Gesunde Pflanzen
https://doi.org/10.1007/s10343-023-00859-8

ORIGINAL ARTICLE / ORIGINALBEITRAG

Yield Traits of Red Radish Seeds Obtained from Plants Produced from γ-Irradiated Seeds and Their Oil Characteristics

Amina A. Aly[1] · **Rabab W. Maraei**[1] · **Reem G. Sharafeldin**[2] · **Gehan Safwat**[2]

Received: 3 November 2022 / Accepted: 13 February 2023
© The Author(s) 2023

Abstract

Red radish is an important root crop worldwide owing to its broad adjustment, high yield, and abundant nutritional contents. So, this study was conducted on radish seeds taken from plants established from seeds that were irradiated by different dose levels of gamma-ray (10, 20, 40 and 80 Gy) as well as the un-irradiated sample (control) to evaluate the changes in seed yield traits (number of pods/plant (NPP); total weight of pods/plant (TWPP) in grams; seed yield/plant (SYP) in grams; 100-seeds weight (100-SW) in grams). Proximate composition of the seeds yield, as well as the oil yield and its physico-chemical properties plus the bioactive ingredients of this oil were concerned. The results indicated that all traits of seeds yield were highly significant for all irradiation treatments except for 100-seed weight, which was not affected by irradiation treatments, and the dose of 40 Gy gave the best traits. There is a positive effect of irradiation on most of the proximate composition, except the content of crude fiber and moisture which were decreased by irradiation treatments. Furthermore, γ-rays improved the minerals content of red radish seeds and the dose of 80 Gy was the most effective dose for increasing the content of nitrogen, potassium, and sodium, while the dose of 20 Gy gave the highest calcium content. As for the oil, the results showed that the oil yield increased by gamma-rays and the maximum yield was gained with dose level of 20 Gy (34.80%). The fatty acids composition was affected by γ-rays different dose levels and erucic & oleic acids were the predominant mono-unsaturated fatty acids (MUFAs) while, linoleic & linolenic acids were the major polyunsaturated fatty acids (PUFAs). Concerning the physico-chemical properties of the oil samples, it was observed that irradiation decreased the iodine value, while the acid, saponification, and ester values increased in all treatments, but on the contrary, the peroxide value was not affected by irradiation. With regard to the bioactive compounds of seeds oil and their antioxidant activity, were increased by irradiation.

Therefore, radish oil is considered unconventional oil and can be evaluated as an alternative to traditionally consumed vegetable oils or as additives to them.

Keywords Red radish oil · γ-rays · Seed yield traits · Oil physic-chemical properties

Introduction

Brassicaceae family, which includes leaves, roots, seasoning vegetables beside oilseed, is one of the most popular vegetable families (Gamba et al. 2021). Oilseeds potential health benefits are attributed to its constituting chemical compounds (Manivannan et al. 2019). In addition to being a vegetable crop, radish (*Raphanus sativus*), is a significant source of medicinal compounds. It has been used for treating various disorders including gastrointestinal disorders such as constipation, biliary, hepatic and some respiratory disorders such as asthma as well as some cardiovascular conditions including hypertension (Blazevic' and Mastelic' 2009). Different parts of radish plants (leaves, roots, and seeds) have many medical uses, including treatment of tuberculosis, whooping cough, asthma attacks, laxative to treat constipation, fracture of kidney and bladder stones, thinner, cholesterol-lowering, antiradical, and analgesic pain (Jaafar et al. 2020).

Non-traditional vegetable oils have components that contribute to their unique chemical properties which can be

✉ Amina A. Aly
aly_amina@yahoo.co.uk

1 Natural Products Dept., National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt

2 Faculty of Biotechnology, October University for Modern Science and Arts (MSA), Giza, Egypt

Published online: 09 March 2023

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

used for their health benefits as they contain phytochemicals which demonstrate antioxidative properties. Newer sources of edible oils are vital as they can be used to supplement other types of vegetable oils (Ramadan and Moersel 2006). Radish seeds are edible and occasionally consumed to add crunchiness and spiciness to salads (Elamin 2015). Some of the radish varieties are mainly grown for their seed pods or seeds instead of their roots. Vegetable oils have many applications as they are used in cooking, cosmetic, pharmaceutical and chemical industries (Dugo et al. 2004). Most natural crude oils have limited applications despite the majority of seed oils having good structural chemical profiles (Dwiecki et al. 2007). Radish seeds include a high quantity of oil that ranges between 30 and 50% of their weight which can also be used for biodiesel production (Domings et al. 2008). Radish seeds oil has been utilized in many health applications. Seeds oil are a mixture of saturated and unsaturated fatty acids, whose composition depends on cultivar genetics, nutrients condition, climate, soil types, and the disease presence (Kaymak 2015; Silvestre et al. 2017). There are high similarities between the chromatographic analysis of radish seeds oil and cottonseeds oil (Pérez Gutiérrez et al. 2004). The two major fatty acids found in radish seeds are linolenic acid and oleic acid. The radish oil has shown notable antioxidative activities (Hou et al. 2011).

Gamma-rays as an ionizing radiation and their biological effects depend mainly on the interactions with the atoms or molecules in the cells specially water molecules to generate free radicals which can affect cells by damaging or modifying the cell contents. As well as affecting the morphology, anatomy, biochemistry and physiology of plants. These impacts include modifications in the structure and metabolism of plant cells, such as dilation of thylakoid membranes, alterations in photosynthesis, manipulation of the antioxidant system, and accumulation of phenolic compounds (Kebeish et al. 2015). The main effects of gamma radiation are ionization, degradation and excitation. This excitation causes a weak interaction while ionization and degradation result in high interaction. Absorption of ionizing radiation affects critical targets in the cell directly (Kovacs and Keresztes 2002). The effect of radiation exposure is mainly influenced by multiple factors, some are related to the traits of the plant such as the specie, cultivars, growth stage, tissue architecture, and the organization of the genome while other issues depend on the characteristics of the radiation (Jan et al. 2012).

Gamma irradiation is not only used for medical sterilization, but also used to preserve the nutrition of the seeds in addition to its positive effects such as increasing the content of flavonoids, alkaloids, phenolic compound, and antioxidant activity (Mohajer et al. 2014). However, it has been shown that irradiation rely on a number of factors including species, irradiation dose and type, the effects of irradiation on the physico-chemical qualities of grains, nuts, and the oils obtained from them are rather debatable (Prakash et al. 2007).

Therefore, the plan of this research was to find out the influence of gamma-rays process on the red radish yield traits of seeds taken from plants established from γ-irradiated seeds (10, 20, 40 and 80 Gy) and their oil characteristics, which includes evaluating the changes that occurred in the composition of fatty acids and the physico-chemical properties of the oil and its bioactive ingredients (phenols and tocopherols) in addition to studying the proximate analysis of these seeds.

Material and Methods

Seeds of red radish (*Raphanus sativus-Red*) were taken from plants produced from seeds which were exposed to different doses of gamma-rays (10, 20, 40, and 80 Gy) and untreated used as control and grown in the experimental farm of NCRRT in a randomized complete block design system with 3 replicates (El-Beltagi et al. 2022). Mature seeds were harvested, dried thoroughly, tagged with plastic bags and stored and kept until use.

