

8-31-2018

Effects of Fruit Position in Standard Place Pack Cartons and Gamma 1 Irradiation on the Postharvest Quality of 'Barnfield' Navel Oranges

Karina Cruz Rodriguez (Frischia)
Chapman University

José de Jesús Ornelas-Paz
Unidad Cuauhtémoc


Vrani Ibarra-Junquera
Universidad de Colima

Maria Criselda Toto
Chapman University, toto@chapman.edu

Akanksha Jain
Chapman University, jain118@mail.chapman.edu

See next page for additional authors

Follow this and additional works at: https://digitalcommons.chapman.edu/food_science_articles

 Part of the [Agricultural Science Commons](#), [Agriculture Commons](#), [Botany Commons](#), [Food Processing Commons](#), [Fruit Science Commons](#), and the [Other Food Science Commons](#)

Recommended Citation

Rodriguez (Frischia), K.C., Ornelas-Paz, J., Ibarra-Junquera, V. et al. Effects of Fruit Position in Standard Place Pack Cartons and Gamma Irradiation on the Postharvest Quality of 'Barnfield' Navel Oranges. *Food Bioprocess Technol* (2018). <https://doi.org/10.1007/s11947-018-2174-6>

This Article is brought to you for free and open access by the Science and Technology Faculty Articles and Research at Chapman University Digital Commons. It has been accepted for inclusion in Food Science Faculty Articles and Research by an authorized administrator of Chapman University Digital Commons. For more information, please contact laughtin@chapman.edu.

Effects of Fruit Position in Standard Place Pack Cartons and Gamma 1 Irradiation on the Postharvest Quality of 'Barnfield' Navel Oranges

Comments

This is a pre-copy-editing, author-produced PDF of an article accepted for publication in *Food and Bioprocess Technology* in 2018 following peer review. The final publication is available at Springer via DOI: [10.1007/s11947-018-2174-6](https://doi.org/10.1007/s11947-018-2174-6).

Copyright

Springer

Authors

Karina Cruz Rodriguez (Frischia), José de Jesús Ornelas-Paz, Vrani Ibarra-Junquera, Maria Criselda Toto, Akanksha Jain, and Anuradha Prakash

1 **Effects of Fruit Position in Standard Place Pack Cartons and Gamma**
2 **Irradiation on the Postharvest Quality of ‘Barnfield’ Navel Oranges**

3
4 Karina Cruz Rodriguez (Frischia)¹, José de Jesús Ornelas-Paz^{2,*}, Vrani Ibarra-
5 Junquera³, Maria Criselda Toto¹, Akanksha Jain¹, Anuradha Prakash¹

6
7 ¹ Food Science Program, Schmid College of Science and Technology, Chapman
8 University, One University Drive, Orange, CA 92866, United States

9 ² Centro de Investigación en Alimentación y Desarrollo A. C.-Unidad Cuauhtémoc,
10 Av. Río Conchos S/N, Parque Industrial, C.P. 31570, Cd. Cuauhtémoc, Chihuahua,
11 México

12 ³ Universidad de Colima, Bioengineering Laboratory, Km. 9 carretera Coquimatlán-
13 Colima. C.P. 28400. Coquimatlán, Colima, México.

14
15 ***Corresponding author.** *E-mail address:* jornelas@ciad.mx (J.J. Ornelas-Paz)

16
17 ***Running head:*** Postharvest quality of irradiated oranges

18 **Acknowledgements**

19 This work was supported by a TASC grant from USDA-FAS. J.J. Ornelas-Paz
20 thanks CONACYT (Mexico) for providing support for his sabbatical leave at
21 Chapman University. The authors thank Shantae Thornton and Dhvani Patel for
22 their technical support.

23 **Abstract**

24 The objective of this study was to determine if oranges in the top and bottom layers
25 within a Standard Place Pack were impacted differently by irradiation after long-term
26 storage. 'Barnfield' Navel oranges were packed in Standard Place Pack cartons and
27 treated with 0, 0.15 or 1 kGy of gamma irradiation. The fruit were stored for three
28 weeks at 5 °C and then for one week at 20 °C. After storage, the fruit from the top
29 and bottom layers were separately evaluated for quality. The development of stem
30 end rind breakdown (SERB) was the main cause of quality loss and was greater in
31 irradiated fruit in the top layer. Fruit in the bottom layer showed more physical
32 damage (flattening) but lower incidence of SERB. The changes in individual sugar
33 content were minimal but significant for layer. The content of individual organic acids
34 was consistently lower in irradiated fruit from the bottom layer. Layer type showed a
35 stronger effect on phenolic compounds than irradiation dose. The tristimulus color,
36 total soluble solids, titratable acidity, and firmness of fruit were not influenced by
37 irradiation dose or layer type. The results show that damage in irradiated Navel
38 oranges depends on dose and layer, with the top layers showing greater
39 physiological damage and bottom layers showing more physical damage.

40

41

42 **Keywords:** Ionizing energy; Physiological disorders; Chemical composition; Citrus;
43 Phytosanitary treatment; Postharvest quality

44

45 **Introduction**

46 The US is one of the largest orange producing countries in the world, with California
47 and Florida providing much of the oranges for the fresh market and for processing,
48 respectively (USDA 2017). Fresh oranges from the US are exported to several
49 countries, mainly to South Korea, Canada, and Japan (AMRC 2013). However, the
50 production of oranges in the US has decreased slightly but continuously in recent
51 years, causing an increase in the importation of oranges from countries such as China,
52 Australia, Mexico, Jamaica, and the Philippines (APHIS 2014; USDA 2017). The high
53 volume of international and domestic trade of oranges can infer a high risk for the
54 spread of quarantine pests. Thus, oranges being imported, exported, or even moved
55 within the US must be subjected to phytosanitary treatments before shipment (APHIS
56 2014). Several postharvest phytosanitary treatments have been approved for citrus
57 fruits but irradiation has advantages over the other treatments in terms of exposure of
58 fruit to unsuitable high or low temperatures for extended periods of time, human
59 safety, and environmental impacts (Hallman 2012).

60 Generic doses of 0.15 and 0.4 kGy are approved to control many classes of insects
61 except the pupae and adult stages of Lepidoptera (APHIS 2014), while a maximum of
62 1 kGy is allowed by the FDA for use on fresh fruits and vegetables (Follett and Wall
63 2013; Hallman 2012). The dose of 0.15 kGy is sufficient to control insects commonly
64 found on oranges and may limit the negative effects on quality, which are manifested
65 in oranges as softening, peel injury, chemical (loss of nutrients, bioactive compounds,
66 volatiles) and sensory changes (Ladaniya et al. 2003; McDonald et al. 2013; Miller et
67 al. 2000; Nagai and Moy 1985). Many of these effects have been related to the

68 irradiation-mediated increase in ethylene biosynthesis and respiration rate (Ladaniya
69 et al. 2003), but the incidence and severity of these negative effects depend on orange
70 variety, maturity stage, and irradiation dose (Bustos and Mendieta 1988; Miller et al.
71 2000; Nagai and Moy 1985).

72 Oranges in the US are generally packed precisely in four layers in 18.1 kg Standard
73 Place Pack cartons. They are typically packed without protective trays between layers,
74 resulting in the compression of fruit, especially in the bottom layer during long-distance
75 shipping (Moresi et al. 2012). This kind of damage can compromise the appearance
76 of the fruit and might cause the rejection of the entire fruit shipment (Mazidi et al.
77 2016). Compression damage in citrus fruits, as with any other physical damage,
78 triggers a burst of ethylene production (Lu et al. 2014) directly or indirectly impacting
79 the respiration rate, and resulting in softening, peel injury and chemical changes
80 (Porat et al. 2004; Rojas-Argudo et al. 2010, 2012). Compression damage can alter
81 the levels of sugars, organic acids (mainly ascorbic acid), volatiles, and phenols in
82 citrus fruit (Mazidi et al. 2016; Obenland et al., 2018; Rojas-Argudo et al. 2010, 2012).
83 Transportation temperature and distance also influence the severity and incidence of
84 compression damage (Ahmadi 2012; Ahmadi et al. 2010).

85 Irradiation-induced stress in oranges can elicit a similar physiological response to that
86 of compression damage (Mazidi et al. 2016; Rojas-Argudo et al. 2012). Thus, the
87 combination of compression and irradiation might exacerbate postharvest damage in
88 oranges. In our previous work, we noted that the undesirable effects of irradiation on
89 Navel oranges, especially peel injury, seemed to depend on the position of the fruit
90 within the case, but this phenomenon was not systematically investigated (McDonald

91 et al. 2013), and the literature does not provide any information in this regard. The
92 objective of this study was to determine if oranges in the top and bottom layers within
93 a Standard Place Pack were impacted differently by irradiation after long-term storage.
94 The 0.15 kGy dose was selected since it is the minimum target dose for oriental fruit
95 fly. A dose of 1 kGy was included to accentuate the impacts of irradiation on the fruit
96 to allow these effects to be detected and measured.

