Previously published in: Anonymous. 2008. CRI Group Annual Research Report for January 2007 to March 2008. Citrus Research International, Nelspruit, South Africa. pp. 530-550.

EFFECTS OF IRRADIATION ON PRODUCT QUALITY OF CITRUS, WITH EMPHASIS ON RIND AND SENSORY QUALITY

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Summary

During the 2005 and 2007 seasons, citrus fruit were tested for sensitivity to a wide range of irradiation dosages. Three cultivars were used *viz*. Clementine mandarin, Navel orange and lemon and their rind conditions as well as internal quality aspects were evaluated. The irradiation dosages used in 2005 were as follows; 0, 75, 100, 225, 300, 450, 600, 750 and 900 Gy and in 2007; 0, 300, 400, 500, 600 en 700 Gy. The irradiation treatments were administered at Hepro's BP1 cobalt pallet irradiator in Montague Gardens, Cape Town. Thereafter the fruit were stored at 4°C for a maximum period of 10 weeks. During this period samples were taken every 2 weeks for the visual rind and internal quality evaluations. In both seasons, irradiation affected internal quality aspects, e.g. the total sugar content was increased, while juice content decreased in some varieties. Irradiation leads to a drastic increase in decay of especially lemon fruit during storage, as well as a very high incidence of rind physiological disorders. Navel orange and Clementine mandarin rind quality were both negatively affected at high dosages but lemon rind was extremely sensitive even at low dosages. Off-taste also developed in the irradiated fruit as the time in storage increased (probably due to anaerobic respiration setting in). On the whole, irradiation at 300 Gy seems to be the limit at which certain citrus species could tolerate this treatment. However, there are other aspects also playing a role, such as season-to-season and fruit-to-fruit variation, but cultivar choice seems to be the biggest factor in determining sensitivity to irradiation. Type of irradiation equipment is also very important and the whole pallet system used in this experiment does not seem to be a practical solution. The reason being that those fruit positioned in the outside cartons of the pallet are exposed to very high dosages (3-4 times required) in order to realise the desired dose in the middle of the pallet.

Introduction

Citrus fruit exported to certain markets, especially those with a citrus industry of their own, have to undergo strict commercial insect quarantine treatments in order to comply with phytosanitary trade barriers. There are a few options currently available and used in horticultural exports, *viz*. postharvest methyl bromide application as well as in-transit cold sterilisation treatments. However, citrus fruit react negatively to methyl bromide and develop off- tastes during storage. Therefore, export programmes of citrus fruit to special markets (prescribing insect sterilisation treatments, i.e. USA, Japan, China, Iran etc.) use cold sterilisation treatments during shipment. The level of chilling injury due to the prolonged exposure (e.g. 22 days at -0.6°C for the USA and China) can be severe and economically damaging. This loss of quality as well as questions regarding the efficacy of the cold sterilisation treatments on insect larvae has led to irradiation of fruit being studied as an alternative to cold sterilisation for the control of false codling moth and fruit fly larvae.

Irradiation was approved in 1986 by the Food and Drug Administration (FDA) in the USA for use on fruit and vegetables at up to 1 kGy (100 krad). Even though most research has focussed on extending fruit and vegetable life by reducing decay organisms, irradiation has been shown to have a high efficacy of killing, sterilising or preventing further development of various insect species. The dosages required have also been illustrated to be significantly lower for insect sterilisation than necessary for effective decay control (Mitcham, 1999). In various studies this low dose of gamma irradiation as a quarantine treatment has been shown to be effective for various insect species, for example Hall and Martinez (2001) reported a minimum dose for Mexican fruit fly of 58-69 Gy to be effective even though 3 times higher could be absorbed by the citrus fruit without damage to the fruit.

Reports on dose levels detrimental to fruit quality (internal and external) vary. This is probably due to the irradiation equipment and experimental set-up used. The Floridian researchers (Miller and McDonald, 1996) applied 0.3 or 0.6 kGy to 15 fruit packed in a commercial fibreboard citrus box. The minimum and maximum deviations were 0.23 and 0.33 kGy and 0.49 and 0.67 kGy for the 0.3 and 0.6 kGy treatments, respectively. From the report it seems that these fruit were irradiated in single cartons and not palletised. They concluded that grapefruit used in the experiment tolerate dosage of 0.3 kGy without serious damages, however at 0.6 kGy severe rind damage developed in 12.5% of treated fruit during storage. Ladaniya *et al*. (2003) in India, irradiated 24 fruit (not describing the container or if palletised) of three cultivars, *viz*. 'Nagpur' mandarin, 'Mosambi' orange and 'Kagzi' acid lime at 0.25, 0.5, 1 and 1.5 kGy at the rate of 2.5 kGy/h with the D_{max}/D_{min} ratio of 1:21. Treatments were done in such a manner that 90% of fruit received the target dosage, which suggests the use of non-palletised irradiation equipment. They reported effective control of *Penicillium* rot at 1.5 kGy, but no positive result on *Alternaria citri* and *Bortyodiplodia theobromae.* Rind damage was recorded on oranges as well as a reduction in firmness, acidity and Vitamin C content at most dosages. They also found higher TSS in all irradiation-treated fruit as well as a significant increase in respiration.

Irradiation of 'Rio Red' grapefruit with 70, 200, 400 and 700 Gy by Patil *et al*. (2004) in what seems to be non-palletised conditions, showed that not only does irradiation dosage play a role in eventual quality but also fruit maturity (time of harvest). Early season fruit were more sensitive than later hanging fruit. They also showed at lowered dosages (≤ 200 Gy) an enhancement of health-promoting compounds (flavonone, Vitamin C, limonin glycoside), but treatments ≥ 400 Gy increased the incidence of rind disorders. Canopy position of grapefruit also had an effect on irradiation sensitivity and interior fruit had 27% compared with 15% pitting (zero in control fruit) (McDonald *et al*., 2000).

The objective of this study was to determine at which dosage three citrus types could be irradiated in a pallet system without negative impact on their fruit quality (internal and external). The second object was to determine the irradiation dose distribution in a pallet of fruit.

Materials and methods

The study to determine the effect of irradiation on internal and external (rind condition) quality of citrus fruit was done during the 2005 and 2007 seasons. The same cultivars and evaluation parameters were used in both seasons, although the dosages differed between the two years. The irradiation treatments were administered at Hepro's BP1 cobalt pallet irradiator in Montague Gardens, Cape Town.

The dose response study included three citrus types, namely Clementine mandarin, Navel orange and lemons. All the fruit received normal commercial postharvest packhouse treatments, i.e. chlorine bath, drying tunnels, fungicide treatment, waxing and packing before being irradiated. The Clementine mandarin fruit were packed in 400 x 300 mm 10 kg cartons and were calibre 2 fruit. The Navel orange and lemons were packed in 400 x 300 mm 15 kg telescopic cartons. The Navel oranges were count 64 and the lemons 115.

Irradiation treatments

The 2005 target dosages were 0 (control), 75, 100, 150, 225, 300, 450, 600, 700 and 900 Gy. For replication purposes 12 cartons per variety were used. One dosimeter was placed in the middle of each carton for a total number of twelve dosimeters per variety per dosage. The 2007 target dosages were 0 (control), 300, 400, 500, 600, 700 Gy. The dosage selections were based on the results from the 2005 data and were a narrower dose range with the dosages below and above the sensitivity dosages determined in 2005. During both seasons the cartons were stacked in a pallet with normal commercial dimensions prior to irradiation treatments. In the irradiation chamber the pallets were placed on rotation tables to ensure all sides received the same dosage.

Dose distribution

As a separate experiment in 2005, the dose distributions in a pallet of fruit were determined by placing dosimeters in positions representing all positions in separate pallets of Clementine mandarins and Navel oranges. The fruit was packed onto a pallet of 1.2 m x 1.0 m x 1.57 m (height taken from the pallet). The dosimeters were attached to rigid boards (3 mm thick) so as to provide a stable height per layer and exact positions for the dosimeters placement. An example of dosimeter distribution can be seen in Figure 1.

- The Clementine mandarin cartons were stacked to a 15 layer pallet consisting of 18 cartons per layer. The stack density was 0.51 T/m^3. The dosimeters were placed at the bottom and top of the pallet as well as in every third layer (4, 7, 10 and 13).

- The Navel orange cartons were stacked into 6 layers of 10 cartons per layer and the stack density was 0.47 T/m^3. The dosimeters were placed at the bottom, top and in the middle of the pallet.