Seed Yield Traits

Data were recorded on 10 randomly picked plants from every plot from each of the three replicates for the following traits:

Number of pods/plant (NPP); total weight of pods/plant (TWPP) in grams; seeds yield/plant (SYP) in grams; 100-seed weight (100-SW) in grams.

Proximate Composition of Red Radish Seeds

The following parameters were used to determine the proximate composition of seeds:

As moisture, crude lipid, ash, crude fiber, and crude proteins according to AOAC (2005). The moisture contents were calculated by drying seeds at 105 °C until they reached stable weights. The ash content was obtained by incineration of the seeds at 550 °C. The Nitrogen (N) value was evaluated using the Kjeldahl system. Crude proteins were evaluated as N × 6.25 (Imran et al. 2008). The lipid content was determined on a Soxhlet system. Difference as stated by calculating the total carbohydrate contents (Muller and Tobin 1980) by colleting the sample's total fiber, fats, proteins, moisture, and ash levels and then subtracted from 100. Each treatment was examined three times.

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Mineral Content in Radish Seeds

A burning cup was filled with approximately 0.5 g of dry and crushed samples, along with 15 ml of pure HNO_3. The samples were burned in a microwave digester (Milstone digester; Ethose—D, GmbH, Leutkirch, Germany) at 200 °C, and deionized water was used to dilute the solution to the required level. Minerals content were evaluated as follow:

Total nitrogen content was calculated by Kjeldahl's protocols (Motsara and Roy 2008). The content of calcium (Ca), potassium (K) and sodium (Na) in digested dry samples of red radish seeds were analyzed separately, using (Pfp7 flame photometer Jenway, UK) and the concentrations were expressed as mg/kg dry sample.

Extraction of the Oil

Crude oils were obtained from radish seeds by crushing with a clean coffee grinder for 15 s and then fed to a Soxhlet system (AOAC 2005). Briefly, crushed treatment of 100 g each was recovered using petroleum ether (60–80) at 60 °C for an approximate 6 h. Then the petroleum ether was vaporized using a rotary evaporator and the extracted oils were kept in glasses bottle at –20 °C for subsequent use. This was repeated till finish the required amount of oil.

Fatty Acid Composition

Gas chromatography (A HP 6890) instrument (Hamilton, CA, USA) fitted with an Innowax crosslinked polyethylene glycol column (30 m; i.d. 0.32 nm; 0.5 µm film thickness) was used to analyze fatty acid methyl esters (FAME), which were calculated from the corresponding fatty acids in the seeds oil following the protocol of IUPAC (1987). The fatty acids content were calculated using the retention times of the samples' fatty acids peak to the retention times of the standards. The standards used were capric acid (C10:0), lauric acid (C12:0), myristic acid (C14:0), palmitic acid (C16:0), arachidic acid (C20:0), lignoceric acid (C24:0), oleic acid (C18:1), linoleic acid (C18:2), linolenic acid (C18:3), eicosenoic (C20:1) and erucic acid (C22:1).

Physico-Chemical Characteristics of Oil

The physico-chemical characteristics of oil were determined by evaluating the following parameters: acid, peroxide, iodine and saponification values. The acid and saponification values were evaluated using the standard methods described by AOAC (2000) while the peroxide value was determined according to AOAC (1990). Iodine value was determined according to the method of Thomas (2002):

Ester value = saponification value – acid value

Tocopherols Content of Seeds Oil

Oils' tocopherol was performed by Agilent1260 infinity HPLC series (Agilent®, USA), outfitted by a quaternary pump. Column: Hyper Clone TM BDS C18, 130 Å 100 mm × 4.6 mm (Phenomenex®, USA), managed at 35 °C. After separation the mixture of acetonitrile: methanol (70:30) is eluted. The injection quantity was 20 µl. Detection: fluorescence detector (excitation wavelength; 230 nm and emission wavelength; 460 nm). Tocopherols were calculated by comparing the samples' retention time with authentic standard retention times. The tocopherols content were specified as mg/kg oil.

Total Phenolic Contents

The phenolic contents of radish seed oil were evaluated following the protocol of Shahidi and Naczk (1995) utilizing the Folin–Denis reagent. The samples' phenolic contents were determined by the standard curve of gallic acid (GA). The findings were evaluated as milligram of gallic acid/gram oil.

Antioxidant Activity Using DPPH Radical

Antioxidants activity of each sample was measured against the radical 2,2-diphenyl-1 picryl hydrazyl (DPPH) using the method illustrated by Gulluce et al. (2004).

Statistical Analysis

Three replicates were used in a randomized complete block design and the data were displayed as mean ± standard deviation. Statistical analysis has been done using one-way ANOVA, as well as the differences in averages were evaluated utilizing Duncan's multiple range tests (Duncan 1955) at $p \leq 0.05$.

Results and Discussion

Seed Yield Traits

The effect of gamma-rays on the seed yield traits (number of pods/plant (NPP); total weight of pods/plant (TWPP) in grams; seed yield/plant (SYP) in grams; 100-seeds weight (100-SW) in gram) are presented in Table 1. It is clear from the results that gamma rays improved the traits of the seed

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

yield of red radish, as it was noted that the pods number/plant, total weight of pods/plant and seed yield/plant were increased by using the radiation, where the dose of 20 Gy provided the premier value for these traits (412.5, 29.10 g and 30.0 g, respectively) compared with the control (357.0, 19.78 g and 15.0 g, respectively). Meanwhile, there were no considerable variations between the control and irradiated treatments for the 100-seed weight. The current findings are in line with that achieved by Aly et al. (2023) and Aly et al. (2021) who illustrated that irradiated treatments increased the morphological traits of white radish and red radish, respectively. Also, Singh et al. (2012) found that radiation treatments, are commonly, led to an enhancement in plant development and yield traits. Also, the use of gamma-rays at dose levels from 25–200 Gy had an affirmative impact on the pods number/plant and seeds weight per plant. This suggests that selection in the mutated generation created by gamma irradiated fenugreek may be able to improve the quantitative traits (Hanafy and Akladious 2018). Low-doses of gamma-rays have been proven to be improved plant vigor and wheat yield (Singh and Datta 2010).