97

98 **Materials and Methods**

99 **Fruit Procurement, Treatment, and Storage**

100 'Barnfield' Navel Oranges (*Citrus sinensis* (L.) Osbeck) (size 72) were harvested from
101 a commercial orchard in Kern County, CA, USA. The fruit were commercially treated
102 and packed by Paramount Citrus Exchange (Delano, CA, USA). The handling involved
103 three washing steps with chlorine; one at dumping point (150 mg/L), then at high
104 pressure (200 mg/L, 862 kPa) and a final immersion for 3 min in 3% sodium
105 bicarbonate solution containing chlorine (200 mg/L). After rinsing with water, the fruit
106 were treated with Imazalil (300 mg/L) for 30 s in an immersion tank, then rinsed with
107 water. Finally, the fruits were waxed with a carnauba based wax containing Imazalil
108 (1 g/L) and thiabendazole (3.5 g/L). The oranges were bulk packed in 18.14 kg (72-
109 80 fruits) Standard Place Pack cartons (40.6 x 27.9 x 25.4 cm) and refrigerated at 5
110 °C. In each carton, the fruit were distributed in four layers; each layer containing ~20
111 fruit. The oranges were transported to Sterigenics, Inc. (Tustin, CA, USA), for
112 treatment, where six cases of oranges were placed two rows high and three across at
113 a precise distance from a ⁶⁰Co source (~37PBq). Dose mapping was conducted by

114 placing 24 alanine pellet dosimeters (FarWest Technology, Inc., Goleta, CA, USA) at
115 various locations in the cases. The dose rate was determined to be 0.637 Gy/s. Six
116 cases of oranges were placed exactly in the same configuration as the dummy cases
117 to receive treatment at a target dose of 0.15 and 1 kGy (4.6-5.5% uncertainty) and
118 Dmax/Dmin ratio of 1.33. Midway through treatment, the boxes were rotated 180° to
119 ensure uniform treatment. After treatment, the oranges were transported to Chapman
120 University, and stored at 5 °C and 95% RH for 3 weeks to simulate sea shipment to
121 Asian markets. After cold storage, the oranges were placed at room temperature (20
122 °C) for one week to simulate retail display. Following this four week storage, twenty
123 fruit from the top and bottom layers of each of the four cases were pooled, to obtain a
124 total of 80 fruit for each layer. Of the 80 fruit per layer, ten were used to measure
125 tristimulus color and ten for firmness. Sixty fruits were distributed in five subsamples,
126 juiced and the juice was used to measure titratable acidity (TA), total soluble solids
127 (TSS), individual sugars, organic acids, and total and individual phenols. Twenty
128 oranges from top and bottom layers from the remaining two cartons were evaluated
129 for stem-end breakdown (SERB), fungal infections, shape deformation and weight
130 loss. All fruits included in the experiment were free of physiological, physical and
131 biological damage (flattening, SERB, fungal infections and insect damage). Their
132 average weight (270.7 ± 3.8 g), peel color ($L^* = 65.1 \pm 0.3$, $a^* = 29.4 \pm 0.5$, $b^* = 48.1 \pm$
133 0.9), internal color ($L^* = 46.4 \pm 0.4$, $a^* = 8.7 \pm 0.2$, $b^* = 31.1 \pm 0.6$), peel firmness, (6.8
134 ± 0.5 N), pulp firmness (3321.8 ± 173.0 N mm), TSS content (12.6 ± 0.03 %) and
135 TA (0.43 ± 0.006 %) at the beginning of the experiment were characteristic of ripe
136 Navel oranges.

137 **Peel Damage**

138 Shape deformation by compression was reported as the percentage of fruit showing
139 flattening. These fruit were also grouped according to the severity of compression
140 damage. The severity of flattening was estimated by calculating the percent of fruit
141 surface area showing flattening. These areas were converted into a 5 point scale
142 according to Yue et al. (2007), with 0= no damage, 1= 1-4%, 2= 5-8%, 3= 9-12%,
143 4=13-15%, and 5= 16% or more of damaged surface. The fruit surface area was
144 determined by measuring their equatorial diameter and assuming a spherical shape
145 while the flattened areas were measured using a Vernier caliper.

146 The incidence and severity of SERB were determined by digital image analysis, given
147 the irregular shape of SERB lesions and the consequent difficulty to be evaluated
148 using a Vernier caliper. The incidence of SERB was determined by calculating the
149 percent of fruit showing this damage. The severity of SERB was determined by
150 estimating the area and color of SERB lesions by digital image analysis. The peduncle
151 side of 20 fruit per layer was photographed using a digital camera. An algorithm,
152 designed in MATLAB (R2010a, MathWorks, USA), was used to determine the area
153 and tristimulus color of the SERB lesions in the digital images. The digital image is an
154 $M \times N \times P$ array, where $M \times N$ represents the image dimension in pixels, while P is the
155 number of color planes, three in this case, corresponding to the matrices R' , G' , and
156 B' . In order to convert an $R'G'B'$ digital image to an $L^*a^*b^*$ color space (CIE Lab), the
157 MatLab object ColorSpaceConverter was used. In the $L^*a^*b^*$ color space, L^* indicates
158 lightness, a^* is the red (+a)/green coordinate (-a), and b^* is the yellow (+b)/blue
159 coordinate (-b) (Chen et al., 2010). For the determination of SERB area, the digital

160 image was transformed to a gray-scale image. The % of area showing SERB lesions
161 was calculated relative to the area of the fruit in the picture.

162 The incidence of fungal infections was determined by calculating the percent of fruits
163 per layer showing areas with mycelia. The area of the fungal infection (severity) was
164 not determined since under commercial conditions any fruit showing fungal infection
165 must be discarded, in contrast to fruit showing SERB or flattening.

166

167 **Tristimulus Color of Fruits**

168 Peel color was measured in areas free of injuries at two equidistant points on the
169 equatorial axis of 10 fruit using a CM-2500d Konica Minolta Spectrophotometer
170 (Ramsey, New Jersey, USA). Then, the oranges were cut at the equatorial axis and
171 two color measurements were taken on the internal surface of each half. The L*, a*
172 and b* values were recorded.

173

174 **Firmness**

175 Firmness of the peels and intact segments of the fruit was measured. For peel
176 firmness, four peel sections were vertically excised from 10 fruit using a paring knife
177 and evaluated for penetration resistance to a 3 mm puncture probe using a TA-XT2
178 Texture Analyzer (Texture Technology Corp; Scarsdale, NY, USA), which moved
179 downward through the peel at 3 mm/s until breakpoint. The maximum force (N)
180 required to puncture the peel was recorded. For pulp firmness, the segments from
181 the peeled oranges were carefully separated by hand and distributed in eight
182 subsamples of 150 g each. Each subsample of intact segments was placed into a

183 Kramer Shear Cell (TA-91) and the five flat-blade press, set at 80 mm from the bottom
184 of the cell platform, was moved downward through the segments at 5 mm/s for 75
185 mm. The area (N.mm) under the force deformation curve was determined.

186

187 **Weight Loss, Titratable Acidity (TA) and Total Soluble Solids content (TSS)**

188 Weight loss (%) was determined by measuring the change in weight during storage in
189 the fruit used for peel damage determination. For TA, 5 g of juice were diluted with 50
190 g of water and titrated to a pH of 8.2 with 0.1N NaOH. TA was calculated using the
191 factor of 0.064 for citric acid, according to McDonald et al. (2013). The content of TSS
192 of the juice was directly determined by placing a few drops of juice on the glass surface
193 of a PAL digital refractometer (Atago Co., LTD, Tokyo, Japan).

194

195 **Sugars**

196 Glucose, fructose, and sucrose were measured according to Ornelas-Paz et al.
197 (2013), with some modifications. An aliquot of juice (100 μ L) was mixed with 2 mL of
198 HPLC water. The mixture was filtered with a 45 μ m pore size acrodisk and
199 automatically injected (20 μ L) into an Agilent 1100 series HPLC system (Agilent Inc.,
200 Santa Clara, CA, USA) equipped with a refractive index detector. The separation was
201 performed in a Sugar SC 1821 (8.0 x 300 mm, 6 μ m) column at 80 °C with a Sugar
202 SC-LG (6.0 x 50 mm, 10 μ m) precolumn (Showa Denko K.K.; Tokyo, Japan). The
203 mobile phase was 100% HPLC grade water at a flow rate of 0.8 mL/min. The sugars

204 were quantified using calibration curves constructed with at least three independent
205 sets of dilutions of glucose, sucrose, and fructose.

206 **Organic Acids**

207 One mL of juice was mixed with 3 mL of 5 mM H₂SO₄. The mixture was filtered using
208 a 45 µm pore acrodisk and automatically injected (20 µL) into the HPLC system
209 described above, which is also equipped with a diode array detector. The separation
210 was performed using an Aminex HPX-87H ion exchange column (7.8 x 300 mm; Bio-
211 Rad Laboratories, Hercules, CA, USA) at 60 °C. The mobile phase was 5 mM H₂SO₄
212 and acetonitrile (90:10, v/v) at flow rate of 0.4 mL/min. Oxalic, citric, tartaric, malic,
213 quinnic, succinic, and fumaric acids were monitored at λ=210 nm while ascorbic acid
214 was monitored at λ=260 nm. The quantification was based on calibration curves
215 constructed with at least three independent sets of dilutions of standard compounds.