After a total run time of 30 minutes the dosimeters were removed from the stack and read in the calibrated spectrophotometer at a wavelength of 530 nm as well as the measurements of the dosimeters taken by calibrated micrometer.

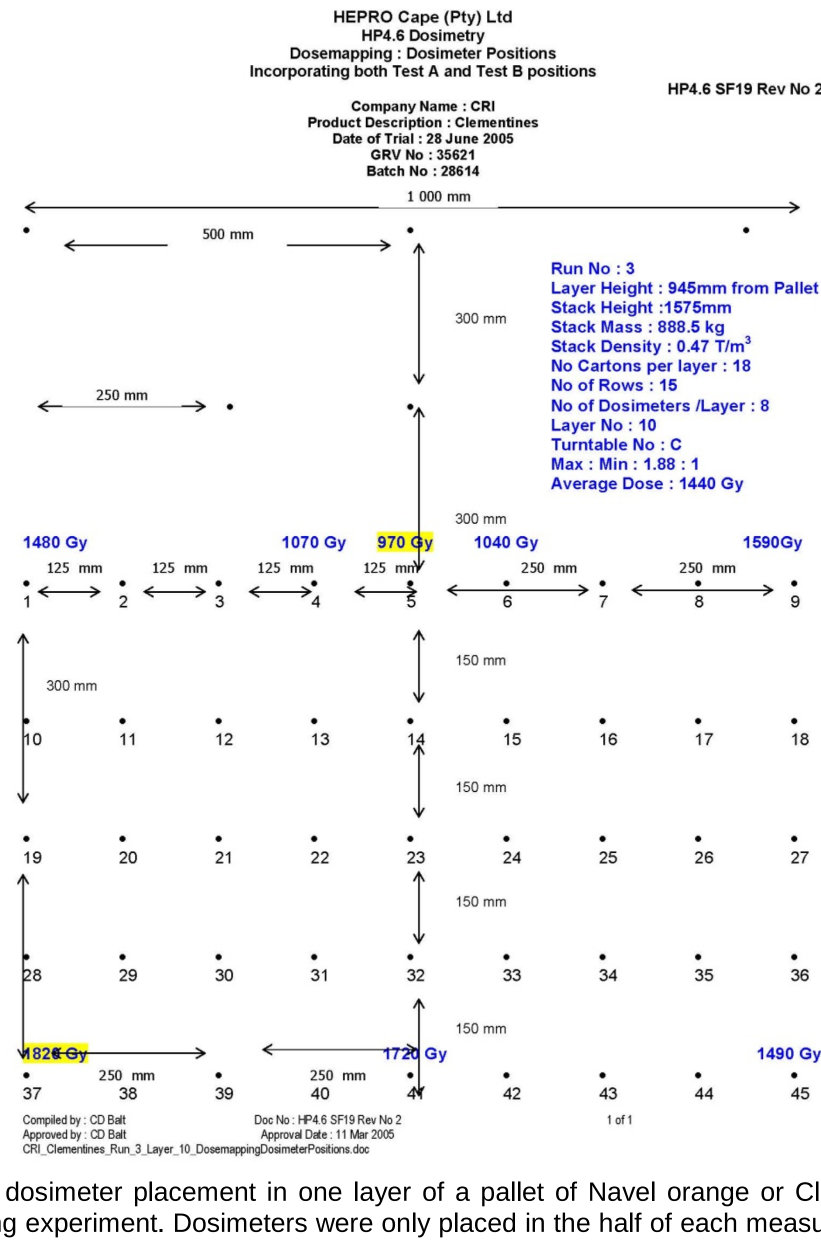

Figure 1. Example of dosimeter placement in one layer of a pallet of Navel orange or Clementine mandarin during the dose mapping experiment. Dosimeters were only placed in the half of each measured layer as pallets were rotated during irradiation and all sides of the pallet receive even doses. In the Navel orange pallet this configuration was repeated at the bottom, top and in the middle of the pallet. In the Clementine mandarin pallet the dosimeter pattern was repeated every 3rd layer (bottom, 4, 7, 10, 13 and top). The data collected from these

readings is summarised in Tables A and B. The maximum dose measured can be seen in cartons on the side of the pallet and the minimum levels were consistently measured in the middle of the pallet (position 5).

<u>Measurements</u>

After irradiation, fruit were stored at 4°C for a maximum of 10 weeks to simulate commercial handling, shipping and storage duration. Fruit were removed for evaluation every 2 weeks. For each sampling date eight replications of 10 fruit each were removed from the cold store of each variety. Severely decayed fruit were removed from the cartons and not used in the visual or internal evaluation. The first evaluation date was the day after treatment to give a baseline for changes in the internal quality evaluations. At each evaluation the fruit were first visually evaluated for various rind disorders and appearance before being destructively sampled for internal quality, i.e. °Brix, acidity, juice content and taste. The rind condition evaluations were done according to known rind disorders specific to each variety, as well as some general classes for all varieties, *viz*. browning (more internal discoloration occurring in the flavedo), scalding (a discoloration of the epiticular cells of the rind as seen in chilling injury, rind collapse (total softness of the rind followed by decay). The specific evaluation parameters per cultivar are as follows (Figures 1 and 2):

- **Clementine mandarin**: Puffiness (separation of the pulp and rind), rind collapse,.

- **Navel orange**: Pitting (dark brown depressions in the flavedo, similar to postharvest pitting and chilling injury), rind collapse, including stem end rind breakdown (SERB).

- **Lemons**: Peteca spot (oil gland leaking into flavedo/albedo resulting in a collapse of the tissue).

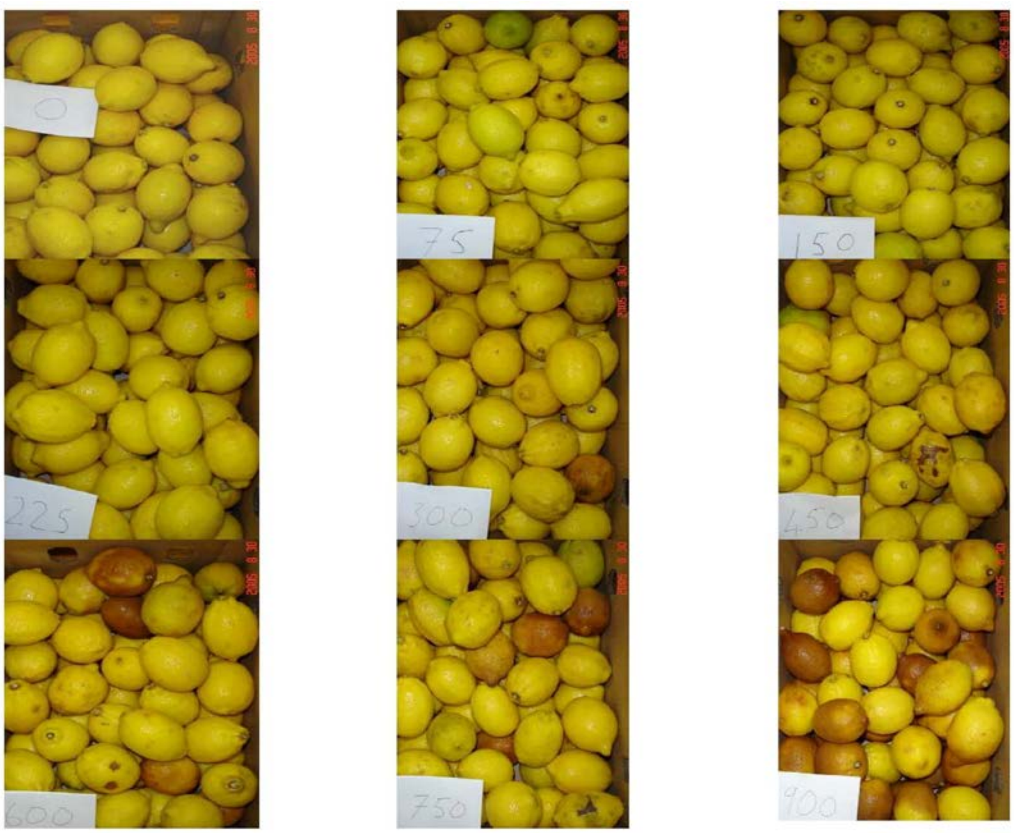

Figure 2. Effect of irradiation at 0, 75, 150, 225, 300, 450, 600, 750, and 900 Gy on lemons during 2005. Severe incidence of scalding, peteca spot and total rind collapse can be seen as the irradiation dose increases.

