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ORIGINAL RESEARCH PAPER

STUDY OF THE QUALITY OF SYRIAN OLIVE OIL EXTRACTED FROM IRRADIATED AND UN-IRRADIATED FRUIT AND FRUIT FLESHES

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The effects of 0, 2 and 3 kGy doses of gamma rays in chemical and physical properties of olive oils extracted from whole and flesh of olive fruits were investigated. The results indicated that the acid value of samples ranged from 0.32 to 1.78%, the peroxide value ranged from 4.79 to 21.19 mEq O_2 kg^{-1} oil, iodine value ranged from 81.73 to 91.25 g I_2 100 g^{-1} oil, saponification value ranged from 185.93 to 197.71 mg KOH g^{-1} oil, thiobarbituric acid (TBA) value ranged from 0.028 to 0.057 mg MDA kg^{-1} oil, refractive index ranged 1.4642 to 1.4691 nD at 25°C, viscosity ranged from 126.33 to 162.00 mPa·s, and total phenolic ranged from 42.73 to 339.52 mg gallic acid kg^{-1} oil. The effect of gamma irradiation on the quality properties of olive oil was minimized.

Keywords: olive oil, Kaissy cultivar, chemical properties, physical properties

Introduction

Olive (*Olea europaea*) cultivation is widespread throughout the Mediterranean region and is important for the rural economy, local heritage and environment (Gargouri *et al.*, 2013). The beneficial effects of the olive oil including protection against cardiovascular and metabolic diseases have been the focus of several studies conducted on the Mediterranean diet (Bulotta *et al.*, 2014). Thus, as a result of the high nutritional value and the unique flavor characteristics of olive oil, it is a price premium product when compared to other vegetable oils.

Incorporating olive oil with lower quality oils such as seed oils has become recently a major issue for both merchants and consumers (Garcia *et al.*, 2013). A series of limits, based on both sensory and chemical tests, have been developed to determine the purity of oil and the absence of adulterants (IOOCS, 2014). The characterization, differentiation and classification of olive oils have been intensively carried out and performed deploying quantitative descriptive analysis (QDA) (Rial and Falque, 2003).

Once the VOO is extracted, the oxidation which is an unavoidable process that leads to deterioration becomes further distinct during oil storage (Bendini *et al.*, 2007).

Lipid oxidation is unleashed by factors, such as oxygen availability, the presence of light and temperature. If certain limits of lipid oxidation products (hydroperoxide, conjugated dienes and triens) are exceeded and/or rancid off-flavors occur, the olive oil may lose the permission to carry the label "extra virgin" or even "virgin" (Hrncirik and Fritsche, 2005). Several studies have reported free fatty acids, change of color, low smoke point, low iodine values, elevated total polar materials, high peroxide values, high foaming properties and increased viscosity as indicators of a poor quality oil (Turan and Yalcuk, 2013).

Ionizing irradiations are used for treatment of various food products. The irradiation extends the storage life of food and improves the safety via reduction of pathogenic and spoilage microorganisms (Al-Bachir, 2016; Al-Bachir, 2004). The advantages of irradiation processing include no undesirable residues in the foods treated, no resistance developed by pest insects or microorganisms and few significant changes in the physicochemical properties or nutritive value of treated products (Abbas *et al.*, 2011; Al-Bachir, 2015). Despite the fact that irradiation is a beneficial technology, its application can cause many changes which may somehow influence the nutritional value and sensory characteristics of irradiated commodities (Al-Bachir, 2015). To our knowledge, no studies have investigated the effect of gamma irradiation on virgin olive oil. Therefore, the present study aimed to evaluate the effect of gamma irradiation (2 and 3 kGy) on the properties of Syrian olive oil (SOO) extracted from different part of the fruits (whole fruit or fruit flesh) produced under Syria conditions.

Materials and methods

Kaissy, a common Syrian cultivar, was used in the current study and good quality fruits were harvested in 2009/2010 season from a region near the capital, Damascus (Deer Al Hajar, Syria). Fruits were weighed, packed into polyethylene pouches (a pouch containing 1 kg of fruit was considered as a replicate) and irradiated. Fruit samples were divided into three groups; the first is the control and groups 2 and 3 were irradiated with 2 and 3 kGy of gamma irradiation respectively.

