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Determination of Quality Parameters and Sensory Attributes of 'Jaffa' Oranges Irradiated as Postharvest Quarantine Treatment Throughout Long-Term Cold Storage

Nurcan ÇETİNKAYA[1a], Ayça AYLANGAN[2b], Mine UYĞUN[2c], Erhan İÇ[2d*]

[1]Ondokuz Mayıs Üniversitesi Veteriner Fakültesi, Samsun, Turkey
[2]TENMAK, Nükleer Enerji Araştırma Enstitüsü, Ankara, Turkey

[a]https://orcid.org/ 0000-0002-9977-2937, [b]https://orcid.org/ 0000-0002-3003-133X;
[c]https://orcid.org/ 0000-0001-9792-7651; [d]https://orcid.org/ 0000-0002-0612-1845

*Corresponding author: erhan.ic@taek.gov.tr

ABSTRACT

The Mediterranean fruit fly (*Ceratitis capitata*) is one of the major problems in the citrus producing and trading countries including Turkey. Commercial application of radiation processing can be the alternative and effective solution to overcome this problem. The objective of the present study was the determination of the sensory attributes, quality parameters and also cold storage shelf-life of 'Jaffa' oranges (*Citrus sinensis* (L) Osbeck) irradiated (0, 0.5, 1.0 and 1.5 kGy) as considering postharvest quarantine treatment for the Mediterranean fruit fly (*Ceratitis capitata*). The quality parameters of the control and irradiated oranges were determined in terms of weight loss, pH, titratable acidity, total soluble solids, reducing sugars, vitamin C content, total carotenoids, pectin, color of fruit during cold storage at 4 ± 0.1 °C and 85 - 90 % relative humidity (RH) on the 0, 15, 30 and 45 d of storage. Obtained results showed that, low dose irradiation is applicable regarding other significant quality parameters of 'Jaffa' oranges such as vitamin C, total carotenoids, invert sugars, pectin, weight loss, pH, acidity and total soluble solids did not affect consumption and commercial value of 'Jaffa' sweet oranges up to 45 d of storage at 4 °C. According to overall sensory attributes, irradiated fruit was still acceptable as judged by panelists and ≤1.0 kGy irradiation dose more suitable for keeping important attributes of processed 'Jaffa' orange fruit.

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INTRODUCTION

Citrus is one of the most important fruit crop groups in the world, and these fruits are regarded as important household foods in more than 100 countries (Yesiloglu et al., 2017). Traditionally, Turkey has been a major producer and exporter of citrus fruit in the world (FAO, 2017). *The total production quantity* of citrus fruit was 4.902.052 tons, and orange production's share of total volume was 1.900.000 tons in 2018 (Anonymous, 2019). Previously, occurrences of the Mediterranean fruit fly (*Ceratitis capitata*) on citrus fruit affected the export of oranges. Whereas, irradiation has been a well-known approach for phytosanitary and quarantine treatment methods for fruit and also citrus fruit to meet safety concerns.

Potential quarantine pests are disinfested by phytosanitary treatments. Phytosanitary irradiation (PI) treatments use ionizing radiation to accomplish this, and since their international commercial debut in 2004, the use of this technology has increased by ~10 % annually. PI has been applied commercially to a wide variety of fresh commodities and the fact that they have been successfully marketed after receiving doses that may considerably exceed the minimum doses required for efficacy attests to the broad tolerance of fresh commodities at the doses of radiation required for

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phytosanitation (Hallman and Blackburn, 2016). The International Plant Protection Convention (IPPC) approved the generic dose of 0.15 kGy for fruit flies of the family Tephritidae (Diptera: Tephritidae) for all fruit and vegetables that are hosts to fruit flies of the family Tephritidae (IPPC, 2009).

The advantages of using ionising irradiation as a phytosanitary treatment have been demonstrated commercially in the past two decades and several countries currently use the technology for commercial treatments to meet plant quarantine requirements (Griffin et al., 2014). The number of irradiation facilities being established to provide PI on a commercial basis is increasing steadily, as is the number of countries (Australia, China, Dominic, India, Malaysia, Mexico, New Zealand, Pakistan, Peru, South Africa, Thailand, USA and Vietnam) involved in the export and import of produce irradiated for phytosanitary purposes. There are currently at least 13 irradiation facilities that regularly irradiate food for phytosanitary points (Hallman et al., 2016).

In the international trade of irradiated fruit and vegetables, according to Cetinkaya et al. (2016), quarantine inspectors only control the irradiation certificate travel with irradiated produces. That’s why the irradiation facilities are specifically designed and established for low-dose quarantine method application to fresh fruit. However, multipurpose irradiation facilities should also be used for commercial fresh fruit irradiation. Besides the irradiation certificate, there is a need for a justification method to control generic low-dose irradiated fresh fruit to be certain about good radiation processing and not changing the sensory properties of fruit. Different fruit species and even different cultivars of a given species may differ in their tolerance to ionizing radiation. Furthermore, dose tolerance may be influenced by a variety of factors, including the stage of fruit ripeness at the time of treatment and the subsequent storage conditions and duration (Barkai-Golan and Follett, 2017). Besides, irradiation proved to be extremely beneficial in terms of prolonging the fruit and vegetable shelf life by 3 - 5 times (Arvanitoyannis et al., 2009). In general, the quality of irradiated citrus fruit is affected by factors related to the fruit itself (e.g. cultivar, physical and physiological condition), the irradiation treatment (e.g. source, dose), and the postharvest fruit handling (e.g. the postharvest treatments, storage conditions). As a function of these factors, both beneficial (extension of shelf life) and detrimental (rind injuries) effects have been reported for citrus fruit (Alonso et al., 2007).

The purpose of the present study was to investigate the important quality parameters and sensory properties of ‘Jaffa’ oranges and orange juice after postharvest irradiation treatment during long-term cold storage between 0 - 45 d at 4 °C and 85 - 90 % RH.

MATERIALS AND METHOD

Materials and Irradiation

The ‘Jaffa’ of sweet oranges (*C. sinensis* (L.) Osbeck) were grown in West-Mediterranean region of Turkey. The varieties in the maturity stage were purchased from the local market in commercial packages. The samples were irradiated at doses of 0.5, 1 and 1.5 kGy at ambient temperature (24 ± 1 ºC) with a Hungarian made SVST-1 Category IV tote type irradiator (activity was 246 kCi) in the TAEA Gamma Irradiation Facility in Ankara. A routine dosimetry during the irradiation experiment was carried out with radiochromic film (Harwell Gammachrome YR, Batch: 64) and absorbance at 530 nm was read with a spectrophotometer (UV-4 ATI Unicam) using the Fricke centerline determination as the standard. The control and irradiated fruit were subjected to the cold storage at +4 ± 0.1 ºC and 85 - 90 % RH up to 45 d. The analyses were performed at regular intervals of 0, 15, 30, and 45 d of storage.