Proximate Composition

The proximate composition of red radish seeds obtained from plants produced from un-irradiated and gamma-treated seeds is shown in Fig. 1. The results provided that there is diversity in the impact of irradiation on the proximate con-

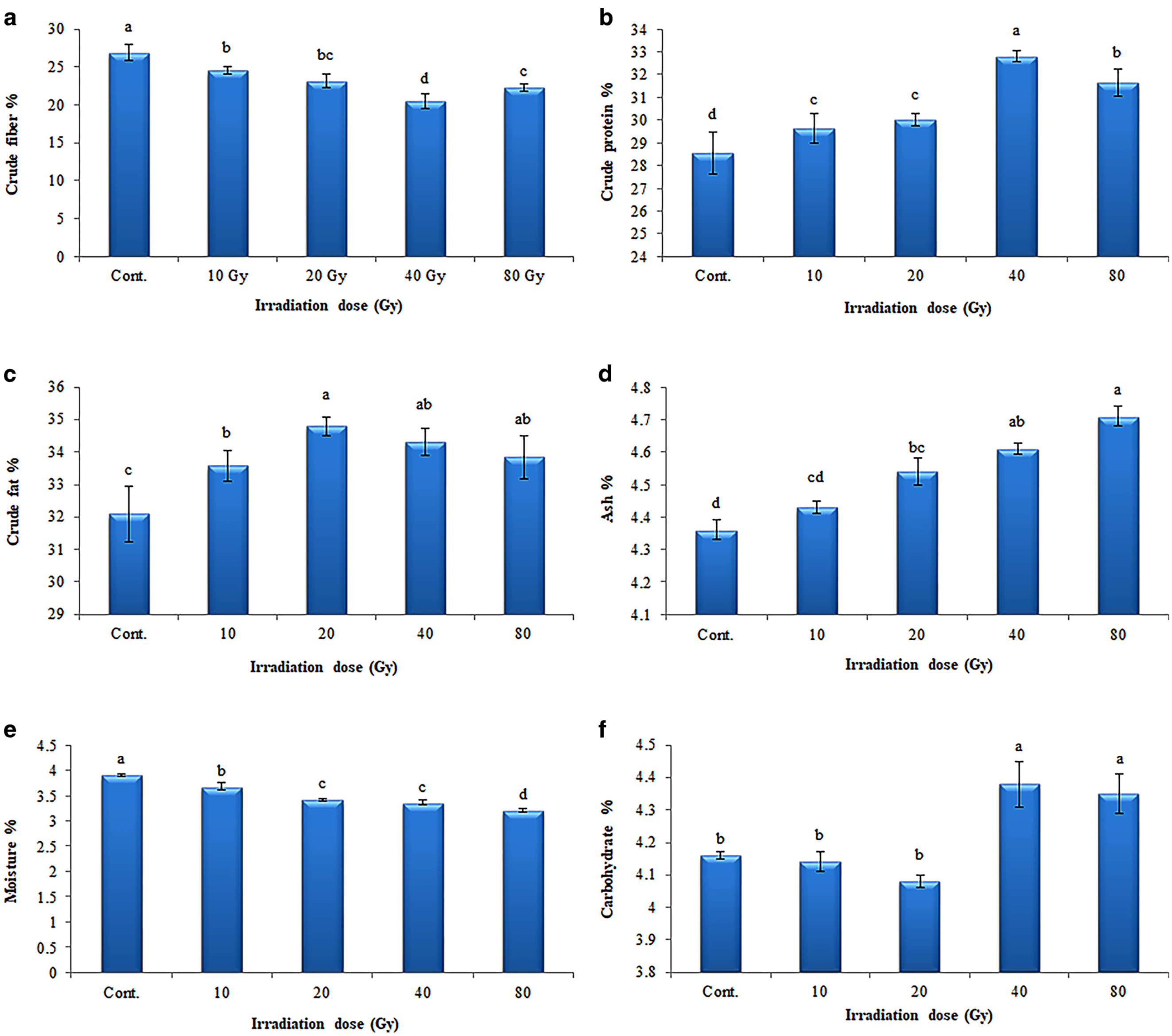

Fig. 1 Proximate composition of red radish seeds obtained from plants produced from un-irradiated and irradiated seeds. *Vertical bars* ± SD ($n = 3$) and *varying letters on the bars* in every sample are significantly differed at ($p \leq 0.05$). **a** Crude fiber %, **b** crude protein %, **c** crude fat %, **d** ash %, **e** moisture %, and **f** carbohydrate %

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Table 1 Effect of gamma-rays on seed yield traits of red radish

Irradiation dose level (Gy)	No. pods/plant	Weight of pods/plant (g)	Seeds yield/plant (g)	100-seed weight (g)
Cont	357.0 ± 10.82^{c}	19.78 ± 0.87^{d}	15 ± 1.00^{e}	0.695 ± 0.005^{a}
10	361.5 ± 11.53^{c}	21.90 ± 0.94^{c}	21 ± 1.73^{d}	0.702 ± 0.004^{a}
20	412.5 ± 7.21^{a}	29.10 ± 0.50^{a}	30 ± 2.00^{a}	0.705 ± 0.004^{a}
40	397.7 ± 17.79^{ab}	25.60 ± 1.01^{b}	28 ± 1.00^{b}	0.699 ± 0.006^{a}
80	388.3 ± 10.50^{b}	24.80 ± 0.81^{b}	25 ± 1.73^{c}	0.700 ± 0.003^{a}

Results are expressed as means ± SD ($n = 3$), and means by various letters inside the same column are significantly difference ($p \leq 0.05$)

Table 2 Minerals content of red radish seeds obtained from plants produced from un-irradiated and irradiated seeds

Irradiation dose level (Gy)	N (%)	Ca (mg/kg)	K (mg/kg)	Na (mg/kg)
Cont	3.02 ± 0.07^{e}	575 ± 5.00^{e}	4500 ± 100^{d}	2500 ± 91.7^{e}
10	3.68 ± 0.03^{d}	850 ± 26.50^{b}	5000 ± 100^{c}	2625 ± 75.0^{d}
20	3.81 ± 0.06^{c}	950 ± 5.00^{a}	6250 ± 45.8^{b}	2950 ± 96.4^{c}
40	3.95 ± 0.05^{b}	775 ± 9.54^{c}	6400 ± 100^{ab}	3250 ± 70.0^{b}
80	4.16 ± 0.05^{a}	675 ± 3.61^{d}	6500 ± 95.4^{a}	3625 ± 25.0^{a}

Results are expressed as means ± SD ($n = 3$), and means with various letters inside the same column are significantly differed ($p \leq 0.05$)

tents of red radish seeds taken from plants established from irradiated seeds compared to the control sample, and there is a positive effect of radiation on most of these analyses.

It was noticed that the content of crude protein, crude fat, ash and carbohydrate were all increased by irradiation, where the highest values of crude protein and carbohydrate content (32.81 and 4.38%, respectively) were obtained from dose level 40 Gy, while the highest values of crude fat and ash content (34.80 and 4.70%) were obtained from 20 and 80 Gy, respectively.

On the contrary, the seeds' crude fiber and moisture were reduced with rising irradiation dose level comparison with the control. These findings are in consistent with those obtained by Maraei and Hammoud (2019) on date seeds and Khan et al. (2018) on peach.

Nail (2016) showed that the oil content and analysis of radish seeds were; moisture contents (3.74%), crude proteins (32.1%), crude fiber (26.144%), total ash (4.33%) as well as total carbohydrates (3.69%). The increase of crude proteins levels by irradiation could be attributed to the breakdown of complex molecules of proteins into smaller molecules.

Nevertheless, the moisture could have been a contributor to the noted enhancement in the concentrations of crude proteins, where the possibility of the reduction in water content could be related to an equivalent enhancement in the relative abundance of the main components of the samples (Bhat et al. 2009).

It was noted that radish seeds contain a high percentage of crude fat and this percentage has been increased by irradiation.