Irradiation treatments

Olive fruit samples were irradiated at 0, 2 and 3 kGy doses in a ^{60}CO package irradiator (ROBO, Techsnabexport, Moscow, Russia) in a stationary mode taking into account the likelihood of dose rate variation (10.846 to 3.921 kGy h^{-1}) depending on the location and the distance from the source (10 to 40 cm). Samples were irradiated at room temperature and 15 cm from source with a dose rate of 9.571 kGy h^{-1}. The absorbed dose was determined using alcoholic chlorobenzene dosimeter (Al-Bachir, 2004).

Oil extraction

Samples of each treatment were divided into two groups in the first one oil was extracted from whole fruits and from fruit flesh in the second group. Oils were extracted from control and irradiated olive fruits at the shortest storage time possible (Blatchly *et al.*, 2014). Olive fruits were crushed with hummer crusher, slowly mixed for about 30 min at 27 ºC, and centrifuged at 3000 rpm for 3 min without any water addition. Finally, oils were decanted, immediately transferred into dark glass bottles and stored at room temperature (20–25 ºC). Physical and chemical analyses of oils extracted from irradiated and non-irradiated olive fruit samples were performed immediately after irradiation, and 6 and 12 months post storage.

Chemical and physical analyses of oils

Acid value (AV) in terms of (Oleic acid %), peroxide value (PV) in terms of mEq O_2 kg^{-1} oil, iodine value (IV) in g I_2 100 g^{-1}, saponification (specification) value (SV) in terms of mg KOH g^{-1} oil sample and the refractive index (RI) at 25 ºC were determined according to standard methods (AOAC, 2010). TBA number (2-thiobarbituric acid) in mg MDA kg^{-1} sample was measured according to IUPAC direct method (IUPAC, 1992). HAAKE viscometer 6 R plus Model (RTM) with a R2 column at 200 rpm was utilized to measure oil viscosity that was calculated and presented as mPa·s. The refractive index of olive oil samples was measured in daylight with an Abbe refractometer (VED Carl Zeiss JENA, German) calibrated against pure water at 25 ºC.

Determination of total phenol content of olive oil extracts

Phenolic compounds found in olive oils were isolated by a 3-time extraction solution of oil in hexane mixed with water (60:40. v/v). The Folin-Ciocalteau reagent (Merck Schuchardt OHG, Hohenbrunn, Germany) was added and the absorption of the solution was measured at 725 nm using UV-VIS spectrophotometer. Results were expressed in milligrams of gallic acid per kilogram of oil (Gutfinger, 1981).

Statistical analysis

All treatments including irradiation doses (0, 2 and 3 kGy), storage time (0, 6 and 12 months) and oil sources (whole fruit and fruit flesh) were distributed in a completely randomized design with three replicates. Variance test (ANOVA) included in the SUPERANOVA computer package (Abacus Concepts Inc, Berkeley, CA, USA; 1998) was used for data analysis. The p value of less than 0.05 was considered statistically significant and was denoted as: $p<0.05$*, $p<0.01$**. (Snedecor and Cochran, 1988).

Results and discussion

Effect of gamma irradiation and storage period on the acid value of EVOO

The mean±standard deviation of acid value (AV) (free fatty acid (FFA)) content (expressed as oleic acid %) of olive oil samples extracted from irradiated and un-

irradiated whole olive fruits and fruit flesh during storage time is given in Table 1. As it can be seen, 2 kGy and 3 kGy of gamma irradiation showed a significant ($p<0.01$) increase in AV of oil obtained from whole olive fruits and fruit flesh. The oils extracted immediately post-harvest from whole fruits irradiated with 0, 2 and 3 kGy had an average AV of 0.32, 0.35 and 0.38%, respectively.

