hard and rating 5 is soft (Figure 1).

Figure 1: Changes in fruit firmness over the assessment period comparing the two storage treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.



Irradiation and storage had a significant (P<0.001) influence on fruit firmness. The effect of the different irradiation doses was small yet more pronounced in the 12/20°C storage treatment (Figure 2).

Figure 2: Changes in fruit firmness over the assessment period comparing the two storage treatments and four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.



Skin colour

Storage conditions had a significant (P<0.001) effect on skin colour (Figures 3 & 4) while irradiation levels did not. The cooler storage conditions delayed the development of yellow skin colour.

Figure 3: Changes in skin colour over the assessment period comparing the two storage treatments averaged for the four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.

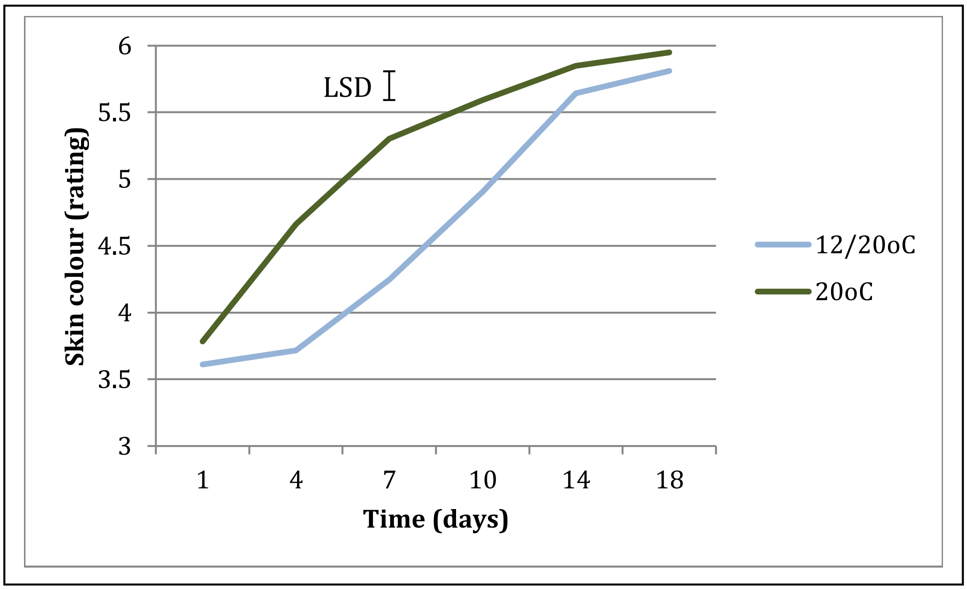
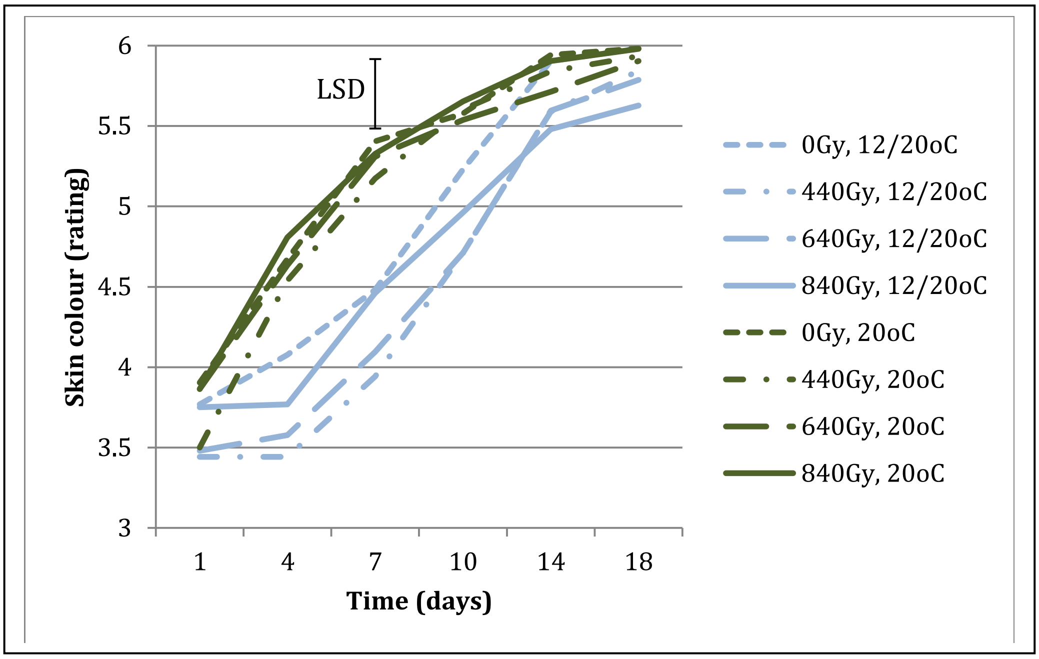