Minerals Content in Seeds of Red Radish

The minerals content of red radish seeds (N, Ca, K and Na) are presented in Table 2. The findings provided that gamma rays improved the concentration of minerals as well as the 80 Gy dose level was the most effective dose for increasing the content of nitrogen, potassium and sodium (4.16%, 6500 mg/kg DW and 3625 mg/kg DW, respectively). While the 20 Gy dose level gave the highest calcium content (950 mg/kg DW). The mineral content changes after irradiation could be linked to the exposure dose which might have affected the extraction yield (Sanni et al. 2015). Minerals content have been found to be greatly affected by cultivar locations and environmental factors (Sanni et al. 2015). Current findings are in line with El-Beltagi et al. (2022) who found that exposing red radish seeds to γ-rays before planting enhanced roots minerals content (N, K, S, P, Ca, and Mg).

Fatty Acid Composition of Seeds Oil

The fatty acid compositions of the red radish seed oils are provided in Table 3. In general, the composition of fatty acids in seeds oil is altered due to the varieties and specie of the plants (Matthäus et al. 2021). Eight fatty acids at different quantities were detected in all samples. The oils were extracted from seeds taken from plants produced from un-irradiated and irradiated seeds. There was a significant difference in some fatty acids and no significant in others. Unsaturated fatty acid, which consists of MUFAs and PUFAs, were found to be for more than 80% of the total fatty acids. The predominant MUFAs were erucic and oleic acids while linoleic and linolenic acids were the major PUFAs (Kaymak 2015; Qian et al. 2017).

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Table 3 Fatty acids composition of red radish seeds oil obtained from plants produced from un-irradiated and irradiated seeds

Fatty acids	Irradiation dose (Gy)				
	Control	10	20	40	80
Myristic (C14:0)	0.08 ± 0.004	0.10 ± 0.01	0.12 ± 0.016	0.11 ± 0.015	0.10 ± 0.012
Palmitic (C16:0)	5.34 ± 0.04	5.36 ± 0.036	5.60 ± 0.036	5.66 ± 0.026	6.14 ± 0.03
Oleic (C18:1)	21.14 ± 0.046	21.37 ± 0.02	21.73 ± 0.036	21.90 ± 0.053	22.51 ± 0.036
Linoleic (C18:2)	13.51 ± 0.02	13.41 ± 0.02	13.36 ± 0.0	13.25 ± 0.01	13.28 ± 0.03
Linolenic (C18:3)	9.43 ± 0.046	9.34 ± 0.046	9.36 ± 0.044	9.35 ± 0.036	9.34 ± 0.04
Arachidic (C20:0)	1.16 ± 0.03	1.58 ± 0.05	1.41 ± 0.02	1.52 ± 0.03	1.74 ± 0.03
Eicosenoic (C20:1)	9.08 ± 0.098	9.16 ± 0.05	9.18 ± 0.01	9.17 ± 0.075	9.22 ± 0.056
Erucic (C22:1)	37.61 ± 0.16	36.01 ± 0.12	35.57 ± 0.08	35.18 ± 0.09	34.89 ± 0.07
Lignoceric (C24:0)	2.24 ± 0.05	2.29 ± 0.046	2.26 ± 0.062	2.31 ± 0.053	2.29 ± 0.046
ΣSFA	8.82 ± 0.11	9.33 ± 0.10	9.39 ± 0.11	9.60 ± 0.11	10.27 ± 0.07
ΣMUFA	67.83 ± 0.19	66.54 ± 0.09	66.48 ± 0.06	66.25 ± 0.17	66.62 ± 0.03
ΣPUFA	22.94 ± 0.03	22.75 ± 0.06	22.72 ± 0.04	22.60 ± 0.04	22.62 ± 0.04
ΣUFA	90.77 ± 0.21	89.29 ± 0.14	89.20 ± 0.11	88.85 ± 0.19	89.24 ± 0.06
SFA/UFA	0.097 ± 0.001	0.104 ± 0.001	0.105 ± 0.001	0.108 ± 0.001	0.115 ± 0.001
UFA/SFA	10.29 ± 0.11	9.57 ± 0.12	9.50 ± 0.10	9.26 ± 0.08	8.69 ± 0.05

Findings are given as mean ± standard deviation

SFAs saturated fatty acids, *MUFAs* monounsaturated fatty acids, *PUFAs* polyunsaturated fatty acids, *UFAs* unsaturated fatty acids

The data showed an enhancement in the SFAs and a reduction in the PUFAs by gamma-rays. Also, linoleic, linolenic, and erucic acids are the fatty acids that have been the mainly influenced with gamma-rays. This data is consistent with the findings of Al-Bachir (2017), who found that gamma-rays caused alterations in UFAs and SFAs, these modifications were considerably in sunflower and sesame oils, although no significance was observed in peanut oil. However, Barreira et al. (2012) reported that irradiation made no difference between MUFAs and PUFAs.

The ratio of UFAs/SFAs is vital for health and nutritious and it illustrates the damaging impacts of dietary fats (Ogungbenle and Afolayan 2015) and this relative percent is utilized to estimate the shelf-life of seeds oil, as lower ratios extending the shelf life of the products (Fokou et al. 2009). The recent investigation pointed that, the ratios of UFAs/SFAs were reduced by gamma-rays and the 80 Gy dose gave the lowest ratio, while the ratio of SFAs/UFAs increased by irradiation. The seeds content and healthy characteristics of radish cultivars may be varied according to the geographic site (Qian et al. 2017).

Physico-Chemical Properties of Red Radish Seeds Oil

Physico-chemical characteristics of un-irradiated and γ-irradiated seeds oil are found in Table 4.

Peroxide content determines oil deterioration due to oxidation, as a result, the oil may be stored for a very long time due to the low peroxide value (Chopra and Kanwar 1991). The eatable oils and fat have an initial peroxide value ranged from 0.9–15.9 meq/kg oil. There are no significant differences between the oil samples in the peroxide value (Table 4). The peroxide values for all samples were inside the FAO/WHO and TBS requirements for eatable vegetables oil.

The peroxidation value is differed from oil to another linked to the various treatments used. The peroxide value is a measure of the concentrations of peroxide and hydroperoxide which were formed during the early stage of lipid-oxidation. Milli equivalents of peroxides/kg of fat are evaluated by titration iodine ion. Since peroxide value is not static, handling and testing the samples must be done with great care. Providing a specific guideline which relates the peroxide value of oil to its rancidity is difficult. High levels of peroxide value are a clear indication that the fat is spoiled whilst temperate value might be due to the peroxide depletion after reaching great concentration. High iodine value indicates a high content of un-saturation, while oxidation decreases the level of un-saturation. The presence of a significant amount of un-saturated fatty acids can be an indicator of the suitability of the oil for food and may also be used to make nondrying oil, which is important in soap production (Kamalu and Oghome 2008). Gamma irradiation treatment caused the maximum decline of iodine value at the highest dose level 80 Gy (59.99 g/100 g oil) while the iodine value for the control sample was found to be 65.03 g/100 g oil. In general, high gamma ray dose showed the most remarkable decline in the iodine value, in the current investigation, the reduction in the iodine values after irradiation might be caused by the saturation of oil due to the breaking of double bonds which is referred to fatty acid

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Table 4 Physico-chemical properties of red radish seeds oil obtained from plants produced from un-irradiated and irradiated seeds