However, the oils extracted immediately post-harvest from fruit flesh irradiated with the same doses of irradiation had an average AV of 0.40, 0.93 and 0.96%, respectively. With respect to storage, it can be seen that the increase ($p<0.01$) in AV was related to the variables of storage time.

After 12 months of storage, the AV of olive oil obtained from whole fruits irradiated with 0, 2 and 3 kGy were 1.35, 1.66 and 1.29%, respectively, while the oils extracted from fruit flesh irradiated with 0, 2 and 3 kGy were 0.49, 1.13 and 1.78 %., respectively. In the present study, both gamma irradiation doses and storage time showed a significant ($p<0.01$) increase in AV in oil obtained from whole olive fruits and fruit flesh. This can be explained by the high level of the moisture (around 50%) in the olive fruits as the source of the oil. This condition is favorable to lipase activity before extraction. Indeed, AV were partly formed by hydrolysis of triacylglycerols, which was promoted by the presence of food moisture (Elleuch *et al.*, 2007). Acid value is a measure of the free fatty acid in oil. Normally, fatty acids are found in the triglyceride form. However, during processing, the fatty acids may get hydrolyzed into free fatty acids. The higher levels of free fatty acids are responsible for lower oil quality (Atinafu and Bedemo, 2011).

Effect of gamma irradiation and storage period on the peroxide value of EVOO

The effect of gamma irradiation doses (0, 2 and 3 kGy) and the source of the oil (whole olive fruits or fruit flesh), as well as the storage time of the olive oils (0, 6 and 12 months) were assessed by evaluating changes in peroxide value (PV) of selected extra virgin olive oil samples, and the results of the evaluation are presented in Table 1.

At the beginning of the storage (time 0), the PV of olive oil extracted from whole fruit and fruit flesh were 4.79 and 6.13 mEq O_2 kg^{-1} oil respectively. PV in both olive oil extracted from whole fruit and fruit flesh increased significantly ($p<0.01$) in magnitude due to irradiation doses and storage time (Table 1). At the beginning of the storage period, the PV of oil extracted from whole fruit and fruit flesh treated with 3 kGy of gamma irradiation were 5.54 and 10.42 mEq O_2 kg^{-1} oil respectively. At the end of the storage period, the PV of oil extracted from non-irradiated whole fruit and fruit flesh were 11.19 and 19.43 mEq O_2 kg^{-1} oil, respectively.

The peroxide values of the samples are usually affected by the conditions before extraction and storage conditions after extraction. One of the most important parameters that influence lipid oxidation is the degree of un-saturation of its fatty acids. Un-saturated fatty acids, prevalent in bulk oils, are extremely susceptible to oxidation, leading to the formation of off-flavors. The quality and shelf-life of fats and oils, and products incorporating these, are largely determined by the progress

of lipid oxidation (Makhoul *et al.*, 2006). When double bonds of un-saturated fats are oxidized, peroxides are among the oxidation products formed. High peroxide value is an indicator of oxidation level and the greater the peroxide value, the more oxidized the oil (Atinafu and Bedemo, 2011).

Harvest and transportation damage, together with long storage time before olive milling, and improper handling and storage conditions cause immediate increases of PV (Ogutcu *et al.*, 2008). Moreover, the cultivar and the geographical origin of the oil samples have a significant influence on peroxide values (Noorali *et al.*, 2014).

Effect of gamma irradiation and storage period on the TBA value of EVOO

The 2-thiobarbituric acid (TBA) values were taken as a measure for the degree of oxidation during the irradiation of olive fruits and during the storage of olive oil extracted from irradiated and non-irradiated olives.

The effects of gamma irradiation doses and storage time on the TBA values of extra virgin olive oil are shown in Table 1.

