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Effects of gamma irradiation on the sensory and metabolic profiles of two peach cultivars

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Abstract

Background: The aptitude of commercial peaches for minimal processing (MP) is still limited, mainly due to shorten the shelf-life. Gamma irradiation has emerged in MP fruits as a promising technology.

This study aimed to investigate the effects of gamma irradiation on the sensory and metabolic profiles of MP peaches from two cultivars, 'Forastero' (FT) and 'Ruby Prince' (RP), and evaluate the relationship between both profiles. MP peaches were packaged, and divided into two groups: one without additional treatment (K), and the other was subjected to gamma irradiation (1.0 kGy - I), making up a total of four samples (FTK, FTI, RPK, and RPI). The sensory profile was carried out by an assessor panel. Metabolite analysis was accomplished by gas chromatography-mass spectrometry (GC–MS).

Results: Irradiation significantly affected color, homogeneity, peach aroma, total flavor intensity, peach flavor, sweetness, and juiciness in FT, increasing their intensities. In the RP cultivar, irradiation increased brightness, total aroma intensity, peach aroma, and flavor and texture descriptors. Regarding the metabolites, only malic acid and sucrose increased their concentrations in the irradiated samples. Partial least squares showed that sucrose was mainly correlated with sweet, total aroma intensity and peach flavors; and linked with FTI sample. Bitter along with to peach aroma and total intensity flavor were associated with RPI sample.

Conclusion: The applied dose accelerated the ripening process of the peach. The study highlights the importance of complementing the sensory analysis with metabolomics tools to optimize fruit quality in minimally processed peaches.

1. Introduction

Peach (*Prunus persica* (L) Batsch) has a production of nearly 20 million tons per year.[1] It represents one of the most economically important fruit crops because of its adaptability to a broad climate range and its high production yield. From the nutritional viewpoint, this China-native species constitutes a rich source of minerals, vitamins, and antioxidants,[2,3] a feature highly regarded by nowadays consumers.

Peach is a climacteric fruit that undergoes a rapid ripening after harvest. The fast ripening of the fruit is responsible for its short shelf-life and represents a serious constraint for its efficient handling and transportation.[4,5] The extent to which these changes occur strongly depends on the variety, reflecting the wide phenotypic and metabolic variability. These different cultivars also show a rich diversity in the content of metabolites with a potential impact on organoleptic and nutritional quality.[5-7]

Peaches can be consumed either fresh or processed. Most processed peaches (~80%) are canned and the remainder are frozen, dried, used in marmalade and juices.[8]

The current pace of life with little time to prepare balanced meals brings out the demand for natural, fresh, healthy, and ready-to-eat plant products, such as those minimally processed (MP).[9] MP fresh fruit and vegetables are commonly defined as any fruit and vegetable subjected to different processing steps (e.g., peeling, trimming, cutting, washing, disinfection, rinsing, etc.) to obtain a fully edible product while providing convenience and functionality to consumers and ensuring food safety. [10]

Different studies have explored the aptitude of peach species for minimal processing, although the commercial availability in this presentation form is still limited, mainly due to alterations such as browning on the cut surface, the rapid loss of firmness, and the generation of exudation,[11,12] which will shorten the shelf-life.

To overcome this drawback, gamma irradiation has emerged in MP fruits as a promising technology, able to improve the microbiological status, extend the shelf-life, and reduce storage losses, for which a suitable irradiation dose should be determined.[13-15] In this regard, different factors, such as cultivar and maturity stage, are known to affect the tolerance of fruit to this treatment.[16] The most widely adopted application of gamma irradiation in fruits is probably for quarantine disinfestation, which proved effective without significantly affecting the content of bioactive compounds or the sensory quality (pigments, nutrients, bioactive compounds, and flavor). [17,18] Gamma irradiation of different peach cultivars at low (≤1.0 kGy) and higher doses has been previously reported by several researchers.[4,5,16,19,20] In the Argentine Food Code, this technology was included in a recent modification of Resolution 13-E/2017 which promotes its application in different types of products, including fresh fruits. According to the purpose of irradiation, the maximum allowable doses are 1.0 kGy for ripening retardation, insect disinfection, and quarantine control, and 2.5 kGy for spoilage microorganism control.[21]

Previous studies indicate that the most notorious impact of irradiation on peaches is on softening, with the extent of this effect depending on the dose, the cultivar, and the ripening stage upon treatment. [5,19,22,]

It is well known that both the sensory quality (as assessed by descriptors) and nutritional value of peaches play an important role in consumer satisfaction, which will in turn influence the decision-making process for future purchases. These attributes are determined by a vast array of metabolites, which are responsible for the organoleptic properties, the nutritional value, and the functional attributes of fruit.[6] Therefore, it would be possible to assess the overall quality of peaches by conducting chemical analyses,[23] since it largely depends on the level of compounds such as sucrose, citric and malic acids, carotenoids, lactones, polyphenols, and pectic substances.[24] In turn, sensory evaluation of the fruit, as performed by assessors, and physical measurements (e.g., color and textural properties) proved useful for the evaluation of quality as perceived by consumers. [25]
In this sense, descriptive analyses have shown a high correlation level with instrumental descriptive measures, which could together help predict consumer preferences. Thus, the establishment of the "desired composition" of a product can be regarded as a powerful tool for quality optimization.
Consequently, validated models able to link descriptive sensory characteristics with relevant instrumental and/or consumer preference measurements have been increasingly used in the food industry, and even more effort can be expected in this direction in the coming years. [23,26] Instrumental methods are easier to perform, standardize and reproduce than sensory measurements. However, the relationship between them should be first established. [27,28]
From the sensory point of view, organic acids and soluble sugars are the main compounds contributing to the overall organoleptic quality of fresh peaches.[29,30] Therefore, a comprehensive study on the levels of these compounds and their correlation with the descriptive sensory analyses will be highly relevant to establish the optimal organoleptic quality.
Considering all the aforementioned aspects, the present study aimed to investigate the effect of gamma irradiation on the sensory and metabolic profile of MP peaches from two different cultivars, to assess the relationship between both profiles.