216

217 **Phenolic Compounds**

218 The analysis of individual and total phenols was performed simultaneously. The juice
219 was filtered with a membrane of 0.45 µm pore size and directly injected (100 µL) into
220 the HPLC described previously. The separation of phenolic compounds was
221 performed using a Kinetex C18 column (4.6 x 100 mm) (Phenomenex; Torrance, CA,
222 USA) at 30 °C. The phenolic compounds were monitored at λ= 280, 320, 350 and 520
223 nm. The mobile phase consisted of 2% acetic acid (A), and acetonitrile (B), according
224 to the following gradient: 100% A at 0 min, 93% A at 12 min, 89% A at 20 min, 86%A
225 at 35 min, 84% A at 36 min, 82% A at 41 min, 79% A at 44, 0% A from min 55 to

226 60. The flow rate was 1 mL/min. The phenolic compounds were identified and
227 quantified by using reference compounds. The UV-Vis spectrum of each phenol was
228 also used for identification purposes.

229 For total phenolic content, 100 μ L of filtered juice were mixed with 100 μ L of Folin-
230 Ciocalteu reagent, 3 mL of deionized water and 100 μ L of 20% Na_2CO_3 . The mixture
231 was vigorously shaken for 1 min and incubated for 1 h in the dark. The absorbance
232 was evaluated five times at 765 nm using a FLUOstar Omega microplate reader (BMG
233 LABTECH Inc.; Cary, NC, USA). The absorbance values were corrected with those
234 generated with blank reactions. Quantification was based on a calibration curve
235 constructed with several sets of dilutions of gallic acid. The results were expressed as
236 mg GAE per liter of juice.

237

238 **Statistical Analysis**

239 The effects of irradiation dose and layer were determined using a linear mixed effects
240 model and pairwise Tukey Kramer Test, using a level of significance of 0.05. Analysis
241 was conducted using R 3.2.3 software with lme4, multcomp, and car packages (R
242 Core Team, 2015, Vienna, Austria).

243

244 **Results and Discussion**

245 **Peel Damage**

246 SERB, flattening and fungal infections were observed in control and irradiated fruit
247 from both layers (Table 1). SERB was characterized by collapsed, darkened, and

248 sunken rind tissue around the calyx, as described by Ritenour et al. (2004). It was
249 observed after cold storage in all treatments, but was more evident after storage at
250 room temperature. This disorder has been observed in other studies for non-irradiated
251 oranges (Alferez et al., 2003). The incidence of SERB lesions increased with
252 irradiation dose (Table 1) ($P < 0.05$). Image analysis showed that the area of the
253 lesions was similar for fruit in the top and bottom layers ($P > 0.05$) (Fig. 1A). Irradiation
254 dose and layer also affected the L^* and b^* values in the SERB lesions (Figs. 1B and
255 1C). Fruit treated with 1 kGy showed darker lesions as compared to 0.15 kGy and
256 control fruit ($P < 0.05$) and, the fruit from top layer showed darker lesions in all
257 experimental groups as compared with fruit from the bottom layer ($P < 0.05$).
258 Differences in gas composition between the top and bottom layers might explain the
259 differences in SERB incidence. Fruit from the bottom layer might produce more CO_2
260 and ethylene because that fruit was subjected to higher stress by compression
261 (flattening). Also, given the higher density of CO_2 , fruit in the bottom layer was
262 probably exposed to higher CO_2 levels which might avoid the oxidation of phenolic
263 compounds. This hypothesis might explain the less darkening (higher L^* values) of
264 SERB lesions for control and irradiated fruit in the bottom layer (Fig. 1). Porat et al.
265 (2004) demonstrated that modified atmosphere packaging (reduced levels of O_2 and
266 increased levels of CO_2) reduced SERB in oranges. On the other hand, most of the
267 C_2H_4 would diffuse from bottom to the top and accumulate there because of its lower
268 density ($CO_2 > O_2 > C_2H_4$). Higher levels of C_2H_4 could lead to increased phenylalanine
269 ammonia lyase (PAL) activity resulting in the production of phenols which are then
270 oxidized by polyphenol oxidase and peroxidase to *o*-quinones that further polymerize

271 to the brown pigments characteristic of SERB lesions (Banerjee et al., 2015).
272 Unfortunately, the low irradiation doses do not inactivate the polyphenol oxidase and
273 peroxidase responsible for phenol oxidation and formation of brown pigments. Alférez
274 et al. (2003) associated the ethylene production of oranges with their susceptibility to
275 develop postharvest browning. Increased ethylene production has also been
276 associated with the development of peel injury in irradiated and wounded citrus fruits,
277 probably due to its involvement in the activation of enzymes such as peroxidase and
278 PAL which are responsible for citrus browning (Ladaniya 2008; Lu et al. 2014;
279 McDonald et al. 2000; Porat et al. 2004). PAL was observed to increase immediately
280 after irradiation treatment in Clementine mandarins (Oufedjikh et al., 2000) and
281 grapefruit (Riov et al., 1975) and correlated with an increase in phenolic compounds
282 in damaged peel cells. Guerrero et al. (1967) attributed rapid rind breakdown to higher
283 respiratory rates in 'Washington Navel' oranges irradiated with 0.5 to 6 kGy.

284 Flattening was clearly observed in all tested fruit. As expected, fruit in the bottom layer
285 always presented larger flat areas than fruit in top layer for all treatments ($P < 0.05$)
286 (Table 2). However, although the incidence of flattening in both layers decreased as
287 the irradiation dose increased, the severity of flattening increased with irradiation dose
288 (Tables 1 and 2). Thus, fruit treated with 0.15 and 1 kGy showed a lower incidence of
289 flattening as compared to control fruit, but the severity of the damage increased with
290 irradiation dose (Tables 1 and 2). Nevertheless, the overall flattened area was no
291 more than 12% of total surface in irradiated fruit and was not the primary contributing
292 factor to a decrease in quality. These findings demonstrate a differential effect of
293 irradiation in non-damaged and compressed (damaged) areas of the oranges. Some

294 studies have demonstrated that irradiation causes different biochemical responses in
295 wounded citrus fruits as compared to fruit that are not wounded (Rojas-Argudo et al,
296 2012); however, there is no information regarding biochemical responses of oranges
297 subjected to compression stress and irradiation as compared with oranges subjected
298 to only irradiation. Besides the mechanical weakening of fruit by compression,
299 ethylene biosynthesis in compressed areas of irradiated oranges might be higher than
300 in not compressed areas, causing a higher enzymatic softening around flattened areas
301 and increasing the severity of this kind of damage. The individual effects of
302 compression and irradiation on ethylene biosynthesis in citrus fruit have been
303 demonstrated previously (Ladaniya et al. 2003; Lu et al. 2014).

304 The incidence of fungal infections was similar for fruit in both layers for all experimental
305 groups ($P>0.05$) (Table 1). Vilanova et al. (2014) observed that the susceptibility of
306 oranges to postharvest infections was increased by fruit wounding. In our study, the
307 0.15 kGy dose did not increase mold growth as compared to the control. However,
308 fruit treated with a dose of 1 kGy showed higher levels of fungal infection most likely
309 due to damage caused to fruit cell walls and release of nutrients that encourage fungal
310 growth (Ladaniya et al. 2003; Zhang et al. 2014). While flattening and decay incidence
311 are both higher in bottom layer fruit and fruit treated at 1 kGy, the high occurrence of
312 decay in the top layer of the 1 kGy fruit, suggests that irradiation by itself at this dose
313 level enhances decay. Rojas-Argudo et al. (2012) demonstrated that low irradiation
314 doses (0.51 kGy) stimulated the biosynthesis of antifungal compounds in citrus fruits
315 and that higher irradiation doses (0.875 kGy) inhibited such biosynthesis, favoring
316 postharvest infections.

317

318 **Tristimulus Color, Firmness and Weight Loss**

319 Neither irradiation dose nor fruit layer affected tristimulus color and firmness of peel
320 or pulp ($P>0.05$) (data not shown). Similarly, McDonald et al. (2013) demonstrated
321 that the color of Navel oranges was not affected by irradiation doses of up to 0.6 kGy.
322 Weight loss after storage ranged from 6.4 to 9% and was not impacted by irradiation
323 treatment and layer type ($P>0.05$) (data not shown). Miller et al. (2000) demonstrated
324 that irradiation at 0.15, 0.3 and 0.45 kGy did not significantly alter the color, firmness
325 and weight loss in five orange cultivars, including Navel oranges.

326

327 **Total Soluble Solids (TSS) and Sugars**

328 TSS values, ranging from 12 to 12.7% (data not shown), were similar to those reported
329 previously for oranges (McDonald et al. 2013; Miller et al. 2000), and were not affected
330 by irradiation dose or layer type ($P>0.05$). Similarly, Miller et al. (2000) evaluated the
331 effect of irradiation (0.15-0.45 kGy) on TSS content in fruit from five orange cultivars,
332 including Navel oranges, and found that irradiation did not affect TSS.