At the beginning of the storage (at time 0), the TBA of olive oil extracted from whole fruit and fruit flesh were 0.056 and 0.52 mg MDA kg^{-1}, respectively. It was found that the effect of irradiation exposure on the TBA of olive oil extracted from whole fruits was not statistically significant ($p>0.05$) at the beginning of the experiment and after 6 months of storage. However, after 12 months of storage, only 3 kGy significantly ($p<0.05$) increased the TBA value in the same samples. On other hand, the used doses of gamma irradiation significantly ($p>0.05$) increased the TBA values of olive oil extracted from fruit flesh at the beginning of the experiment. Nonetheless, after 6 and 12 months of storage, both doses of gamma irradiation decreased significantly ($p<0.01$) the TBA value of extra virgin olive oil extracted from fruit flesh. Al-Bachir (2016) who studied the physicochemical property changes in oil of sesame seeds found that TBA values increased after gamma irradiation process. This could be due to the production during the Maillard reaction of antioxidant products, which are absorbed in the oil (Jittrepotch *et al.*, 2010). The mechanism of the antioxidant action of tocopherols, vitamins and flavonoids is thoroughly described by many authors (Lalas *et al.*, 2007). During storage, the TBA values decreased significantly ($p<0.01$) in oil extracted from irradiated and non-irradiated olive fruits (whole fruit or fruit flesh).

Effect of gamma irradiation and storage period on the iodine value of EVOO

The effects of gamma irradiation (0, 2 and 3 kGy) on iodine value (IV) for both olive oil obtained from whole fruits and fruit flesh during storage (0, 6 and 12 months) are presented in Table 2. Results show that the IV of olive oil extracted from control samples of whole olive fruits and fruit flesh were 84.41 and 83.87 g I_2 100 g^{-1} oil. There were no appreciable differences ($p>0.05$, except for the oil obtained from whole fruits and stored for 6 months) in IV of samples irradiated at 2 and 3 kGy (Table 2). The IV of oil obtained from whole fruit (control) was not affected by storage time, while the IV in oil extracted from fruit flesh increased

(p<0.01) sharply during the first 6 months of storage compared to control, followed thereafter by a gradual reduction (p<0.01) until month 12. IV is an important indicator of the degree of saturation and un-saturation of fat and oils. Saturated fats and oils have low iodine values and un-saturated fat and oils have high iodine values. Moreover, IV depends directly on the number of double bonds present in oils (Sanli *et al.*, 2014). In contrast with our results, other investigator found a decreased in iodine values of oil extracted from gamma irradiated walnuts (Al-Bachir, 2004). The decreasing trend in the oil iodine value upon irradiation in this study might refer to the saturation of the oil as a result of the breakdown of double bonds due to oxidation deterioration in the fatty acids (Al-Bachir, 2015).

Table 1. Effect of gamma irradiation and storage time on acid value (oleic acid%), peroxide value (mEq O_2 kg^{-1} Oil) and TBA value (mg MDA kg^{-1} oil) of extra virgin olive oil extracted from fruits and fruit fleshes