The determination of weight loss

For determining weight loss, 10 fruits for each irradiation dose and control (total 40 fruits) were stored in a cooling room for up to 45 days at 4 ± 0.1 °C, 85 - 90 % RH. The fruits were weighed using a Ranger scale (OHAUS, Germany) having a least count of 0.01 g, and a percentage of weight loss was calculated for each fruit.

Chemical analysis of orange juice

The fruit juice was extracted with a kitchen-type extractor (Type 2154, Beko, Turkey). pH was measured by a pH meter (Mettler Toledo, MP220, Switzerland). Titratable acidity (TA) was determined by titrating an aliquot of juice to pH 8.2 with 0.1 mol L^{-1} NaOH and the results were expressed as a percentage of anhydrous citric acid. The triplicate measurements were obtained and the average values were reported. Total soluble solids (TSS in %) content in the juice was determined with an Abbe refractometer (Atago, Japan). The reducing sugar (D-glucose/D-fructose) analysis was conducted on filtered fruit juice samples, which were diluted with distilled water 100 times. An enzymatic test kit (Boehringer Mannheim, R-Biopharm, Enzymatic BioAnalysis, Darmstadt, Germany, catalog no. 10716260035) was used for the determination of D-glucose and D-fructose with a UV/Vis spectrophotometer (Jenway 6505) at 340 nm according to the assay instructions. The vitamin C (ascorbic acid) content of orange samples was determined by a high performance liquid chromatography method (HPLC) described by Patil et al. (2004). One mL of juice was homogenized with 3 mL of citric acid (3 %). An aliquot of 0.8 mL was centrifuged at 1792 g for 20 min and filtered through a 0.00045 mm nylon filter. 0.02 mL of this solution was injected into the HPLC system (Waters 2695 separation module and Waters 2996 PDA detector). The separations were performed by using a Bondapak-C_{18} column (300x3.9 mm) with a guard column. The mobile phase was acetonitrile:water (70:30, v/v) with 0.01 M ammonium phosphoric acid at a flow rate of 1.5 mL/min. Ascorbic acid levels were detected at 255 nm at ambient temperature. A stock standard solution of ascorbic acid (Merck) was prepared daily by first solving 50 mg of ascorbic acid in citric acid (3 %) and then adjusting to 100 mL with deionized water (500 mg L^{-1}) (Gokmen et al., 2000). It was diluted with deionized water to obtain a final concentration of 50, 100, 150, 200, and 250 mg L^{-1}, respectively. The orange samples were analyzed for total carotenoids according to Alasalvar et al. (2005). Orange samples were portioned into very small pieces. A Potter S Homogenizer (Braun) was used to homogenize 0.5 g of sample in 25 mL of acetone containing dimethyl sulfoxide (10 %) in an ice bath. The homogenate was filtered through a Whatman No. 4 filter paper and washed with an extraction solution until the residue was colorless. Finally, the filtrate was adjusted to 100 mL with the extraction solvent and the absorbances were measured at 471 and 477 nm against an acetone blank using a Jenway 6505 UV/Vis spectrophotometer. Total carotenoids were calculated according to the following equation:

$$\text{Total carotenoids (\%)} = (\text{Abs}_{\text{max}} / 250) \text{ x } [(25 \text{ mL acetone x dilution x } 100) / \text{sample weight}].$$

Determination of pectin in orange peel

Pectin (as alcohol insoluble solids) determination was performed according to Kratchanova et al. (2004) and AOAC (1980) with slight modifications. The five oranges per replication were washed with water and dried for sample preparation. The peels were separated manually from the fruit and cut into small pieces of 0.5 x 0.5 cm. The chopped peels were dried at 60 ºC and 50 g of dried peels were obtained after the drying of 200 g of fresh orange peels and stored in vials. The twenty grams of dry mass were added to 500 mL of boiling water. The pH was adjusted to 1.5 with 0.5 M HCl. The mixture was then heated to 80 - 82 ºC and the extraction was carried out with continuous stirring for 1 h. The hot masses were filtered through a cheese cloth. After cooling, the filtrate was coagulated using an equal volume of 96 % ethanol and left for 1 h. The coagulated pectin was separated by filtration, washed once with 70 % acidic ethanol (0.5 % HCl), then with 70 % ethanol to a neutral pH, and finally with 96 % ethanol. The washed material was dried at 60 ºC in a laboratory drier to yield pectin as alcohol insoluble solids (AIS).

Orange peel color measurement

The color changes of fruit peels (four different sections of each fruit) and fruit juices in 25 mm quarts dishes were measured using a CR-310 Minolta Chroma Meter (Minolta Co., Osaka, Japan) in terms of CIE 'L*' (lightness), 'a*' (redness and greenness), 'b*' (yellowness and blueness) and 'h*' (0' = red-purple, 90" = yellow, 180" = blue-green, 270" = blue). The color was expressed in L*, a*, b* and h* parameters (Singh and Reddy, 2006).

Sensory analysis

The irradiated (0.5, 1.0, and 1.5 kGy) and control orange samples were examined using descriptive analysis (Meilgaard et al., 1999; Wszelaki et al., 2005). The members of the descriptive panel were recruited from our research center. Eight panelists, 3 females and 5 males, were selected. All of the panelists were between 30 and 50 years old, did not smoke, were not allergic to oranges, and were willing to evaluate irradiated orange samples. Each panelist was trained and calibrated. In the first training session, panelists tasted sweet, salty, sour, and bitter solutions. This training session also included descriptive terms that characterized the sensory properties of orange samples with peels and without peels (Table 1) (Civille and Lyon, 1996). In the second training session, panelists determined references that would help them rate the descriptive terms developed. In this training session, panelists were calibrated in terms of rating references and basic solutions. During the third day of training, panelists evaluated the orange samples with peel and without the peel. The evaluation sessions were conducted at the end of 0, 15, 30 and 45 d. The panelists were given labeled samples with selected three-digit codes. The samples were presented monadically. Panelists scored samples with the peels using a nine-point scale (e.g. for sweetness, 1: extremely not sweet, 5: neither sweet nor not sweet, 9: extremely sweet). Then, the samples without the peels were evaluated by the panelists using a nine-point scale. Panelists were given a new tray for each sample, and water was provided to clean their palates between samples.