333 Sucrose was the most abundant of measured sugars in the oranges ($P<0.05$),
334 followed by glucose and fructose, which showed similar content ($P>0.05$) (Fig. 2).
335 Similar sugar composition has been reported previously for oranges (Kelebek et al.
336 2009; Roussos 2011). The changes in sugar content as a function of irradiation dose
337 and layer type were very small but significant in some cases. In fruit from top layer,
338 sucrose content tended to decrease with the irradiation dose while glucose and
339 fructose increased ($P<0.05$). Similar results were reported for mandarins treated with

340 0.15, 0.4 and 1 kGy (Ornelas-Paz et al. 2017). However, irradiation caused a different
341 alteration of sugar content in fruit in the bottom layer, where a slight decreasing trend
342 was observed for glucose and fructose while sucrose content was not altered
343 significantly ($P>0.05$) (Fig. 2). These opposite trends in sugars for fruit in top and
344 bottom layers suggest sugar conversion in the top layer fruit and increased usage of
345 glucose and fructose in the bottom layer fruit. Some studies have demonstrated that
346 irradiation can increase the activity or biosynthesis of enzymes involved in sugar
347 conversion (invertases, sucrose synthases, fructokinase, hexokinase and sucrose
348 phosphate synthases) (Shi et al. 2016; Yativ et al. 2010). Other studies have
349 demonstrated that, depending on severity, physical damage can induce biological
350 stress in fruits and ethylene biosynthesis, causing the expression of gene coding
351 enzymes involved in the sugar composition of citrus fruits (Ladaniya et al. 2003; Lu et
352 al. 2014; Rojas-Argudo et al. 2012; Shi et al. 2016). The conversion of sucrose to
353 glucose and fructose is a genetic response of fruit to satisfy the demand for hexoses
354 due to the increased respiration rate mediated by ethylene exposure and/or wounding,
355 but generated hexoses are also used for signaling and as precursors for sucrose
356 biosynthesis in highly damaged fruit because sucrose confers tolerance to fruit against
357 damage (Cao et al., 2013; Lin et al., 2015). Thus, bottom fruit showed lower levels of
358 glucose and fructose without alteration of the sucrose content probably because the
359 hexoses were used for respiration and also to maintain normal levels of the protective
360 sucrose.

361

362 **Titrateable Acidity (TA) and Organic Acids**

363 TA values (0.44-0.49%) showed no effect of layer or irradiation dose ($P>0.05$) (data
364 not shown). Other studies have also shown that irradiation doses of up to 3 kGy do
365 not significantly alter the TA of orange juice (Miller et al. 2000). Our TA values were
366 similar to those previously reported for oranges (Flores et al. 2012; Kelebek et al.
367 2009; Roussos et al. 2011). The most abundant organic acids found in 'Barnfield'
368 Navel oranges were citric and quinnic acids while fumaric and oxalic were the least
369 abundant, as reported by Flores et al. (2012).

370 With few exceptions, the content of tested individual organic acids was consistently
371 lower in irradiated fruit in the bottom layer as compared with that of top layer ($P<0.05$)
372 (Fig. 3), suggesting that the metabolic activity was exacerbated in irradiated fruit by
373 irradiation and physical damage, leading to a higher respiration rate and consequently
374 to an increased utilization of organic acids. Different types of stress accelerate the
375 glycolysis and tricarboxylic acid cycle in citrus fruits, enhancing the transition from
376 sucrose metabolism to organic acid metabolism and leading to extensive citrate
377 degradation mainly through the gamma-aminobutyric acid and acetyl-CoA pathways
378 (Lin et al., 2015). These changes are genetically regulated, with the gene cascade
379 Aco3-IDH2/3-GAD4 serving as the major contributor to acid degradation (Chen et al.,
380 2012). Thus, irradiation and physical damage might induce a higher reduction of the
381 organic acid content in the bottom fruit as compared with the top fruit. This behavior
382 was clearly observed for ascorbic acid, which has been related to oxidation of ascorbic
383 acid by irradiation-generated reactive oxygen species (Wong and Kitts 2001).
384 Recently, Ramírez-Cahero and Valdivia-López (2018) demonstrated that irradiation
385 (0.5, 0.7 and 1 kGy) of ascorbic acid model solutions led to the formation of several

386 compounds (2-furaldehyde, 2(5*H*)-furanone, 2-furoic acid, furfuryl alcohol,
387 glycolaldehyde, and formic, oxalic, succinic and L-tartaric acids) with the formation of
388 these compounds dependent on irradiation dose. This direct degradation of certain
389 organic acids by irradiation, and consequent increase in others could occur in our
390 study, but the bottom layer almost always showed a reduction in organic acids at 1
391 kGy, due most likely to accelerated glycolysis and respiration rate of the bottom layer
392 fruit. The negative effects of irradiation and mechanical damage on ascorbic acid
393 content have been separately reported for oranges (Ladaniya 2008; Lee and Kader
394 2000). In contrast to irradiated fruit, the acid content in control group was generally
395 higher in fruit from bottom layer as compared with that of the top layer ($P < 0.05$).
396 Recently, Ornelas-Paz et al. (2017) also observed a generally higher content of
397 organic acids in non-irradiated mandarins after simulated sea shipment as compared
398 to irradiated fruit. Our findings demonstrated that irradiation and compression and their
399 combination affected differentially the metabolism of oranges.

400

401 **Total and Individual Phenols**

402 The total phenolic content in fruit of the same layer was unchanged with irradiation
403 ($P > 0.05$), but showed minor differences between layers. Fruit in the bottom layer
404 exhibited a lower total phenolic content, as compared to fruit in the top layer ($P < 0.05$)
405 (Fig. 4). This suggested a wounding-mediated deterioration of phenolic compounds.
406 The concentration of phenolic substances following irradiation can increase with low
407 doses but higher doses can lead to reduced synthesis or destruction (Oufedjikh et al.,
408 2000). Some studies have demonstrated that the combination of wounding and

409 irradiation at some doses reduced the biosynthesis of phenolic compounds, as
410 compared with the individual effects of wounding and irradiation, promoting a higher
411 incidence of fungal infections (Rojas-Argudo et al., 2012). This might explain the
412 higher incidence of fungal infections observed in this study for fruit in the bottom layer
413 (Table 1). Some studies have demonstrated that wounding causes an immediate
414 increase in the concentration of antifungal compounds, i.e. phytoalexins, which
415 prevent spore germination and mycelium growth but do not damage the fungal
416 structures or their viability (Kim et al., 1991; Ben Yehoshua et al., 1992). This
417 wounding-mediated increase of antifungal compounds is transient (Rojas-Argudo et
418 al., 2012), favoring the initiation of the disease in wounds as the levels of antifungal
419 compounds decrease during storage (Kim et al., 1991; Ben Yehoshua et al., 1992).
420 Thus, the combination of this transient effect of wounding and the well-known
421 phytotoxic effect of irradiation can, in combination, exacerbate the incidence of fungal
422 infections.

423 Some phenolic acids (chlorogenic, *p*-coumaric, and ferulic acids) and flavonoids (rutin,
424 narirutin, hesperidin and naringenin) were identified and quantified in the juice of the
425 tested fruit (Fig. 4). The content of narirutin (93.3-100.2 mg/L) did not change
426 significantly as a function of irradiation or layer type ($P>0.05$) (data not shown).
427 Hesperidin, narirutin, and naringenin were the most abundant phenolic compounds in
428 tested oranges. Similar concentrations of these compounds have been reported
429 previously for oranges (Agcam et al. 2014; Rocco et al. 2014). In general, oranges in
430 the bottom layer had a lower ($P<0.05$) concentration of hesperidin, *p*-coumaric acid,
431 rutin and naringenin compared to oranges in the top layer, although this trend was

432 less evident for naringenin. Wounding and other types of mechanical injury increase
433 PAL activity and the content of phenolic compounds. However, irradiation is able to
434 inhibit the wounding-mediated activation of PAL, favoring the reduction of phenolic
435 content by injury (Banerjee et al., 2015). This might be the reason why fruit from
436 bottom layer showed a lower content of individual phenols. In contrast, the content of
437 chlorogenic acid was lower in bottom layer of control fruit, while the opposite was
438 observed for irradiated oranges ($P < 0.05$). This phenomenon might be a consequence
439 of irradiation-mediated transformation of phenols. As indicated above, the content of
440 total phenols showed minor changes among experimental groups, suggesting the
441 transformation of phenolic compounds by irradiation or compression damage, as
442 reported by Breitfellner et al. (2003) in irradiated strawberries. In our study, the effect
443 of irradiation dose on individual phenolic compounds was lower than that of the layer
444 type ($P < 0.05$). Only the content of hesperidin and chlorogenic acid was clearly
445 affected by irradiation dose ($P < 0.05$). McDonald et al. (2013) did not observe changes
446 in the phenolic content of Navel oranges treated with several irradiation doses (0.2-
447 0.6 kGy). In our study, the phenolic content in tested fruit depended on layer type,
448 showing the negative effect of compression damage on this quality attribute. Several
449 studies have already demonstrated that physical damage of citrus fruits alters the
450 content of some individual phenols (Mazidi et al. 2016; Rojas-Argudo et al. 2010,
451 2012). Our study demonstrated that the combination of physical damage and
452 irradiation affected differently the content of phenolic compounds of citrus fruits.
453

454 **Conclusions**

455 This work demonstrated that the position of the fruit within a case plays a role in the
456 postharvest quality of irradiated oranges. The observed chemical changes seemed to
457 be a response to stress caused by irradiation as well as location in the case, as
458 evidenced by small alterations in sugars, acids and phenol compounds. Irradiation
459 exacerbated SERB but unexpectedly this disorder was more severe in the top than in
460 the bottom fruit, probably due to differences in the gas composition and/or relative
461 humidity inside the case or phenolic compounds. Flattening and fungal decay
462 depended on irradiation dose and layer type, once again highlighting the combined
463 effect of irradiation and fruit placement in the case. This study shows that for large
464 and heavy fruit such as oranges, which are often packed in multiple layers, packaging
465 type should be considered when evaluating the effect of irradiation on quality. Fruit
466 treated at 0.15 kGy showed minimal alterations in quality independent of fruit position
467 inside the case, demonstrating that Navel oranges tolerate phytosanitary irradiation at
468 this low dose.