Treatments		Control	2 KGY	3 KGY	P-Value
Source		Acid value Free Fatty Acid (%)			
Whole fruits	0 months	0.32 ± 0.01^{cB}	0.35 ± 0.02^{bB}	0.38 ± 0.01^{aB}	**
	6 months	0.28 ± 0.01^{bB}	0.28 ± 0.00^{bC}	0.30 ± 0.01^{aB}	*
	12 months	1.35 ± 0.03^{bA}	1.66 ± 0.04^{aA}	1.29 ± 0.06^{bA}	**
	P-Value	**	**	**	
Fruit flesh	0 months	0.40 ± 0.02^{bB}	0.93 ± 0.02^{aAB}	0.96 ± 0.01^{aC}	**
	6 months	0.35 ± 0.01^{cB}	0.89 ± 0.01^{bB}	1.54 ± 0.03^{aB}	**
	12 months	0.49 ± 0.01^{cA}	1.13 ± 0.19^{bA}	1.78 ± 0.02^{aA}	**
	P-Value	**	*	**	
		Peroxide value (m EqO_2 Kg^{-1} oil)			
Whole fruits	0 months	4.79 ± 0.12^{bC}	4.97 ± 0.27^{bB}	5.54 ± 0.08^{aB}	**
	6 months	8.64 ± 0.56^{aB}	9.66 ± 2.48^{aA}	10.67 ± 0.70^{aA}	NS
	12 months	11.19 ± 0.78^{aA}	10.62 ± 0.60^{aA}	11.35 ± 1.36^{aA}	NS
	P-Value	**	**	**	
Fruit flesh	0 months	6.13±0.22cC	8.06 ± 0.25^{bC}	10.42 ± 0.05^{aC}	**
	6 months	16.42 ± 0.17^{aB}	17.19 ± 0.62^{aB}	16.76 ± 0.52^{aB}	NS
	12 months	19.43 ± 0.35^{bA}	20.22 ± 0.32^{abA}	21.19 ± 0.74^{aA}	**
	P-Value	**	**	**	
		TBA value (mg MDA Kg-1 oil)			
Whole fruits	0 months	0.056 ± 0.001^{aA}	0.058 ± 0.003^{aA}	0.055 ± 0.003^{aA}	NS
	6 months	0.028 ± 0.001^{aB}	0.029 ± 0.001^{aB}	0.030 ± 0.002^{aC}	NS
	12 months	0.030 ± 0.006^{bB}	0.033 ± 0.002^{bB}	0.043 ± 0.001^{aB}	*
	P-Value	**	**	**	
Fruit flesh	0 months	0.052 ± 0.001^{bA}	0.056 ± 0.003^{abA}	0.057 ± 0.002^{aB}	*
	6 months	0.032 ± 0.001^{bC}	0.030 ± 0.001^{aB}	0.030 ± 0.001^{aC}	**
	12 months	0.044 ± 0.005^{bB}	0.033 ± 0.003^{cB}	0.126 ± 0.002^{aA}	**
	P-Value	**	**	**	

^{abc} Means values in the same column not sharing a superscript are significantly different; ^{ABC} Means values in the same row not sharing a superscript are significantly different; NS: not significant; * Significant at p<0.05; ** Significant at p<0.01.

Effect of gamma irradiation and storage period on the saponification value of EVOO

Table 2 shows that the olive oil obtained from non-irradiated control samples of whole fruits revealed higher saponification value (SV) (195.48 mg KOH g^{-1} oil), while, the olive oil obtained from the fruit flesh of the same control sample revealed lower SV (187.56 mg KOH g^{-1} oil). These values indicated that the extra virgin olive oil had fatty acids with a higher number of carbon atoms in comparison with coconut (248-265) and palm kernel (230-254) oils (Nichols and Sanderson, 2003). SV is an indicator of the average molecular weight of the triglyceride composition of the oil and, hence, chain length (Yahaya *et al.*, 2012). Saponification values above 200 mg KOH g^{-1} oil indicate the presence of fatty acids of low or fairly low molecular weight, while values below 190 mg KOH g^{-1} are an indication the high molecular weight fatty acids are present (Aremu and Akinwumi, 2014). The applied higher dose (3 kGy) of gamma irradiation significantly ($p<0.01$) decreased the SV (192.73 mg KOH g^{-1} oil) in oil obtained from whole fruits, and significantly ($p<0.01$) increased the SV (190.48 mg KOH g^{-1} oil) in oil obtained from fruit fleshes comparing to the control sample. Likewise, during storage, the SV significantly ($p<0.05$) decreased (during the first 6 months) in oil obtained from whole fruits, and significantly ($p<0.05$) increased in oil obtained from fruit fleshes. Generally, the saponification values of olive oil obtained from this study are in agreement with those reported by Al-Bachir (2015) in oil extracted from pistachio.

