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Research Article

EFFECT OF GAMMA RADIATION ON STORAGE OF PEANUT SEEDS

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Abstract: Peanut are semi-perishable and are subject to quality losses during storage through insect and rodent infestation, fungal development, flavour changes, rancidity, . Gamma (γ) radiation is recognized as a techno-commercially feasible method for reducing postharvest food losses, ensuring the hygienic quality and preservation of food, extending its shelf life and facilitating wider trade. Therefore, present study was planned with the broad aim of study the effect of gamma irradiation dose (2.5, 5.0, 7.5 and 10.0 kGy) and storage (in sealed in 40μ pp bags) period upto 6 months on peanut (GG-20) seed and its oil quality. Physico-chemical and sensory attributes of the selected oilseeds were evaluated before and after irradiation and during storage. Samples were periodically evaluated at every 15 days interval for physico-chemical analysis of peanut seeds and their oils quality. Effect of gamma irradiation doses was significant ($p<0.05$) on a) moisture and oil content of the oilseeds, b) acid, iodine and peroxide values of the extracted oils. While effect was non-significant ($p>0.05$) on a) protein and ash content, b) sensory attributes of oilseed, and c) physical attributes of oils such as refractive index and colour value.

Keywords: *Gamma radiation, Gamma irradiation, Peanut, Oilseed, Groundnut, Ionizing radiation, Storage*

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Introduction

Arachis hypogaea L., commonly known as groundnut or peanut, serves as a valuable source of edible oil, comprising lipids, proteins, and vitamins. Nuts play a pivotal role in a well-rounded dietary regimen due to their elevated nutritional content. They are rich in mono- and polyunsaturated fatty acids, vitamin E, and fiber [1]. Peanut oil contents in 17 cultivars ranged from 45.7% to 51.8% [2]. It is a pale yellow, non-drying oil containing large quantities of arachidonic, oleic, linoleic, palmitic, and stearic acids. There are also small concentrations of behenic and lignoceric acids, about 1.5% each [3]. The groundnut production in India was 7.18 million metric tonnes in 2015-16. Nine states exhibited groundnut production exceeding 100,000 metric tonnes, namely Gujarat, Rajasthan, Tamil Nadu, Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, West Bengal, and Telangana. The groundnut production in Gujarat was 2.89 million metric tonnes in 2015-16. Out of 56 varieties, the GG-20 variety was the most widely cultivated in Gujarat [4]. Gamma irradiation is recognized as a technically feasible method for reducing postharvest food losses, ensuring the hygienic quality of food, preserving food, extending its shelf life, and facilitating wider food trade [5-7]. Irradiation treatments have been used to reduce the microbiological load. However, a major challenge in the application of high-energy radiation to food is the development of unpleasant flavors. Ionizing radiation, especially, affects the quality of oilseed by increasing its oxidation rate. Ionizing radiation may also produce active species like free radicals, which initiate certain chemical reactions, resulting in the rancidity of the oils [8,9]. The irradiation of lipids at high doses in the presence of oxygen can lead to the formation of lipid hydroperoxides [10]. Therefore, the present study was planned with the broad aim of studying the effect of gamma irradiation dose (2.5, 5.0, 7.5, and 10.0 kGy) and storage (in sealed 40μm polypropylene bags) for up to 6 months on peanut (GG-20) seed and its oil quality.

Materials and Methods

GG-20, one of the available peanut varieties (including GG-2 and GG-23), is commonly grown in Gujarat due to its large kernel size and high oil content. Peanut variety GG-20 was obtained in bulk from Sameer traders in Anand and was cleaned. Since the initial moisture content of the peanuts was high, approximately 13% (w.b.), the peanut samples were dried before packaging to reach a safe storage moisture level of around 6%. This drying process was carried out at 52±2°C using a laboratory tray dryer. Samples of approximately 1 kg each were then packed in 40-micron virgin polypropylene (PP) bags for gamma irradiation. Gamma radiation treatments (using Co-60) were conducted in the Gamma Chamber 5000 unit at the College of Food Processing Technology and Bio-energy, Anand Agriculture University, Anand. The procedures for proximate analysis, including moisture, protein, ash, crude fiber, and fat contents, followed the guidelines outlined by the Association of Official Analytical Chemists [11]. Sensory evaluation (acceptability test) was conducted with the participation of 18 untrained panel members. The quality of extracted oil from both gamma irradiated and non-irradiated samples was evaluated based on parameters such as Acid Value, Peroxide Value, Iodine Value, Refractive Index, Color Value, and Fatty Acid Compositions. Both gamma irradiated and non-irradiated peanuts were packed in 40-micron PP bags and stored at ambient temperature. Control and irradiated samples were stored at ambient temperature for six months, with samples analyzed at 15-day intervals for chemical analysis. A complete randomized design (full factorial) was adopted as the experimental design.

Results and discussion

Microbial quality parameters of peanut

Total plate count was found to be 2.51 log (cfu/g) in peanut. The yeast and mold count was less than 1.0 log (spores/g) in these samples. Al-Bachir (2016a)[12] reported that the peanut samples contained low population of total bacterial and fungal counts of 2.68 log (cfu/g) and 3.19 log (spores/g), respectively. A total aflatoxin level of 2 ppb was detected in the peanut sample, which is below the US-FDA specified minimum action level of 30 ppb [13]. *Aspergillus flavus* and *Aspergillus parasiticus* are reported sources of aflatoxins (B1, B2, G1, G2) in seeds [14].