Table 1. *The attributes are used to describe irradiated oranges with or without peel.*

Irradiated oranges with peel		**Irradiated oranges without peel**	
Appearance	Orange color intensity Peel brightness Peel oil	**Appearance**	The difficulty of removing peel Orange color intensity
Aroma	Total orange flavor Off-flavor	**Flavor**	Total orange flavor Juicy Fermented flavor Off-flavor Sweet Sour Bitter
Texture	Hardness	**Texture**	Chewing hardness

Statistical analysis

The data were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test using the IBM SPPS software version 21.00. The effects of dose and storage time were considered significantly different when P <0.05.

RESULTS AND DISCUSSION

Orange Quality Parameters

Weight loss (WL), pH, titratable acidity (TA), total soluble solids (TSS) and invert sugars

Weight loss (g). Table 2 shows the effect of irradiation treatment on fruit weight loss during cold storage (+4 °C, 85 - 90 % RH). The obtained data (lost weight as g) compared with the results of the previous period and percentage values were calculated according to the 0 d results in each interval. In particular, all of the samples (0, 0.5, 1, and 1.5 kGy) lost a little weight (g) after each interval of storage (Table 2).

Table 2. *The weight loss (WL), pH, titratable acidity (TA), total soluble solids (TSS) and invert sugars (g L^{-1}) assessments of samples during storage (4 ℃, 85 - 90 % RH).*

Parameters	**Dose (kGy)**	**Storage (d)**			
		0	**15**	**30**	**45**
WL (g)	0	-	1.854^{Aa}, 0.38 %	1.846^{Aa}, 0.81 %	1.827^{Aa}, 1.82 %
	0.5	-	1.850^{Aa}, 0.96 %	1.828^{Aa}, 2.14 %	1.781^{Aa}, 4.65 %
	1	-	1.824^{Aa}, 0.32 %	1.820^{Aa}, 0.55 %	1.799^{Aa}, 1.69 %
	1.5	-	1.796^{Aa}, 0.88 %	1.789^{Aa}, 1.26 %	1.768^{Aa}, 2.42 %
pH	0	3.69^{Bd}	3.80^{Dc}	3.83^{Cb}	3.91^{Da}
	0.5	3.58^{Dd}	3.86^{Cc}	3.91^{Ab}	3.94^{Ca}
	1	3.81^{Ad}	3.91^{Bb}	3.86^{Bc}	4.09^{Aa}
	1.5	3.60^{Cd}	4.00^{Ab}	3.91^{Ac}	4.03^{Ba}
TA (%, citric acid)	0	0.74^{Ca}	0.69^{Ab}	0.64^{Ac}	0.59^{Ad}
	0.5	0.85^{Ba}	0.63^{Bb}	0.60^{Cc}	0.57^{Bd}
	1	0.72^{Da}	0.61^{Cb}	0.61^{Cb}	0.47^{Dc}
	1.5	0.87^{Aa}	0.55^{Dc}	0.62^{Bb}	0.55^{Cc}
TSS (%)	0	12.20^{Bd}	12.50^{Ac}	13.00^{Ab}	13.40^{Aa}
	0.5	11.73^{Cc}	12.00^{BCb}	12.63^{Ba}	12.57^{Ba}
	1	12.70^{Aa}	12.17^{Bb}	12.00^{Cbc}	11.90^{Cc}
	1.5	12.43^{Ba}	11.83^{Cb}	12.00^{Cb}	12.00^{Cb}
Invert Sugar D-Glucose (g L^{-1})	0	31.37^{Bc}	31.23^{Cc}	43.38^{Aa}	36.77^{Ab}
	0.5	36.53^{Ab}	36.00^{ABb}	42.90^{Aa}	36.87^{Ab}
	1	35.57^{Aa}	34.50^{Ba}	34.67^{Ba}	27.60^{Bb}
	1.5	37.30^{Aa}	37.43^{Aa}	23.13^{Cc}	29.23^{Bb}
Invert Sugar D-Fructose (g L^{-1})	0	35.70^{ABc}	35.23^{Bc}	42.12^{Ab}	43.63^{Aa}
	0.5	35.03^{Ba}	34.63^{Ba}	30.17^{Bb}	35.03^{Ba}
	1	34.67^{Ba}	34.40^{Ba}	27.67^{Cb}	26.77^{Cb}
	1.5	36.83^{Aa}	36.87^{Aa}	24.60^{Dc}	29.03^{Cb}

A,B,C Means not followed by the same letter in a column are significantly different (p <0.05)
a,b,c Means not followed by the same letter in a row are significantly different (p <0.05)

This may be due to the fact that respiration and refrigeration can cause reduction in weight. Simultaneously, weight loss was slightly increased with prolonged storage in all treatments. The irradiated oranges (interestingly, 5 kGy) lost more weight compared to untreated controls. Especially, considering storage intervals of 15, 30 and 45 d, maximum weight loss determined as 1 %, 2.1 % and 4.7 %, respectively. Consequently, there was a statistically insignificant difference ($P < 0.05$) in the weight loss of irradiated and control fruit after 15, 30, and 45 d of intervals. Our results were comparable with Miller et al. (2000) in five orange cultivars (Ambersweet, Hamlin, Navel, Pineapple and Valencia) and the five mandarin hybrids (Fallglo, Minneola, Murcott, Sunburst and Temple), Ladaniya et al. (2003) in 'Nagpur' mandarin,'Mosambi' sweet orange and 'Kagzi' acid lime and Jo et al. (2018) in two Korean citrus fruit (Jinjihyang and Chunggyun).

pH and titratable acidity (TA). pH and titratable acidity (TA) values are shown in Table 2. According to Kefford (1959), most of the ripe orange juices have a pH 2.9 - 3.8. The determined pH values in the sweet orange juices in Turkey ranged from 3.2 to 3.5 (Karadeniz, 2004). In the present study, the pH of juice extracted from control samples of fruit varied from 3.7 to 3.9 during cold storage. The same situation was observed in irradiated samples, and pH increased up to 45 d (Table 2). The effect of irradiation as well as storage time was significant ($P < 0.05$) on pH. Regardless of the storage time, the increase in the pH value could not be determined with an increasing dose over four different storage periods except for (15 and 45 d) due to the increased dose. When pH was measured in all samples, as expected, a correlation was noticed between pH and TA with increased pH vs. decreased TA during the storage periods. pH values increased gradually (nearly 5 %) in the 15 d period from 3.8 to 4.0 and increased slightly from 3.9 to 4.0 in the 45 d period.