Effect of gamma irradiation and storage period on the phenolic content of EVOO

The levels of phenolic compounds in Syrian extra virgin olive oil (EVOO) extracted from irradiated and un-irradiated whole fruit and fruit flesh of Kaissy cultivar are presented in Table 2. The total phenol contents, expressed as gallic acid equivalent (GAE), in oil samples extracted from control samples of whole fruit and fruit flesh were 339.52 and 226.68 mg GAE kg^{-1} oil, respectively. Montedoro *et al*. (1992) reported that the total phenol contents of Italian olive oils were found between 50 to 1000 ppm and classified as 50-200 ppm (low), 200-500 ppm (middle) and 500-1000 ppm (high). Our results fall within the middle range (200-500) according to this classification. However, the total phenol contents of oils were affected by maturation, nature of the cultivar and geographical origin (Tanilgan *et al.*, 2007). In the present study, 2 kGy and 3 kGy of gamma irradiation showed a significant ($p<0.01$) decrease in total phenolics in oil obtained from whole olive fruits (control, 339.52 vs. 2 kGy, 308.80, and 3 kGy, 285.87 mg GAE kg^{-1} oil. Meanwhile, 2 kGy and 3 kGy of gamma irradiation showed a slight decrease ($p>0.05$) in total phenolics in oil obtained from olive fruit fleshes (control, 226.68 vs. 2 kGy, 222.84, and 3 kGy, 222.26 mg GAE kg^{-1} oil. However, the phenolic compound level of the irradiated sample became higher after day 1 than the one of the control. This phenomenon was attributed to the immediate oxidation of the phenolic compounds, which played an antioxidant role by reducing the free

radicals and the reactive oxygen species induced by irradiation (Alothman *et al.*, 2009). In contrast with our results, Siddhuraju *et al*. (2002) found increased phenolics in sesbania and green gram seeds on soaking, followed by irradiation. Bhat *et al.* (2007) reported that 5 kGy dose of gamma irradiation showed a significant increase in total phenolics in velvent bean seeds. The ability of gamma irradiation to increase phenolic content in plant material has been observed in soybean and spices (Variyar *et al.*, 2004), and in almond skin extracts (Harrison and Were, 2007). They attributed such increase in phenolics to higher extractability by depolymerization and dissolution of cell wall polysaccharides by irradiation.

Table 2. Effect of gamma irradiation and storage period on iodine number (g I_2 100 g^{-1} oil), saponification value (mg KOH g^{-1} oil) and total phenolic (mg gallic acid kg^{-1} oil) of extra virgin olive oil extracted from fruits and fruit fleshes

	Treatments	**Control**	**2 KGY**	**3 KGY**	**P-Value**
Source		Iodine number (g I_2 100 g^{-1} oil)			
Whole fruits	0 months	84.41 ± 1.71^{aA}	83.56 ± 1.71^{aAB}	84.44 ± 1.49^{aB}	NS
	6 months	84.57 ± 1.66^{bA}	86.22 ± 2.69^{abA}	90.51 ± 2.29^{aA}	*
	12 months	83.05 ± 1.43^{aA}	81.73 ± 2.07^{aB}	82.23 ± 1.42^{aB}	NS
	P-Value	NS	*	**	
Fruit flesh	0 months	83.87 ± 0.84^{aB}	83.65 ± 0.33^{aB}	84.56 ± 1.84^{aB}	NS
	6 months	87.42 ± 0.58^{aA}	91.25 ± 2.32^{aA}	91.25 ± 3.86^{aA}	NS
	12 months	81.78 ± 0.34^{aC}	84.88 ± 1.13^{aB}	83.28 ± 2.61^{aB}	NS
	P-Value	**	**	**	
		Saponification value (mg KOH g^{-1} oil)			
Whole fruits	0 months	195.48 ± 0.75^{aA}	194.19 ± 0.61^{aA}	192.73 ± 0.74^{bA}	**
	6 months	190.81 ± 5.71^{aAB}	195.08 ± 1.00^{aA}	193.96 ± 2.00^{aA}	NS
	12 months	187.66 ± 1.54^{bB}	185.93 ± 1.28^{aB}	186.10 ± 2.52^{bB}	NS
	P-Value	*****	******	******	
Fruit flesh	0 months	187.56 ± 1.30^{bC}	184.39 ± 0.97^{cC}	190.48 ± 0.45^{aB}	**
	6 months	195.02 ± 0.43^{aB}	194.32 ± 0.27^{abA}	194.09 ± 0.43^{bA}	*
	12 months	187.71 ± 1.19^{bA}	188.80 ± 0.50^{aB}	190.62 ± 0.38^{aB}	**
	P-Value	**	**	**	
		Total phenolic (mg gallic acid kg^{-1} oil)			
Whole fruits	0 months	339.52 ± 13.56^{aA}	308.80 ± 13.30^{bA}	285.87 ± 9.47^{bA}	**
	6 months	193.80 ± 5.89^{bB}	219.90 ± 2.72^{aB}	217.19 ± 4.03^{aB}	**
	12 months	160.05 ± 0.13^{aC}	136.61 ± 2.33^{bC}	132.07 ± 6.47^{bC}	**
	P-Value	**	**	**	
Fruit flesh	0 months	226.68 ± 3.92^{aA}	222.33 ± 4.25^{aA}	222.26 ± 3.26^{aA}	NS
	6 months	189.51 ± 4.80^{aB}	125.85 ± 3.89^{bB}	86.66 ± 6.68^{cB}	**
	12 months	84.55 ± 1.14^{aC}	55.43 ± 0.87^{bC}	42.73 ± 2.00^{cC}	**
	P-Value	**	**	**	