Proximate composition of peanut

The data are presented in [Table-1]. The moisture content in the peanut samples ranged from 5.2% to 6.1% (w.b.). Agropedia (2010) has reported a maximum safe moisture level of 7.0% (w.b.) for peanuts. The protein content in peanuts varied from 25.1% to 28.15%. Oil content ranged from 49.48% to 51.6%. Ash content showed variations between 1.99% and 2.12%. Crude fiber content in peanuts ranged from 4.98% to 5.76%. These composition values for peanuts are somewhat consistent with data reported by Al-Bachir (2016a)[15], De Camargo *et al.* (2012)[16], Bhatti *et al.* (2010)[17], Azim *et al.* (2009)[18], and Grosso *et al.* (2000)[19] for peanuts.

Table-1 Proximate composition of peanut

SN	Proximate parameters	Peanut (GG-20)
1	Moisture content (% w.b.)	5.27 ± 0.01
2	Protein content (%)	27.25 ± 0.97
3	Oil content (%)	50.10 ± 0.22
4	Ash content (%)	2.07 ± 0.06
5	Crude fiber content (%)	5.45 ± 0.02
6	Carbohydrate content (%)	9.86 ± 0.05

Physico-chemical parameters of peanut oil

The data on the physico-chemical characteristics of peanut oil are presented in [Table-2]. The acid value (or neutralization number or acid number or acidity) of peanut oil ranged from 1.20 to 1.35 mg/g of oil. This acid value is well below the maximum specified level of 6 mg/g of oil for edible oils [20]. The peroxide value ranged from 0.124 to 0.172 meq/kg of oil for peanuts. These peroxide values are significantly lower than the accepted threshold of 10 meq/kg for edible oils, indicating a lower degree of primary oxidation in the oil and a reduced risk of oxidative rancidity. The iodine value (or iodine adsorption value or iodine number or iodine index) ranged from 111.45 to 114.25 g/100 g of oil for peanuts (the typical range for peanut oil is 85-99 g/100 g, as per FSS 2011 standards). The refractive index was measured at 1.46975, which falls within the range of 1.4620-1.4640 for peanut oil, according to FSS 2011 standards.

Table-2 Physico-chemical parameters of peanut oil

SN	Proximate parameters	Peanut (GG-20)
1	Acid value (mg/g oil)	1.40 ± 0.02
2	Peroxide value (meq./kg oil)	0.148 ± 0.024
3	Iodine value (g/100g oil)	112.85 ± 1.40
4	Refractive index	1.46975
5	Colour value	L* = 8.64
		a*= -1.34
		b* = 5.23

Effect of gamma radiation on sensory parameters of peanut

Irradiated and control samples were evaluated for sensory attributes such as color, texture, taste, odour and overall acceptability and results are presented in [Table-3]. The gamma radiation at the levels of 5 % has non-significant effect on all samples. All irradiated samples were similar to the judges. Al-Bachir (2015a, 2015b, 2016a and 2016b) [21,22] reported non-significant effect of gamma radiation treatment on flavor, color, taste and texture of pistachio nut, almond, peanut and sesame.

Effect of gamma radiation on proximate composition of peanut

The results, presented in [Table-4], reveal the average moisture content at radiation doses of 0.0, 2.5, 5.0, 7.5, and 10.0 kGy for peanuts, which were observed to be 5.70%, 5.63%, 5.57%, 5.50%, and 5.36% (w.b.), respectively. Gamma radiation was found to have a significant ($p < 0.05$) effect on the moisture content of the samples. With an increase in gamma radiation dose from 0 to 10.0 kGy, there was a decrease in the moisture content of peanut oilseeds. This decrease can be attributed to the fact that the samples remained in the radiation chamber at approximately 47±2 °C for the desired radiation dose, corresponding to an exposure time ranging from 0 seconds to 1 hour 15 minutes and 30 seconds. The average solvent-extractable oil content at radiation doses of 0.0, 2.5, 5.0, 7.5, and 10.0 kGy was observed to be 51.11%, 50.67%, 49.96%, 49.76%, and 49.65% for peanuts, respectively. The effect of gamma radiation dose was significant ($p < 0.05$) on the oil content of the peanut samples. As the gamma radiation dose increased, the oil content in the seeds decreased. This reduction in oil content may be attributed to cleavages in some triglyceride molecules, resulting in decreased oil extractability. This finding is consistent with previous observations reported by Bishnoia and Chandrab (2014) [23], Fapohunda *et al.* (2012), and Al-Bachir (2016a, 2016b) for peanuts. The protein content in peanuts ranged from 27.49% to 28.19% after exposure to radiation doses ranging from 0.0 to 10.0 kGy. The effect of radiation doses on protein content in peanut seeds was observed to be non-significant ($p > 0.05$). Similarly, the effect of gamma radiation doses was non-significant on the ash content of peanut seeds, which ranged from 1.53% to 2.06%. This aligns with findings reported by Sanchez-Bel *et al.* (2008) for almonds, Al-Bachir (2004) [24] for walnuts, Al-Bachir (2015a, 2015b) for pistachios and almonds, Bhatti *et al.* (2010) for peanuts, Mahrous (2007) [25] for soybeans, and Seda *et al.* (2001) for groundnuts, all of whom reported that gamma radiation had no significant effect on protein content, ash content, and fiber content.