469

470 **References**

- 471 Agcam, E., Akyıldız, A., & Akdemir Evrendilek, G. (2014). Comparison of phenolic
472 compounds of orange juice processed by pulsed electric fields (PEF) and
473 conventional thermal pasteurisation. *Food Chemistry*, 143, 354-361,
474 doi:<https://doi.org/10.1016/j.foodchem.2013.07.115>.
- 475 Ahmadi, E. (2012). Bruise susceptibilities of kiwifruit affected by impact and fruit
476 properties. *Research in Agricultural Engineering*, 52(3), 107-113.

477 Ahmadi, E., Ghassemzadeh, H., Sadeghi, M., M., M., & Neshat, S. (2010). The effect
478 of impact and fruit properties on the bruising of peach. *Journal of Food*
479 *Engineering*, 97, 110-117, <https://doi.org/10.1016/j.jfoodeng.2009.09.024>

480 Alférez, F., Agusti, M., & Zacarías, L. (2003). Postharvest rind staining in Navel
481 oranges is aggravated by changes in storage relative humidity: effect on
482 respiration, ethylene production and water potential. *Postharvest Biology and*
483 *Technology*, 28(1), 143-152, [https://doi.org/10.1016/S0925-5214\(02\)00120-5](https://doi.org/10.1016/S0925-5214(02)00120-5)

484 AMRC (2013). [AMRC] Agricultural Marketing Resource Center. Citrus Profile.
485 http://www.agmrc.org/commodities__products/fruits/citrus/citrus-profile/.
486 Accessed 6 March 2015.

487 APHIS (2014). [APHIS] Animal and Plant Health Inspection Service. Proposes to allow
488 the importation of fresh citrus from China into the continental United
489 States.http://www.aphis.usda.gov/newsroom/2014/08/pdf/china_citrus_import
490 [ation.pdf](http://www.aphis.usda.gov/newsroom/2014/08/pdf/china_citrus_import). Accessed 2 February 2015.

491 Banerjee, A., Penna, P., Variyar, P.S., & Sharma, A. (2015). Gamma irradiation
492 inhibits wound induced browning in shredded cabbage. *Food Chemistry*, 173,
493 38-44, <https://doi.org/10.1016/j.foodchem.2014.09.166>

494 Ben Yehoshua, S., Rodov, V., Kim, J.J., & Carmeli, S. (1992). Performed and induced
495 antifungal materials of citrus-fruits in relation to the enhancement of decay
496 resistance by heat and ultraviolet treatments. *Journal of Agricultural and Food*
497 *Chemistry*, 40, 1217–1221, DOI: 10.1021/jf00019a029

498 Breitfellner, F., Solar, S., & Sontag, G. (2003). Radiation induced chemical changes
499 of phenolic compounds in strawberries. *Radiation Physics and Chemistry*,
500 67(3), 497-499, [https://doi.org/10.1016/S0969-806X\(03\)00092-6](https://doi.org/10.1016/S0969-806X(03)00092-6)

501 Bustos, M. E., & Mendieta, R. C. (1988). Physiological evaluation of Valencia oranges
502 treated with cobalt 60 gamma radiation. *International Journal of Radiation*
503 *Applications and Instrumentation. Part C. Radiation Physics and Chemistry*,
504 31(1-3), 215-223, [https://doi.org/10.1016/1359-0197\(88\)90129-4](https://doi.org/10.1016/1359-0197(88)90129-4)

505 Cao, S., Yang, Z., & Zheng, Y. (2013). Sugar metabolism in relation to chilling
506 tolerance of loquat fruit. *Food Chemistry*, 136, 139–143,
507 <https://doi.org/10.1016/j.foodchem.2012.07.113>

508 Chen, M., Jiang, Q., Yin, X. R., Lin, Q., Chen, J. Y., Allan, A. C., Xu, C. J., & Chen,
509 K.S. (2012). Effect of hot air treatment on organic acid- and sugar-metabolism in
510 Ponkan (*Citrus reticulata*) fruit. *Scientia Horticulturae*, 147, 118–125,
511 <https://doi.org/10.1016/j.scienta.2012.09.011>

512 Chen, Z., Zhu, C., Zhang, Y., Niu, D., & Du, J. (2010). Effects of aqueous chlorine
513 dioxide treatment on enzymatic browning and shelf-life of fresh-cut asparagus
514 lettuce (*Lactuca sativa* L.). *Postharvest Biology and Technology*, 58(3), 232-
515 238. <https://doi.org/10.1016/j.postharvbio.2010.06.004>

516 Flores, P., Hellín, P., & Fenoll, J. (2012). Determination of organic acids in fruits and
517 vegetables by liquid chromatography with tandem-mass spectrometry. *Food*
518 *Chemistry*, 132(2), 1049-1054,
519 [doi:https://doi.org/10.1016/j.foodchem.2011.10.064](https://doi.org/10.1016/j.foodchem.2011.10.064).

520 Follett, P. A., & Wall, M. M. (2013). Phytosanitary irradiation for export of fresh
521 produce: commercial adoption in Hawaii and current issues. *Journal of*
522 *Radioanalytical and Nuclear Chemistry*, 296(1), 517-522, doi:10.1007/s10967-
523 012-1970-0.

524 Guerrero, F., Maxie, E., Johnson, C., Eaks, I., & Sommer, N. (1967) Effects of
525 postharvest gamma irradiation on orange fruits. In *Proceedings of the American*
526 *Society for Horticultural Science*. 90, 515-540

527 Hallman, G. J. (2012). Generic phytosanitary irradiation treatments. *Radiation Physics*
528 *and Chemistry*, 81(7), 861-866,
529 doi:<https://doi.org/10.1016/j.radphyschem.2012.03.010>.

530 Kelebek, H., Selli, S., Canbas, A., & Cabaroglu, T. (2009). HPLC determination of
531 organic acids, sugars, phenolic compositions and antioxidant capacity of
532 orange juice and orange wine made from a Turkish cv. Kozan. *Microchemical*
533 *Journal*, 91(2), 187-192, doi:<https://doi.org/10.1016/j.microc.2008.10.008>.

534 Kim, J.J., Ben-Yehoshua, S., Shapiro, B., Henis, Y., & Carmeli, S. (1991).
535 Accumulation of scoparone in heat-treated lemon fruit inoculated with
536 *Penicillium digitatum* Sacc. *Plant Physiology*, 97, 880–885, DOI:
537 <https://doi.org/10.1104/pp.97.3.880>

538 Ladaniya, M. S. (2008). Citrus Fruit: Biology, Technology, and Evaluation (Citrus
539 Fruit). San Diego: Academic Press.

540 Ladaniya, M. S., Singh, S., & Wadhawan, A. K. (2003). Response of ‘Nagpur’
541 mandarin, ‘Mosambi’ sweet orange and ‘Kagzi’ acid lime to gamma radiation.

542 *Radiation Physics and Chemistry*, 67(5), 665-675,
543 doi:[https://doi.org/10.1016/S0969-806X\(02\)00480-2](https://doi.org/10.1016/S0969-806X(02)00480-2).

544 Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing
545 vitamin C content of horticultural crops. *Postharvest Biology and Technology*,
546 20(3), 207-220, doi:[https://doi.org/10.1016/S0925-5214\(00\)00133-2](https://doi.org/10.1016/S0925-5214(00)00133-2).

547 Lin, Q., Wang, C., Dong, W., Jiang, Q., Wang, D., Li, S., Chen, M., Liu, C., Sun, C., &
548 Chen, K. (2015). Transcriptome and metabolome analyses of sugar and
549 organic acid metabolism in Ponkan (*Citrus reticulata*) fruit during fruit
550 maturation. *Gene*, 554, 64–74, <https://doi.org/10.1016/j.gene.2014.10.025>

551 Liu, C., Cai, L., Han, X., & Ying, T. (2011). Temporary effect of postharvest UV-C
552 irradiation on gene expression profile in tomato fruit. *Gene*, 486(1), 56-64,
553 doi:<https://doi.org/10.1016/j.gene.2011.07.001>.

554 Lu, L., Xu, S., Zeng, L., Zheng, X., & Yu, T. (2014). *Rhodosporidium paludigenum*
555 induced resistance in Ponkan mandarin against *Penicillium digitatum* requires
556 ethylene-dependent signaling pathway. *Postharvest Biology and Technology*,
557 97, 93-101, doi:<https://doi.org/10.1016/j.postharvbio.2014.06.007>.