2. Materials and Methods

2.1. Samples

Assays were conducted with two peach cultivars ‘Forastero’ (FT) and ‘Ruby Prince’ (RP) grown in the Estación Experimental Agropecuaria INTA, San Pedro, Buenos Aires, Argentina (Latitude 33°41_S, Longitude 59°41_W) under experimental control: a plantation area of 3.5 x 5 m without artificial irrigation, soil management is grass in the interrow, and herbicide is applied in the total row, and the sanitary management and fertilization are similar to those carried out in commercial forests in the area. Fruits were collected at commercial maturity in November 2019 and manually selected for uniformity of color (Visual inspection of the fruit was individually performed. Fruits with a greener and more yellow background color were discarded) and firmness. They were kept in a modular chamber (2.4 x 2.4 x 2.2 m) Frutitec SRL brand with Coirón Model M2500 HT equipment at 0 °C and 90 % relative humidity for 24 hours. Then, the fruits were transferred to Instituto de Tecnología de Alimentos, ITA-INTA, Castelar, Buenos Aires, Argentina for processing.

2.2. Sample preparation and treatment

Before processing, the fruits were washed in running tap water. Slices (10-mm width, which included the peel) were obtained from the parenchyma tissue by using a 7-inch ceramic knife (Accurato Ceramic Knife, Design Collection, Tramontina). Subsequently, the slides were dipped in tap water containing 20 mg L^{-1} NaClO for 2 min. After draining, the slices were dipped in an aqueous solution containing 10 g L^{-1} ascorbic acid (ACS, Biopack, Argentina) and 5 g L^{-1} citric acid (USP, Anedra, Austria) for 2 min to prevent surface browning and to remove the remaining NaClO. The slices were drained, arranged in PET plastic trays (eight units each), and sealed with film Cryovac BB2620 (O2 transmission rate: 6–14 cm^3 m^{-2} 24 h^{-1} at 23 °C, 1 atm).

The packed slides from the two cultivars (FT and RP) were divided into two groups: control samples with no additional treatment (K), and Gamma Irradiation-treated samples (I), making up a total of four (FTK, FTI, RPK, RPI). FTI and RPI samples were irradiated using Cobalt-60 as a gamma irradiation source at the National Atomic Energy Commission of Ezeiza (CAE-CNEA), Buenos Aires, Argentina. Fruits were placed in custom-built three-shelf sample holders at a distance of 100 mm from the irradiation source to receive a dose rate of ~ 1.0 kGy.

Then, halves of the four samples were transported to 9 de Julio (Buenos Aires, Argentina) in Styrofoam boxes with refrigerants (2-hour journey) for sensory analysis and refrigerated at 0 °C in a cold-room COSTAN® Model PubMPDO 90 until evaluation in a time of 24 hours. The other halves were frozen in liquid nitrogen (-180 °C) and sent to Centro de Estudios Fotosintéticos y Bioquímicos (CEFOBI), Rosario, Santa Fe, Argentina, for metabolite analysis.

2.3. Methodology

Ethics statement: This study was approved by the ethical committee of the Instituto Superior Experimental de Tecnología Alimentaria (ISETA) and consent was obtained from each subject before their participation.

2.3.1. Sensory Profile

The sensory profile was carried out by a panel of nine assessors, who were selected and trained following the guidelines of ISO-8586-1[31] "Sensory analysis – General guidance for the selection, training, and monitoring assessors". They all register a minimum of 100 h of experience in discrimination and descriptive tests, and specifically in peach descriptive tests, the panel presents 25 h of experience following the guidelines of ISO-13299[32] "Sensory analysis. Methodology- General guidance for establishing a sensory profile". In this experience, assessors developed descriptors individually of both whole and MP peaches, followed by a round-table discussion to reach a consensus. The peaches used in this period were of different cultivars and different degrees of maturation to identify possible descriptors and their different intensities on the worksheet with unstructured scales from 0 to 10. The four samples were tested in a sensory laboratory equipped with individual booths, day-light type fluorescent lighting, an air extractor, and controlled temperature.

The appearance, aroma, flavor, and mouth texture of the four samples were evaluated. All assessors completed two training sessions before sample measurement; these sessions involved term generation based on the samples presented, references selection, and then discussion in an open session[33] (Table 1).

Samples were presented in 180 mL disposable plastic cups with lids, labeled with a three-digit random code. From each sample, three trays were randomly taken. Each assessor received two slices randomly to evaluate the aroma; then, one slice was used to evaluate the taste and the other, to evaluate mouth texture. So that there was no bias in the attributes already evaluated (aroma, flavor, mouth texture), the appearance was evaluated in disposable plastic trays identified with random codes of three different digits. A single measurement session was carried out, and samples were evaluated by duplicate. The order of presentation was randomized among assessors and water was provided to clean their palates between samples.

2.3.2. Metabolic profile

Metabolite analysis by gas chromatography-mass spectrometry (GC–MS) was mainly carried out as described by Roessner- Tunali.[34] Representative mesocarp tissues of peaches from each sample (250 mg) were ground using ceramic mortar and pestle pre-cooled with liquid nitrogen and extracted in three ml of methanol. Internal standard (180 µl, 0.2 mg ribitol- 1 ml water MilliQ) was subsequently added for quantification purposes. The mixture was extracted for 15 min at 70 °C (vortexing every three min) and mixed vigorously with pre-cooled water MilliQ (1.5 ml). After centrifugation at 2,200 × *g*, an aliquot of the supernatant (50 µl) was transferred to a reaction tube (1.5 ml) and vacuum dried. Tubes were filled with N_2 gas and stored at -80 °C. Samples were derivative using methoxyamine hydrochloride in pyridine followed by N-methyl-N-[trimethylsilyl]trifluoroacetamide treatment. Derivatization and GC–MS were performed as described by Roessner-Tunali.[34] Mass spectra were cross-referenced with those in the Golm Metabolome Database.[35] Metabolite quantification was based on the relative peak response area of each chromatogram and expressed relative to the internal standard (ribitol). By this technique, 13 metabolites (malic acid, lactic acid, benzoic acid, phosphoric acid, succinic acid, citric acid, sucrose, glycerol, ribose, glucose, fructose, talofuranose, and turanose) were monitored.

2.4. Statistical analysis

The sensory descriptors and metabolites were analyzed by two-way ANOVA to study the influence of treatment and cultivar. Means were compared using Fisher's least significant difference (LSD) at a 5 % significance level.

A principal component analysis (PCA) was performed on the covariance matrix[36] of the averaged data of the samples considering the repetitions. The PCA was performed to establish relationships between the sensory descriptors and metabolic profile with the four samples. In this analysis, all attributes of sensory profile were considered.