The titratable acidity (TA) of the analyzed samples was calculated as % citric acid. The acidity of citrus juices is due primarily to citric and malic acids (Kale and Adsule, 1995). TA of the sweet oranges in citrus juice in Turkey varied as 11.1 - 15.6 g L-1 (Karadeniz, 2004). In this research, TA values were significantly ($P < 0.05$) decreased due to prolonged cold storage (45 d) in treated and control samples. Irrespective of storage time, it was observed that values significantly ($P < 0.05$) declined in the irradiated samples (Table 2). But Mitchell et al. (1992) and Fan et al. (2005) reported that no considerable effect was observed on the titratable acidity of irradiated apple slices or tropical fruits (like lemons, mangoes, mandarins, and nectarines), respectively. In this study, as the irradiation dose increased, the most significant ($P < 0.05$) decrease occurred in the interval of 15 d in control samples as 0.7 % and 1.5 kGy irradiated as 0.6 %, respectively. In the other intervals, the decline caused by the increased irradiation dose was quite low. As a result, the effects of the treatments and storage time on acidity (%) were significant ($P < 0.05$). However, their interaction was insignificant. Our findings are similar to those reported by Miller et al. (2000), Ladaniya et al. (2003), Khalil et al. (2009), Ahmad et al. (2012), McDonald et al. (2013), Zhang et al. (2014), Ahmad and Ahmad, (2017) and Nam et al. (2019) as lower titratable acidity determined in irradiated different citrus fruit in comparison to unirradiated ones.

Total soluble solids (%). The soluble solids content is a chemical factor used as an indicator to define the optimum stage of fruit maturity. This parameter is also associated with the sweet flavor of the product (Seymour et al., 1993). In citrus fruit, 80 % of the total soluble dry matter consists of sugars, 10 % acids and 10 % nitrogenous compounds. The increase in sugar content leads to an increase in total soluble dry matter (Ladaniya, 2008). According to Karadeniz (2004), total soluble solids of sweet orange juices in Turkey were found to be around 11.4 - 14 %. The amounts of total soluble solids (TSS) are presented in Table 2. Our results have shown that the effects of irradiation and cold storage time were statistically significant ($P < 0.05$). As for the influence of irradiation dose, a decrease was determined in the last three intervals with increased irradiation doses. However, determined changes in TSS statistically significant ($P < 0.05$) in all periods. TSS increased in control and 0.5 kGy gamma irradiated samples compared to the beginning of storage, from 12.2 to 13.4 and from 11.7 to 12.6 %, respectively, during storage. However, TSS values in 1 and 1.5 kGy treated samples declined slightly throughout the storage time, from 12.7 to 11.9 %, from 12.4 to 12 %, respectively (Table 2). Whereas, previously, Patil et al. (2004) stated that irradiation (≤0.7 kGy) did not cause a decline in TSS value in early 'Rio Red' grapefruit samples. In contrast, McDonald et al. (2013) demonstrated that irradiation gives rise to a decrease in the TSS for 'Ambersweet' oranges (0.3 kGy), navel oranges (0.4 kGy) and 'Sunburst' mandarins (0.45 kGy). But Ladaniya et al. (2003) explained that factors such as accelerated respiration and depletion of fruit create a decrease in sugar and TSS levels during storage.

Invert sugars (D-Glucose and D-Fructose). Glucose, sucrose, and fructose are the most common sugars found in fruit, and their content varies considerably with the variety of the fruit (Seymour et al., 1993). While citrus juices contain mainly glucose, fructose and sucrose and may vary between 1 and 9 % and bitter orange juice and sweet orange juice contain total sugars as 5.7 % and 8.5 %, respectively (Kale and Adsule, 1995). In this work, in relation to TSS results, increased irradiation dose and extended cold storage had a statistically significant ($P < 0.05$) effect on D-glucose and D-fructose content in all samples. D-glucose content increased ($P < 0.05$) with the applied irradiation dose in the intervals of 0 and 15 d, from 31.4 to 37.3 g/l and from 32.2 to 37.4 g L^{-1}, respectively. In the same period, determined D-fructose levels were nearly stable (Table 2). Increased irradiation doses led to a significant ($P < 0.05$) decline in the D-glucose and D-fructose content in the last two intervals of storage (30 and 45 d), from 43.4 to 23.1, from 36.8 to 23.1, from 42.1 to 24.6, and from 43.6 to 29 g L^{-1}, respectively. Prolonged storage resulted in a significant ($P < 0.05$) decline in D-glucose and D-fructose levels, with the exception of control and 0.5 kGy treated samples compared to the beginning. These results are consistent with O'Mahony et al. (1985), Miller et al. (2000), Khalil et al. (2009) and Ahmad and Ahmad, (2017) in irradiated various citrus fruits.

Pectin, vitamin C, total carotenoids (TC) and color

Pectin. Chemical and enzymatic changes during plant development, ripening, and storage of fruit ultimately alter the structure of pectins as a result of the processing of fruit and vegetables (Schols and Voragen, 2002). Citrus fruits contain insoluble carbohydrates that provide the structural materials and consist of roughly equal proportions of cellulose and pectin. The peel is particularly rich in pectin, which may make up 20 - 40 % of the dry matter. In the fruit tissues, pectin is present in a water-insoluble form known as protopectin (Kale and Adsule, 1995). During storage of the fruit, the firmness of the fruit decreases due to the degradation of the insoluble form of protopectin into the soluble form of pectic acid and pectin. Compared to other climatic fruits, such changes occur relatively slowly in citrus fruit (Ladaniya, 2008). Alcohol insoluble pectin in plant tissues consists of cell wall material, that is, pectic compounds, hemicellulose and cellulose. The starch and lignin are at very low levels. Citrus fruits are rich in pectin in plant products. When considering the whole peel of the fruit (flavedo + albedo), the amount of alcohol insoluble fraction (% of dry matter) was reported to be 42.7 in Valencia oranges (Kefford, 1959). The alcohol-insoluble solids (AIS) can be used to extract four fractions of pectic substances such as water-soluble pectic substances (WSP), oxalate-soluble pectic substances (OXP), the acid-soluble pectic substances (HP) and the alkali-soluble pectic substances (OHP) (Majumder and Mazumdar, 2002). Pectin data (as alcohol-insoluble solids) were evaluated in dried orange peels during storage and presented in Table 3.