Figure 4: Changes in skin colour over the assessment period comparing the two storage and four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.



Lenticel spotting

The 12°C storage treatment caused a small but significant delay to the onset of lenticel spotting (Figure 5). All three irradiation treatments had significantly more lenticel spotting than in the control treatment (Figures 6 & 7).

Figure 5: Changes in lenticel spotting over the assessment period comparing the two storage treatments averaged across the four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.

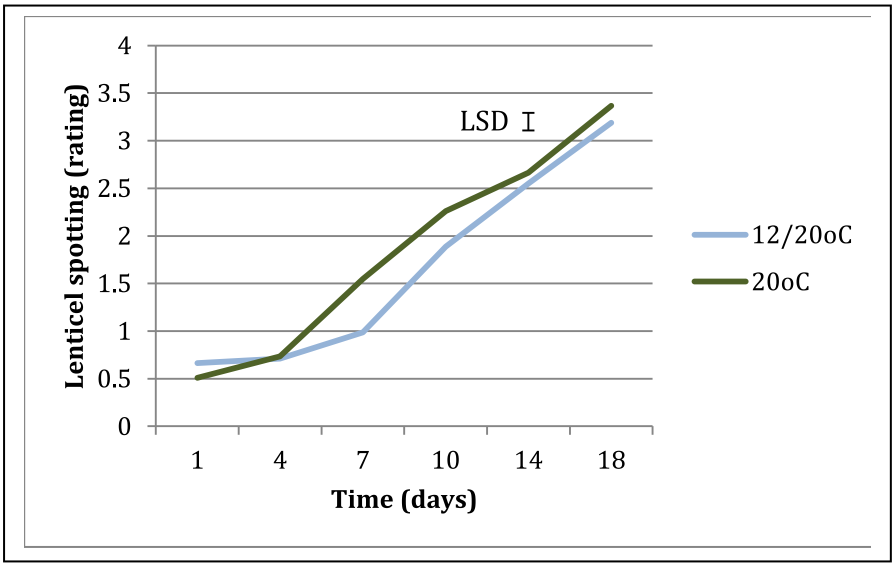


Figure 6: Changes in lenticel spotting over the assessment period comparing the four irradiation treatments averaged across the two storage treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.