An understanding of the relationships between sensory panel results and metabolite measurements can provide insights into which metabolites or a combination of metabolites will best predict relevant sensory attributes. Partial Least Squares (PLS) is a technique of multivariate regression analysis that can be used to compare two blocks of variables.[37] In this study, PLS was used to examine peach quality data derived from sensory and metabolic analysis. Aroma and flavor attributes were only considered since they have a direct relationship with the metabolites evaluated.

Statistical analyses were performed using the software package Genstat (VSN International Ltd., Hempstead, United Kingdom).

3. Results

3.1 ANOVA

Sensory analysis ANOVA showed that the interaction cultivar*treatment was significant for most descriptors. The dose's main effect was significant for peach aroma and total flavor intensity. In the case of the descriptors: dehydration, overripe aroma and flavor, astringency, and pasty were not significant on any effect or interaction.

For appearance descriptors (Table 2), the FT cultivar was affected to a greater extent by the irradiation exposure, with FTI presenting a higher color intensity and homogeneity than FTK; however, regarding the brightness descriptor, the sample affected by the treatment was the RP, being RPI the one with the highest intensity.

In aroma, the RP cultivar was affected in total aroma intensity by treatment to a greater extent than for FT, being the effect higher for the case of treated samples (RPI) (Figure 2a). In turn, the peach aroma was higher in treated samples, regardless of the cultivar (FTI and RPI samples – Figure 2b); meanwhile, RPK presented the highest green aroma, while RPI had the lowest value (Figure 2c).

Flavor evaluation shows that the total flavor intensity was higher in irradiated samples (FTI and RPI – Figure 3a). In turn, for peach and sweetness descriptors, the treatment affected similarly (by increasing its intensity) both cultivars (Figures 3b and f), with the highest value corresponding to the RPI sample. The treatment also affected the green and acid flavors in RP by decreasing their intensities, showing greater differences between RP samples than between FT samples (Figures 3c and d). In the FT cultivar, the bitter descriptor slightly increased its intensity because of the application of the I treatment (Figure 3e).

One of the most relevant differences was found in the mouth texture, which was affected in all descriptors evaluated, except for pasty. Hardness and crunchy were higher in control samples (FTK and RPK) than in treated fruits (FTI and RPI); associated with this, it was observed that the juiciness was higher in FTI and RPI samples (Table 3).

Regarding the analysis of the metabolic profile, the interaction cultivar*treatment showed significant differences for all the metabolites evaluated, except for glucose, fructose, and talofuranose. FT cultivar, especially for the control sample, had the highest concentration of malic, citric, and benzoic acids. In the case of malic acid, concentrations leveled off after irradiation (Figures 4a-c). The two cultivars also showed significant differences in lactic and phosphoric acids, with RP having the highest concentration. In turn, the concentration of these metabolites decreased in irradiated samples. (Figure 4d and e). Succinic acid also presented significant differences, although they were rather of low value (Figure 4f).

In addition, sucrose concentration increased in irradiated samples (FTI and RPI), with this difference being more accentuated for the RP cultivar (Figure 5a). Glycerol decreased in the RP cultivar by the effect of irradiation (Figure 5b), while ribose and turanose presented a higher concentration in untreated samples, with the FT cultivar having the highest value. Both sugars decreased their concentration in FTI concerning the control (Figures 5c and d).

3.2 PCA

Figure 6 presents the PCA of the sensory descriptors and the metabolites corresponding to the four samples (FTK, RPK, FTI, RPI). The percentages of variance, as explained by the two principal components, were 82 % for PC1 and 14 % for PC2. Principal component analysis was performed on those descriptors and metabolites considered significant by ANOVA. FTI and RPK samples were located on the PC1, while FTK sample was on the PC2. The RPI sample is located near the intersection of the axes, which means that it is not explained by any of the components. The RPK sample was mainly associated with the green aroma and flavor, acid flavor, crunchiness, hardness, phosphoric acid, lactic acid and glycerol. To a lesser extent, the total intensity of flavor and the intensity of color were associated with this sample. In turn, the FTK sample was linked to the green aroma, crunchiness, hardness, and homogeneity. Regarding metabolic components, this sample was associated with succinic, benzoic, citric, and malic acid, turanose, and ribose. RPI was mainly associated with the intensity of peach aroma, total flavor and aroma intensity, bitter, and brightness. FTI was mainly associated with sweet flavor, sucrose and juiciness; total aroma intensity, peach flavor, and bitter also were linked to FTI. Peach aroma and homogeneity had a weaker association with this sample. Irradiated samples (RPI and FTI) have a similar profile since they were close to each other.

3.3 Partial least square (PLS)

PLS summarizes the behavior of the samples, aroma and flavor sensory descriptors, and the different metabolites. Data variation is explained by the first 2 dimensions, where PLS1 explained 75 % and PLS2 10 % of this variation (Figure 7). Individual sensory descriptors were explained in more than 70 % by the variance of the first two PLS factors. Therefore, the figure was constructed with the correlation coefficients between the variables (sensory descriptors and metabolites).

Figure 7 shows that FTK samples were mainly associated with the metabolite's ribose, turanose, and malic, citric, benzoic, and succinic acids. Interestingly, these metabolites were far away from all sensory descriptors, in other words, the correlations were null or negative. Phosphoric acid, lactic acid, and glycerol had to a highly correlation with acid flavor, green aroma and flavor descriptors. All of them associated with RPK sample. Sucrose was mainly correlated with sweet, total aroma intensity and peach flavors; and linked with FTI sample. The descriptors and the metabolite also were associated with RPI sample, but in a lesser extent. Bitter had a negative correlation with phosphoric acid and along with peach aroma and total intensity flavor were associated with RPI sample. FTI and RPI samples had a negative association with green aroma and flavor, acid and with glycerol, lactic and phosphoric acid.

4. Discussion and Conclusion

There is a great challenge for food scientists to increase the shelf-life of perishable foods through the use of non-thermal and innovative technologies; therefore, the application of emerging technologies such as gamma irradiation represents an active area of research. The present study was focused on the application of this technology in MP peaches (in two cultivars, FT and RP, grown in the north of Buenos Aires province). The assay was designed to evaluate the change generated by irradiation at sensory and metabolic level.

Results showed that the irradiation treatment increased the intensity of different descriptors linked to the general appearance of peaches, such as color intensity and homogeneity. In a previous study, no visual difference was found in two mango cultivars between the control and those submitted to low doses (0.3–1.0 kGy).[38] In another work, irradiation (doses of 0.4 and 1.0 kGy) was able to slow down the ripening process of mangoes compared to control samples.[39]

This treatment also had a positive effect on aroma, flavor, and texture. By comparing the effect on the cultivars, the most pronounced changes at the sensory level were observed in the RP cultivar, mainly in aroma and flavor. Certain descriptors increased or decreased their intensity in the same way (or in the same direction) in both samples when irradiated, causing slice maturity. Among the induced changes, the peach aroma increased its intensity with the treatment.