^{abc} Means values in the same column not sharing a superscript are significantly different; ^{ABC} Means values in the same row not sharing a superscript are significantly different; NS: not significant; * Significant at $p<0.05$; ** Significant at $p<0.01$.

Effect of gamma irradiation and storage period on the refractive index of EVOO

Refractive indeces (RI) of extra virgin olive oil (EVOO) extracted from irradiated and non-irradiated olive fruits (whole fruits and fruit flesh) during storage are presented in Table 3. The EVOO extracted from the non-irradiated (control) samples of whole olive fruits and fruit flesh showed a RI of 1.4669 and 1.4668 respectively. The RI of EVOO in the present study showed that it is not as thick as most drying oil whose refractive indices fell between 1.475 and 1.485 (Ogunbenle and Afolayan, 2015).

Regarding the effect of gamma irradiation on refractive index, there was no significant difference ($p>0.05$) between EVOO extracted from irradiated and un-irradiated whole olive fruits, while there was significant difference ($p<0.05$) between EVOO extracted from irradiated and un- irradiated fruit fleshes (Table 3). Our results are in accordance with the previously reported findings of Yaqoob *et al.*, (2010), and Bhatti *et al.*, (2010) who also did not observe any significant change in refractive indices between the control and irradiated sunflower and peanut oils respectively.

The results indicated that storage periods had an effect on the RI of EVOO. A significant ($p<0.01$) change in the RI of EVOO extracted from irradiated and non-irradiated samples during storage may be due to the exclusion of some saturated fatty acid and / or compounds which could affect this property (El-Kady *et al.*, 1999). The refractive index depends on the thermal degradation and percentage of polar compounds formed during oxidation and hydrolytic reactions (Benedito *et al.*, 2007). These reactions change the chemical composition of the oils, releasing free fatty acids and free radicals that in turn combine to make monoglycerides diglycerides and polymeric triglycerides. All of these products of alteration are considered polar compounds (Choe and Min, 2007).

Effect of gamma irradiation and storage period on the viscosity of EVOO

Viscosity is a physical characterization constant mostly depending on the temperature and to some extent ono the compositional differences of the vegetable oils. Viscosity is an important parameter for the design of industrial processes. It can also be used to evaluate the quality of fats and oils used in frying (Nichols and Sanderson, 2003).

The levels of viscosity in olive oil obtained from whole fruits and flesh fruit treated with 0, 2 and 3 kGy of Kaissy olive cultivar during storage are shown in Table 3. The viscosity (expressed as mPa·s oil) of oil extracted from control samples of whole fruits (129.33 mPa·s) was similar to those of oil extracted from control samples of fruit flesh (130.00 mPa·s). The absolute viscosity of oil is its resistance to flow and shear due to internal fraction and it is measured with International System of Units of mPa·s (Diamante and Lan, 2014). It is commonly perceived as the thickness or resistance to pouring. Viscosity describes a fluid's internal resistance to flow and may be thought as a measure of fluid friction (Nzikou *et al.*, 2010).