Figure 3. Effect of irradiation on rind condition of Navel orange (top two photos) and Clementine mandarin during 2007. Incidence of scalding, browning and SERB can be seen.

Results

<u>Fruit quality</u>

2005

<u>Navel orange</u>

Higher incidence of granulation/dryness of the pulp was seen in the irradiated fruit. The high incidence of wax flaking can more likely be attributed to application than irradiation treatment. Internal quality of the control Navel fruit had on average less variation in °Brix, acidity (TA), and juice content. The data indicate that above 75 Gy the internal quality could be affected in Navel orange fruit (Fig. 4 and 5).

<u>Clementine mandarin</u>

All the fruit in the experiment (including the control) showed a high incidence of puffiness, the most prevalent disorder in the experiment. Therefore, irradiation did not play a causative role in this disorder as well as in granulation. The rind condition was acceptable during most of the experiment and only showed signs of deterioration after evaluation 4-5 (i.e. 6-8 weeks storage). The internal quality showed a detrimental dosage response and juice content, °Brix and TA all changed on average. The result from these changes was an increase in ratio (TSS:TA) above the control at most dosages (Fig. 6 and 7).

<u>Lemons</u>

Irradiation had the biggest negative impact on the external quality of lemon fruit even though the peteca spot incidence only dramatically increased after evaluation 4, i.e. 6 weeks storage. Visually the fruit had a "tired" look and a high number of fruit were lost even before evaluation due to the high decay in the cartons (data not shown). Juice content was negatively affected after evaluation 3, i.e. 4 weeks storage, by high irradiation dosage (Fig. 8).

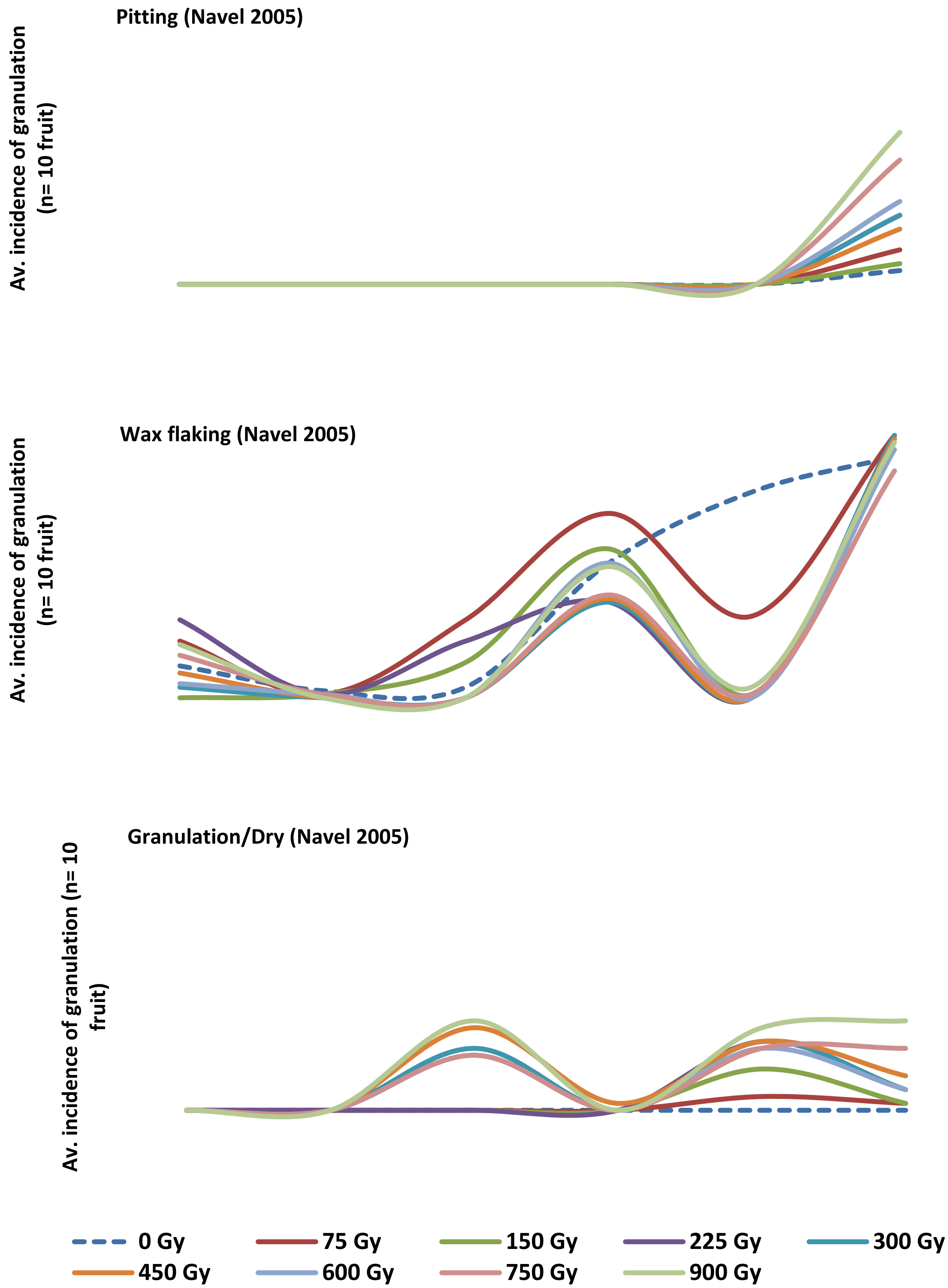

Figure 4. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2005 season on rind condition and incidence of physiological disorders of Navel orange fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

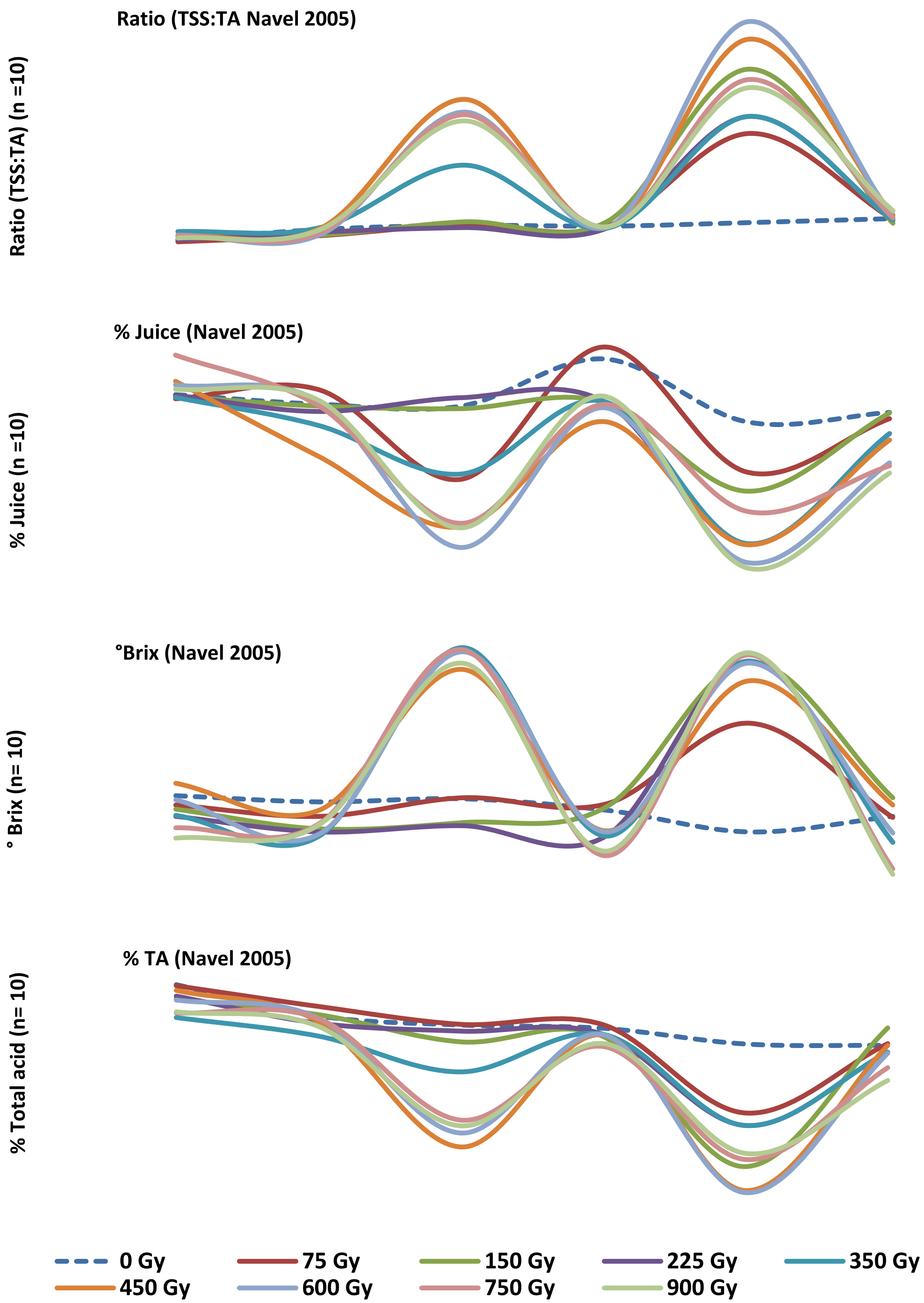

Figure 5. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2005 season on Navel orange fruit internal quality. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