Both FTI and RPI samples showed an increase in peach aroma intensity, total flavor intensity, and sweet and peach flavors. In mango, Sabato[40] found that the odor index of fruits irradiated with 1.0 kGy was significantly lower than control fruit. The effect of irradiation was also verified on chemical compounds. In this regard, acidity was decreased by treatments. Similar results were found by Palekar,[39] who observed that the acid basic taste, slightly decreased in cantaloupe slices, although it was barely detectable when the irradiation dose increased.

In RPI and FTI cultivars juiciness increased, while crispness and hardness decreased. Among all the quality variables evaluated, firmness is the most sensitive attribute. The firmness loss is manifested immediately after irradiation application, even at low irradiation doses (<1.0 kGy). This phenomenon was very consistent in raspberries, kiwis, blueberries, some varieties of apples, some varieties of pear, papaya, oranges, lettuce, and tamarillos, among others.[41]

In other peach cultivars such as Maygold, Suwanne, Southland, and Loring, firmness was reduced at doses ≥1.0 kGy, regardless of the storage temperature. Firmness loss, as induced by irradiation, has been linked to the increased ripening rate as well as to the augmented solubilization of pectin.[41] Ahmed[20] found that Loring and Dixiland peaches were substantially softer than control fruit immediately after treatment when exposed to either 1.5 or 3.0 kGy. The loss of firmness associated with irradiation strongly depends upon the variety, [4,19,43] but also on the irradiation dose.

In strawberries, Panou[44] evaluated two irradiation doses (0.5 and 1.0 kGy), with only the most intense of them (1.0 kGy) being able to accelerate the wall degradation. In McDonald[16] the sensory perception of firmness loss was manifested at doses of 0.6 kGy and higher. Similar results were obtained in Barlett pears irradiated at the preclimacteric stage; whose ripening process was stimulated at doses in the range of 1.0–3.0 kGy. However, gamma irradiation fails to induce the soft and juicy texture characteristic of the Bartlett pear before physiological alterations occur, and the subsequent decomposition usually verified can have a deleterious effect on the fruit.[45]

Regarding the color change, Bramlage and Couey[46] reported that the exposure to 0.45–3.0 kGy was able to accelerate the change from green to the yellow ground color of Redglobe and Halloween peaches, suggesting that irradiation can increase the ripening rate in these cultivars. In turn, Palekar[40] speculates that irradiation-induced texture changes would be mainly associated with changes in pectic substances.

It is well known that the fruit is one of the most metabolite-rich plant tissues and as such, contains a massive range of metabolites, some of them involved in taste and flavor, some with nutritional or pharmaceutical properties, and others with plant defense properties against biotic and abiotic stress.[5]

Among those related to taste, ripe fruits have between 50 to 75 % sucrose, which makes it the most predominant sugar in peaches.[47,48] Both irradiated samples (FTI and RPI) presented a greater concentration of sucrose, in agreement with the higher sweetness rate found by the sensory panel. Previous studies found that irradiation can increase or reduce the content of sugars in fruits, depending on the fruit, ripening stage, and irradiation dose. Prakash and Ornelas-Paz[39] observed that irradiation-mediated changes in individual sugars are small. Very low irradiation doses (0.075 and 0.3 kGy) do not alter the content of glucose, fructose, and sucrose in lemons, cucumbers, nectarines, pawpaws, persimmons, zucchinis, Ellendale mandarins. In agreement with the finding of the present study, Cancino-Vázquez[49] found that the difference in sweetness in mangoes detected by the panelists may be due to a higher proportion of sugars with higher sweetener power, such as sucrose and fructose, and a lower proportion of glucose in the non-irradiated. In irradiated juice from this fruit, glucose content increased when doses of 0.5, 1.0, and 3.0 kGy were applied, but sucrose and fructose content increased only when doses of 3.0 kGy were applied.

Acidity plays an important part in the perception of fruit quality. It affects not only the sour taste of the fruit[50] but also sweetness, by masking the taste of sugars. In the present study, malic and citric acid maintained their concentration after treatment, and negatively correlated with sucrose concentration, although the trained panel detected differences between samples. The least acidic samples were those treated with irradiation. Similar results were found by Cancino-Vázquez, [49]who found that rates given by panelists give were lower for sourness in the case of irradiated fruits (0.15 and 0.30 kGy), although this difference did not correlate with the acid content in mango (mainly citric and malic acid), [51] with no difference between treatments in the titratable acidity.

Glycerol, another metabolite linked to sweetness, only decreased in the RP variety after irradiation. Previous studies found that the peaks of this metabolite occur during harvest and then decrease during post-harvest maturation.[52] Interestingly, green and flavor aroma had similar behavior to glycerol, especially in RP, where a significant decrease in the intensity of these descriptors was observed in the irradiated sample, for which some relationship with this metabolite could be established.

It could be hypothesized that gamma radiation at the dose applied in this work (1.0 kGy) accelerated the maturation of peach slices, since both irradiated samples (FT and RP), were described with sweetness and peach flavor, and sucrose; while control samples were described with acid and green flavor, and organic acids, related to unripe fruit.

The present study evidence that fruit of different peach cultivars presented a variation in the content of key metabolites involved in organoleptic properties.

Even though consumers judge the quality of MP products based on appearance and freshness at the time of the first purchase, subsequent purchases depend on the satisfaction achieved in terms of texture and flavor, while continuing to be interested in their nutritional quality and safety.[53,54] Gamma irradiation could improve the quality and extend the shelf-life of MP peaches. The fact of complementing sensory analysis with metabolomics provides a tool to improve fruit quality in these products.

It remains to be established in future studies the detailed changes bring about in these cultivars by different doses of irradiation over time, to determine the most suitable cultivar for the application of this technology.