Parameter	Irradiation dose level (Gy)				
	Control	10	20	40	80
Peroxide value (meq/kg oil)	5.73 ± 0.05^{b}	5.70 ± 0.01^{b}	5.74 ± 0.04^{b}	5.75 ± 0.04^{b}	5.81 ± 0.02^{a}
Iodine value (g/100g oil)	65.03 ± 0.14^{a}	64.93 ± 0.15^{a}	63.64 ± 0.12^{b}	61.18 ± 0.06^{c}	59.99 ± 0.18^{d}
Saponification value (mg/g oil)	159.4 ± 0.95^{e}	163.8 ± 1.23^{d}	166.4 ± 1.15^{c}	170.0 ± 1.24^{b}	172.3 ± 0.71^{a}
Acid value (mg/g oil)	3.78 ± 0.01^{c}	3.84 ± 0.06^{c}	3.86 ± 0.05^{c}	3.97 ± 0.03^{b}	4.08 ± 0.09^{a}
Ester value (mg/g oil)	155.6 ± 0.67^{e}	160.0 ± 0.96^{d}	162.6 ± 0.78^{c}	166.0 ± 0.93^{b}	168.2 ± 1.01^{a}

Results are presented as means ± SD ($n = 3$), and averages with various letters inside the same row are significantly differed ($p \leq 0.05$)

Table 5 Tochopherols (mg/kg oil) of red radish seeds oil obtained from plants produced from un-irradiated and irradiated seeds

Tocopherol (mg/kg oil)	Irradiation dose (Gy)				
	Control	10	20	40	80
αTochopherol	21.62 ± 1.95^{a}	21.75 ± 1.02^{a}	21.92 ± 1.00^{a}	22.12 ± 1.02^{a}	22.24 ± 0.92^{a}
β-Tochopherol	ND	ND	ND	ND	ND
γ-Tochopherol	513.38 ± 1.03^{d}	515.31 ± 0.61^{cd}	516.84 ± 0.99^{bc}	517.63 ± 1.28^{ab}	519.88 ± 1.39^{a}
δ-Tochopherol	17.31 ± 0.59^{c}	18.22 ± 0.88^{bc}	19.06 ± 0.90^{b}	20.84 ± 0.94^{a}	21.94 ± 0.53^{a}

Findings are presented as means ± SD ($n = 3$), and means with various letters in the same row are significantly differed ($p \leq 0.05$)
ND not detected

oxidative degradation. The findings obtained by Aly et al. (2016) on moringa had a similar tendency decline in iodine values.

The amount of KOH needed to saponify one gram of fat is known as the saponification value, higher values of saponification indicate that more alkali would be needed to influence the neutralization of the free fatty acids released from the oil, through this process neutral fat is broken down into glycerol and fatty acid due to treatment with alkali. As provided in Table 4, gamma-rays significantly impacted the saponification value of the seed oil samples. After the exposure to gamma-rays, the saponification number of the oil recovered from control sample (159.4 mg KOH/g oil) was lower than those recovered from gamma-irradiated samples (163.8, 166.4, 170.0 and 172.3 mg KOH/g oil that had received γ-radiation dose levels; 10, 20, 40, and 80 Gy, respectively). The saponification values of oil samples enhanced by increasing the irradiation dose; indicating that the large original molecules of long chain fatty acids in the oil broken down into smaller molecules due to the bond breaking and oxidation (Agatemor 2006). The recent findings are consistent with the results of previously investigations (Yaqoob et al. 2010; Bhatti et al. 2013; Aly et al. 2016). Acid value is an indicator of oil's edibility and suitability for industrialized applications as well as the total acidity which due to sample fatty acids. The control had an acid value of 3.78 mg KOH/g oil, while it was 4.08 mg KOH/g oil for oil recovered from irradiated seeds with dose level 80 Gy; this might be attributed to the conversion of triacylglycerol molecules into free fatty acids and diacylglycerols (Bhatti et al. 2013; Aly et al. 2016).

The acid value of red radish oil has 3.78–4.08 mg KOH/g oil, this is falls under the recommended codex of 10 mg KOH/g for edibles oil. Current findings are established with a previous study by Abd El-Aziz and Abd El-Khalek (2011) who found that free fatty acids of pumpkin seeds and pumpkin oils elevated by the influence of irradiation dose level. The same trend occurred in the ester value, where gamma-rays increased the ester value, especially the 80 Gy dose which has the highest value (168.2 mg/g oil).

Tocopherols Content of Seeds Oil

Tocopherols identified in seeds' oil of red radish were shown in Table 5, the findings revealed that the γ and δ-tocopherols content were enhanced by gamma-rays and the best concentrations of them were found at a dose of 80 Gy (519.88 and 21.94 mg/kg oil, respectively) followed by 40 Gy (517.63 and 20.84 mg/kg oil, respectively) compared with the control (513.38 and 17.31 mg/kg oil, respectively). There was an observed increase in the content of α-tocopherol, but it was not significant. These findings are in harmony with Hanafy and Akladious (2018) who demonstrated that lower doses of gamma irradiation (25, 50, 100 and 200 Gy) caused a continuing development in α-tocopherol, particularly at 100 Gy in fenugreek leaves while the seeds which were exposed to the highest dose of 400 Gy which demonstrated a significant decline in α-tocopherol. On the other hand, Aly and Mohamed (2005) reported that α-tocopherol was affected by gamma irradiation and decreased by increasing irradiation dose level from 50–150 Gy in *Zea mayes* callus tissue. Gamma tocopherol is the most prevalent type of which exhibits antioxidant characteristics

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

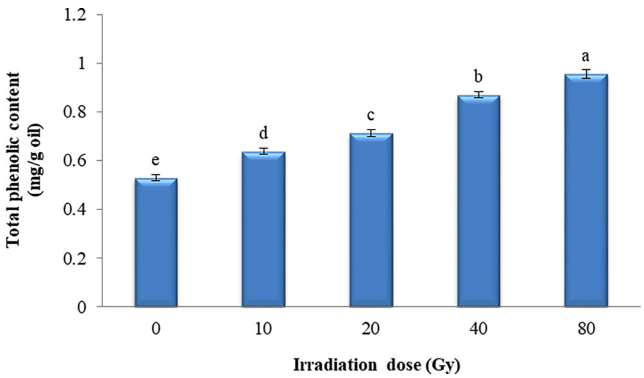

Fig. 2 Total phenolic content (mg/g oil) of red radish seeds taken from plants produced from un-irradiated and irradiated seeds. *Vertical bars* ± SD ($n=3$) and *varying letters on the bars* in every sample are significantly differed at ($p \le 0.05$)