Table 3. *The pectin, total carotenoids (TC) and vitamin C assessments of samplesduring storage (4 ℃, 85 - 90 % RH)*

Parameters		Storage (d)			
	Dose (kGy)	0	15	30	45
Pectin (g kg^{-1})	0	27.35^{Ba}	32.41^{Aa}	30.46^{Aa}	28.82^{Aa}
	0.5	30.58^{ABa}	33.26^{Aa}	29.46^{Aa}	28.10^{Aa}
	1	36.26^{Aa}	31.54^{Aab}	28.37^{Ab}	33.43^{Aab}
	1.5	31.18^{ABa}	29.89^{Aa}	28.29^{Aa}	28.39^{Aa}
Vitamin C (mg kg^{-1})	0	91.73^{Ba}	91.20^{Aa}	92.80^{Aa}	92.93^{Ba}
	0.5	97.33^{Aa}	90.27^{Abc}	93.73^{Aab}	86.67^{Cc}
	1	97.73^{Aa}	87.20^{Ab}	91.20^{Ab}	99.60^{Aa}
	1.5	86.27^{Cb}	87.60^{Aab}	86.40^{Bb}	91.60^{Ba}
TC (mg kg^{-1})	0	9.04^{Ab}	10.46^{Aa}	9.42^{Ab}	8.73^{Ab}
	0.5	8.45^{Aa}	8.64^{Ba}	8.84^{ABa}	8.08^{ABa}
	1	8.69^{Ab}	7.24^{Cb}	9.62^{Aa}	7.31^{Bb}
	1.5	8.98^{Aa}	6.48^{Cc}	8.50^{Ba}	7.31^{Bb}

A,B,C Means not followed by the same letter in a column are significantly different (p <0.05)
a,b,c Means not followed by the same letter in a row are significantly different (p <0.05)

In this research, the results showed that irradiation did not affect the amount of pectin (g kg^{-1}) with regard to irradiation doses, except at 0 d intervals, and these values were statistically different ($p < 0.05$). Extended cold storage caused a decrease after 45 d of storage in control and irradiated samples compared with 0 d results. But, determined values were statistically not different, except for 1 kGy. It was noted that the pectin fractions of 1 kGy treated samples at intervals of 0 and 45 d were the highest among the irradiated and non-irradiated samples. Gunes et al. (2001) demonstrated that the total pectin content was unaffected by irradiation (1.2 kGy), but the softening of apple slices induced by irradiation (> 0.34 kGy) was associated with increased water-soluble pectin and decreased oxalate-soluble pectin content. Melo et al. (2018) revealed that firmness in Mid Pride' peaches was reduced by irradiation (1.03 kGy) treatment, whereas total pectin remained unaltered. WSP, however, increased upon irradiation and also during ripening. According to Kilcast (1994), irradiation of fruit and vegetables often causes tissue softening due to the breakdown of pectin. Whereas most fruit types tolerate doses below 0.5 to 0.6 kGy, except for some species of citrus, physical injury usually occurs in the peel as peel pitting and fruit softening (Wall, 2015). Furthermore, when considering irradiation dose and extended cold storage, no correlation was determined between changes in pectin levels (Table 3) and sensory evaluation of orange firmness in this research (Table 5).

Vitamin C. Vitamin C content has been considered as the most important quality factor in citrus fruit. Regarding the radiation sensitivity of vitamins in fresh fruit and vegetables, vitamin C is highly sensitive to irradiation and the effect of irradiation is influenced by a few factors, including exposure to oxygen, storage, temperature, and pH (Kilcast, 1994). Irradiation can cause partial oxidation of ascorbic acid to dehydroascorbic acid, which also has vitamin activity, but ascorbic acid is more stable than dehydroascorbic acid (Ladaniya et al., 2003). Total vitamin C content (AA+DHA) of California and Florida varieties is 83 and 63 mg kg^{-1}, respectively (Vanderslice et al., 1990). Some reports on evaluating the effect of irradiation on vitamin C content of oranges showed that orange, mandarin and acid lime samples were irradiated at 1.5 kGy using gamma rays and the vitamin C contents of these fruit declined by 16 %, 27 % and 29 %, respectively (Ladaniya et al., 2003), in blood oranges, irradiation with 0.25 and 0.5 kGy slowed the loss of ascorbic acid (AA) during six weeks storage, resulting in higher AA levels in oranges irradiated with 0.5 kGy (Khalil et al., 2009), irradiation (0.2 - 0.6 kGy) on 'Lane Late' Navel oranges had no effect on vitamin C retention (McDonald et al., 2013), irradiated (0 - 0.2 kGy) and non-irradiated Valencia oranges had similar vitamin C content (De Bortoli et al., 2015) and vitamin C was insignificantly different between irradiated (0.2 - 1 kGy) and non-irradiated Navel orange fruit (Cho et al., 2015). Our results revealed that gamma irradiation had a significant effect ($P < 0.05$) on the vitamin C level of fruit juice of 'Jaffa' orange in all intervals except 15 d intervals of cold storage (Table 3). Also, a significant effect ($P < 0.05$) of prolonged storage was observed in vitamin C contents of irradiated samples (0.5, 1 and 1.5 kGy). Our results are agreeing with the findings of Mahrouz et al. (2002), Ladaniya et al. (2003), Ahmad et al., (2012), Ahmad and Ahmad, (2017) and Nam et al. (2019) in the main types of citrus fruit.

Total carotenoids (TC). Color is the most important quality characteristic of fruit, and color changes in fruit are related to (a) the breakdown of cellular chloroplasts and chromoplasts, (b) changes in natural pigments (chlorophylls, carotenoids, and anthocyanins), and (c) the development of enzymatic browning (De Ancos et al., 2006). Carotenoids are lipid-soluble plant pigments that are common in photosynthetic plants. The term "carotenoids" summarizes a class of structurally related pigments, mainly found in plants. At present, more than 600 different carotenoids have been identified (S´anchez-Moreno et al., 2006). In this paper, the TC contents of fruit juices (mg kg^{-1}) are summarized in Table 3. As shown in our results, TC in orange samples did not vary much depending on the irradiation dose at the beginning of cold storage (0 d). However, as the storage period was prolonged, there was a significant ($P < 0.05$) decrease in irradiated samples, especially at doses of 1 and 1.5 kGy after 45 d of intervals. The TC values decreased gradually in intervals of storage, except for a second interval (15 d). The most significant ($P < 0.05$) decline in TC was determined at second intervals of storage when compared to non-irradiated samples.