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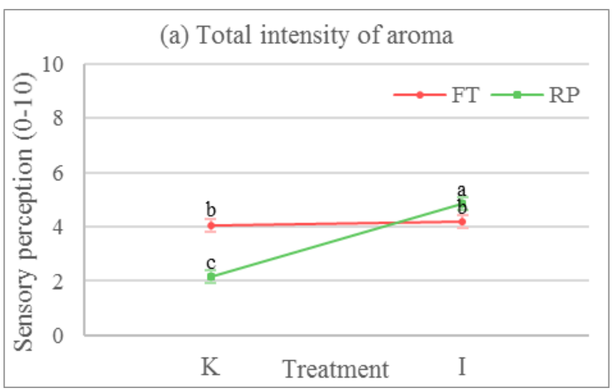
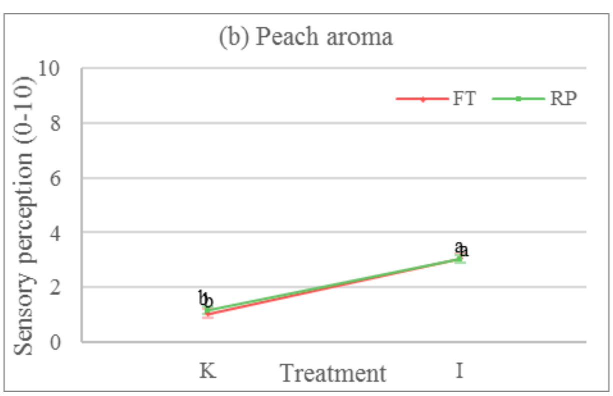
<u>Figures</u>

Figure 1. Picture reference to evaluate Homogeneity color distribution

(a) LSD: 0,2



(b) LSD: 0,2



(c) LSD: 0,2

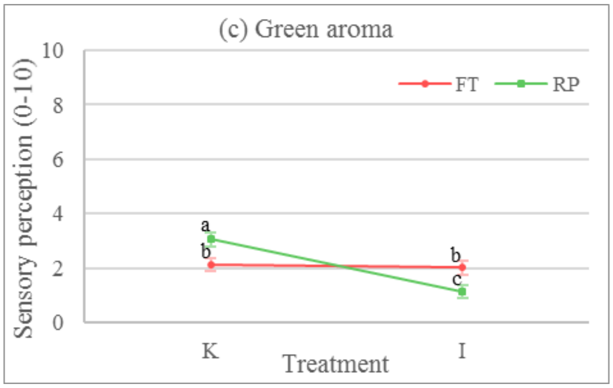
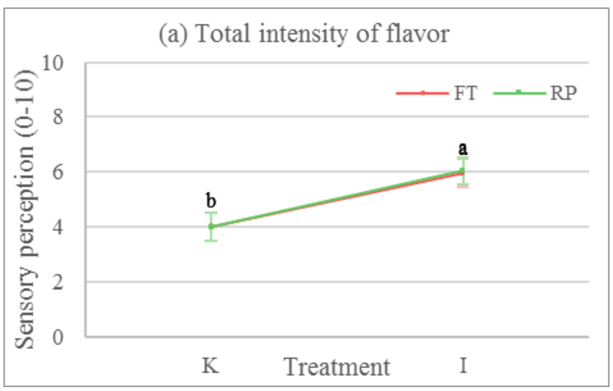
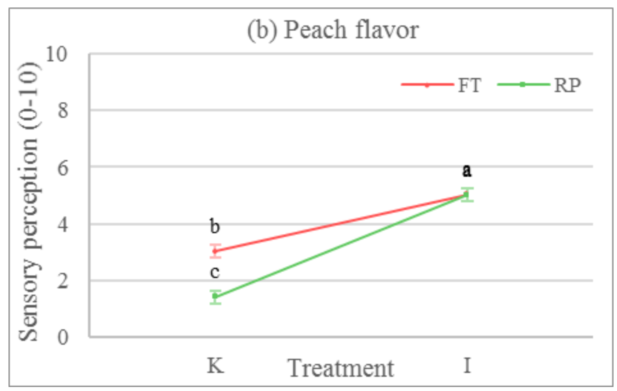


Figure 2. Sensory perception (0–10) of aroma descriptors in Forastero (FT) and Ruby Prince (RP) cultivars for control (K) and irradiated (I) treatment. a)Total intensity of aroma; b)Peach aroma; c)Green aroma. Vertical bars represent LSD.