Effect of gamma radiation on physico-chemical characteristics of peanut oil

The physico-chemical characteristics of peanut oil are presented in [Table-5]. With an increase in gamma radiation dose from 0 to 10 kGy, the acid value of peanut oil increased from 1.53 to 2.06 mg/g, as shown in [Table-6]. Gamma radiation treatment had a significant effect on the acid values of the oil seeds at a 5% level. This increase can be attributed to the hydrolysis of triglycerol molecules into free fatty acids and diacylglycerols, as indicated by studies conducted by Anjum *et al.,* (2006) [26], Al-Bachir (2004), and Boonchoo *et al.,* (2005) [27]. Similar observations were made by Bhatti *et al.,* (2010) for peanuts, Al-Bachir (2016a, 2016b) for peanuts and sesame, Mahrous (2007) for soybeans, Al-Bachir (2015b) for almonds, Al-Bachir (2004) for walnuts, Lutfullah *et al.,* (2003) for soybeans and sunflowers, and Bishnoia and Chandrab (2014) for peanuts, all of whom reported an increase in acid value with an increase in gamma radiation doses.

Gamma radiation also resulted in a reduction ($p < 0.05$) in the iodine value of peanut oil, as shown in [Table-5]. This decrease can be attributed to the breakdown of some double bonds during induced oxidation processes in the fatty acids while undergoing gamma radiation treatment. Similar findings were reported by Afify *et al*., (2013) [29] for peanuts, Lutfullah *et al.,* (2003) for soybeans and sunflowers, Al-Bachir (2004) for walnuts, Bhatti *et al.,* (2010) for peanuts, Mahrous (2007) for soybeans, and Arici *et al.,* (2007) [30].

The peroxide values of peanut oil were significantly affected by gamma radiation doses. As the gamma radiation dose increased, the peroxide value of peanut oil (ranging from 0.162 to 0.413 meq/kg) also increased. These results align with those of Bhatti *et al.,* (2010) for peanuts, Mahrous (2007) for soybeans, Lutfullah *et al*., (2003) for soybeans and sunflowers. Similarly, Al-Bachir (2016a, 2016b) reported a significant increase ($p < 0.05$) in the acid and peroxide value of oil from seed samples irradiated with 6 kGy and 9 kGy. This increase can be attributed to the formation of peroxides in the oils as intermediates of oxidative reactions under gamma radiation, related to lipid oxidation, as noted by Uquiche *et al*., (2008) [31] and Harrison and Were, (2007) [32]. Several studies have shown that gamma rays interact with fat molecules, leading to oxidation, decarboxylation, dehydration, and polymerization reactions that result in lipid oxidation [WHO (1994), Giroux and Lacroix (1998) [33], Stewart (2001) [34]. However, gamma radiation treatment did not have a significant ($p > 0.05$) effect on the refractive index and color value of peanut oil. This finding is in line with the observations made by Bhatti *et al*., (2010), who reported no significant differences in the refractive index between the control and irradiated samples of peanut (golden and bari varieties).

Effect of gamma radiation on fatty acid profile of peanut oil

The fatty acid compositions of oil extracted from treated (2.5, 5.0, 7.5, and 10.0 kGy) and untreated (0.0 kGy) peanut samples were analyzed, and the data are summarized in [Table-6]. The oil from non-irradiated (0.0 kGy) peanut seeds contained Palmitic (C16:0), Stearic (C18:0), Oleic (C18:1), Linoleic (C18:2), Arachidic (C20:0), Behenic (C22:0), and Eurasic (C22:1) acids. Oleic (C18:1) and Linoleic (C18:2) acids accounted for 78.1% of the total fatty acids in the non-irradiated sample.

Table-3 Effect of gamma radiation doses on sensory parameters of peanut seeds

Gamma radiation doses	Sensory Parameters				
	Colour	Texture	Taste	Odour	Overall Acceptability
0.0 (Control)	7.28 ± 0.80	6.61 ± 0.89	7.03 ± 0.89	6.89 ± 0.66	7.11 ± 0.64
2.5	7.50 ± 0.96	7.06 ± 1.35	6.83 ± 1.26	7.28 ± 0.80	7.28 ± 0.80
5.0	6.94 ± 1.13	7.31 ± 0.96	7.44 ± 0.96	7.06 ± 0.91	7.28 ± 0.92
7.5	6.97 ± 1.30	7.28 ± 0.93	6.89 ± 1.29	7.06 ± 1.08	7.11 ± 1.20
10.0	6.89 ± 1.15	7.00 ± 0.94	6.78 ± 1.24	7.17 ± 0.90	6.97 ± 0.86
SEm	0.56	0.53	0.58	0.45	0.46
Test	NS	NS	NS	NS	NS
CV %	15.62	15.03	16.74	12.78	12.96

Table-4 Effect of gamma radiation doses on proximate composition of peanut

Gamma radiation doses (kGy)	Moisture content % w.b.	Protein content % w.b.	Oil content % w.b.	Ash Content % w.b.
0.0 (Control)	5.70 ± 0.02	27.78 ± 0.33	51.11 ± 0.13	1.53 ± 0.12
2.5	5.63 ± 0.06	27.81 ± 0.34	50.67 ± 0.21	1.84 ± 0.02
5.0	5.57 ± 0.03	27.49 ± 0.48	49.96 ± 0.24	1.94 ± 0.08
7.5	5.50 ± 0.02	27.74 ± 0.62	49.76 ± 0.21	2.00 ± 0.02
10.0	5.36 ± 0.13	28.19 ± 0.68	49.65 ± 0.19	2.06 ± 0.03
SEm	0.032	0.294	0.11	0.036
Test	*	NS	*	NS
CD 5%	0.102	--	0.311	--
CV %	1.17	1.83	0.40	3.54

Table-5 Effect of gamma radiation doses on the physicochemical properties of peanut oil