Color. Both peel and pulp colors are important sensory attributes related to the ripening quality of fruit (Jenjob et al., 2017). The L, a, b, and hue values are among the important parameters showing different maturation levels (Singh and Redy, 2006). The orange and grapefruit colors are derived from carotenoids, and the red (blood) varieties are anthocyanins. Carotenoids are divided into two groups: carotene and xanthophyll. The yellow color found in fruit and vegetables is a result of the loss of chlorophyll with the ripening of fruit and the carotenoids becoming more visible (Moussaid et al., 2000). The consequences of different gamma radiation doses on the color parameters of orange peels and juices are determined and presented in Table 4. Color development, particularly carotenoid synthesis, was probably adversely affected due to irradiation in oranges (Ladaniya et al., 2003). Moussaid et al. (2000) explained that irradiation affected h (hue angle) value and C (chroma, color intensity) values more than other parameters in waxed oranges. Although irradiation also affects L (lightness), it does not affect a (redness) and C (color intensity). In this study, determined values show that increased irradiation doses had a statistically significant ($P < 0.05$) effect on fruit juice and peel color parameters (L* lightness, a* redness, b* yellowness, C* chroma, and h* hue angle) during cold storage, except for the 0th day of stored peels. On the other hand, the color parameters of both fruit juices and fruit peels were significantly ($P < 0.05$) affected by prolonged storage. The samples had the highest L* value, indicating that they had a lighter color at the beginning of storage for both orange peels and their juices. Prolonged storage and irradiation interaction had affected the L* values (lightness) of fruit juice and caused browning. The red (a*) color values of extracted juices were remarkably increased ($P < 0.05$) but the yellow (b*) color and C* values were almost the same with a storage period in other samples, including controls, with the exception of 15 d of storage. The effects of extended storage were observed ($P < 0.05$) on the hue angle (h*) especially at the end of storage (45 d). The lowest values of color parameters (L*, a*, b*, C* and h*) compared with initial data were determined in all samples (treated and untreated) in the last intervals of storage (45 d). Also, from Table 4, it could be noticed that increased irradiation doses affected ($P < 0.05$) the color parameters (L*, a*, b*, C*, and h*) in all intervals.

Table 4. *The changes in color parameters of 'Jaffa' orange juice and peels during storage (4 ℃, 85 - 90 % RH).*

		Storage (d)			
	Dose (kGy)	**0**	**15**	**30**	**45**
Fruit juice color parameters					
L*	0	59.63^{Aa}	57.91^{Db}	59.51^{Ba}	56.20^{Ac}
	0.5	59.22^{Bb}	59.88^{Ba}	58.16^{Dc}	55.85^{Bd}
	1	56.13^{Dc}	59.36^{Cb}	62.17^{Aa}	56.17^{Ac}
	1.5	57.93^{Cc}	61.36^{Aa}	58.58^{Cb}	55.47^{Cd}
a*	0	7.06^{Ab}	5.95^{Cc}	7.21^{ABb}	8.77^{Ba}
	0.5	5.78^{Ca}	6.38^{Bb}	7.04^{Ba}	7.23^{Da}
	1	6.94^{Ac}	7.06^{Ac}	7.37^{Ab}	9.13^{Aa}
	1.5	6.11^{Bd}	7.19^{Ab}	6.52^{Cc}	7.83^{Ca}
b*	0	42.57^{Ba}	39.42^{Cb}	42.73^{Ba}	41.67^{Aab}
	0.5	44.97^{Aa}	42.02^{Bb}	41.19^{Bb}	40.88^{Ab}
	1	37.68^{Dc}	42.52^{Bb}	45.47^{Aa}	42.23^{Ab}
	1.5	40.07^{Cb}	45.02^{Aa}	41.49^{Bb}	40.78^{Ab}
C*	0	43.10^{Aa}	39.87^{Cb}	43.32^{Ba}	42.58^{Aa}
	0.5	42.03^{Bbc}	42.50^{Bab}	42.89^{Ba}	41.51^{Bc}
	1	38.33^{Dc}	43.09^{Bb}	46.09^{Aa}	43.19^{Ab}
	1.5	40.53^{Cc}	45.58^{Aa}	41.97^{Cb}	41.54^{Bb}
h*	0	80.69^{Aab}	81.47^{Aa}	80.48^{Aab}	78.21^{ABb}
	0.5	82.18^{Aa}	81.44^{Aa}	80.39^{Aa}	75.67^{Bb}
	1	79.67^{Aa}	80.64^{Aa}	80.90^{Aa}	77.88^{ABa}
	1.5	81.41^{Aa}	80.99^{Aa}	81.17^{Aa}	79.20^{Aa}
Fruit peel color parameters					
L*	0	64.02^{Aa}	63.87^{Aa}	64.52^{ABa}	63.85^{BCa}
	0.5	64.02^{Ab}	64.49^{Ab}	64.09^{Bb}	63.34^{Ca}
	1	63.92^{Ab}	64.12^{Ab}	65.11^{Aa}	64.61^{Aab}
	1.5	63.39^{Ab}	64.25^{Aa}	64.50^{ABa}	64.35^{ABa}
a*	0	35.96^{Aa}	35.63^{ABa}	35.49^{Aa}	34.30^{Ab}
	0.5	36.03^{Aa}	35.35^{Bab}	34.37^{Ab}	34.33^{Ab}
	1	35.90^{Aa}	36.08^{ABa}	34.47^{Ab}	33.04^{Bc}
	1.5	35.56^{Aa}	36.80^{Aa}	35.01^{Ab}	33.69^{ABc}
b*	0	60.42^{Aa}	59.55^{Bab}	59.38^{ABab}	58.35^{Ab}
	0.5	60.23^{Aa}	60.09^{Ba}	59.22^{Ba}	57.09^{Bb}
	1	60.47^{Aa}	60.13^{Bab}	60.48^{Aa}	59.13^{Ab}
	1.5	59.74^{Ab}	61.52^{Aa}	59.37^{ABbc}	58.40^{Ac}
C*	0	70.41^{Aa}	69.60^{Ba}	69.19^{Aa}	67.42^{Ab}
	0.5	70.15^{Aa}	69.78^{Ba}	68.49^{ABa}	66.55^{Ac}
	1	70.21^{Aa}	70.52^{ABa}	69.67^{Aa}	67.63^{Ab}
	1.5	70.00^{Ab}	71.31^{Aa}	67.76^{Bc}	66.87^{Ac}
h*	0	59.32^{Aa}	58.72^{Aa}	59.10^{Ba}	59.55^{BCa}
	0.5	59.10^{Aa}	59.38^{Aa}	59.86^{ABa}	59.89^{Ca}
	1	59.55^{Abc}	59.28^{Ac}	60.34^{Aab}	60.68^{Aa}
	1.5	59.04^{Aa}	59.51^{Aa}	59.45^{ABa}	60.03^{ABa}

A,B,C Means not followed by the same letter in a column are significantly different ($p < 0.05$)
a,b,c Means not followed by the same letter in a row are significantly different ($p < 0.05$)

During storage, irradiated samples showed significant ($P < 0.05$) color parameter' changes that the L* values ranged from 55.5 to 62.2, a* values ranged between 5.8 and 9.1, b* values ranged between 37.7 and 45.5, C* values ranged between 38.3 and 46.1, and h* values also ranged between 75.7 and 82.2 (Table 4).