a) LSD: 0,5

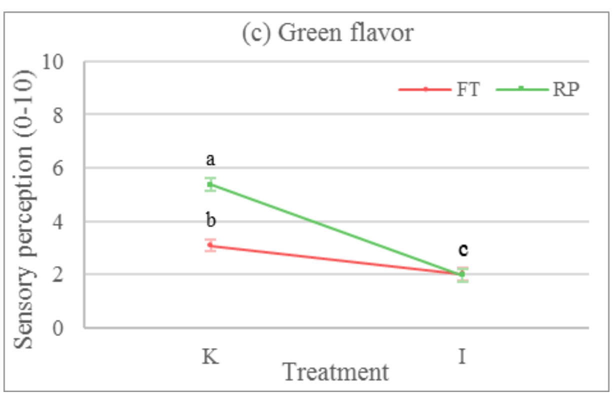
b) LSD: 0,3

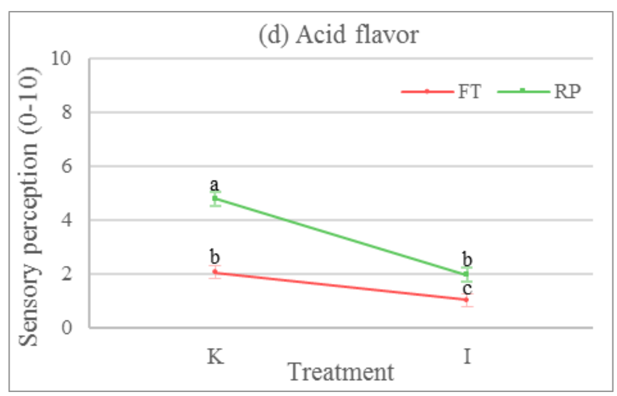




c) LSD: 0,2

d) LSD: 0,2





e) LSD: 0,4

f) LSD: 0,2

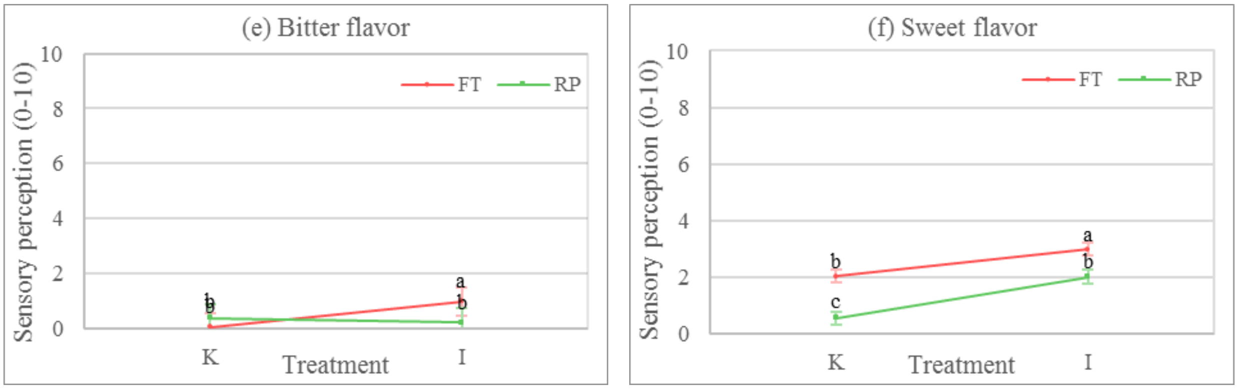
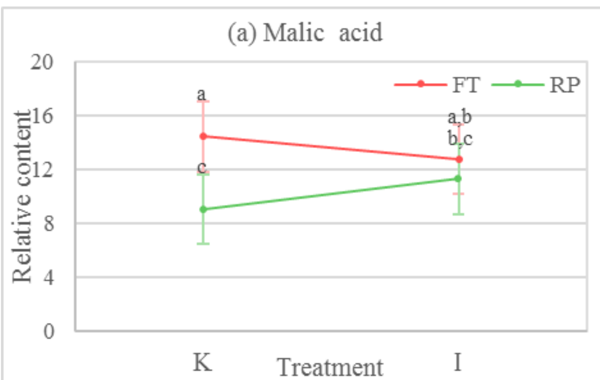
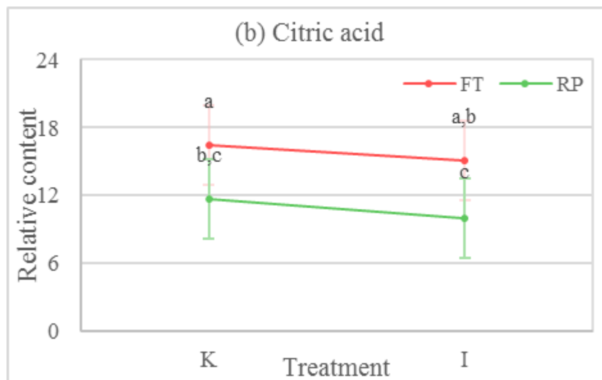


Figure 3. Sensory perception (0–10) of flavor descriptors in Forastero (FT) and Ruby Prince (RP) cultivars for control (K) and irradiated (I) treatment . a)Total intensity of flavor; b) Peach Flavor; c) Green Flavor; d)Acid; e)Bitter; f)Sweet. Vertical bars represent LSD

a) LSD: 2,6

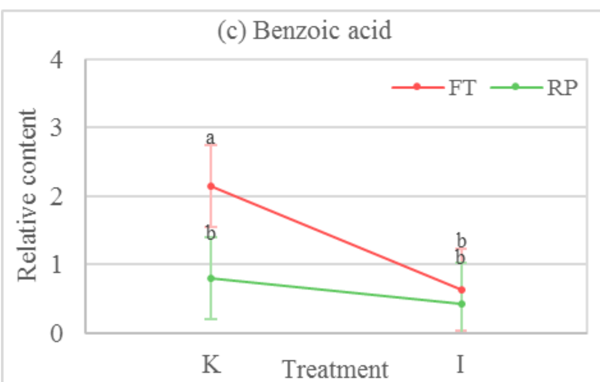
b) LSD: 3,5

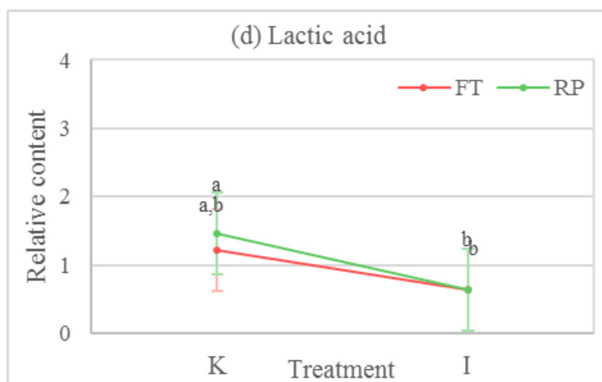




c) LSD: 0,6

d) LSD: 0,6





e) LSD: 1,5

f)LSD: 0,1

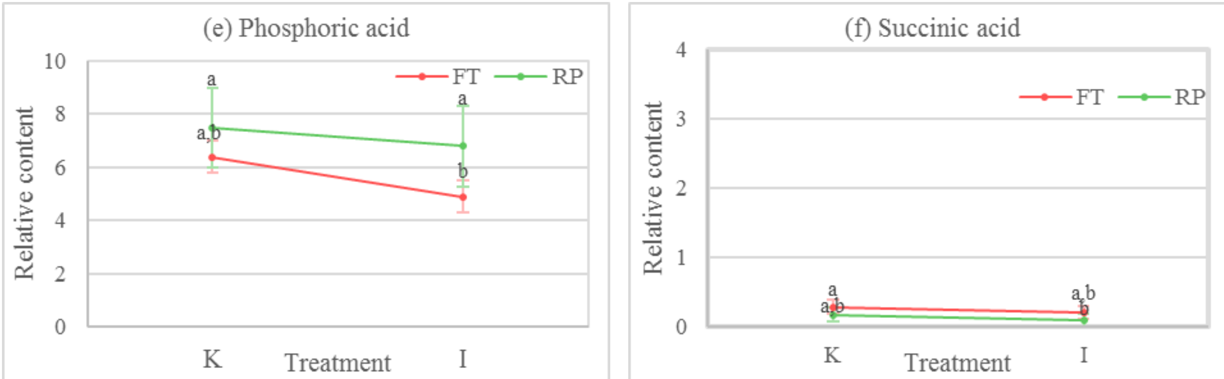
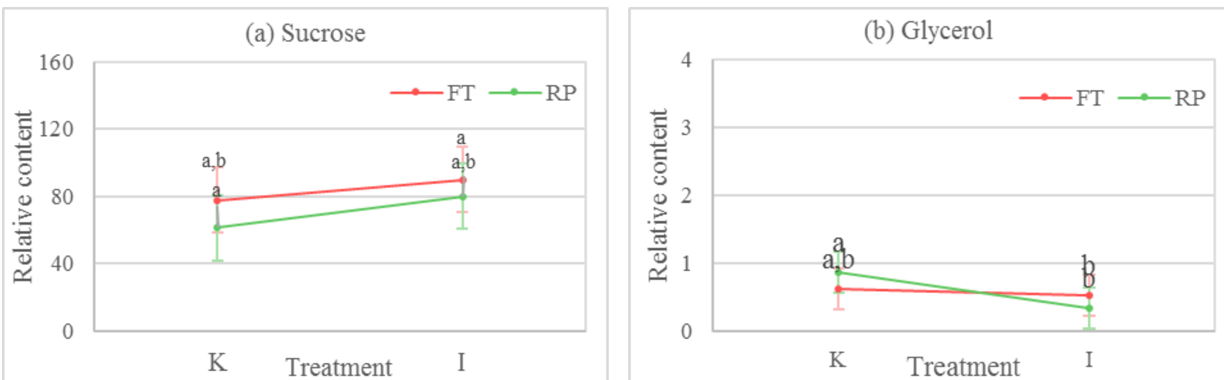