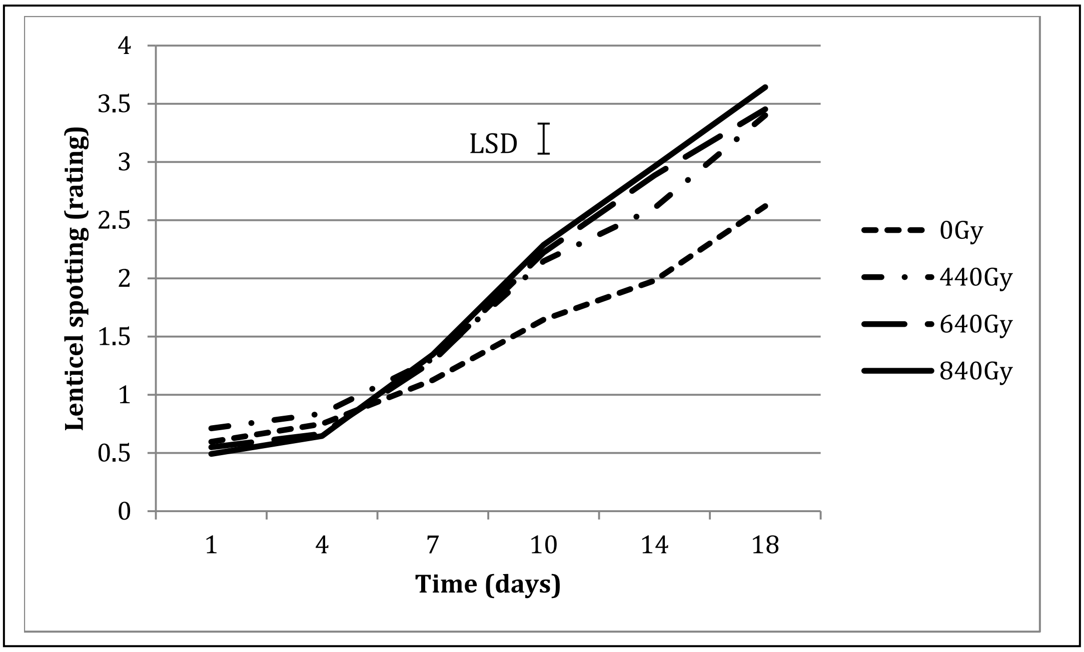
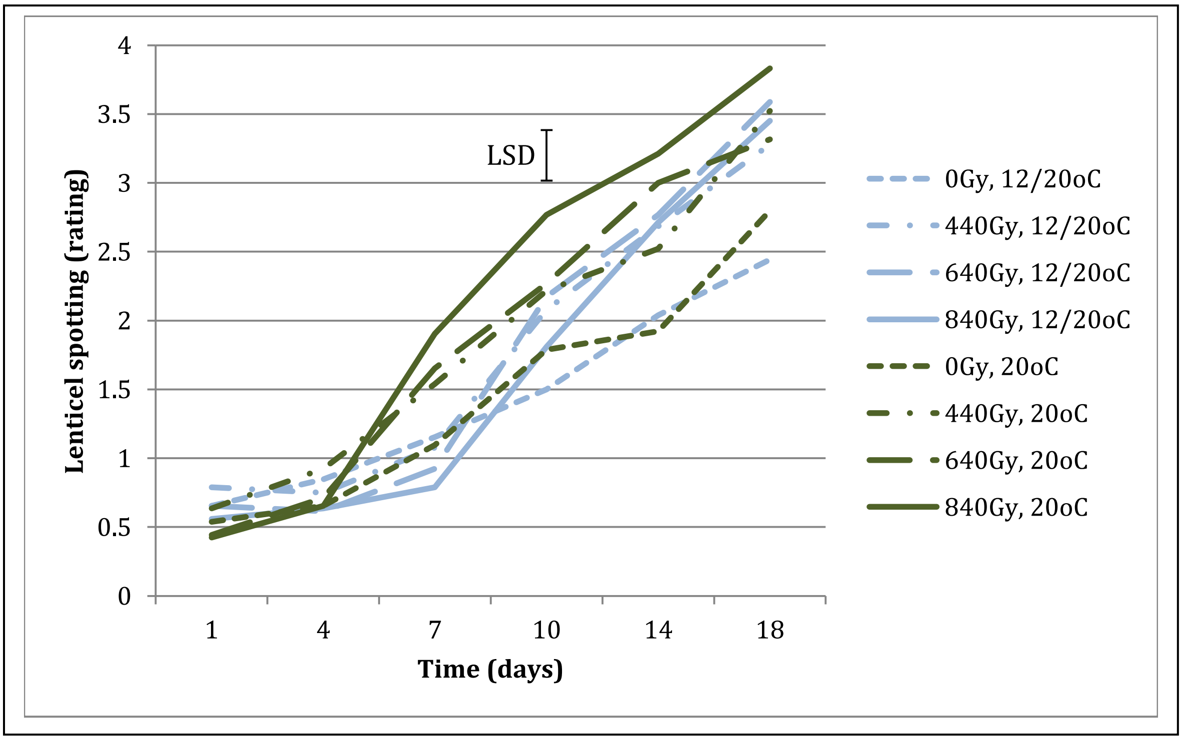


Figure 7: Changes in lenticel spotting over the assessment period comparing the two storage and four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.