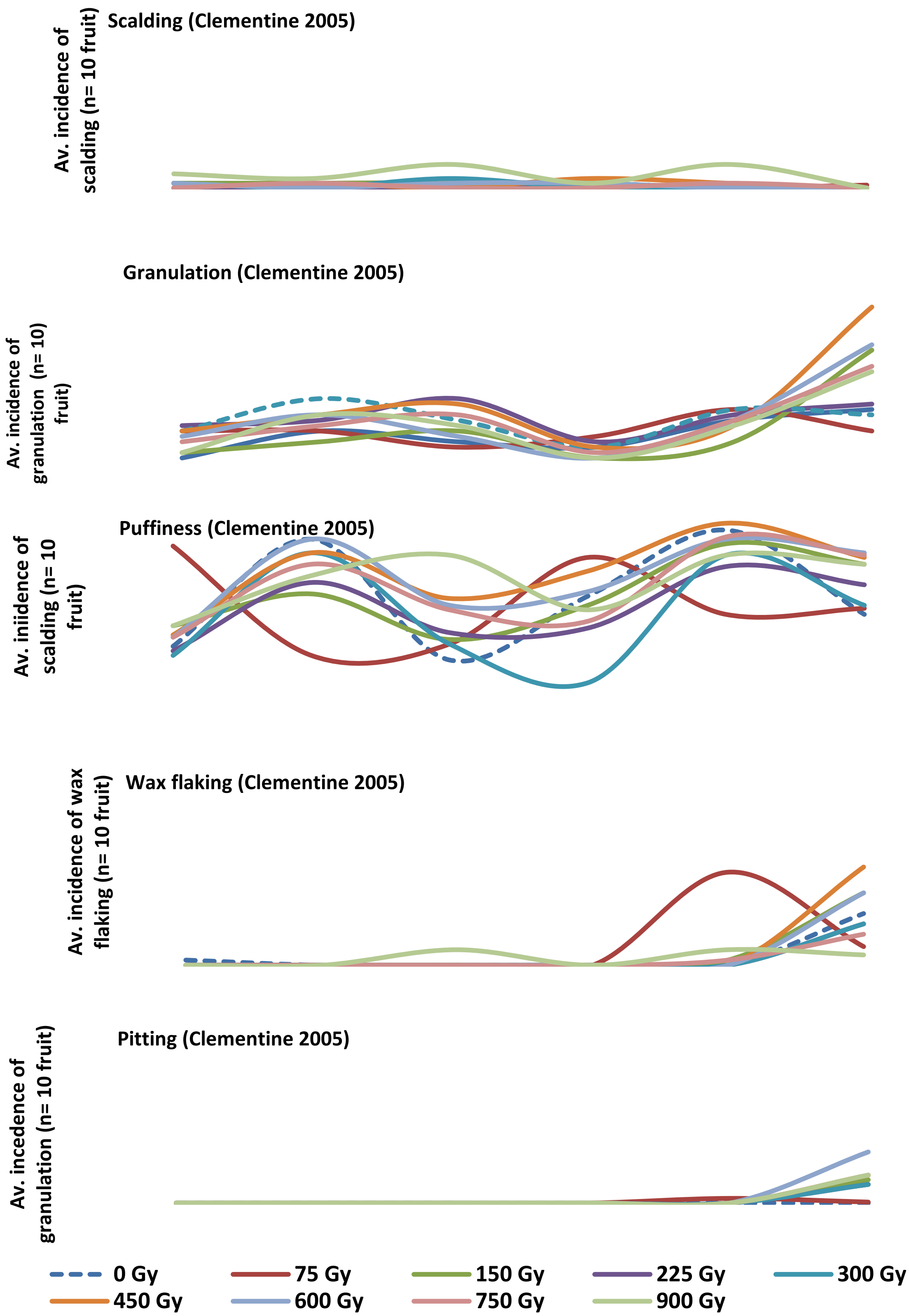

Figure 6. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2005 season on rind condition and incidence of physiological disorders of Clementine mandarin fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

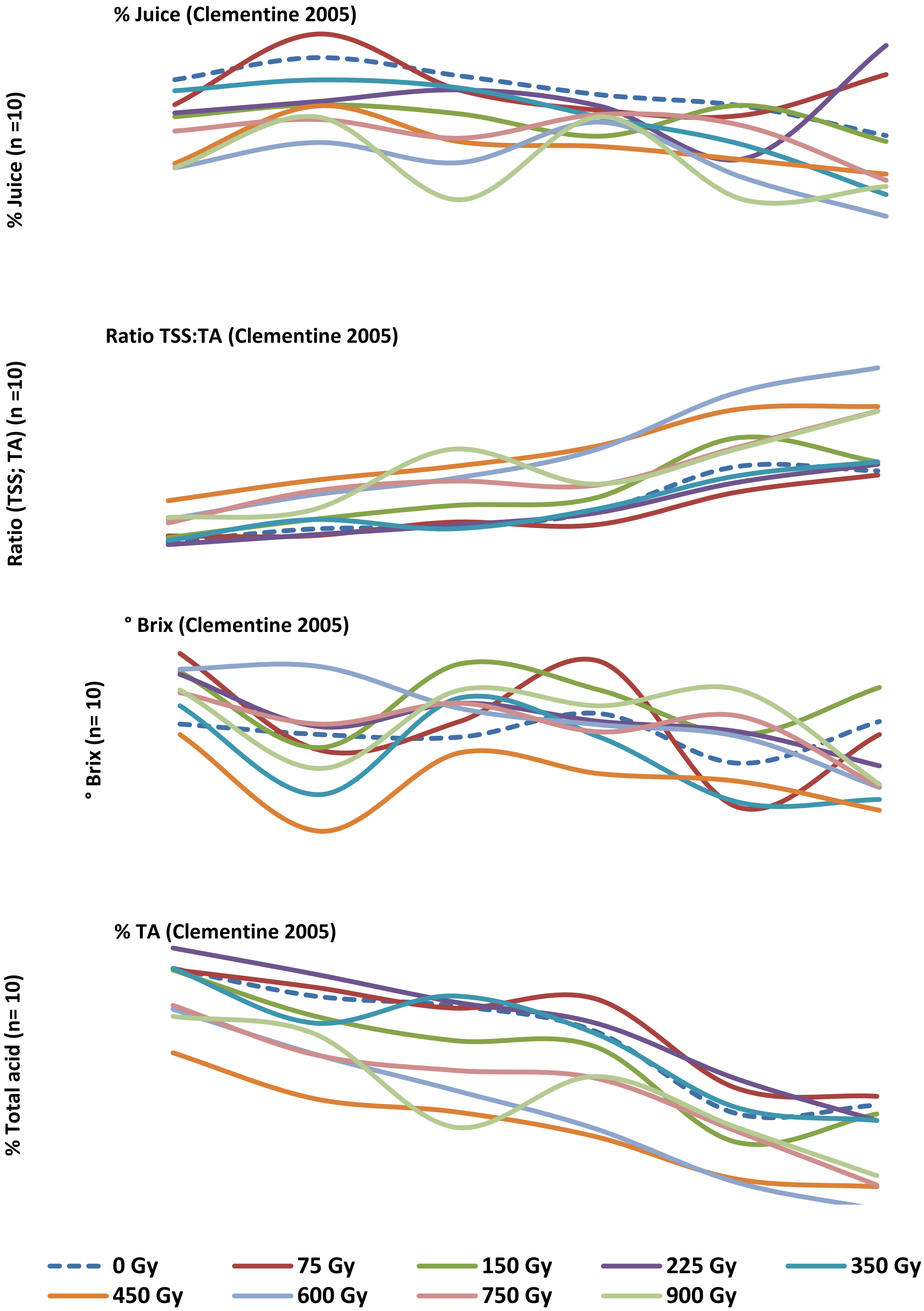

Figure 7. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2005 season on internal quality of Clementine mandarin fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