Gamma radiation doses (kGy)	Acid value (mg/g)	Iodine value (g/100g)	Peroxide value (meq./kg)	Refractive index	Colour value		
					L*	a*	b*
0.0 (Control)	1.53 ± 0.12	113.43 ± 1.11	0.162 ± 0.012	1.4680	8.64	-1.34	5.23
2.5	1.84 ± 0.02	113.00 ± 2.86	0.190 ± 0.034	1.4677	13.97	-0.59	4.09
5.0	1.94 ± 0.08	103.33 ± 1.65	0.279 ± 0.033	1.4695	15.59	-0.47	2.42
7.5	2.00 ± 0.02	96.85 ± 0.53	0.346 ± 0.061	1.4681	11.9	-0.35	4.4
10.0	2.06 ± 0.03	94.42 ± 0.46	0.413 ± 0.061	1.4636	16.71	-0.53	3.27
SEm	0.046	1.89	0.023	-	-	-	-
Test	*	*	*	NS	NS	NS	NS
CD 5%	0.104	5.96	0.075	-	-	-	-
CV %	3.51	3.63	16.73	-	-	-	-

Table-6 Effect of gamma radiation doses on the fatty acid profile of peanut oil

Fatty Acids	Gamma radiation doses					S.Em	Test	CD 5%	CV %
	0	2.5	5	7.5	10				
Palmitic (16:0)	9.36	9.11	9.07	8.86	8.99	0.005	*	0.016	0.11
Stearic 18:0)	6.65	13.01	6.56	15.75	9.53	0.005	*	0.016	0.079
Oleic (18:1)	58.57	52.56	59.92	50.53	57.29	0.025	*	0.079	0.09
Linoleic (18:2)	19.53	19.57	19.11	19.11	18.61	0.025	*	0.078	0.26
Linolinic (18:3)	0.23	-	-	-	-	0.002	*	0.007	9.72
Arachidic (20:0)	1.45	1.56	1.52	1.6	1.61	0.01	*	0.032	1.29
Behenic (22:0)	2.29	2.59	2.39	2.7	2.56	0.01	*	0.032	0.80
Eurasic (22:1)	0.36	0.28	-	0.09	0.09	0.005	*	0.016	6.02

Table-7 Effect of gamma radiation and storage on moisture content of peanut

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5	7.5	10
00	5.64 ± 0.17^{Aa}	5.59 ± 0.06^{Ba}	5.56 ± 0.02^{Ba}	5.49 ± 0.01^{Cb}	5.42 ± 0.15^{Cc}
15	5.46 ± 0.09^{Db}	5.54 ± 0.09^{Ca}	5.59 ± 0.01^{Ba}	5.47 ± 0.16^{Db}	5.67 ± 0.09^{Aa}
30	5.40 ± 0.14^{Db}	5.50 ± 0.12^{Cb}	5.54 ± 0.01^{Ca}	5.61 ± 0.08^{Ba}	5.62 ± 0.07^{Aa}
45	5.36 ± 0.16^{Dc}	5.48 ± 0.10^{Cb}	5.51 ± 0.01^{Ba}	5.56 ± 0.08^{Aa}	5.58 ± 0.09^{Ab}
60	5.31 ± 0.15^{Cc}	5.42 ± 0.13^{Bb}	5.47 ± 0.01^{Ab}	5.50 ± 0.07^{Ab}	5.46 ± 0.08^{Ac}
75	5.28 ± 0.11^{Cc}	5.37 ± 0.11^{Bc}	5.43 ± 0.02^{Ab}	5.44 ± 0.05^{Ab}	5.37 ± 0.08^{Bd}
90	5.23 ± 0.12^{Cd}	5.31 ± 0.11^{Bc}	5.39 ± 0.02^{Ab}	5.37 ± 0.01^{Ac}	5.26 ± 0.11^{Be}
105	5.21 ± 0.13^{Cd}	5.28 ± 0.09^{Bd}	5.36 ± 0.02^{Ac}	5.25 ± 0.04^{Bd}	5.13 ± 0.09^{Df}
120	5.19 ± 0.12^{Bd}	5.23 ± 0.08^{Bd}	5.31 ± 0.02^{Ac}	5.14 ± 0.09^{Ce}	5.01 ± 0.09^{Dg}
135	5.16 ± 0.11^{Bd}	5.15 ± 0.04^{Be}	5.27 ± 0.02^{Ad}	5.01 ± 0.09^{Cf}	4.93 ± 0.10^{Dg}
150	5.13 ± 0.09^{Be}	5.11 ± 0.03^{Be}	5.21 ± 0.02^{Ad}	4.93 ± 0.11^{Cf}	4.85 ± 0.07^{Dh}
165	5.10 ± 0.08^{Ae}	5.06 ± 0.03^{Bf}	5.13 ± 0.02^{Ae}	4.79 ± 0.11^{Cg}	4.73 ± 0.13^{Di}
180	5.05 ± 0.06^{Ae}	5.04 ± 0.04^{Af}	4.98 ± 0.02^{Bf}	4.66 ± 0.07^{Ch}	4.66 ± 0.15^{Cj}

This proportion decreased to 75.9% at 10 kGy. The reduction in the proportions of Oleic (C18:1), Linoleic (C18:2), and Eurasic (C22:1) acids in peanut samples was accompanied by an increase in the amounts of saturated fatty acids, namely Stearic (C18:0), Arachidic (C20:0), and Behenic (C22:0). Among the fatty acids, Linolenic (C18:3) was the most affected by gamma radiation, decreasing to undetectable levels, followed by Eurasic (C22:1) in the peanut sample exposed to a radiation dose of 2.5 kGy. These results confirm that gamma radiation accelerates the autoxidation process in unsaturated fatty acids (Palmitolic (16:1), Oleic (18:1), Linoleic (18:2), Linolenic (18:3), and Eurasic (22:1) through the formation of highly active and very short-lived free radicals in the seeds, as noted by Hafez *et al*., (1985) [35] and Afify *et al.*, (2013). The decrease in iodine value immediately after gamma radiation could also be attributed to the loss of unsaturation in the fatty acid composition of the oils.