Skin browning

There was no significant effect of the storage treatment on skin browning, although the irradiation treatments, particularly at the levels of 640Gy and 840Gy had significantly more and earlier skin browning than the lower doses (Figures 8 & 9).

Figure 8: Changes in skin browning over the assessment period comparing the four irradiation treatments averaged for the two storage treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.

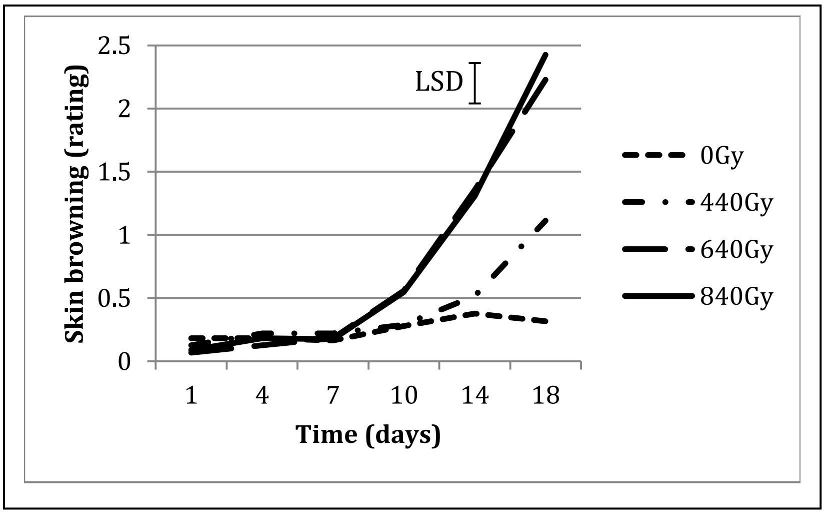
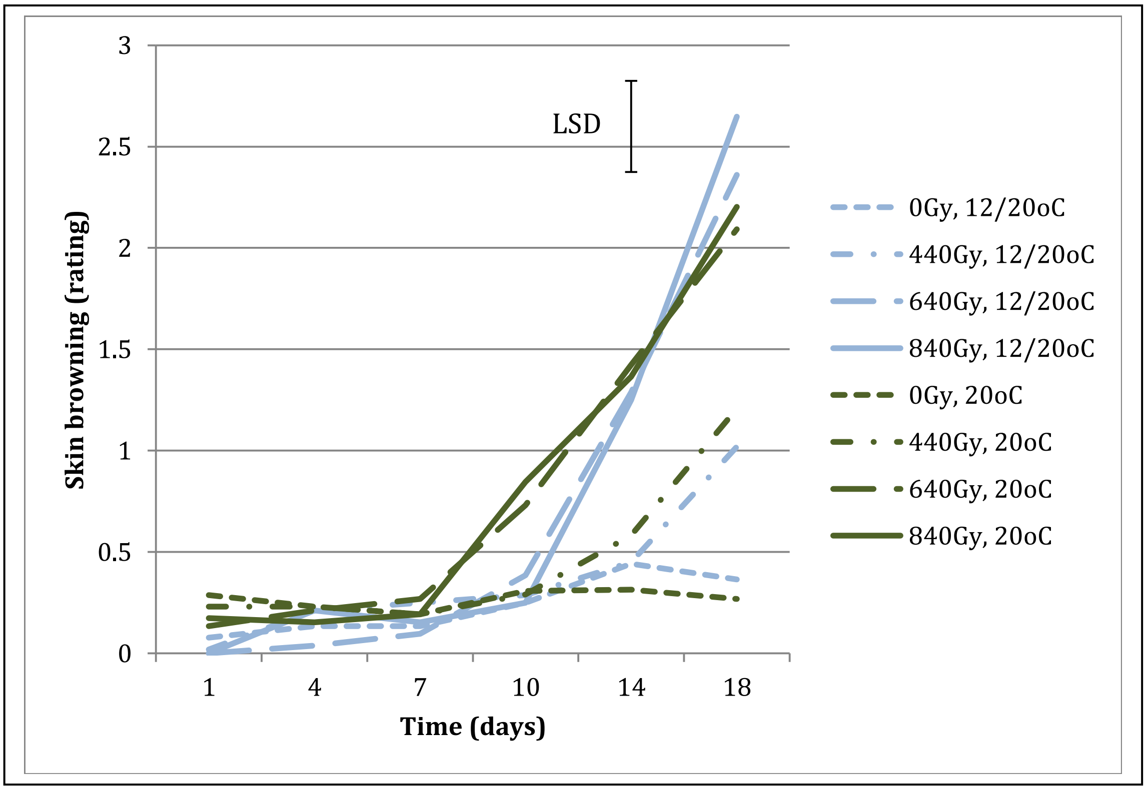