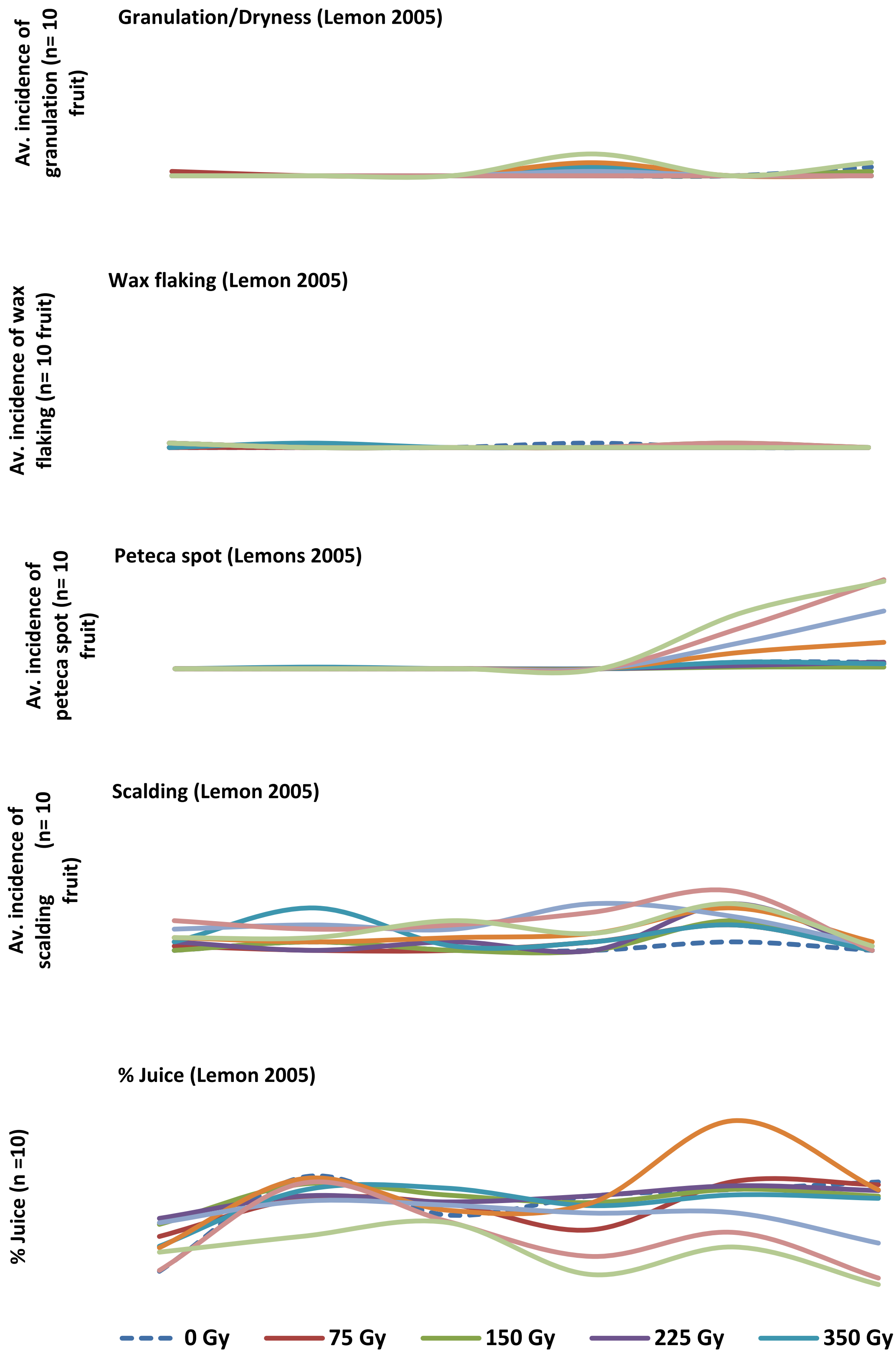

Figure 8. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2005 season on rind condition, incidence of physiological disorders and % juice of lemon fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

Dose distribution

The average maximum dose reading in the Clementine mandarin pallet (Table 1) was 1748 Gy and the minimum dose was 832 Gy. The Max / Min Ratio was 2.21:1 for the average values and 3.32:1 for the worst case scenario (highest and lowest overall dose readings) in the Clementine mandarin pallet. The highest dose readings were in the outside carton position, whereas the minimum in the middle of the pallet. This pattern was the same for both cultivars.

The average maximum dose in the Navel orange pallet (Table 2) was 1687 Gy with a minimum average dose of 728 Gy. This data gave a Max **/** Min Ratio of 2.32:1 for the Navel oranges and a ratio of 3.93:1 for the worst case scenario (highest and lowest values in pallet).

Table 1: Summary of dose mapping in the Clementine mandarin pallet.

Layer Number	Maximum Dose (Gy)	Maximum Position Number	Minimum Dose (Gy)	Minimum Position Number	Maximum: Minimum Ratio
1	1870	41	730	5	2.56 : 1
4	1930	41	930	4	2.08 : 1
7	1880	45	960	4	1.96 : 1
10	1960	42	910	5	2.15 : 1
13	1650	41	870	9	1.9 : 1
15	1200	37	590	5	2.03 : 1
Average	1748		832		2.1 : 1
Overall	1960	Layer 10 Position 42	590	Layer 15 Position 5	3.32 : 1

Table 2: Summary of dose mapping in the Navel orange pallet.

Layer Number	Maximum Dose (Gy)	Maximum Position Number	Minimum Dose (Gy)	Minimum Position Number	Maximum : Minimum Ratio
1	1760	41	700	4	2.51 : 1
4	2050	45	960	5	2.14 : 1
6	1280	37	520	5	2.46 : 1
Average	1687		728		2.32 : 1
Overall	2050		520		3.94 : 1

2007

Fruit quality

During the 2007 season, juice of the mandarin and orange fruit were tasted and casual observations made on the tastes during internal quality evaluations. This is presented in Table 3 and illustrates a decrease in quality soon after the second evaluations and even more so at higher dosages. However, only after 6 to 8 weeks of storage (Eval. 3-4), when anaerobic respiration was probably setting in and resulting in the associated off flavours. It is also evident that Clementine mandarin developed these off flavours on average quicker than Navel orange fruit.

The number of fruit per carton that could not be evaluated during storage due to the incidence of decay was noted (Table 3). It is clear that especially the lemon fruit had a severely negative reaction following irradiation.

Table 2. Tasting and observations of Navel orange and Clementine mandarin juice (only 2007).

Evaluation date	Irradiation dose (Gy)	Navel orange	Clementine mandarin
Evaluation 1 28 June	0	Sweet	Very sweet
	300	Sweet	Juice sweet
	400	Sweet	Sweet
	500	Sweet	Very sweet
	600	Sweet	Very sweet
	700	Sweet	Very sweet
Evaluation 2 11 July	0	Sweet	Sweet
	300	Off taste/milky	Milky
	400	Acidic	Very sweet
	500	Off taste	Off taste
	600	Off taste	Very sweet/milky
	700	Off taste	Very sweet
Evaluation 3 25 July	0	Sweet	Sweet
	300	Milky	Very sweet
	400	Sweet/acidic	Off taste
	500	Off taste	Off taste
	600	Milky/acidic	Off taste
	700	Milky	Off taste
Evaluation 4 8 August	0	No observations	Milky
	300		Milky
	400		Off aftertaste
	500		Sweet/acidic
	600		Sweet
	700		Off aftertaste
Evaluation 5 22 August	0	Sweet/pleasant taste	Sweet/pleasant taste
	300	Sweet/milky	Sweet
	400	Sweet/milky	Sweet
	500	Bitter after taste	Sweet/decaying taste
	600	Milky/bland	Sweet/decaying taste
	700	Sweet	Sweet/milky
Evaluation 6 2 September	0	Sweet/bland	Sweet
	300	Sweet/decaying taste	Watery
	400	Sweet/decaying taste	Unpalatable/unappetising
	500	Bland	Unpalatable/unappetising
	600	Unpalatable/unappetising	Very unpalatable/unappetising
	700	Unpalatable/unappetising	Very unpalatable/unappetising

Table 3. Incidence of decayed fruit in cartons in 2007 that had to be removed/discarded and could not be used in evaluation due to unidentifiable rind defect/blemish.