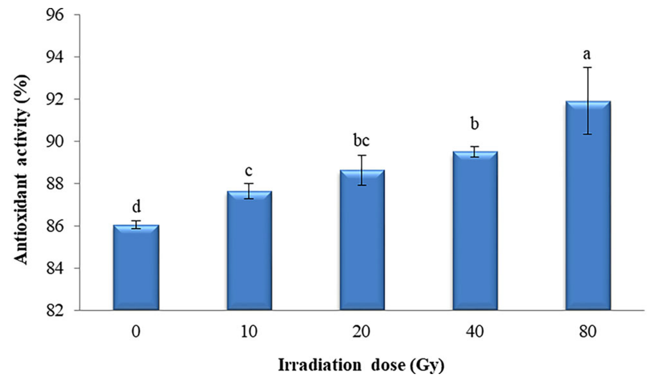

Fig. 3 Antioxidant activity (%) of red radish seeds obtained from plants produced from un-irradiated and irradiated seeds. *Vertical bars* ± SD ($n=3$) and *differed letters on the bars* of every treatment are significantly varied at ($p \le 0.05$)

and contributes for protection the body's cells membrane through scavenging the free radicals (Matthäus et al. 2021). Tocopherols are essential antioxidants in oils and the oxidative stability of the oils based on these compounds (Uluata and Özdemir 2012). In the food industry, antioxidants are utilized as lipid stabilizers (Schmidt and Pokorny 2005). Furthermore, antioxidant has essential impact on oxidation that accelerates aging and promotes cancer (Ramadan and Moersel 2006). In recent years, natural antioxidants have been preferable over synthetic sources owing to benefits. Consequently, cold-pressed seeds oil might be utilized as food additive to improve the food qualities and stabilities. Additionally, α-tocopherol could improve some quality criteria, for instance, it has been used to inhibit the formation of phytosterol oxidation products at high temperatures in oils (Matthäus et al. 2021). The tocopherols content of seeds oil varies depending on the plants type.

Total Phenolic Content and Antioxidant Activity of Red Radish Oil

Impacts of gamma-rays on the phenolic content of oil recovered from red radish seed are found in Fig. 2. The findings shown that the gamma-rays caused a significant increase in the phenols content of the oil samples compared to the un-irradiated sample. The samples exposed to 40 Gy had the greatest phenols concentration (0.955 mg/g oil) comparison with un-irradiated sample (0.529 mg/g oil). The current data are in harmony with the findings of Antognoni et al. (2007) on *Passiflora*, http://repository.sustech.edu/handle/123456789/12335. Aly et al. (2019) on eggplant fruits, Aly et al. (2018) on wheat and Aly (2010) on culantro plantlets. The increasing of the phenols content has been correlated to the PAL activities (EL-Samahy et al. 2000). There is an affirmative association noticed among the phenols contents and phenylalanine ammonia lyase activity, indicating that the enhancement in total phenol is linked by enhancing the PAL activity (El-Beltagi et al. 2013, 2011).

This increasing in the phenolic content is owing to the breakdown of the large phenolic compounds to small phenols as well as the releasing of the phenolic molecules from glycosidic components as a result of gamma irradiation treatment. Differences in gamma-rays impacts on phenolic concentrations (increasing or decreasing) might be attributed to the plants type, environmental and geographical conditions, the sample kind (dry or fresh), the extraction solvent, extraction method, temperature, irradiation doses etc. (Khattak and Simpson 2010). In the same concern, Aly et al. (2016) reported that gamma rays increased total phenolic content in moringa oil.

The results presented in Fig. 3 indicated the scavenging activity against DPPH radicals of the oils recovered from irradiated radish seeds enhanced as the irradiation dose levels increased till reached the highest activity percentage (91.92%) at 40 Gy. Meanwhile, the un-irradiated sample had the lowest scavenging activity percentage (86.05%). Current data are in line with the findings of El-Beltagi et al. (2022) on red radish roots and Aly et al. (2022) on blackberry, who established that the increase in irradiation doses resulted in an increase of the DPPH radical scavenging activity. Oxidation and γ-irradiation procedures can break polyphenol chemicals bond, releasing phenols which are soluble and have low-molecular-weights resulting in increasing of antioxidant-rich phenols (Adamo et al. 2004). Such observed findings indicated a relationship between total phenols contents and the scavenging activity.

Conclusion

The findings of the current investigation confirmed that gamma-rays improved the quality of red radish oil in terms

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

of physico-chemical properties and bioactive ingredients present in it. The outcome of the recent study indicated that all traits of seed yield were highly significant for all irradiation treatments except for 100-seed weight, which was not affected by irradiation treatments. The proximate composition and minerals content of seeds were also affected positively by the irradiation treatments. As for the oil, the results demonstrated an increase in the yield of oil and SFAs, while PUFAs decreased with irradiation. Concerning the physico-chemical properties of the oil samples, it was observed that irradiation decreased the iodine value, while the acid, saponification and ester values were increased in all treatments. On the contrary, the peroxide value was not affected by irradiation. Regarding the bioactive compounds, tocopherols and phenolic content increased by irradiation and the dose of 40 Gy gave them the best values. This study provides significant information for enhancing consuming of radish seed oils as nutraceuticals or functional food ingredients and the use of unconventional oils such as radish oil as substitute or additive for conventionally used vegetables oil.

Acknowledgements The authors grateful to express their gratitude to the Egyptian Atomic Energy authority as well as October University for Modern Science and Arts (MSA), Faculty of Biotechnology for helping and supporting to conduct the recent research.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB).

Conflict of interest A.A. Aly, R.W. Maraei, R.G. Sharafeldin and G. Safwat declare that they have no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Abd El-Aziz AB, Abd El-Khalek HH (2011) Antimicrobial proteins and oil seeds from pumpkin (*Cucurbita moschata*). Nat Sci 9:105–119

Adamo M, Capitani D, Mannina L, Cristinzio M, Ragni P, Tata A, Coppola R (2004) Truffles decontamination treatment by ionizing radiation. Radiat Phys Chem 71(1–2):167–170. https://doi.org/10.1016/j.radphyschem.2004.03.073

Agatemor C (2006) Studies of selected physicochemical properties of fluted pumpkin (*Telfairia occidetalisn* Hook F) seed oil and tropical almond (*Terminalia catappia* L.) seed oil. Pak J Nutr 5(4):306–307. https://doi.org/10.3923/pjn.2006.306.307

Al-Bachir M (2017) Fatty acid contents of gamma irradiated sesame (*Sesamum indicum* L.) peanut (*Arachis hypogaea* L.) and sunflower (*Helianthus annuus* L.) seeds. J Food Chem Nanotechnol 3(1):31–37. https://doi.org/10.17756/jfcn.2017-034

Aly AA (2010) Biosynthesis of phenolic compounds and water soluble vitamins in culantro (*Eryngium foetidum* L.) plantlets as affected by low doses of gamma irradiation. Nalele Univ Oradea Fasc Biol 2(17):356–361

Aly AA, Mohamed AA (2005) Natural antioxidants in maize callus tissue as enhanced by gamma irradiation. Egypt J Radiat Sci Appl 18:221–236

Aly AA, Maraei RW, Ali HGM (2016) Fatty acids profile and chemical composition of Egyptian *Moringa oleifera* seed oils. J Am Oil Chem Soc 93:397–404. https://doi.org/10.1007/s11746-015-2781-6

Aly AA, Maraei RW, Ayadi S (2018) Some biochemical changes in two Egyptian bread wheat cultivars in response to gamma irradiation and salt stress. Bulg J Agric Sci 24(1):50–59

Aly AA, Eliwa NE, AbdEl-Megid MH (2019) Stimulating effect of gamma radiation on some active compounds in eggplant fruits. Egypt J Rad Sci Applic 32(1):61–73. https://doi.org/10.21608/ejrsa.2019.10024.1066