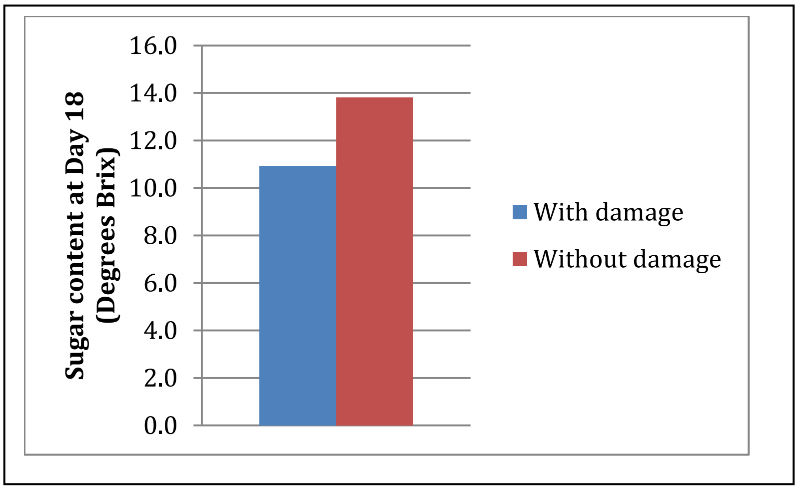
Figure 9: Changes in skin browning over the assessment period comparing the two storage and four irradiation treatments. For each assessment time, differences between the storage treatments that are greater than the LSD bar are considered to be statistically different at the 95% confidence level.



Fruit Brix

Averaged fruit Brix levels were significantly ($P<0.001$) different in the fruit with damage when compared with the fruit selected without damage (Figure 10).

Figure 10: Average °Brix levels in fruit with and without damage from the 840Gy irradiation dose treatment



Other

Most suspected stem end rot became apparent at the day 14 and day 18 assessments. A total of 6% of fruit succumbed to stem end rot over the 18 day assessment period and there was no discernible link between the incidence of suspected stem end rot and either the storage or irradiation treatments.

Outcomes

Predicting the impact of irradiation on mango quality is important to enable exporters to gauge the potential for and to manage the risk associated with using irradiation as a treatment protocol. There are a suite of variables affecting the likelihood of damage from irradiation including where and how the fruit are grown, the environmental conditions leading up to and at harvest, the post treatment storage conditions as well as the mango variety itself. The trial undertook detailed dose mapping of a commercial sized pallet using Mod12 trays suitable for cost effective export, to better understand the likely variation in dose anticipated in pallets of fruit exposed to irradiation. This trial also examined the effect of irradiating pre-ripening Kensington Pride mangoes using two post irradiation storage regimes, three irradiation level treatments (plus a control). Combined this was designed to give an exporter a reasonable expectation of what potential damage will occur, when and where in the pallet of commercially pre-ripened Kensington Pride mangoes.

Dosimetry illustrated that the irradiation service provider's process of using pallet density to define the length of exposure to reach a desired minimum irradiation dose, worked well. However it also reinforced the risk that the dose required to ensure the minimum dose (400Gy) to all fruit can result in some fruit receiving more than 850Gy. This equates to a Dose Uniformity Ratio (DUR) of well over 2.0. This can pose risk of the fruit being damaged, depending on the variables mentioned above. The dose mapping and quality assessment suggests that the fruit at greatest risk of quality loss are those in trays at the front or back (rather than in the middle) of the pallet. These trays should be targeted during export market quality inspections at arrival.