Evaluation date	Irradiation dose (Gy)	Lemon	Navel orange	Clementine Mandarin
Evaluation 1 28 June	0 300 400 500 600 700	Zero decay	Zero decay	Zero decay
Evaluation 2 11 July	0 300 400 500 600 700	4 4 6 6 4 0	2 4 3 3 1 2	2 3 0 0 1 1
Evaluation 3 25 July	0 300 400 500 600 700	7 4 2 6 3 8	1 1 3 0 1 2	0 0 0 1 1 1
Evaluation 4 8 August	0 300 400 500 600 700	0 3 1 1 11 8	5 1 2 3 1 0	2 2 4 1 2 0
Evaluation 5 22 August	0 300 400 500 600 700	8 1 1 11 27 38	3 1 4 10 1 1	0 2 1 1 2 0
Evaluation 6 2 September	0 300 400 500 600 700	25 35 22 44 31 78	3 2 9 4 0 0	1 3 2 3 3 1

Navel orange

During this season, much more pronounced rind damage occurred than during 2005 illustrating a year-to-year variation in rind sensitivity. Rind browning, as well as scalding, increased at almost all irradiation dosages to high levels. The probable reason for these categories decreasing after evaluation 4, i.e. 6 weeks storage, was the higher decay development and resultant discarding of fruit before evaluation (Fig. 9). The only internal quality aspect that differed noticeably between treatments and control was the increase in °Brix of almost all irradiation dosages (Fig. 10).

Clementine mandarin

Roughly the same pattern repeated itself in incidence of physiological disorders during 2007 (Fig. 11) compared with 2005, especially in puffiness showing no real difference between treatments and control. The total acid (TA) of the Clementine mandarin during this season was reduced by the irradiation in comparison with the control, as well as what seems to be an increase in the °Brix during storage. The ratio (TSS:TA) as a result increased as seen in 2005, which could indicate a higher rate of metabolism due to irradiation (Fig. 12).

Lemons

Of the three varieties used, lemons had the highest degree of sensitivity to irradiation in both seasons. Even only after 2 weeks storage nearly 100% of the fruit had one or the other rind disorder, making it unmarketable. Most fruit also showed more than one symptom of rind disorder at the same time, i.e. peteca spot and scalding (Fig. 13). The late loss in juice content of the lemons after evaluation 4, i.e. week 6 of storage, could be due to total loss of rind integrity and a resulting loss of moisture for the rind and pulp (Fig. 14).

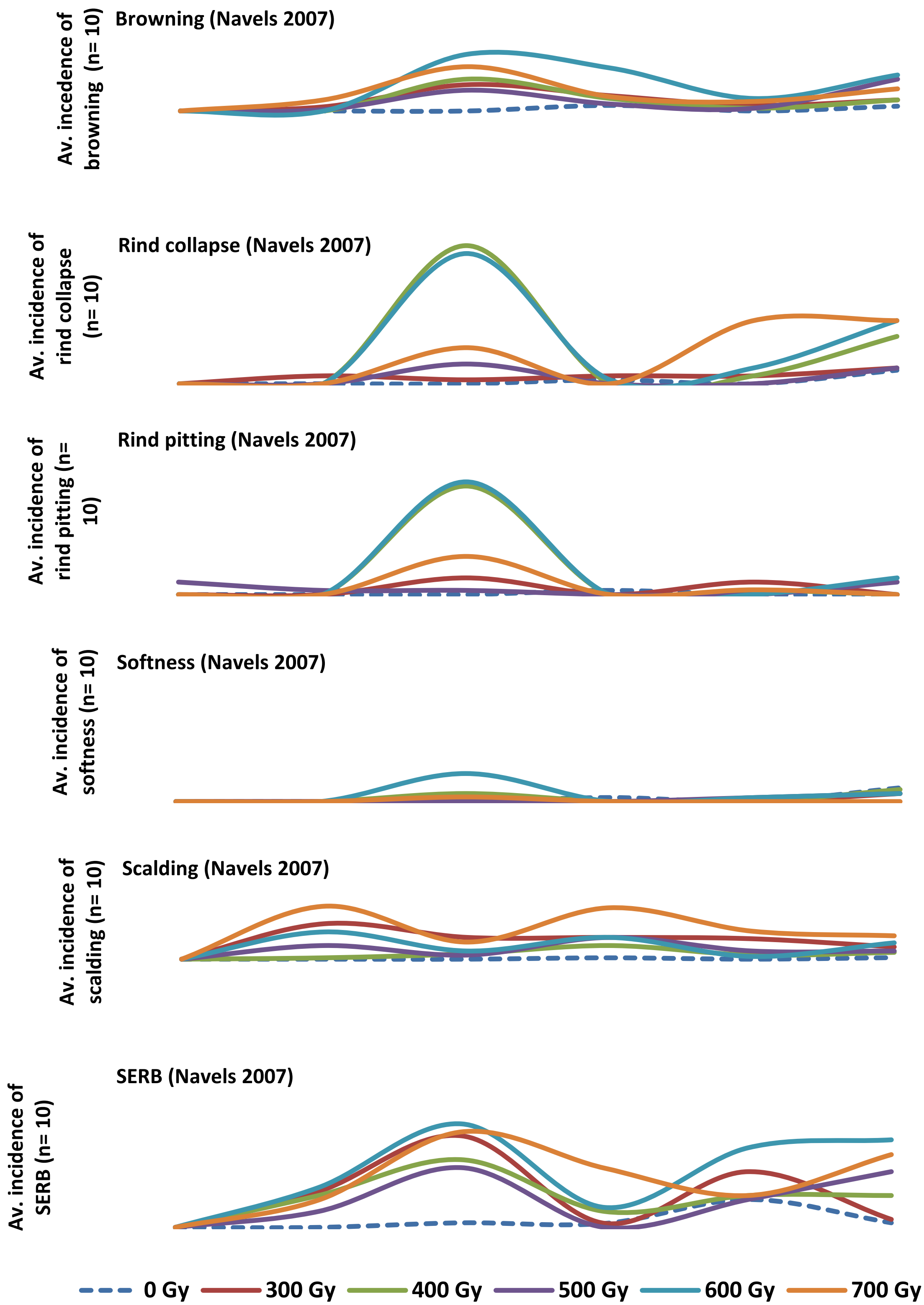

Figure 9. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on rind condition and incidence of physiological disorders of Navel orange fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