Effect of gamma radiation and storage on moisture content of peanut

The moisture content data for peanuts at varying gamma radiation doses and storage periods are presented in [Table-7]. As both the gamma radiation dose and storage period increased, the moisture content in the peanuts decreased. Interestingly, these findings diverge from those reported by Al-Bachir (2016a), who documented an increase in moisture content in irradiated peanut seeds (3, 6, and 9 kGy) from 2.02 to 3.91 during a twelve-month storage period. However, it's worth noting that the effect of the storage period was the only factor reported to be statistically significant ($p < 0.01$) in their study. Conversely, our current observations align with the research of Mahrous (2007) and Mohsen (1996)[36], who both reported a statistically significant decrease in moisture content in both irradiated and non-irradiated soybean seeds during a 12-month storage period

Table-8 Effect of gamma radiation and storage on oil content of peanut

Days	Gamma radiation doses(kGy)				
	0.0	2.5	5.0	7.5	10.0
00	49.87±0.20^{Aa}	50.01±0.17^{Aa}	49.90±0.15^{Aa}	49.80±0.17^{Ba}	50.01±0.15^{Aa}
15	49.35±0.77^{Cb}	49.84±0.20^{Aa}	49.75±0.09^{Aa}	49.62±0.19^{Ba}	49.88±0.09^{Aa}
30	48.85±0.52^{Cc}	49.60±0.20^{Bb}	49.44±0.10^{Bb}	49.56±0.23^{Ba}	49.82±0.15^{Aa}
45	48.39±0.36^{Cd}	49.32±0.25^{Ab}	49.04±0.14^{Bc}	49.42±0.04^{Ab}	49.52±0.13^{Ab}
60	47.83±0.52^{De}	49.04±0.22^{Cc}	48.83±0.09^{Cc}	49.56±0.37^{Aa}	49.26±0.12^{Bb}
75	47.47±0.37^{Df}	48.89±0.18^{Bc}	48.57±0.03^{Cd}	49.76±0.53^{Aa}	49.10±0.09^{Bc}
90	47.06±0.44^{Dg}	48.66±0.23^{Bd}	48.20±0.09^{Cd}	49.31±0.34^{Ab}	48.77±0.09^{Bc}
105	46.70±0.48^{Dg}	48.42±0.14^{Bd}	47.84±0.13^{Ce}	49.14±0.28^{Ab}	48.46±0.12^{Bd}
120	46.35±0.41^{Dh}	48.22±0.14^{Be}	47.57±0.16^{Cf}	49.08±0.18^{Ab}	48.12±0.21^{Bd}
135	45.83±0.37^{Di}	49.09±1.64^{Ac}	48.11±1.08^{Ce}	48.82±0.24^{Bc}	47.92±0.23^{Ce}
150	45.39±0.47^{Dj}	47.76±0.10^{Bf}	46.85±0.18^{Cg}	48.75±0.20^{Ac}	47.65±0.30^{Be}
165	45.02±0.46^{Ej}	47.45±0.16^{Cf}	46.50±0.21^{Dg}	48.64±0.22^{Ac}	48.24±1.08^{Bd}
180	44.25±0.19^{Dk}	47.25±0.17^{Bg}	46.18± 0.19^{Ch}	48.28±0.35^{Ad}	47.35± 0.39^{Bf}

Table-9 Effect of gamma radiation and storage on acid value of peanut oil

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
00	1.56 ±0.09^{Aa}	1.80 ±0.06^{Ba}	1.91 ±0.05^{Ca}	1.99 ±0.01^{Ca}	2.16 ±0.08^{Da}
15	1.64 ±0.08^{Aa}	1.83 ±0.03^{Ba}	1.98 ±0.01^{Ca}	2.01 ±0.03^{Ca}	2.28 ±0.01^{Db}
30	1.76 ±0.01^{Ab}	1.86 ±0.01^{Ba}	2.10 ±0.05^{Cc}	2.05 ±0.05^{Ca}	2.44 ±0.03^{Bc}
45	1.74 ±0.05^{Ab}	1.95 ±0.02^{Bb}	2.23 ±0.03^{Cd}	2.10 ±0.02^{Cb}	2.73 ±0.05^{Dd}
60	1.84 ±0.02^{Ab}	2.11 ±0.09^{Bc}	2.32 ±0.05^{De}	2.21 ±0.06^{Cc}	2.93 ±0.05^{Ee}
75	1.89 ±0.05^{Ac}	2.32 ±0.05^{Bd}	2.46 ±0.03^{Cf}	2.31 ±0.05^{Bd}	2.98 ±0.02^{De}
90	1.96 ±0.04^{Ac}	2.45 ±0.06^{Be}	2.49 ±0.09^{Cf}	2.42 ±0.05^{Be}	3.35 ±0.01^{Df}
105	2.13 ±0.10^{Ad}	2.61 ±0.03^{Bf}	2.66 ±0.04^{Cg}	2.57 ±0.06^{Bf}	3.66 ±0.01^{Dg}
120	2.41 ±0.18^{Ae}	2.82 ±0.02^{Cg}	2.78 ±0.06^{Ch}	2.70 ±0.06^{Bg}	3.61 ±0.30^{Dh}
135	2.53 ±0.05^{Ae}	3.02 ±0.02^{Dh}	2.88 ±0.05^{Ci}	2.77 ±0.04^{Bg}	3.84 ±0.04^{Ei}
150	2.74 ±0.12^{Ag}	3.07 ±0.04^{Ch}	2.94 ±0.03^{Bi}	2.90 ±0.03^{Bh}	4.06 ±0.05^{Dj}
165	2.87 ±0.13^{Ah}	3.16 ±0.03^{Di}	3.01 ±0.01^{Cg}	3.07 ±0.09^{Bi}	4.26 ± 0.36$_{Ek}$
180	2.88 ±0.11^{Ah}	3.11 ±0.08^{Bi}	3.12 ±0.01^{Bk}	3.22 ±0.02^{Cj}	4.42 ± 0.36^{Dl}