558 Mazidi, M., Sadrnia, H., & Khojastehpour, M. (2016). Evaluation of orange mechanical
559 damage during packaging by study of changes in firmness. *International Food*
560 *Research Journal*, 23(2), 899-903.

561 McDonald, H., Arpaia, M. L., Caporaso, F., Obenland, D., Were, L., Rakovski, C., et
562 al. (2013). Effect of gamma irradiation treatment at phytosanitary dose levels
563 on the quality of 'Lane Late' Navel oranges. *Postharvest Biology and*
564 *Technology*, 86, 91-99, doi:10.1016/j.postharvbio.2013.06.018.

565 McDonald, R., Miller, W., & McCollum, T. (2000). Canopy position and heat treatments
566 influence gamma-irradiation-induced changes in phenylpropanoid metabolism
567 in grapefruit. *Journal of the American Society for Horticultural Science*, 125(3),
568 364-369.

569 Miller, W. R., McDonald, R. E., & Chaparro, J. (2000). Tolerance of selected orange
570 and mandarin hybrid fruit to low-dose irradiation for quarantine purposes.
571 *HortScience*, 35(7), 1288-1291.

572 Moresi, M., Pallottino, F., Costa, C., & Menesatti, P. (2012). Viscoelastic properties of
573 tarocco orange fruit. *Food and Bioprocess Technology*, 5(6), 2360-2369,
574 doi:10.1007/s11947-011-0528-4.

575 Nagai, N. Y., & Moy, J. H. (1985). Quality of gamma irradiated California Valencia
576 oranges. *Journal of Food Science*, 50(1), 215-219, doi:10.1111/j.1365-
577 2621.1985.tb13312.x.

578 Obenland, D., Collin, S., Sievert, J., Fjeld, K., Doctor, J., & Arpaia, M. L. (2008).
579 Commercial packing and storage of Navel oranges alters aroma volatiles and
580 reduces flavor quality. *Postharvest Biology and Technology*, 47(2), 159-167,
581 doi:https://doi.org/10.1016/j.postharvbio.2007.06.015.

582 Ornelas-Paz, J. d. J., Meza, M. B., Obenland, D., Rodríguez, K., Jain, A., Thornton,
583 S., et al. (2017). Effect of phytosanitary irradiation on the postharvest quality of
584 Seedless Kishu mandarins (*Citrus kinokuni mukakukishu*). *Food Chemistry*,
585 230, 712-720, doi:https://doi.org/10.1016/j.foodchem.2017.02.125.

586 Ornelas-Paz, J. d. J., Yahia, E. M., Ramirez-Bustamante, N., Perez-Martinez, J. D.,
587 Escalante-Minakata, M. d. P., Ibarra-Junquera, V., et al. (2013). Physical

588 attributes and chemical composition of organic strawberry fruit (*Fragaria x*
589 *ananassa* Duch, Cv. Albion) at six stages of ripening. *Food Chemistry*, 138(1),
590 372-381, doi:10.1016/j.foodchem.2012.11.006.

591 Oufedjikh, H., Mahrouz M., Amiot, M.J., & Lacroix, M. (2000). Effect of γ -irradiation
592 on phenolic compounds and phenylalanine ammonia-lyase activity during
593 storage in relation to peel injury from peel of *Citrus clementina* Hort. Ex.
594 Tanaka. *Journal of Agriculture and Food Chemistry*, 48, 559-565, DOI:
595 10.1021/jf9902402

596 Porat, R., Weiss, B., Cohen, L., Daus, A., & Aharoni, N. (2004). Reduction of
597 postharvest rind disorders in citrus fruit by modified atmosphere packaging.
598 *Postharvest Biology and Technology*, 33(1), 35-43,
599 doi:https://doi.org/10.1016/j.postharvbio.2004.01.010.

600 Ramírez-Cahero, H.F., & Valdivia-López, M.A. (2018). Effect of gamma radiation on
601 sugars and vitamin C: Radiolytic pathways. *Food Chemistry*, 245, 1131–1140,
602 https://doi.org/10.1016/j.foodchem.2017.11.057

603 Riov, J. (1975). Histochemical evidence for the relationship between peel damage and
604 the accumulation of phenolic compounds in gamma-irradiated citrus fruit.
605 *Radiation Botany*. 15, 257-260, https://doi.org/10.1016/S0033-7560(75)80024-
606 X

607 Ritenour, M. A., Stover, E., Boman, B. J., Dou, H., Bowman, K. D., & Castle, W. S.
608 (2004). Effect of rootstock on stem-end rind breakdown and decay of fresh
609 citrus. *HortTechnology*, 14(3), 315-319.

610 Rocco, A., Fanali, C., Dugo, L., & Mondello, L. (2014). A nano-LC/UV method for the
611 analysis of principal phenolic compounds in commercial citrus juices and
612 evaluation of antioxidant potential. *Electrophoresis*, 35(11), 1701-1708, doi:
613 10.1002/elps.201300621

614 Rojas-Argudo, C., Ángel Del Río, M., Montesinos-Herrero, C., & Palou, L. (2010).
615 Effects of CO₂ and O₂ shocks at high temperature on postharvest quality of
616 cold-stored citrus fruit. *International Journal of Food Science & Technology*,
617 45(10), 2062-2070, doi:10.1111/j.1365-2621.2010.02371.x.

618 Rojas-Argudo, C., Palou, L., Bermejo, A., Cano, A., del Río, M. A., & González-Mas,
619 M. C. (2012). Effect of X-ray irradiation on nutritional and antifungal bioactive
620 compounds of 'Clemenules' clementine mandarins. *Postharvest Biology and*
621 *Technology*, 68, 47-53, doi:https://doi.org/10.1016/j.postharvbio.2012.02.004.

622 Roussos, P. A. (2011). Phytochemicals and antioxidant capacity of orange (*Citrus*
623 *sinensis* (L.) Osbeck cv. Salustiana) juice produced under organic and
624 integrated farming system in Greece. *Scientia Horticulturae*, 129(2), 253-258,
625 doi:https://doi.org/10.1016/j.scienta.2011.03.040.

626 Saltveit, M. E. (2000). Wound induced changes in phenolic metabolism and tissue
627 browning are altered by heat shock. *Postharvest Biology and Technology*,
628 21(1), 61-69, doi:https://doi.org/10.1016/S0925-5214(00)00165-4.

629 Shi, L., Cao, S., Shao, J., Chen, W., Yang, Z., & Zheng, Y. (2016). Chinese bayberry
630 fruit treated with blue light after harvest exhibit enhanced sugar production and
631 expression of cryptochrome genes. *Postharvest Biology and Technology*, 111,
632 197-204, doi:https://doi.org/10.1016/j.postharvbio.2015.08.013.

- 633 USDA, 2017. Citrus: world markets and trade. Foreign Agricultural Service/USDA
634 Office of Global Analysis. July, 2017.
- 635 Vilanova, L., Torres, R., Usall, J., Teixidó, N., González-Candelas, L., Viñas, I., et al.
636 (2014). Effect of fruit maturity stage of orange on the wound response to
637 *Penicillium digitatum* (pathogen) and *P. expansum* (non-host pathogen). In *II*
638 *International Symposium on Discovery and Development of Innovative*
639 *Strategies for Postharvest Disease Management 1053* (pp. 177-183).
- 640 Wong, P. Y. Y., & Kitts, D. D. (2001). Factors influencing ultraviolet and electron beam
641 irradiation-induced free radical damage of ascorbic acid. *Food Chemistry*, 74,
642 75–84, [https://doi.org/10.1016/S0308-8146\(01\)00101-7](https://doi.org/10.1016/S0308-8146(01)00101-7)
- 643 Yativ, M., Harary, I., & Wolf, S. (2010). Sucrose accumulation in watermelon fruits:
644 Genetic variation and biochemical analysis. *Journal of Plant Physiology*,
645 167(8), 589-596, doi:<https://doi.org/10.1016/j.jplph.2009.11.009>.
- 646 Yue, C., Jensen, H. H., Mueller, D. S., Nonnecke, G. R., Bonnet, D., & Gleason, M. L.
647 (2007). Estimating consumers' valuation of organic and cosmetically damaged
648 apples. *HortScience*, 42(6), 1366-1371.
- 649 Zhang, K., Deng, Y., Fu, H., & Weng, Q. (2014). Effects of Co-60 gamma-irradiation
650 and refrigerated storage on the quality of Shatang mandarin. *Food Science and*
651 *Human Wellness*, 3, 9-15, <https://doi.org/10.1016/j.fshw.2014.01.002>

652

653 **Table captions**

654 **Table 1.** Incidence of stem end rind breakdown (SERB), flattening and fungal
655 infections in oranges taken from top and bottom layers of Standard Place Pack cartons
656 after storage (3 weeks at 5 °C + 1 week at 20 °C).

657 **Table 2.** Percentage of fruits from top and bottom layers of Standard Place Pack
658 cartons showing different levels of flattening after storage (3 weeks at 5 °C + 1 week
659 at 20 °C).