Figure 4. Relative level content of acid metabolites in Forastero (FT) and Ruby Prince (RP) cultivars for control (K) and irradiated (I) treatment . a) Malic acid; b) Citric acid; c) Benzoic acid; d) Lactic acid; e) Phosphoric acid: f) Succinic acid. Vertical bars represent LSD.

a) LSD: 19,4

b)LSD: 0,3



c)LSD: 0,5

d)LSD: 3,1

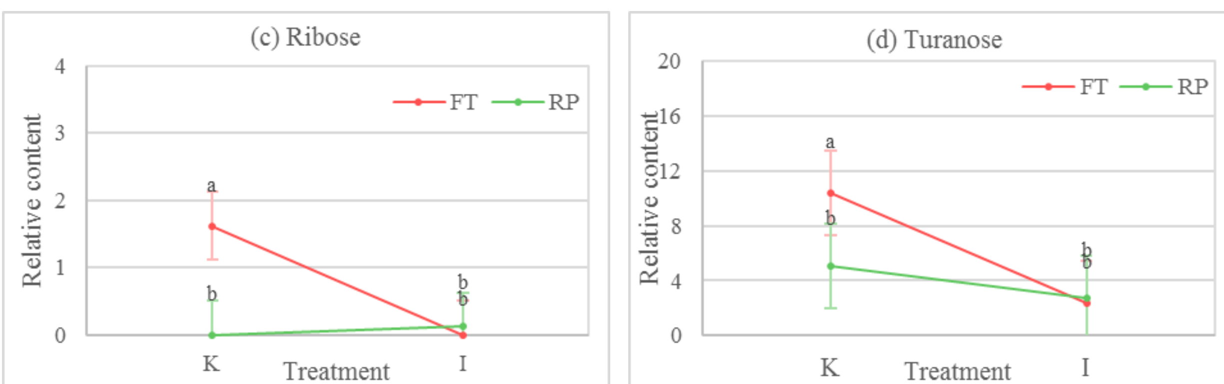


Figure 5. Relative level content of sugar metabolites in Forastero (FT) and Ruby Prince (RP) cultivars for control (K) and irradiated (I) treatment. a) Sucrose; b) Glycerol; c) Ribose; d) Turanose. Vertical bars represent LSD.

Figure 6. Graphical representation of the Principal Component Analysis (PCA) of samples, showing the sensory descriptors and the metabolites analyzed with the first two principal components. References: FTK: Forastero cultivar control treatment, FTI: Forastero cultivar irradiated treatment, RPK: Ruby Prince cultivar control treatment, RPI: Ruby Prince cultivar irradiated treatment. CI: Color intensity, HO: Homogeneity of color distribution, BR: Brightness, TIA: Total aroma intensity, PA: Peach aroma, GA: Green aroma; TIF: Total flavor intensity; PF: Peach flavor; GF: Green flavor; AC: Acid flavor, BI: Bitter, SW: Sweet; HA: Hardness; JU: Juiciness; CR: Crunchy; MA: Malic acid; LA: Lactic acid; BA: Benzoic acid; PHA: Phosphoric acid; SA: Succinic acid; SU: sucrose; CA: Citric acid; GL: Glicerol; RI: Ribose; TU: Turanose.