Not surprisingly, the use of 12°C storage for the first seven days (then 20°C for the remaining 11 days of assessment) post irradiation held back the ripening of the fruit by 2 and 5 days as indicated by fruit firmness and skin colour, respectively when compared with fruit held at 20°C for the entire 18 day assessment period. The cooler storage condition also delayed the expression of lenticel spotting and skin browning by about 3 days.

The irradiation dose did not have a significant effect on fruit ripening for this pre-ripened fruit, but all three irradiation doses (440Gy, 640Gy and 840Gy) resulted in higher (but similar) lenticel spotting than the control treatment (0Gy). Fruit receiving 640Gy and 840Gy did show a greater level of skin browning than those receiving 440Gy or 0Gy. Cool storage delayed the start of visible skin browning by 3 days (from 7 to 10 days after irradiation) for the 640Gy and 840Gy treatments, while skin browning in the 440Gy treatment did not start to express until day 14 after irradiation. Skin browning with a rating of greater than 2 exceeds the accepted Australian grade 1 industry standard at retail.

The anecdotal, yet significantly different, fruit Brix levels at day 18 in the fruit exposed to 840Gy with and without damage has at least three possible explanations

- The less mature fruit in the trays incurred the worst skin browning, which could only be confirmed if measures of individual fruit dry matter levels had been taken at the start of the trial,
- The high irradiation dose (840Gy) retarded the ripening process in some fruit, including colour and firmness changes along with the conversion of starches to sugars.

Evaluation and Discussion

These results have the following implications in relation to irradiation disinfestation of 'Kensington Pride':

- Previous research indicated that irradiation damage can be reduced by treating fruit that have been pre-ripened to at least colour stage 3.
- There is still considerable variation in doses received by fruit throughout the pallet, with the highest doses received by fruit mid height in the pallet at the front or the back.
- Even the minimum dose of 440Gy increased lenticel spotting, while doses from 640Gy increased skin browning. Inspecting the fruit in the locations that received the highest doses will give a good indication of maximum likely damage.
- Low temperature holding delayed both ripening and damage expression but did not affect the loss of quality if fruit are ripened to the ripe stage.
- Previous research suggests that fruit harvested soon after or during rain are more likely to develop lenticel damage, and these should not be irradiated for export.

The planned use of out-turn quality assessments in the export markets together with monitoring of conditions in the supply chain are both key to understanding the interplay of factors affecting quality, maximising saleability and securing long term profits.

This work assumes the need to maximise the value that can be achieved from supply chains. The most important aspect to this is understanding and delivering customer expectations for the product. Class 1 mango grade standards in Australian retail outlets (including limits for similar aspects graded for in the packing sheds) also includes emergent fruit ripeness (colour and firmness), fruit maturity (Brix levels), emergent fruit quality characteristics (limits on sap-burn, skin browning etc) and other critical aspects (fruit temperature). Confirming that the customer needs in overseas markets mirror those Class 1 standards in Australia is important to increasing market share and customer satisfaction.

While the current risk of high irradiation dose can be better understood to make monitoring the potential impact more efficient, to significantly lower the Dmax (and DUR) would require an alternate irradiation treatment process. While the pallet system in place is cost effective for many products, for sensitive products like mangoes it is not ideal. Creating an inline system that treats one tray at a time world offer vastly reduced Dmax levels and significantly lower the risk of irradiation damage in mangoes. Another alternative would include an alternate treatment protocol for mangoes entering USA that reduces the risk of damage to the fruit while maintaining biosecurity.

Further trial work that would probably reduce the risk of irradiating mangoes would include assessing the impact of irradiating mangoes of differing maturity (non-destructive dry matter assessment using near Infra-red technology) at or before irradiation, then following fruit through monitoring levels of damage and resultant Brix levels at eating ripe.

Scientific refereed publications

None were developed as a result of this investigation.

Intellectual Property

No commercial IP was generated as a result of this investigation.

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Appendices

Appendix 1 Dosimetry

This is the '**Body style**' and should be used for general content. Any words that need emphasis should use the '**Bold**' or '*Italic*' character styles.