660 **Figure captions**

661 **Figure 1.** Percentage of fruit surface area affected by SERB (A) and L* (B) and b* (C)
662 values on SERB lesions in oranges taken from top (■) and bottom (■) layers
663 of Standard Place Pack cartons after storage (3 weeks at 5 °C + 1 week at 20 °C).
664 Data represent the mean value of twenty fruits ± the standard error.

665 **Figure 2.** Content of sucrose, glucose, and fructose in juice of Navel oranges taken
666 from top (■) and bottom (■) layers of Standard Place Pack cartons after
667 storage (3 weeks at 5 °C + 1 week at 20 °C). Data represent the mean value of five
668 measurements ± the standard error.

669 **Figure 3.** Content of organic acids in juice of Navel oranges taken from top (■)
670 and bottom (■) layers of Standard Place Pack cartons after storage (3 weeks at 5
671 °C + 1 week at 20 °C). Data represent the mean value of five measurements ± the
672 standard error.

673 **Figure 4.** Content of total and individual phenols in juice of Navel oranges taken from
674 top (■) and bottom (■) layers of Standard Place Pack cartons after storage (3
675 weeks at 5 °C + 1 week at 20 °C). Data represent the mean value of five
676 measurements ± the standard error.

Table 1.

Irradiation dose (kGy)	Layer	Damaged fruit (%)		
		SERB	Flattening	Fungal infections
0	Top	10.0±10.0a	58.8±21.2b	8.8±8.8a
	Bottom	6.3±6.3a	100±0a	19.4±2.3a
0.15	Top	48.2±23.2a	35.7±35.7b	12.1±0.4a
	Bottom	16.3±3.8b	95±5.0a	13.9±2.8a
1	Top	100±0a	6.3±6.3b	22.2±0.7a
	Bottom	100±0a	81.3±6.3a	27.8±5.6a

Data represent the mean values ± the standard error. Mean values in the same column for every irradiation dose connected by the same letter are not significantly different.

Table 2

Irradiation dose (kGy)	Layer	Damage level					
		0	1	2	3	4	5
0	Top	41.3±21.3a	58.8±21.3a	0.0±0.0b	0.0±0.0a	0.0±0.0a	0.0±0.0a
	Bottom	0.0±0.0b	87.5±12.5a	12.5±0.0a	0.0±0.0a	0.0±0.0a	0.0±0.0a
0.15	Top	64.3±35.7a	35.7±35.7a	0.0±0.0b	0.0±0.0b	0.0±0.0a	0.0±0.0a
	Bottom	5.0±5.0b	55.0±5.0a	22.5±2.5a	17.5±7.5a	0.0±0.0a	0.0±0.0a
1	Top	93.8±6.3a	6.3±6.3b	0.0±0.0b	0.0±0.0b	0.0±0.0a	0.0±0.0a
	Bottom	18.8±6.3b	50.0±0a	18.8±6.3a	12.5±0.0a	0.0±0.0a	0.0±0.0a

Severity values were based on % of fruit surface showing flat areas: 0 (no damage), 1 (1-4%), 2 (5-8%), 3 (9-12%), 4 (13-15%), and 5 (>16%). Data represent the mean values ± the standard error. Mean values in the same column for every irradiation dose connected by the same letter are not significantly different.

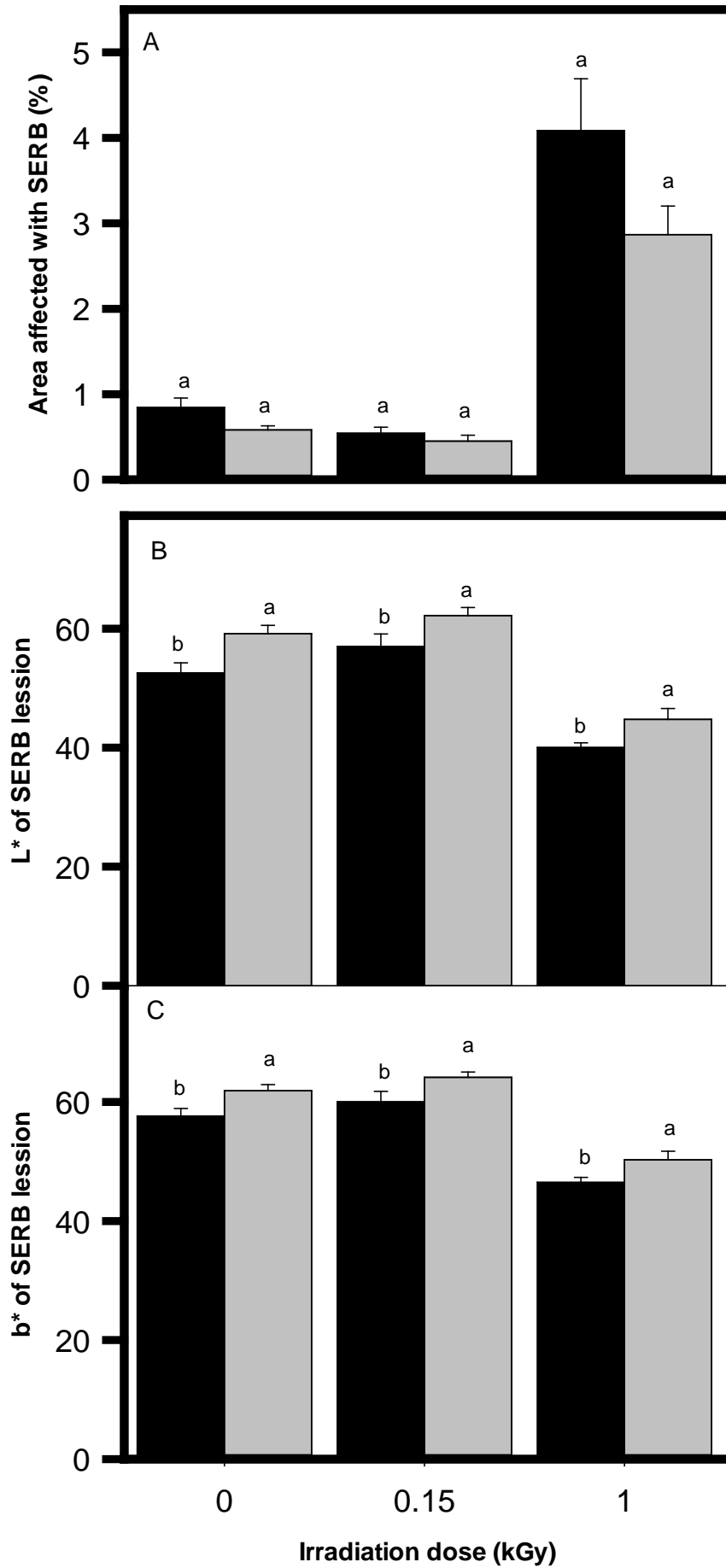


Fig 1.