Table-10 Effect of gamma radiation and storage on peroxide value of peanut oil

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
0	0.171±0.018^{Aa}	0.229±0.053^{Ba}	0.277±0.044^{Ba}	0.309±0.111^{Ca}	0.368±0.093^{Da}
15	0.293±0.002^{Ab}	0.312±0.091^{Aa}	0.311±0.011^{Aa}	0.283±0.015^{Aa}	0.307±0.004^{Aa}
30	0.332±0.004^{Ab}	0.400±0.047^{Bb}	0.346±0.001^{Aa}	0.307±0.017^{Aa}	0.338±0.004^{Aa}
45	0.363±0.007^{Ab}	0.447±0.040^{Bc}	0.434±0.001^{Bb}	0.331±0.003^{Aa}	0.469±0.006^{Bb}
60	0.441±0.029^{Bc}	0.327±0.074^{Ab}	0.524±0.026^{Cc}	0.444±0.018^{Bb}	0.558±0.012^{Cc}
75	0.532±0.016^{Ad}	0.502±0.046^{Ac}	0.608±0.067^{Bc}	0.537±0.036^{Ac}	0.638±0.002^{Bc}
90	0.546±0.102^{Ad}	0.542±0.040^{Ad}	0.581±0.132^{Ac}	0.595±0.039^{Ac}	0.648±0.091^{Bd}
105	0.608±0.085^{Ad}	0.569±0.037^{Ad}	0.827±0.001^{Bd}	0.834±0.047^{Bd}	0.836±0.048^{Be}
120	0.794±0.026^{Be}	0.712±0.012^{Ae}	0.879±0.036^{Cd}	0.887±0.028^{Cd}	0.791±0.067^{Be}
135	0.909±0.020^{Bf}	0.813±0.025^{Af}	0.948±0.036^{Ce}	0.954±0.005^{Cd}	0.871±0.033^{Be}
150	0.966±0.024^{Af}	0.915±0.048^{Ag}	1.054±0.059^{Cf}	1.065±0.032^{Ce}	0.972±0.009^{Bf}
165	0.994±0.016^{Ag}	1.064±0.073^{Bh}	1.185±0.131^{Dg}	1.118±0.004^{Ce}	1.116±0.011^{Bg}
180	1.124±0.007^{Ah}	1.179±0.046^{Bi}	1.264±0.113^{Cg}	1.230±0.013^{Bf}	1.263±0.064^{Ch}

Table-11 Effect of gamma radiation and storage on iodine value of peanut oil

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
00	113.67±0.70^{Aa}	107.02±0.25^{Ba}	104.30±0.19^{Ca}	97.27±0.27^{Da}	94.65±0.15^{Ea}
15	109.63±0.47^{Ab}	103.50±0.29^{Bb}	100.67±0.39^{Cb}	96.40±0.61^{Db}	87.15±4.43^{Ec}
30	106.53±0.24^{Ac}	99.08±0.16^{Bc}	98.30±1.12^{Cc}	95.32±0.49^{Db}	91.48±0.54^{Eb}
45	102.33±0.41^{Ad}	97.43±0.95^{Bd}	95.98±0.27^{Cd}	91.85±0.78^{Dc}	87.37±0.89^{Ec}
60	97.08±2.01^{Ae}	90.02±0.76^{Be}	88.27±0.06^{Cf}	87.78±0.92^{Cd}	84.08±0.25^{Dd}
75	94.73±0.27^{Af}	94.15±0.16^{Be}	92.17±2.17^{Ce}	84.58±1.20^{De}	81.02±0.16^{Ee}
90	92.27±0.39^{Ag}	88.47±0.68^{Bg}	83.37±0.35^{Cg}	78.85±0.39^{Df}	76.23±0.96^{Ef}
105	86.62±0.27^{Ah}	82.72±0.10^{Bh}	79.18±0.58^{Ch}	73.75±0.27^{Dg}	73.17±1.73^{Eg}
120	82.82±0.87^{Ai}	77.15±0.15^{Bi}	75.95±0.63^{Ci}	73.30±0.47^{Dg}	71.83±1.15^{Eh}
135	78.55±0.46^{Aj}	72.15±0.27^{Bj}	70.47±0.27^{Cj}	69.10±0.25^{Ch}	67.37±0.40^{Di}
150	72.02±0.15^{Ak}	67.92±0.32^{Bk}	66.27±0.32^{Ck}	64.22±0.61^{Di}	61.63±0.52^{Ek}
165	70.90±0.29^{Al}	67.05±0.46^{Bk}	66.00±0.19^{Ck}	64.85±0.43^{Di}	62.80±0.25^{Ej}
180	64.53±2.92^{Am}	64.60±0.24^{Al}	62.63±0.51^{Bl}	61.07±0.19^{Cj}	59.33±0.35^{Dl}

Effect of gamma radiation and storage on oil content of peanut

The oil content data for peanut samples subjected to various gamma radiation doses during storage are detailed in [Table-8]. Notably, there were significant differences ($p < 0.05$) observed among the treatments with different gamma radiation doses. Additionally, the data reveal significant differences ($p < 0.05$) in oil content across different storage days.