Sensory Properties

Sensory analysis examines the relationship between a given physical stimulus and the subject's response. The sensory attributes perceived in a food product are appearance, odor/aroma, consistency and texture, and flavors (aromatics, chemical feelings, and taste) (Meilgaard et al., 1999). The results of the sensory quality criteria of shelled citrus samples after irradiation at different doses are given in Table 5.

Table 5. *The effect of irradiation on sensory properties of 'Jaffa' orange during storage (4 ℃, 85 - 90 % RH).*

			Storage (d)			
Attributes		**Dose (kGy)**	**0**	**15**	**30**	**45**
Appearance	Orange color intensity	0	6.75^{Aa}	6.75^{Aa}	5.50^{ABa}	5.75^{Aa}
		0.5	6.88^{Aa}	6.50^{Aab}	5.25^{ABb}	6.00^{Aab}
		1	6.75^{Aa}	5.88^{Aab}	5.00^{Bb}	5.63^{Aab}
		1.5	6.88^{Aa}	6.63^{Aab}	6.63^{Aab}	5.25^{Ab}
	Peel brightness	0	6.63^{Aa}	5.88^{Aab}	4.50^{Ab}	4.63^{Ab}
		0.5	6.13^{Aa}	6.13^{Aa}	4.63^{Aab}	4.38^{Ab}
		1	6.88^{Aa}	5.50^{Aa}	5.38^{Aa}	5.50^{Aa}
		1.5	6.50^{Aa}	6.63^{Aa}	6.00^{Aab}	4.75^{Ab}
	Peel oil	0	3.13^{Aa}	3.75^{Aa}	3.13^{Aa}	3.13^{Aa}
		0.5	2.25^{Ab}	4.88^{Aa}	2.63^{Ab}	2.75^{Aab}
		1	2.88^{Aa}	4.00^{Aa}	3.50^{Aa}	4.00^{Aa}
		1.5	2.63^{Aa}	3.88^{Aa}	2.63^{Aa}	3.13^{Aa}
Aroma	Total orange flavor	0	6.38^{Aa}	6.38^{Aa}	5.13^{Aab}	4.38^{Ab}
		0.5	6.13^{Aa}	5.25^{Aa}	5.75^{Aa}	5.13^{Aa}
		1	7.00^{Aa}	5.00^{Ab}	5.38^{Aab}	4.50^{Ab}
		1.5	7.13^{Aa}	4.75^{Ab}	5.63^{Aab}	4.38^{Ab}
	Off flavor	0	2.50^{Aa}	2.50^{Aa}	2.63^{Aa}	3.13^{Aa}
		0.5	1.63^{Aa}	3.50^{Aa}	2.38^{Aa}	2.75^{Aa}
		1	2.25^{Aa}	3.50^{Aa}	3.50^{Aa}	2.75^{Aa}
		1.5	1.25^{Ab}	3.50^{Aa}	2.38^{Aab}	3.38^{Aa}
Texture	Hardness	0	8.00^{Aa}	6.13^{Aab}	4.88^{Ab}	4.75^{ABb}
		0.5	6.00^{Aa}	5.63^{Aa}	5.13^{Aa}	5.13^{ABa}
		1	6.13^{Aa}	5.75^{Aa}	5.13^{Aa}	5.25^{Aa}
		1.5	6.38^{Aa}	6.00^{Aa}	4.63^{Aab}	3.13^{Bb}

A,B,C Means not followed by the same letter in a column are significantly different (p <0.05)
a,b,c Means not followed by the same letter in a row are significantly different (p <0.05)

In this research, after evaluation by trained panelists, it was statistically revealed (P <0.05) that no effect was observed on the attributes of orange peel samples with the exception of orange color intensity and hardness (30 d). Additionally, effect of extended cold storage (up to 45 d) was more noticeable than irradiation doses. Statistically, extended storage had a significant (P <0.05) effect on all parameters. Data in Table 6 shows how irradiation and cold storage affects the sensory quality criteria of peeled oranges. Regarding the irradiation treatment, no significant (P <0.05) effect determined on appearance (difficulty of removing peel, orange color intensity) by the panelist. Whereas, some statistically (P <0.05) changes noticed in flavor and texture in peeled orange fruit throughout the entire cold storage period except the criteria of juicy and sweet.

Furthermore, the occurrence of stale taste and off-flavor increased in fruit due to increased irradiation dose. The prolonged storage (45 d) had statistically no effect on appearance (the difficulty of removing peel), flavor (sour) and texture (chewing hardness), but significant (P <0.05) changes determined on appearance (orange color intensity in 0.5 kGy), and flavor (total orange flavor in 0 and 1.5 kGy, juicy in 0, 0.5, 1 and 1.5 kGy, fermented flavor in 1.5 kGy, off flavor in 0 and 1 kGy, sweet in 0, bitter in 1 and 1.5 kGy).

When considered as a total evaluation, according to overall attributes, irradiated fruits were still acceptable as judged by panelists, and ≤1.0 kGy irradiation dose was more suitable for keeping important attributes of processed 'Jaffa' orange fruit. In particular, up to 0.5 kGy irradiation dose for Mediterranean fruit fly (*Ceratitis capitata*) on citrus fruit has been considered suitable to maintain overall fruit quality. Similarly, Hallman and Martinez (2001) stated that irradiation up to 0.5 kGy in citrus fruit irradiated for quarantine purposes had no negative effect on sensory quality. juiciness, pulp texture, orange flavor, off flavor, sweetness, tartness, aftertaste, skin firmness. In contrast, the development of off-flavor in irradiated (≤1 kGy) citrus fruit has been reported (Nagai and Moy, 1985; O'Mahony et al., 1985; Mitchell et al., 1992; Miller et al., 2000). Our sensory evaluation results lead to similar conclusions as O'Mahony and Goldstein, (1987), Jessup et al. (1992), Ladaniya et al. (2003) and Jain et al. (2017).