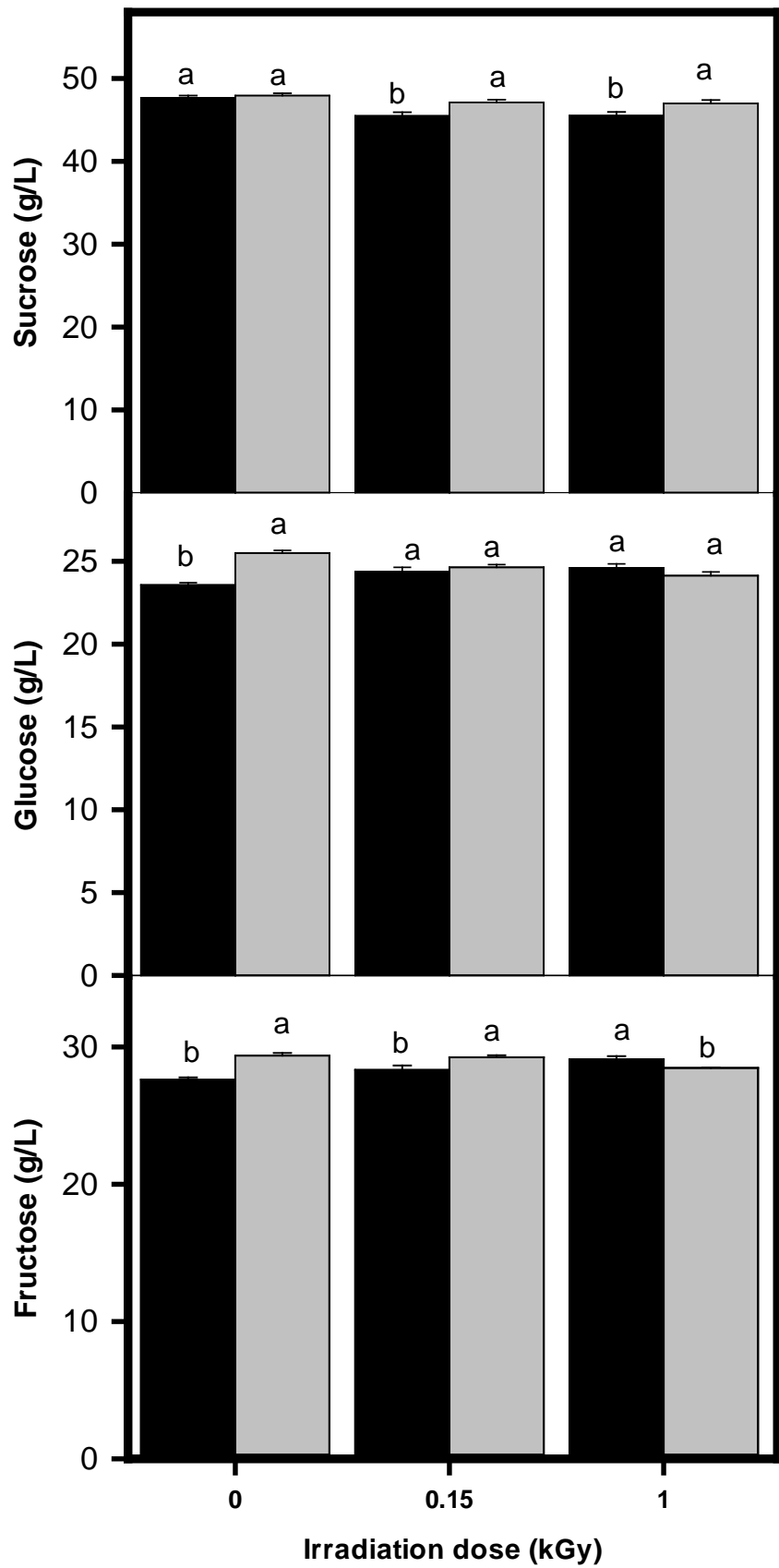


Fig. 2

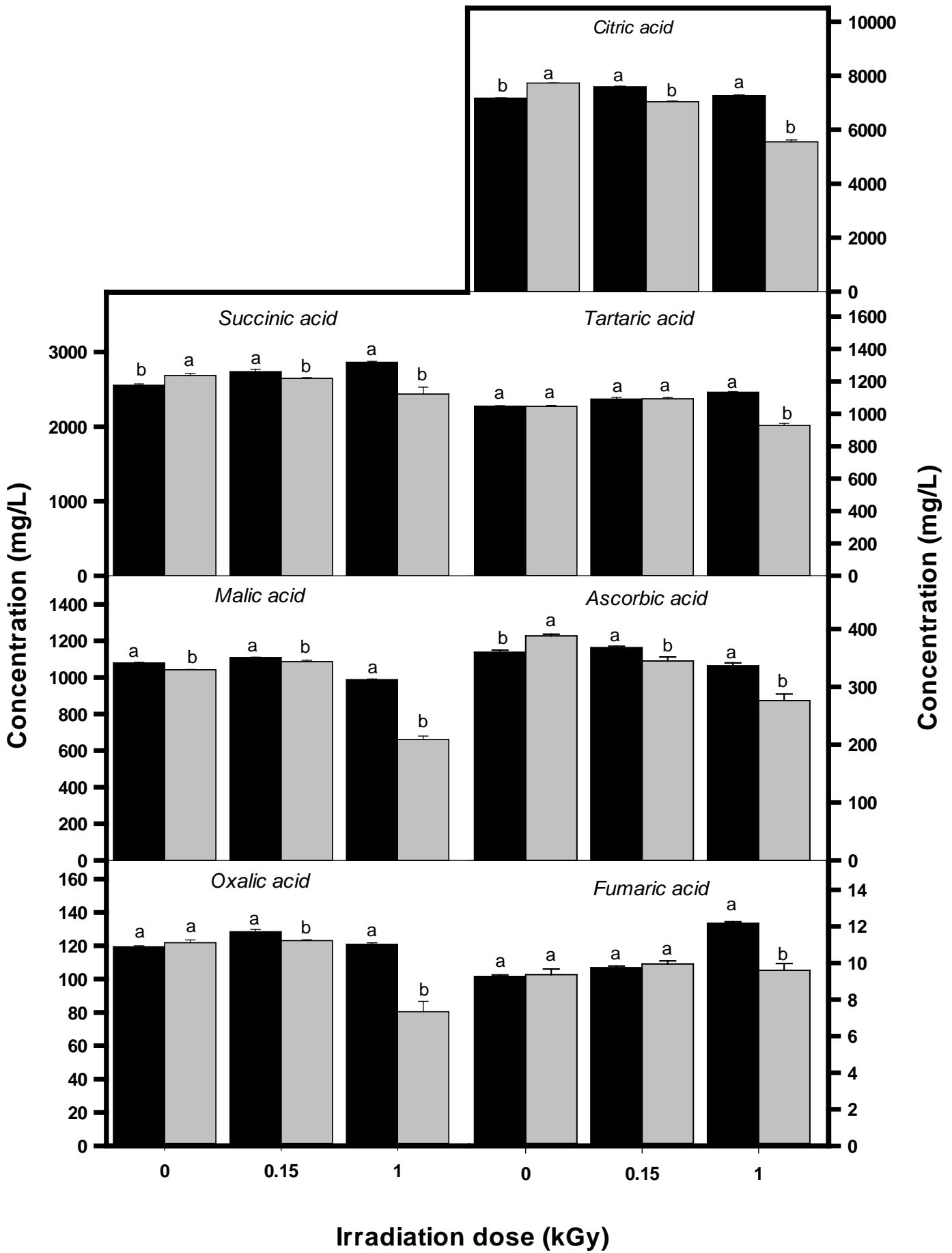


Fig. 3

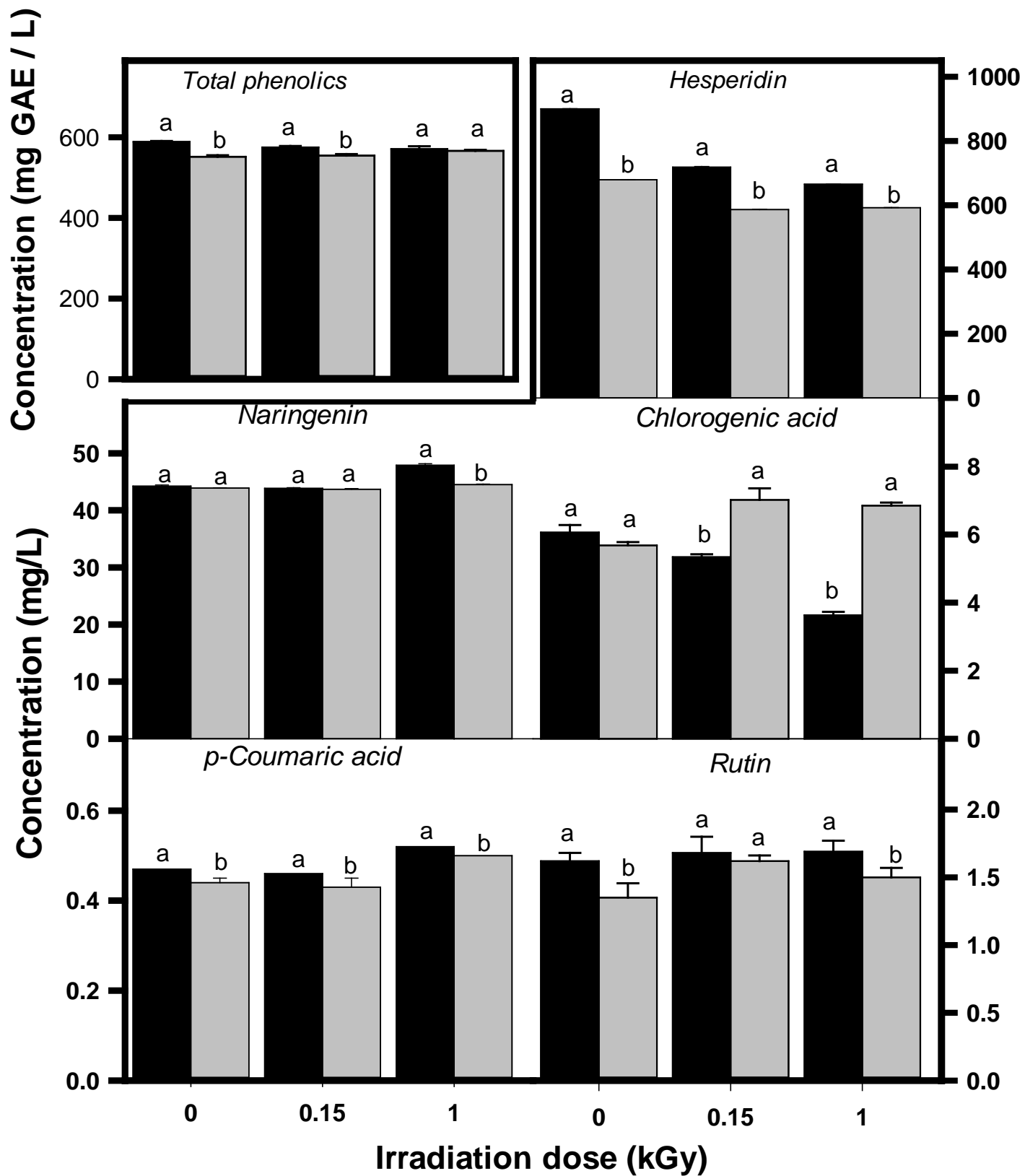


Fig. 4