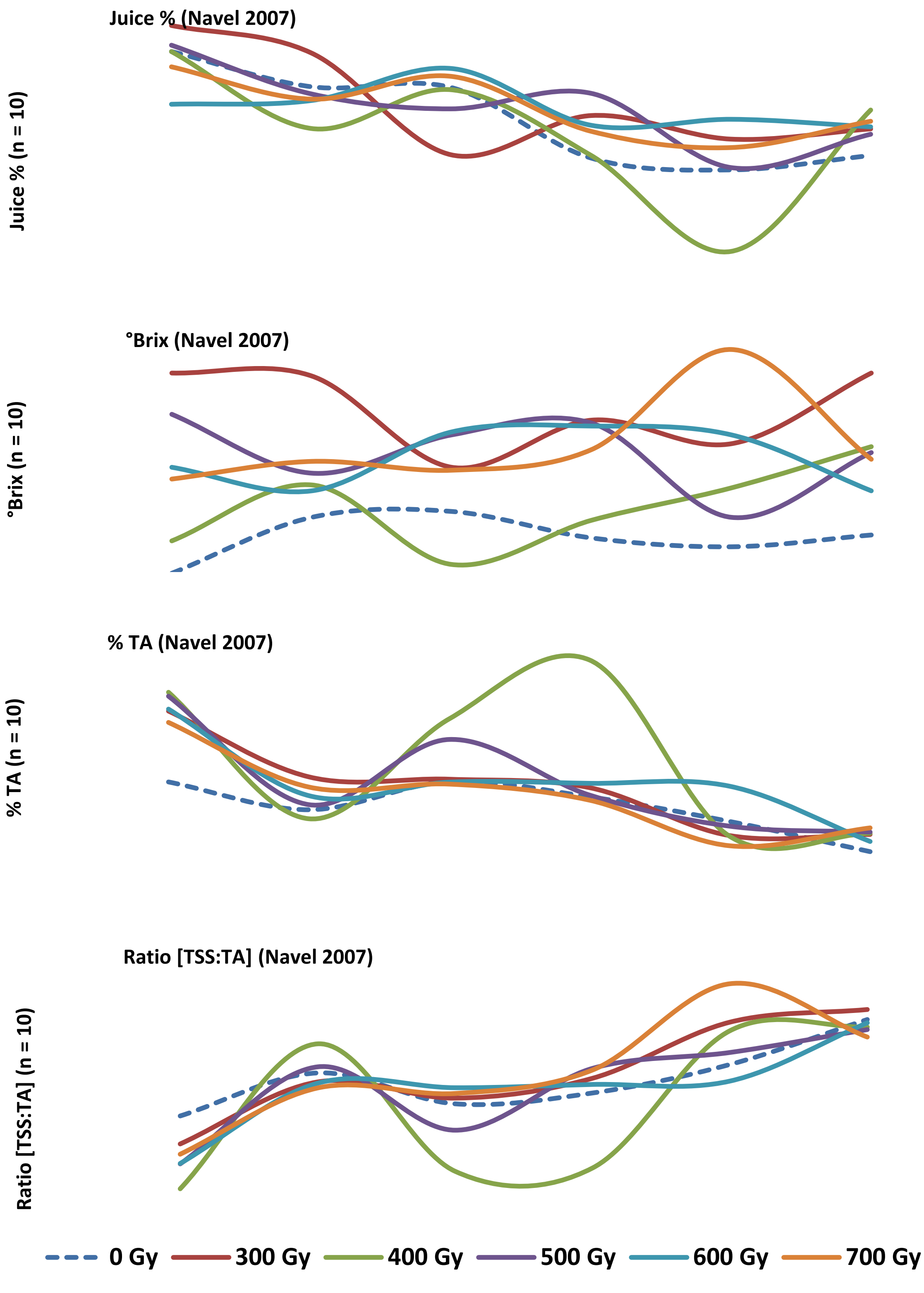

Figure 10. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on internal quality of Navel orange fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

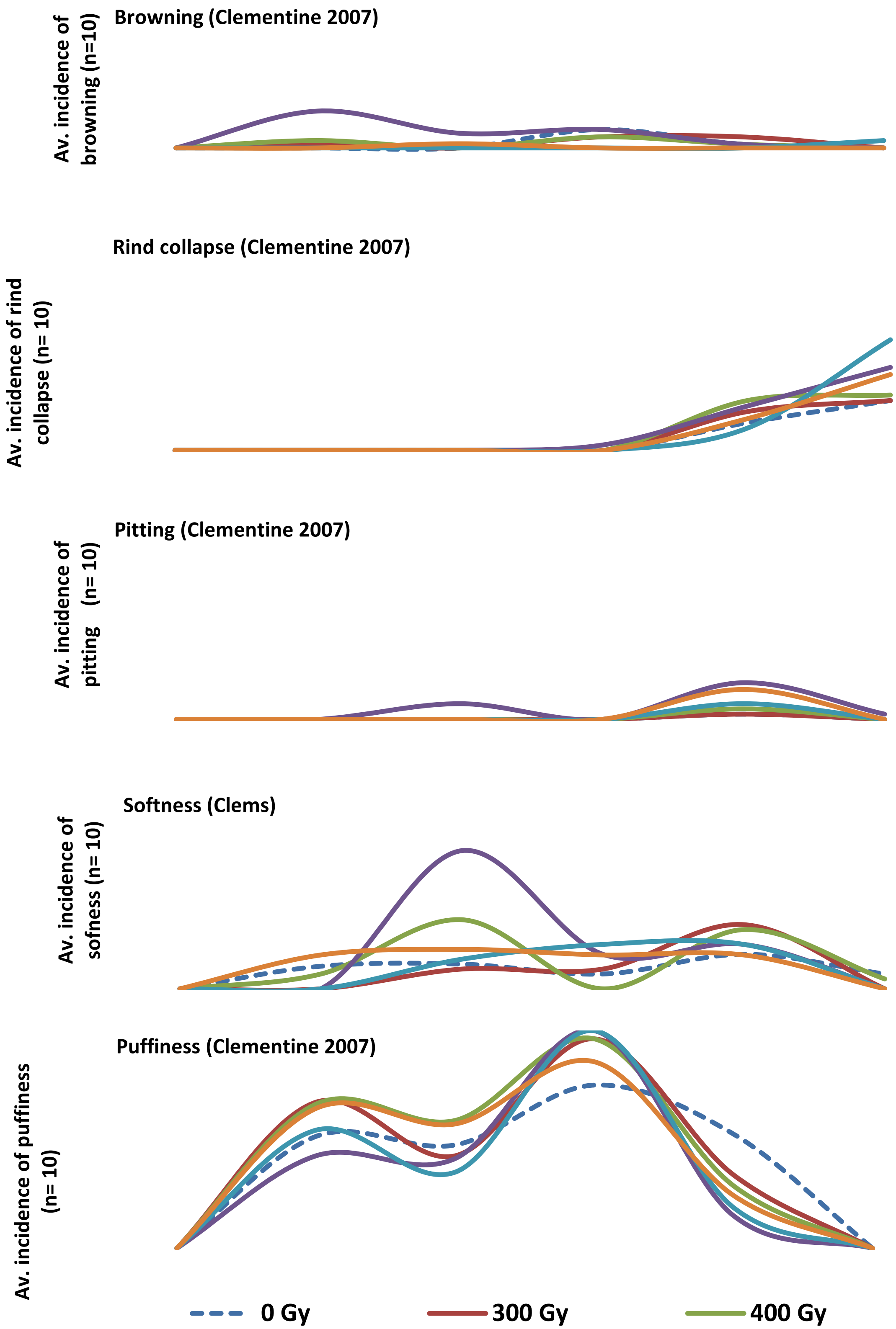

Figure 11. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on rind condition and incidence of physiological disorders of Clementine mandarin fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

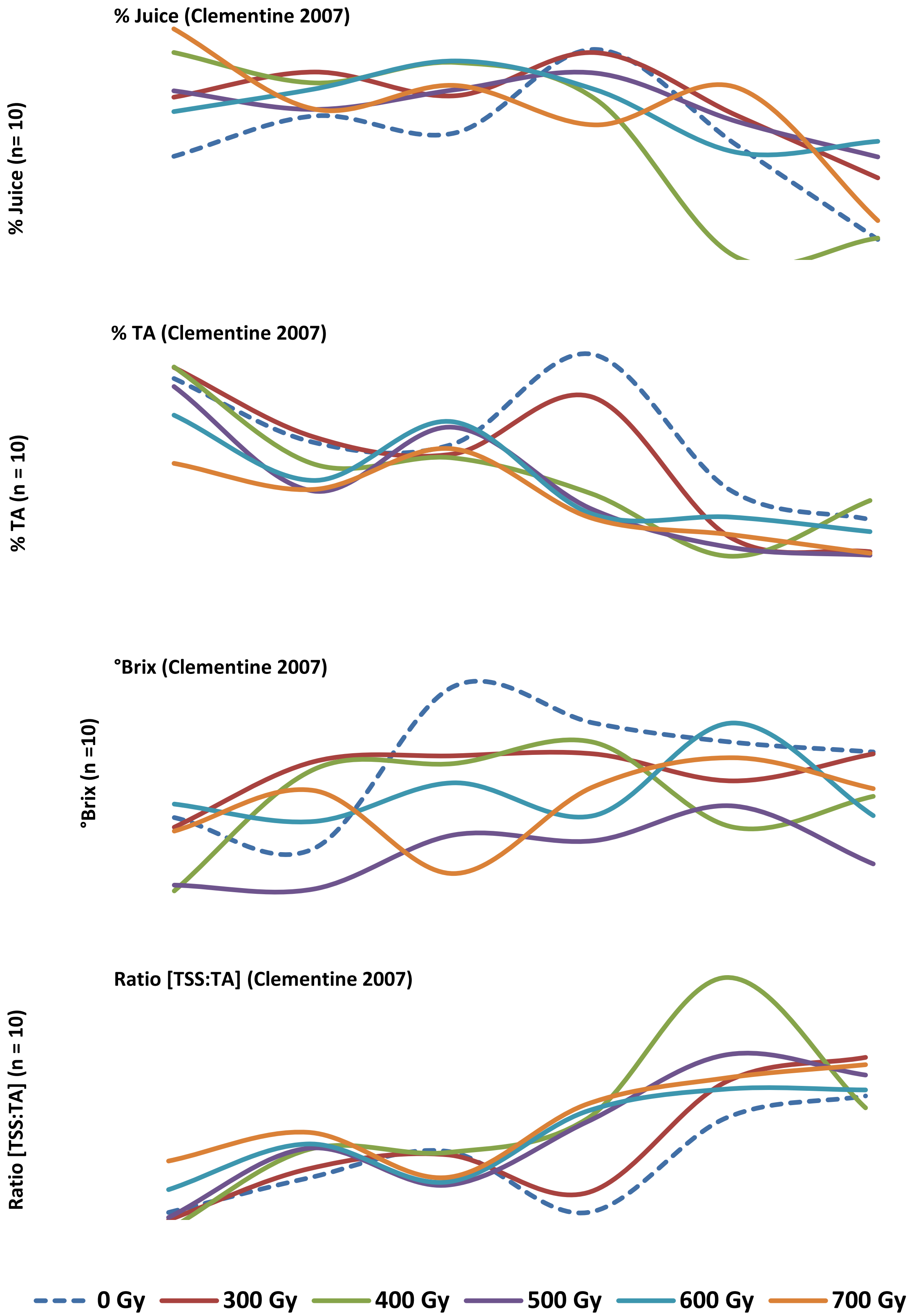

Figure 12. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on internal quality of Clementine mandarin fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