Aly AA, Eliwa NE, Borik ZM, Safwat G (2021) Physiological variation of irradiated red radish plants and their phylogenic relationship using SCoT and CDDP markers. Not Bot Horti Agrobot Cluj Napocaj 49:12396

Aly AA, El-Desouky W, Abou El-Leel OF (2022) Micropropagation, phytochemical content and antioxidant activity of gamma irradiated blackberry (*Rubus fruticosus* L.) plantlets. In Vitro Cell Dev Biol, Plant 58:457–469. https://doi.org/10.1007/s11627-021-10244-7

Aly AA, Eliwa NE, Ahmed T, Borik ZM (2023) Physiological and biochemical markers of gamma irradiated white radish (*Raphanus sativus*) https://doi.org/10.1080/09553002.2023.2176561

Antognoni F, Zheng S, Pagnucco C, Baraldi R, Poli F, Biondi S (2007) Induction of flavonoid production by UV-B radiation in *Passiflora quadrangularis* callus cultures. Fitoterapia 78(5):345–352. https://doi.org/10.1016/j.fitote.2007.02.001

AOAC (1990) Official methods of analysis, of the association of the official chemistry, 15th edn.

AOAC (2000) Official methods of analysis of the association of official analytical chemist, 14th edn. AOAC, Washington DC

AOAC (2005) Official methods of analysis, 18th edn. Association of Official Analytical Chemists. Chemists' Society Press, Washington, DC

Barreira JCM, Antonio AL, Gunaydi T, Alkan H, Bento A, Botelho ML, Ferreira ICFR (2012) Chemometric characterization of gamma irradiated chestnuts from Turkey. Radiat Phys Chem 81(9):1520–1524. https://doi.org/10.1016/j.radphyschem.2012.01.005

Bhat R, Sridhar KR, Karim AA, Young CC, Arun AB (2009) Influence of γ-radiation on the nutritional and functional qualities of lotus seed flour. J Agric Food Chem 57(20):9524–9531. https://doi.org/10.1021/jf902287e

Bhatti IA, Iqbal M, Anwar F, Shahid SA, Shahid M (2013) Quality characteristics and microbiological safety evaluation of oils extracted from gamma irradiated almond (*Prunus dulcis* Mill.) seeds. Grasas Aceites 64(1):68–76. https://doi.org/10.3989/gya.071512

Blazevic' I, Mastelic' J (2009) Glucosinolate degradation products and other bound and free volatiles in the leaves and roots of radish (*Raphanus sativus* L.). Food Chem 113(1):96–102. https://doi.org/10.1016/j.foodchem.2008.07.029

Chopra SL, Kanwar JS (1991) Analytical agricultural chemistry, 4th edn. Kalyami, New Delhi, pp 12–15

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Domingos AK, Saad EB, Wilhelm HM, Ramos LP (2008) Optimization of the ethanolysis of Raphanus sativus (L. Var.) crude oil applying the response surface methodology. Bioresour Technol 99:1837–1845. https://doi.org/10.1016/j.biortech.2007.03.063

Dugo G, La Pera L, Torre GLL, Giuffrida D (2004) Determination of Cd (II), Cu (II), Pb (II), and Zn (II) content in commercial vegetable oils using derivative potentiometric stripping analysis. Food Chem 87(4):639–645. https://doi.org/10.1016/j.foodchem.2003.12.035

Duncan DB (1955) Multiple range and multiple 'F' tests. Biometrics 11(1):1–42. https://doi.org/10.2307/3001478

Dwiecki K, Górnaś P, Jackowiak H, Nogala-Kałucka M, Polewski K (2007) The effect of D-alpha-tocopherol on the solubilisation of dipalmitoylphosphatidylcholine membrane by anionic detergent sodium dodecyl sulphate. J Food Lipid 14(1):50–61. https://doi.org/10.1111/j.1745-4522.2006.00070.x

El-Beltagi HS, Ahmed OK, El-Desouky W (2011) Efect of low doses γ-irradiation on oxidative stress and secondary metabolites production of rosemary (*Rosmarinus ofcinalis* L.) callus culture. Radiat Phys Chem 80:968–976. https://doi.org/10.1016/j.radphyschem.2011.05.002

El-Beltagi HS, Mohamed HI, Mohammed AMA, Zaki LM, Mogazy AM (2013) Physiological and biochemical effects of γ-irradiation on cowpea plants (*Vigna synesis*) under salt stress. Not Bot Horti Agrobo Cluj Napoca 41(1):104–114

El-Beltagi HS, Maraei RW, Shalaby TA, Aly AA (2022) Metabolites, nutritional quality and antioxidant activity of red radish roots affected by gamma rays. Agronomy 12:1916. https://doi.org/10.3390/agronomy12081916

EL-Samahy SK, Youssef BM, Askar AA, Swailam HMM (2000) Microbiological and chemical properties of irradiated mango. J Food Saf 20(3):139–156. https://doi.org/10.1111/j.1745-4565.2000.tb00294.x

Elamin SEE (2015) Extraction and physicochemical study of Raphanus sativus seeds oil. Biology, Corpus ID: 67792279. http://repository.sustech.edu/handle/123456789/12335 Accessdate: 19.11.2015

Fokou E, Achu MB, Kansci G, Ponka R, Fotso M, Tchiegang C, Tchouanguep FM (2009) Chemical properties of some cucurbitaceae oils from Cameroon. Pak J Nutr 8(9):1325–1334. https://doi.org/10.3923/pjn.2009.1325.1334

Gamba M, Asllanaj E, Raguindin PF, Glisic M, Franco OH, Minder B, Busslerf W, Metzgerf B, Kern H, Muka T (2021) Nutritional and phytochemical characterization of radish (*Raphanus sativus*): a systematic review. Food Sci Technol 113(11):205–218. https://doi.org/10.1016/j.tifs.2021.04.045

Gulluce M, Sokmen M, Sahin F, Sokmen A, Adiguzel A, Ozer H (2004) Biological activities of the essential oil and methanolic extract of *Micromeria fruticosa* (L) Druce ssp serpyllifolia (Bieb) PH davis plants from the Eastern Anatolia region of Turkey. J Sci Food Agric 84(7):735–741. https://doi.org/10.1002/jsfa.1728

Gutiérrez PRM, Perez RL (2004) *Raphanus sativus* (Radish): their chemistry and biology. Sci World J 4:811–837. https://doi.org/10.1100/tsw.2004.131

Hanafy RS, Akladious SA (2018) Physiological and molecular studies on the effect of gamma radiation in fenugreek (*Trigonella foenum*—graecum L.) plants. J Genet Eng Biotechnol 16(2): 683–692. https://doi.org/10.1016/j.jgeb.2018.02.012

Hou DY, Hui RH, Li TC, Liu XY (2011) Determination of fatty acids and octadecatrienoic acid in radish seed. J Chin Mass Spectrom Soc 32:108–111

Imran M, Khan H, Hassan SS, Khan R (2008) Physicochemical characteristics of various milk samples available in Pakistan. J Zhejiang Univ Sci B 9(7):546–551. https://doi.org/10.1631/jzus.B0820052