Specifically, the oil content of irradiated peanut samples decreased with increasing storage days and gamma radiation doses. However, it's important to highlight that storage period had a more pronounced effect on untreated (i.e., 0.0 kGy) peanuts, where the oil content declined from 49.87% to 44.25% over a 180-day storage period. Among the radiation treatments, a minimal reduction of 1.52% in oil content was observed for peanuts exposed to a radiation dose of 7.5 kGy. Interestingly, these results differ from those reported by Al-Bachir (2016a), who observed a non-significant effect of gamma radiation doses (3, 6, and 9 kGy) and a twelve-month storage period on peanuts with moisture content ranging from 2.02% to 3.91%. This effect was attributed to the low moisture content, which may not have provided sufficient free radicals needed to induce changes in proximate composition. However, in our present study, the moisture content of the samples exceeded 5.4%, which could be a contributing factor to the reduction in oil content.

Table-12 Effect of gamma radiation and storage on refractive index of peanut oil

Days	Gamma radiation doses (kGy)				
	0	2.5	5	7.5	10
0	1.4698	1.4675	1.4596	1.4672	1.4618
15	1.4625	1.4688	1.4579	1.4568	1.4623
30	1.4587	1.4636	1.4612	1.4689	1.4615
45	1.4598	1.4685	1.4632	1.4623	1.4648
60	1.4583	1.4649	1.4685	1.4635	1.4586
75	1.4693	1.4562	1.4599	1.4631	1.4598
90	1.4662	1.4584	1.4536	1.4587	1.4582
105	1.4656	1.4618	1.4639	1.4598	1.4633
120	1.4603	1.4673	1.4623	1.4616	1.4675
135	1.4578	1.4679	1.4584	1.4652	1.4525
150	1.4698	1.4689	1.4617	1.4665	1.4623
165	1.4674	1.4673	1.4623	1.4589	1.4653
180	1.4589	1.4624	1.4579	1.4659	1.4645

Table-13(a) Colour 'L' value of peanut oil at different radiation dose and storage period of seed*

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
0	8.64	13.97	15.59	11.9	16.9
15	11.02	13.25	13.25	11.98	12.34
30	12.54	13.25	11.94	14.35	10.24
45	9.12	12.54	10.25	12.46	13.24
60	10.72	11.85	9.246	11.26	14.38
75	9.86	13.25	12.24	15.15	15.43
90	10.25	15.42	13.59	14.66	15.43
105	8.46	10.76	14.24	13.79	9.87
120	12.14	11.84	15.83	10.23	11.24
135	10.65	12.46	8.45	12.47	14.25
150	9.54	12.48	10.56	9.97	11.24
165	10.25	13.78	12.78	13.5	16.75
180	11.2	13.45	13.45	11.2	16.45

Table-13(b) Color 'a' value of peanut oil at different radiation dose and storage period of seed*

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
0	-1.34	-0.59	-0.47	-0.35	-0.53
15	-0.95	-0.98	-0.45	-0.82	-0.76
30	-0.65	-0.42	-1.56	-0.24	-0.35
45	-0.26	-1.04	-0.76	-0.39	-0.48
60	-1.34	-0.45	-0.97	-0.75	-0.75
75	-0.75	-0.64	-0.46	-0.58	-0.56
90	-0.98	-0.86	-0.37	-0.66	-0.46
105	-0.74	-0.45	-0.78	-0.34	-0.28
120	-1.27	-0.34	-0.53	-0.94	-0.65
135	-0.62	-0.83	-1.05	-0.39	-0.97
150	-0.78	-0.63	-0.85	-0.82	-0.49
165	-1.08	-0.52	-0.98	-0.32	-0.75
180	-0.46	-0.38	-0.52	-0.74	-0.36

Table-13(c) Color 'b' value of peanut oil at different radiation dose and storage period of seed*

Days	Gamma radiation doses (kGy)				
	0.0	2.5	5.0	7.5	10.0
0	5.23	4.09	2.42	4.4	3.27
15	3.28	1.36	4.51	3.64	3.48
30	2.35	3.76	1.83	2.54	2.45
45	2.86	1.97	2.04	2.82	2.46
60	1.86	4.56	2.15	5.26	1.89
75	3.12	3.26	3.85	1.26	4.52
90	3.08	2.87	5.08	5.52	4.34
105	1.97	5.03	2.63	2.14	1.97
120	4.36	2.78	3.59	4.26	5.47
135	2.94	2.85	2.06	2.46	4.24
150	3.05	5.08	5.35	3.22	3.48
165	5.23	4.25	3.87	2.86	3.45
180	2.38	3.05	2.45	3.95	2.64

Effect of gamma radiation and storage on acid value of peanut oil

The acid value data for peanut oil is presented in [Table-9]. As both gamma radiation doses and storage time increased, the acid value of the peanut samples reached a maximum of 4.42 mg/g of oil. However, it remained below the prescribed maximum limit of 6 mg/g of oil as per the FSSAI standards for oil and fat (FSS, 2011). This increase in acid value may be attributed to the dissociation of certain fatty acids from triglycerides during gamma radiation and storage, especially in the presence of free moisture within the peanut kernels (El Tom and Yagoub, 2007). Al-Bachir (2004) reported an increase in the percentage of free fatty acids in both irradiated (0.5-2.0 kGy) and unirradiated (0.0 kGy) walnuts during 12 months of storage, which aligns with our observations. However, in another study (Al-Bachir, 2016a), the effect of radiation doses on total acidity (% lactic acid) and pH of peanuts was reported to be statistically non-significant ($p > 0.05$) at the beginning of the experiments. After 6 months of storage, only the 9 kGy radiation dose significantly ($p < 0.01$) decreased the total acidity, while after 12 months of storage, both radiation doses of 6 and 9 kGy significantly ($p < 0.01$) increased the total acidity in peanut seeds.