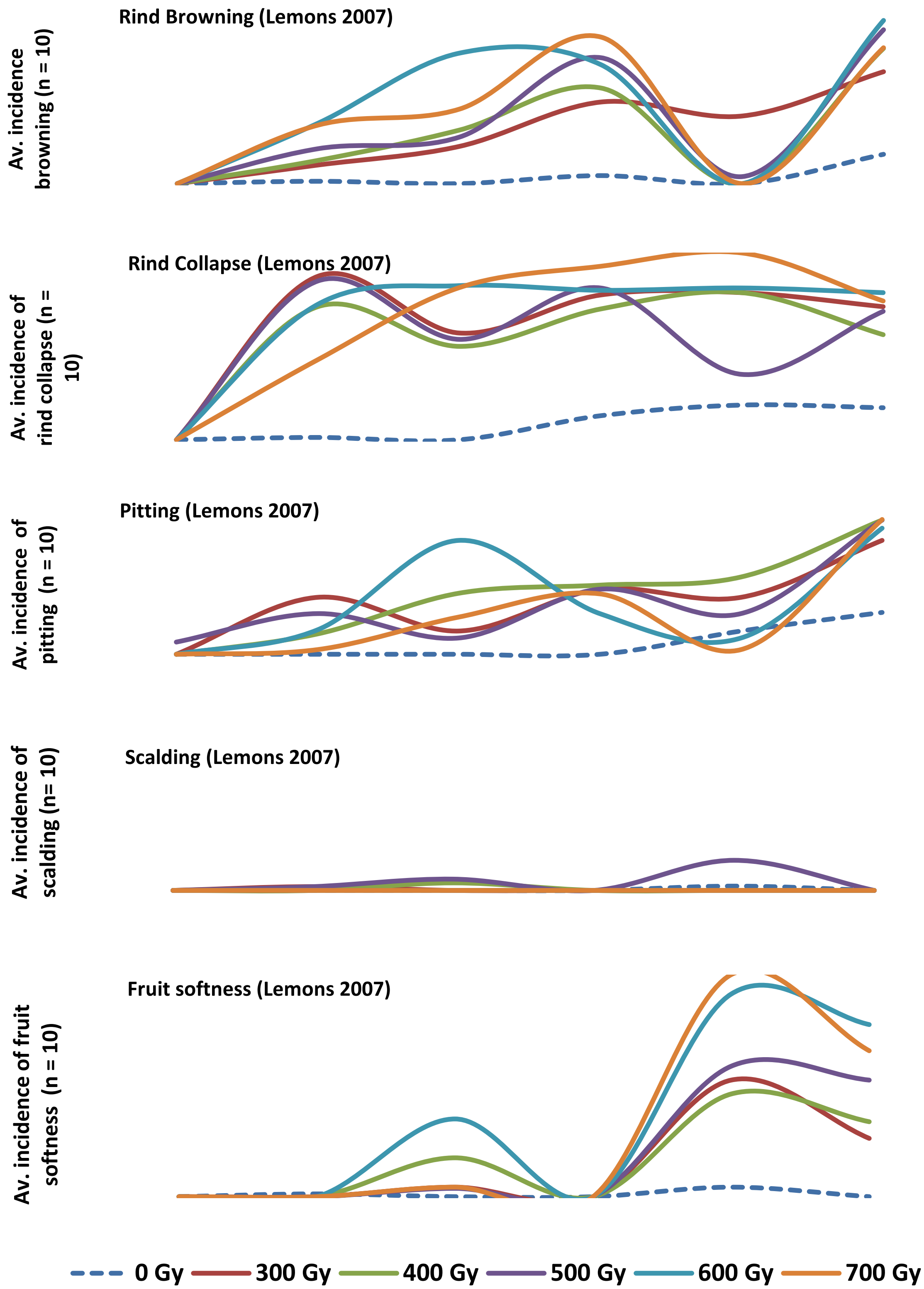

Figure 13. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on rind condition, incidence of physiological disorders of lemon fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

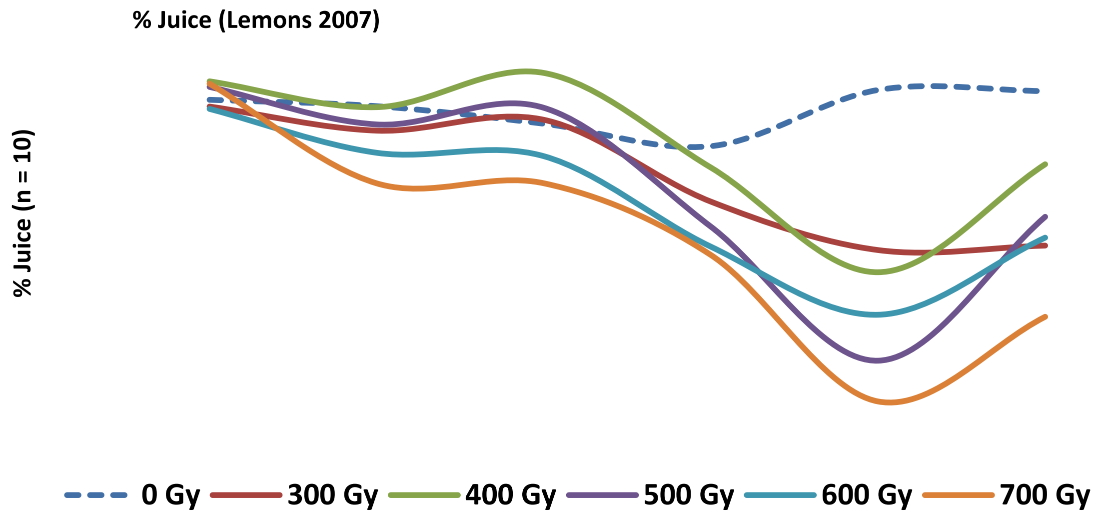

Figure 14. Effect of various dosages of irradiation and subsequent storage at 4°C during the 2007 season on % Juice of lemon fruit. Evaluations (2-6) were done every second week with evaluation 1 being done the day after irradiation treatment.

Conclusions

Irradiation could potentially be a valuable tool to replace, or use in combination with, cold sterilisation treatments for false codling moth and fruit fly control in export citrus fruit. However, this technology will require low dosages, i.e. <300 Gy, before practical solutions can be found to administer the correct dose to all fruit in the shortest time without being detrimental to fruit quality.

Dosages above 300 Gy will probably be detrimental during most seasons in not only damaging rind quality but also internal quality aspects of all three citrus types tested. In comparing these results with literature the obvious difference is the application equipment, *viz*. in a pallet in contrast to loose fruit or individual cartons being irradiated. The second option will allow lower dosages due to the gradient from the source to the point furthest away being very short due to less hindrance by packaging and other fruit in the pallet system.

The dose distribution values, especially the minimum values indicate there are some differences between cultivars in dose distribution. This could be due to fruit physical characteristic such as rind thickness and sugar content. To address this variation the cartons in the pallet could be differently stacked, e.g. leaving a central column in the stack open.

The dose ratios show that in a pallet irradiating system, such as used here, in order to reach the desired levels in each and every position a dose 4 times above the required minimum dose would have to be administered by the radiation source to ensure adequate levels in a worst case scenario, i.e. the carton in the middle of the pallet

The variation seen between seasons also concurs with other studies and shows that if this technology is to be used commercially, serious consideration should be given to horticultural aspects such as maturity, cultivar selection and canopy management.

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