Front view - average

	Left (P1)		Right (P3)
L13	749	749	776
L12			
L11			
L10	679	601	698
L9	680	584	702
L8			
L7			
L6	701	609	711
L5	684	599	690
L4			
L3			
L2	645	619	697
L1	604	612	637
		Front of skid pallet	

Front view - front

	Left (P1)		Right (P3)
L13	839	848	810
L12			
L11			
L10	763	674	795
L9	738	648	801
L8			
L7			
L6	808	684	810
L5	839	683	812
L4			
L3			
L2	697	674	823
L1	603	626	687
		Front of skid pallet	

Front view - middle

	Left (P1)		Right (P3)
L13	547	636	650
L12			
L11			
L10	440	430	452
L9	473	420	465
L8			
L7			
L6	465	418	486
L5	423	416	452
L4			
L3			
L2	469	410	491
L1	533	469	529
		Front of skid pallet	

Front view - back

	Left (P1)		Right (P3)
L13	861	763	867
L12			
L11			
L10	833	699	848
L9	828	683	840
L8			
L7			
L6	831	725	836
L5	791	699	806
L4			
L3			
L2	769	773	778
L1	675	742	696
		Front of skid pallet	

Side view - average

	Back (RC)		Front (RA)
L13	830	611	832
L12			
L11			
L10	793	441	744
L9	784	453	729
L8			
L7			
L6	797	456	767
L5	765	430	778
L4			
L3			
L2	773	457	731
L1	704	510	639
		Left side of skid pallet	

Side view - left

	Back (RC)		Front (RA)
L13	861	547	839
L12			
L11			
L10	833	440	763
L9	828	473	738
L8			
L7			
L6	831	465	808
L5	791	423	839
L4			
L3			
L2	769	469	697
L1	675	533	603
		Left side of skid pallet	

Side view - middle

	Back (RC)		Front (RA)
L13	763	636	848
L12			
L11			
L10	699	430	674
L9	683	420	648
L8			
L7			
L6	725	418	684
L5	699	416	683
L4			
L3			
L2	773	410	674
L1	742	469	626
		Left side of skid pallet	

Side view - right

	Back (RC)		Front (RA)
L13	867	650	810
L12			
L11			
L10	848	452	795
L9	840	465	801
L8			
L7			
L6	836	486	810
L5	806	452	812
L4			
L3			
L2	778	491	823
L1	696	529	687
		Left side of skid pallet	

Appendix 2 Irradiation trial photos (0Gy, Storage 12/20°C)

Treatment details: Control dose 0Gy, Storage @ 12°C for first 7 days, then 20°C for last 11 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 3 Irradiation trial photos (440Gy, Storage 12/20°C)

Treatment details: Irradiation dose 440Gy, Storage @ 12°C for first 7 days, then 20°C for last 11 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 4 Irradiation trial photos (640Gy, Storage 12/20°C)

Treatment details: Irradiation dose 640Gy, Storage @ 12°C for first 7 days, then 20°C for last 11 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 5 Irradiation trial photos (840Gy, Storage 12/20°C)

Treatment details: Irradiation dose 840Gy, Storage @ 12°C for first 7 days, then 20°C for last 11 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 6 Irradiation trial photos (0Gy, Storage 20°C)

Treatment details: Irradiation dose 0Gy, Storage @ 20°C with 75% relative humidity for 18 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 7 Irradiation trial photos (440Gy, Storage 20°C)

Treatment details: Irradiation dose 440Gy, Storage @ 20°C with 75% relative humidity for 18 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 8 Irradiation trial photos (640Gy, Storage 20°C)

Treatment details: Irradiation dose 640Gy, Storage @ 20°C with 75% relative humidity for 18 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18				

Appendix 9 Irradiation trial photos (840Gy, Storage 20°C)

Treatment details: Irradiation dose 840Gy, Storage @ 20°C with 75% relative humidity for 18 days.

Days after irradiation	Rep 1	Rep 2	Rep 3	Rep 4
Day 1				
Day 4				
Day 7				
Day 10				
Day 14				
Day 18