Table 6. *The effect of irradiation on sensory properties of peeled 'Jaffa' orange during storage (4 ℃, 85 - 90 % RH).*

Attributes			Storage (d)			
		Dose (kGy)	0	15	30	45
Appearance	The difficulty of removing peel	0	4.13^{Aa}	3.63^{Aa}	4.75^{Aa}	3.38^{Aa}
		0.5	4.88^{Aa}	4.25^{Aa}	4.63^{Aa}	4.50^{Aa}
		1	2.75^{Aa}	5.00^{Aa}	3.63^{Aa}	4.25^{Aa}
		1.5	3.25^{Aa}	3.88^{Aa}	3.63^{Aa}	2.50^{Aa}
	Orange color intensity	0	5.88^{Aa}	6.00^{Aa}	5.88^{Aa}	4.63^{Aa}
		0.5	6.38^{Aa}	6.13^{Aab}	4.63^{Ab}	5.75^{Aab}
		1	5.75^{Aa}	6.00^{Aa}	5.50^{Aa}	5.38^{Aa}
		1.5	6.75^{Aa}	5.50^{Aa}	5.88^{Aa}	5.50^{Aa}
Flavor	Total orange flavor	0	6.38^{Aa}	7.13^{Aa}	6.25^{Aa}	4.50^{ABb}
		0.5	5.88^{ABa}	5.25^{Ba}	4.88^{ABa}	5.13^{Aa}
		1	5.50^{ABa}	4.25^{Ba}	4.50^{Ba}	5.00^{Aa}
		1.5	4.38^{Bab}	4.38^{Bab}	5.63^{ABa}	3.13^{Bb}
	Juicy	0	7.50^{Aa}	6.88^{Aab}	6.25^{Aab}	5.75^{Ab}
		0.5	7.25^{Aa}	6.75^{Aab}	5.38^{Ac}	5.63^{Abc}
		1	7.13^{Aa}	5.88^{Aab}	5.63^{Ab}	5.63^{Ab}
		1.5	6.75^{Aa}	6.38^{Aa}	6.25^{Aa}	4.88^{Ab}
	Fermented flavor	0	2.63^{Ba}	1.75^{Ba}	3.38^{Aa}	3.75^{Ba}
		0.5	4.13^{ABa}	3.75^{ABa}	3.13^{Aa}	4.25^{ABa}
		1	3.88^{ABa}	4.75^{Aa}	5.25^{Aa}	3.63^{Ba}
		1.5	6.00^{Aa}	4.88^{Aab}	3.50^{Ab}	6.25^{Aa}
	Off flavor	0	1.88^{Ba}	2.25^{Ba}	2.75^{Aa}	2.88^{Aa}
		0.5	3.13^{ABa}	4.50^{ABa}	3.63^{Aa}	3.50^{Aa}
		1	3.13^{ABb}	6.25^{Aa}	4.25^{Aab}	3.75^{Ab}
		1.5	5.25^{Aa}	5.38^{Aa}	3.75^{Aa}	4.88^{Aa}
	Sweet	0	6.63^{Aa}	6.63^{Aa}	5.75^{Aab}	4.63^{Ab}
		0.5	6.38^{Aa}	5.13^{Aa}	5.13^{Aa}	5.38^{Aa}
		1	6.00^{Aa}	6.13^{Aa}	4.75^{Aa}	5.00^{Aa}
		1.5	5.88^{Aa}	5.75^{Aa}	5.88^{Aa}	4.25^{Aa}
	Sour	0	2.38^{Ba}	2.75^{Aa}	2.75^{Aa}	2.63^{Aa}
		0.5	2.75^{ABa}	3.63^{Aa}	3.75^{Aa}	2.38^{Aa}
		1	2.50^{Ba}	3.63^{Aa}	3.50^{Aa}	2.38^{Aa}
		1.5	4.50^{Aa}	3.63^{Aa}	2.88^{Aa}	3.00^{Aa}
	Bitter	0	1.25^{Ba}	1.50^{Ba}	1.50^{Aa}	1.75^{Aa}
		0.5	1.88^{Ba}	2.63^{ABa}	1.75^{Aa}	1.75^{Aa}
		1	1.63^{Bb}	3.00^{Aa}	2.13^{Aab}	1.88^{Aab}
		1.5	4.00^{Aa}	2.00^{ABb}	1.50^{Ab}	2.38^{Ab}
Texture	Chewing hardness	0	6.63^{Aa}	6.13^{Aa}	6.00^{Aa}	6.13^{Aa}
		0.5	6.13^{ABa}	6.38^{Aa}	6.00^{Aa}	5.75^{Aa}
		1	4.75^{Ba}	6.13^{Aa}	5.88^{Aa}	5.88^{Aa}
		1.5	5.25^{ABa}	5.88^{Aa}	6.25^{Aa}	4.63^{Aa}

A,B,C Means not followed by the same letter in a column are significantly different ($p < 0.05$)
a,b,c Means not followed by the same letter in a row are significantly different ($p < 0.05$)

In an orange study, irradiation at a dose of 0.5 kGy was reported to be an effective method for maintaining post-harvest physicochemical and sensory quality (Khalil et al., 2009). O'Mahony et al. (1985) also observed that untrained consumers were not able to tell the difference between untreated and irradiated Navel oranges (0.6 - 0.8 kGy) even though expert judges were able to detect differences in brown blemishing and flavor of irradiated fruit after 5-6 weeks in storage. But, Miller et al. (2000) reported that the juice flavors of 'Hamlin', 'Navel', 'Valencia', and 'Minneola', and the pulp flavor of 'Hamlin', 'Valencia', 'Fallglo', 'Minneola', and 'Murcott' were less acceptable after irradiation at 0.3 or 0.45 kGy. The appearance of all cultivars was negatively affected by the loss of glossiness with the 0.45 kGy dose. Less than 1.0 % of fruit decayed, and irradiation treatment had no effect on decay. McDonalds et al. (2013) showed that irradiation (up to 0.6 kGy) did not affect the following sensory attributes of Lane Late' navel oranges throughout the shelf life of 4 w: color, aroma, off-aroma, dryness, granulation, aroma inside, off aroma inside,

CONCLUSION

It is well known that several processing factors affect the quality of citrus and citrus juice during storage. Compared to other phytosanitary applications, irradiation is a process with proven effectiveness against all growth forms of the Mediterranean fruit fly and extends the post-harvest storage period. Obtained results in this research showed that low-dose irradiation of citrus fruit such as 'Jaffa' oranges as a quarantine treatment had no statistically significant changes in most of the quality parameters between irradiated and control fruit. Besides, our results were in line with previous reports and, with regard to low dose irradiation (≤1.0 kGy) ensured physico-chemical and sensory changes were at an acceptable level and were not affecting consumption and commercial value of 'Jaffa' oranges.

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ETHICAL STATEMENT

During the writing process of the study titled " Determination of Quality Parameters and Sensory Attributes of 'Jaffa' Oranges Irradiated as Postharvest Quarantine Treatment Throughout Long-Term Cold Storage ", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Since this research is based on document analysis and descriptive analysis, there is no obligation for an ethics committee decision.

CONFLICT OF INTERESTS

The authors declared no conflict of interest.

AUTHORS CONTRIBUTION

All authors contributed equally

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