Effect of gamma radiation and storage on peroxide value of peanut oil

The data pertaining to peroxide values of oils extracted from both irradiated (2.5, 5.0, 7.5, and 10.0 kGy) and unirradiated (0.0 kGy) peanut seeds, stored for varying periods, are compiled in [Table-10]. It's evident that both gamma radiation doses and storage periods exerted a significant influence on the peroxide values of the oils. As the gamma radiation dose and storage time increased, the peroxide values of peanut oils also rose. This increase in peroxide value is indicative of oxidation within the seeds, a phenomenon that intensifies with higher gamma radiation doses and longer storage durations. These findings are consistent with the outcomes of numerous studies that have explored the interaction between gamma rays and fat molecules, leading to oxidation, decarboxylation, dehydration, and polymerization reactions, ultimately resulting in lipid oxidation. Various studies have revealed the effect of gamma radiation on oxidation and antioxidative activity. Sajilata and Singhal (2006) [37] concluded that antioxidative activity decreases with higher gamma radiation doses and longer exposure times in cashew nuts. The antioxidative activity decreases with the gamma radiation dose in black pepper irradiated between 5 and 30 kGy, but it increases during storage. Chiou (1991) [38] found that the peroxide content of peanut oils extracted from irradiated peanuts increased with higher gamma radiation doses (2.5, 5.0, 7.5, and 10 kGy). Mozingo *et al.* (2004) [39] reported that the peroxide value of peanuts increased during storage. Fullerton *et al.* (1982) [40] and Hanis and Mnukova (1985) [41] similarly observed that peroxide values of cereal-based mixtures and food ingredients increased in direct proportion to the gamma radiation dose.

Effect of gamma radiation and storage on iodine value of peanut oil

The iodine value data for oils extracted from both irradiated (2.5, 5.0, 7.5, and 10.0 kGy) and unirradiated (0.0 kGy) peanut seeds, subjected to different storage periods, is presented in [Table-11]. Notably, both gamma radiation doses and storage periods had a significant impact on the iodine value of the oils. As the gamma radiation dose and storage time increased, the iodine value of peanut oil decreased. This decline in the iodine value indicates a reduction in the degree of partial and/or total unsaturation in the oil, both during the gamma radiation treatment and subsequent storage. These findings align with the results obtained by several researchers, including Afify (2013) and Mahrous (2007) for soybean oil, Shahin (1993) [42] for sesame oil, Hamza (1994) [43] for corn oil, and Mohsen (1996) for soybean and cottonseed oils. They all reported a marked decrease in iodine value during storage, irrespective of whether the oils were irradiated or not. Additionally, they noted a similar trend of decreasing iodine value with gamma radiation, with the decrease being proportionate to the gamma radiation doses.

Effect of gamma radiation and storage on refractive index of peanut oil

The data regarding the refractive index of oils extracted from both irradiated (2.5, 5.0, 7.5, and 10.0 kGy) and unirradiated (0.0 kGy) peanut seeds, stored for various periods, are outlined in [Table-12]. It's worth noting that neither gamma radiation doses nor storage periods had a significant effect on the refractive index of the oils.

Effect of gamma radiation and storage on colour ‘L*’, ‘a*’ and ‘b*’ value of peanut oil

The data pertaining to the color values L*, a*, and b* of oils extracted from both irradiated (2.5, 5.0, 7.5, and 10.0 kGy) and unirradiated (0.0 kGy) peanut seeds, stored for various durations, are displayed in [Table-13a, b, c]. It's noteworthy that neither gamma radiation doses nor storage periods had a significant effect on the color values of the oils.

Conclusion

Gamma radiation has shown potential as a method to enhance the safety and prolong the shelf life of peanut seeds. This study found that while it had minimal impact on sensory attributes, protein, ash, and fiber content of the seeds, gamma radiation led to slight reductions in moisture and oil content. It significantly affected the acid, peroxide, and iodine values of peanut oil, as well as the fatty acid composition. Notably, insect infestation was evident in non-irradiated seeds after a 30-day storage period. These findings suggest that gamma radiation can serve as a valuable tool for enhancing the safety and extending the shelf life of peanut seeds while preserving many of their nutritional and sensory qualities.

Application of research: The developed technology enhances the safety of peanuts by reducing or eliminating microorganisms and insects, thereby extending their shelf life. This research investigates the impact of Gamma radiation on peanut seeds.

Research Category: Food Science Technology

Abbreviations: kGy-KiloGray, PPB-Parts per billion

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Research project name or number: MTech Thesis Effect of Gamma Radiation on Storage of Peanut and Sesame

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Study area / Sample Collection: Anand Agricultural University, Anand, 388 110

Cultivar / Variety / Breed name: *Arachis hypogaea* L- GG-20

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