IUPAC (1987) Standard methods for the analysis of oils, fats and derivatives: international union of pure and applied chemistry (IUPAC) method 2.301. Report of IUPAC Working Group WG 2/87. Blackwell, Palo Alto, pp 568–574

Jaafar NA, Ahmed AS, Al-Sandooq DL (2020) Detection of active compounds in Radish (*Raphanus sativus* L.) and their various biological effects. Plant Arch 20(2):1647–1650

Jan S, Parween T, Siddiqi TO, Uzzafar M (2012) Effect of gamma radiation on morphological, biochemical and physiological aspects of plants and plant products. Environ Rev 20:17–39. https://doi.org/10.1139/a11-021

Kamalu CIO, Oghome P (2008) Extraction and characterization of tiger nut oil. J Chem Soc Niger 33:79–87

Kaymak HC (2015) Profile of (n-9) and (n-7) isomers of monounsaturated fatty acids of radish (*Raphanus sativus* L.) seeds. J Am Oil Chem Soc 92:345–351. https://doi.org/10.1007/s11746-015-2600-0

Kebeish R, Deef HE, El-Bialy N (2015) Effect of gamma radiation on growth, oxidative stress, antioxidant system, and alliin producing gene transcripts in *Allium sativum*. Int J Res Stud Biosci 3(3):161–174

Khan QU, Mohammadzai I, Shah Z, Ihsanullah, Khattak TN, Noreen H, Hassan W (2018) Effect of gamma irradiation on nutrients and shelf life of peach (*Prunus persica*) stored at ambient temperature. Open Conf Proc J 9:8–15. https://doi.org/10.2174/2210289201809010008

Khattak KF, Simpson TJ (2010) Effect of gamma irradiation on the antimicrobial and free radical scavenging activities of *Glycyrrhiza glabra* root. Radiat Phys Chem 79(4):507–512. https://doi.org/10.1016/j.radphyschem.2009.10.005

Kovacs E, Keresztes A (2002) Effect of gamma and UV-B/C radiation on plant cells. Micron 33(2):199–210. https://doi.org/10.1016/S0968-4328(01)00012-9

Manivannan A, Kim J-H, Kim D-S, Lee E-S, Lee H-E (2019) Deciphering the nutraceutical potential of *Raphanus sativus*—a comprehensive overview. Nutrients 11(2):402. https://doi.org/10.3390/nu11020402

Maraei RW, Hammoud GM (2019) Study the effect of gamma rays on chemical components, antimicrobial activity and the nutritional value of date seeds. Analele Univ Din Oradea Fasc Biol 26(2):79–85

Matthäus B, Babiker EE, Özcan MM, Al-Juhaimi FY, Ahmed IAM, Ghafoor K (2021) Changes in fatty acid, tocopherol and sterol contents of oils extracted from several vegetable seeds. J Oleo Sci 70(11):1607–1614. https://doi.org/10.5650/jos.ess21225

Mohajer S, Taha RM, Lay MM, Esmaeili AK, Khalili M (2014) Stimulatory effects of gamma irradiation on phytochemical properties, mitotic behaviour, and nutritional composition of Sainfoin (*Onobrychis viciifolia* Scop.). Sci World J. https://doi.org/10.13140/2.1.3294.7840

Motsara MR, Roy RN (2008) Guide to laboratory establishment for plant nutrient analysis. FAO Fertilizer and Plant Nutrition Bulletin. Food and Agricultural Organisation of the United Nations, Rome, p 219

Muller H, Tobin G (1980) Nutrition and food processing. Croom Helm, applied biology series, 5th edition. Anybook Ltd., Lincoin, UK

Nail TNA (2016) Chemical and physical properties of seed oil from some Cruciferea plants growing in the Sudan. MSc thesis in chemistry IUA.

Ogungbenle HN, Afolayan MF (2015) Physical and chemical characterization of roasted cashew nut (*Anacardium occidentale*) flour and oil. Int J Food Sci Nutr Eng 5(1):1–7. https://doi.org/10.5923/j.food.20150501.01

Prakash A, Chen PC, Pilling RL, Johnson N, Foley D (2007) 1% calcium chloride treatment in combination with gamma irradiation improves microbial and physicochemical properties of diced tomatoes. Foodborne Pathog Dis 4(1):89–98. https://doi.org/10.1089/fpd.2006.0069

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Qian B, Pan Y, Cai Z, Jing P (2017) Phytochemical composition, antioxidant capacity and ACE-inhibitory activity of China-grown radish seeds. J Appl Bot Food Qual 90:315–322. https://doi.org/10.5073/JABFQ.2017.090.039

Ramadan MF, Moersel JT (2006) Screening of the antiradical action of vegetable oils. J Food Comp Anal 19(8):838–842. https://doi.org/10.1016/j.jfca.2006.02.013

Sanni TA, Ogundele JO, Ogunbusola EM, Oladimeji O (2015) Effect of gamma irradiation on mineral, vitamins and cooking properties of sorrel (*Hibiscus sabdariffa* Ll) seeds. 2nd International Conference on Chemical, Biological, and Environmental Sciences (ICCBES'15), Dubai, May 20–21. https://doi.org/10.17758/IAAST.A0515044

Schmidt S, Pokorny J (2005) Potential application of oilseeds as source of antioxidants for food lipids—a review. Czech J Food Sci 23:93–102

Shahidi F, Naczk M (1995) Methods of analysis and quantification of phenolic compounds. In: Shahidi F, Naczk M (eds) Food phenolic: sources, chemistry, effects and applications. Technomic, Lancaster, pp 287–293

Silvestre WP, Pauletti GF, Godinho M, Baldasso C (2017) Fodder radish seed cake pyrolysis for bio-oil production in a rotary kiln reactor. Chem Eng Proc Process Intensification 124:235–244. https://doi.org/10.1016/j.cep.2017.12.020

Singh B, Datta PS (2010) Gamma irradiation to improve plant vigor, grain development, and yield attributes of wheat. Rad Phys Chem 79(2):139–143. https://doi.org/10.1016/j.radphyschem.2009.05.025

Singh B, Ahuja S, Singhal RK, Babu PV (2012) Effect of gamma radiation on wheat plant growth due to impact on gas exchange characteristics and mineral nutrient uptake and utilization. J Rad Nucl Chem. https://doi.org/10.1007/s10967-012-2342-5

Thomas A (2002) Fats and fatty oils. In: Ullmann's encyclopedia of industrial chemistry. Wiley, Weinheim https://doi.org/10.1002/14356007.a10_173

Uluata S, Özdemir N (2012) Antioxidant activities and oxidative stabilities of some unconventional oilseeds. J Am Oil Chem Soc 89:551–559. https://doi.org/10.1007/s11746-011-1955-0

Yaqoob N, Bhatti IA, Anwar F, Asi MR (2010) Oil quality characteristics of irradiated sunflower and maiz seed. Eur J Lipid Sci Technol 112:488–495. https://doi.org/10.1002/ejlt.200900148

Content courtesy of Springer Nature, terms of use apply. Rights reserved.

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH ("Springer Nature").

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users ("Users"), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use ("Terms"). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com