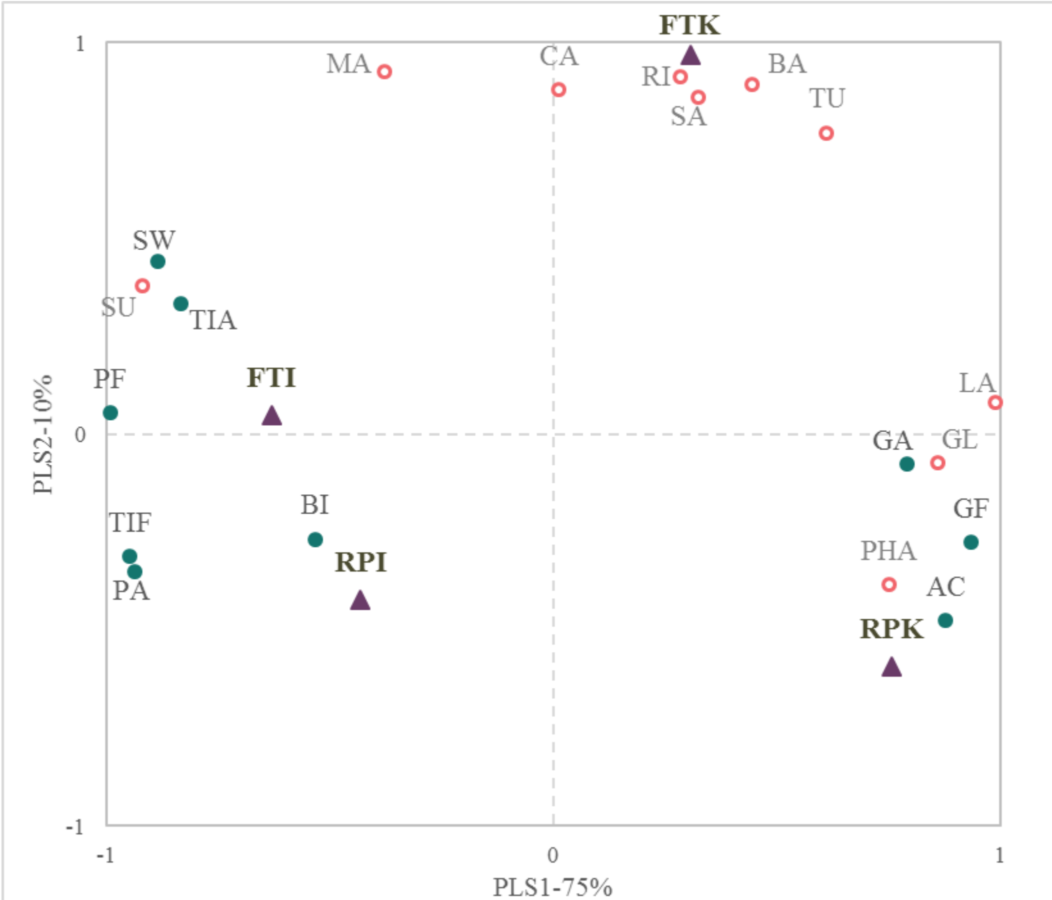


Figure 7. Graphical representation of partial less square regression (PLS) of samples, showing the sensory descriptors and metabolites analyzed with the first two dimensions. References: FTK: Forastero cultivar control treatment, FTI: Forastero cultivar irradiated treatment, RPK: Ruby Prince cultivar control treatment, RPI: Ruby Prince cultivar irradiated treatment. TIA: Total Aroma Intensity, PA: Peach aroma, GA: Green aroma; TIF: Total flavor intensity; AC: Acid flavor, BI: Bitter, SW: Sweet; PF: Peach flavor; GF: Green flavor; MA: Malic acid; LA: Lactic acid; BA: Benzoic acid; PHA: Phosphoric acid; SA: Succinic acid; CA: Citric acid; SU: Sucrose; GL: Glycerol; RI: Ribose; TU: Turanose.

Table

Table 1. Descriptors definitions and references used in the training sessions

APPEARANCE			
Descriptor	**Definition**	**Reference**	**Scale 0-10**
Color intensity	Pulp color	Pantone 134 U	8
Homogeneity of color distribution	Color uniformity presented by the slices of a sample in each tray	Picture of the peach slices (see figure 1)	6
Brightness	Presence of brightness on the surface of the segments that the tray of each sample presents.	----	
Dehydration	Dry appearance and presence of wrinkles or cracks on the surface of the slices	----	

AROMA			
Descriptor	**Definition**	**Reference**	**Scale 0-10**
Total intensity	Total aroma intensity perceived in the sample	----	
Peach	Peach aroma (fruit)	Ripe peach, soft to the touch (obtained at a local greengrocery), peeled and sliced.	9
Green	Green peach aroma (unripe fruit)	Unripe peach, hard to the touch, (obtained at a local greengrocery), peeled and sliced	9
Overripe	Overripe peach aroma	Overripe peach, very soft to the touch (obtained at a local greengrocery), peeled and sliced.	6

FLAVOR

Descriptor	Definition	Reference	Scale 0-10
Total intensity	Total flavor intensity perceived in the sample	----	
Peach	Peach flavor, fruit	Translate from aroma to flavor	6
Green	Green peach flavor, unripe fruit	Translate from aroma to flavor	6
Overripe	Peach Flavor, overripe fruit	Translate from aroma to flavor	5
Acid	Perceived acid taste in the oral cavity	----	
Bitter	Perceived bitter taste in the oral cavity	----	
Astringent	Perceived astringent taste in the oral cavity	----	
Sweet	Perceived sweet taste in the oral cavity	Sucrose solution 4%	5

MOUTH TEXTURE

Descriptor	Definition	Reference	Scale 0-10
Hardness	Force needed to cut a slice of peach with incisors	Unripe peach, hard to the touch, peeled and sliced	8
Juiciness	After the first 2 or 3 chews, juice released by the sample	Ripe peach, soft to the touch, peeled and slices	5
Crunchy	Perceived noise during 2 or 3 first chews	Unripe peach, hard to the touch, peeled and sliced	8
Pasty	After the first 2 or 3 chews, the sample remains together without disintegrating or crumbling and without releasing juice.		----

Table 2. Average sensory scores of appearance descriptors for Cultivar*Treatment interaction.

Descriptor	Samples				**LSD[a]**
	FTK	FTI	RPK	RPI	
Color intensity	4.8 ± 0.1 a	6.1 ± 0.1 b	8.1 ± 0.1 c	8.1 ± 0.0 c	**0.2**
Homogeneity	4.8 ± 0.1 b	6.0 ± 0.0 c	3.5 ± 0.1 a	3.3 ± 0.1 a	**0.3**
Brightness	0.1 ± 0.1 a	0.1 ± 0.0 a	0.0 ± 0.0 a	2.5 ± 0.2 b	**0.3**
Dehydration	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	**NS**

References: FTK: Forastero cultivar control treatment, FTI: Forastero cultivar irradiated treatment, RPK: Ruby Prince cultivar control treatment, RPI: Ruby Prince cultivar irradiated treatment.
Values of the mean and standard error of the mean (SE)
[a] Least significant difference (LSD) at a 5 % significance level. NS: No significance
Note: different letters denote significant differences at 5% for Cultivar*Treatment interaction.

Table 3. Average sensory scores of mouth texture descriptors for Treatment*Cultivar interaction.

Descriptor	Samples				**LSD[a]**
	FTK	FTI	RPK	RPI	
Hardness	6.0 ± 0.1 b	2.1 ± 0.1 a	7.9 ± 0.2 c	2.0 ± 0.1 a	**0.4**
Juiciness	4.1 ± 0.0 c	5.0 ± 0.2 d	2.2 ± 0.2 a	5.0 ± 0.1 b	**0.4**
Crunchy	6.1 ± 0.0 c	1.0 ± 0.1 a	7.9 ± 0.1 d	1.0 ± 0.1 b	**0.3**
Pasty	0.1 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.4 ± 0.0	**NS**

References: FTK: Forastero cultivar control treatment, FTI: Forastero cultivar irradiated treatment, RPK: Ruby Prince cultivar control treatment, RPI: Ruby Prince cultivar irradiated treatment.
Values of the mean and standard error of the mean (SE)
[a] Least significant difference (LSD) at a 5 % significance level.
Note: different letters denote significant differences at 5% for Cultivar*Treatment interaction.