Gamma irradiation at 2 and 3 kGy had no significant ($p>0.05$) effect on the viscosity of EVOO obtained from whole fruit or fruit flesh. Nonetheless, storage periods had significant ($p<0.01$) effect on the viscosity of EVOO obtained from irradiated and un-irradiated olive fruits (whole fruits or flesh fruits). At the end of the storage periods (after 12 months), the viscosity of the oil extracted from whole olive fruits treated with 0, 2 and 3 kGy were 160.33, 162.00 and 161.67 mPa·s, respectively, while the viscosity of the oil extracted from fruit flesh treated with the same doses were 161.00, 160.33 and 160.00 mPa·s, respectively.

The differences in the viscosity between EVOO extracted from irradiated and non-irradiated fruit samples at zero month and after 12 months of storage may be attributed to the degradation of some high molecular weight components and to the change of these components from non-soluble to soluble ones in the tested oils. However, by lowering the molecular weight of polysaccharides, they would likely be depleted of some important properties and it does not compromise the rheological properties of the polymers (Byun *et al.*, 2008).

Table 3. Effect of gamma irradiation and storage period on refractive index (nD 25 °C) and viscosity (mPa·s) of extra virgin olive oil extracted from fruits and fruit fleshes

Treatments		Control	2 KGY	3 KGY	P-Value
Source		Refractive Index (nD 25 ^{0}C)			
Whole fruits	0 months	1.4669 ± 0.0001^{aA}	1.4651 ± 0.0002^{aA}	1.4689 ± 0.0001^{aA}	NS
	6 months	1.4668 ± 0.0001^{aA}	1.4642 ± 0.0002^{aA}	1.4691 ± 0.0001^{aA}	**
	12 months	1.4668 ± 0.0001^{aA}	1.4655 ± 0.0002^{aA}	1.4690 ± 0.0001^{aA}	**
	P-Value	**	**	**	
Fruit flesh	0 months	1.4668 ± 0.0001^{aA}	1.4649 ± 0.0001^{aA}	1.4691 ± 0.0001^{aA}	**
	6 months	1.4668 ± 0.0001^{aA}	1.4648 ± 0.0001^{aA}	1.4691 ± 0.0001^{aA}	**
	12 months	1.4670 ± 0.0001^{aA}	1.4651 ± 0.0001^{aA}	1.4690 ± 0.0001^{aA}	NS
	P-Value	**	**	**	
		Viscosity (mPa·s)			
Whole fruits	0 months	129.33 ± 0.58^{aB}	129.67 ± 1.16^{aB}	130.67 ± 0.58^{aB}	NS
	6 months	126.33 ± 0.58^{bC}	126.33 ± 0.58^{bC}	128.00 ± 1.00^{aC}	*
	12 months	160.33 ± 0.58^{bA}	162.00 ± 1.00^{aA}	161.67 ± 0.58^{bA}	*
	P-Value	**	**	**	
Fruit flesh	0 months	130.00 ± 1.00^{aB}	130.33 ± 0.58^{aB}	131.00 ± 1.00^{aB}	NS
	6 months	126.67 ± 0.58^{aC}	127.67 ± 1.53^{aC}	128.00 ± 1.00^{aC}	NS
	12 months	161.00 ± 0.00^{aA}	160.33 ± 0.58^{bA}	160.00 ± 0.00^{abA}	*
	P-Value	**	**	**	

^{abc} Means values in the same column not sharing a superscript are significantly different; ^{ABC} Means values in the same row not sharing a superscript are significantly different; NS: not significant; * Significant at $p<0.05$; ** Significant at $p<0.01$.

Conclusion

The results of this study revealed that the used doses of gamma irradiation (0, 2 and 3 kGy) and storage time (0, 6 and 12 months) have a significant effect on some physical and chemical properties of Syrian extra virgin olive oil (EVOO) extracted from whole fruits and fruit flesh. The present study demonstrated that the effect of

gamma irradiation on the quality properties of EVOO was minimized. Generally, the physical and chemical characteristics remained below the maximum desirable limits for EVOO set by Codex regulations.

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