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Gamma Irradiation Effect on the Phytochemical and Sensory Quality of Minimally Processed Cabbage in Selected Supermarkets in Accra – Ghana

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Abstract

Low fruit and vegetable intake is estimated to cause about 31% of ischaemic heartdisease and 11% of stroke worldwide. It is estimated that up to 2.7 million lives couldpotentially be saved each year if fresh fruits and vegetables such as cabbageconsumption was sufficiently increased.The effect of ionizing radiation onphytochemical and sensory quality on minimally processed cabbage was studied for 15days. The aim was to investigate the effect of irradiation on phytochemical content aswell as sensory quality of cut cabbage sold in selected supermarkets in Accra, Ghana.Ascorbic acid, total antioxidant activity, total flavonoid and phenolic contents wereanalyzed for phytochemical analysis. Redox titration with iodine method was used indetermining the total ascorbic acid content while antioxidant activity, total flavonoid andphenolic content were determined by DPPH, Folin-Ciocalteu and Aluminium chloridecolorimetric method respectively. Nine-point Hedonic scale was also used for thesensory evaluation. Even though irradiation doses affected texture for that matterfirmness greatly, it showed no significant differences ($p \leq 0.05$) in phytochemical contentsuch as ascorbic acid, phenolics, flavonoids as well as antioxidant activity in theirradiated cut cabbage. Panelists' scores for colour, textue and aroma from sensoryevaluation showed significant differences ($p<0.05$) in irradiated cut cabbage samples.Itwas concluded that 2 kGy was most effective for medium dose decontamination ofminimally processed cabbage for shelf- life extension contrarily to claims of other workspegging it at 1 kGy.

Keywords: Irradiation; Cabbage; Phytochemicals; Minimally processed

Introduction

Fruits and vegetables in the fresh state are reported to have greater nutritional benefits and it has been recommended that they are eaten first to prepare the stomach for handling preceding foods. Eating enough vegetables each day is important to help maintain healthy body. Along with tasting great, vegetables are low in calories and fat and high in vitamins, minerals, and fiber. Cabbage contains more vitamin C than oranges, as well as a wide range of minerals, including iodine, sulphur, calcium, magnesium, and potassium. The outer leaves of cabbage contain more Vitamin E and calcium than the inner leaves (International Gardening Guide, 2000). Phytochemicals induction susceptibility in vegetables depends on various factors such as type of cultivar, maturity stage, initial phenolic levels within tissues, and stress intensity, among others Cisneros-Zevallos [1]. Unlike cereals and legumes, the water activity in most fruits and vegetables is very high. Therefore, most fruits and vegetables are highly perishable because they play host to several micro-organisms and insect pests supporting their growth and proliferation [2]. Several researchers have reported the use of irradiation as a decontamination method for several fresh vegetables. Frimpong et al. reported that the higher the dose of radiation applied to cabbage, the higher the reduction of the total viable count of microorganisms [3]. However, extremely high doses have been reported to affect the textural quality Lafortune et al., as well as phytochemical content of vegetables [4]. It is therefore hypothesized that low- dose gamma irradiation would not have effect on phytochemical and sensory qualities on cut cabbage. The aim of this study was to assess gamma radiation effect on sensory and phytochemical content on cut cabbage.

Objectives

a) To evaluate effect of radiation dose on phytochemical content in cut cabbage.

b) To assess consumer acceptance of irradiated cut cabbage.

Sample Preparation for phytochemical analysis: One hundred grams sample of the cabbage sample was blended in a Binatone blender (model: BLG-401) together with about 50 mL of distilled water. After blending, the pulps were strained through a cheese cloth, washed with 10 ml portions of distilled water, and made up to 100 mL in a volumetric flask.

Materials and Methods

A single tablet of vitamin C was dissolved in 200 mL of distilled water as standard in a volumetric flask.

1. Twenty milliliter aliquot of the sample solution was pipetted into a 250 mL conical flask and about 150 mL of distilled water was added. One milliliter of starch indicator solution was added.

2. The sample was titrated with 0.005 mol L^{-1} iodine solution. The endpoint of the titration was identified as the permanent trace of a dark blue-black colour due to the starch-iodine complex.

3. The titration was repeated with further aliquot of sample solution until concordant results (titres agreeing within 0.1 mL) were obtained.

The average volume of iodine solution used was calculated from

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concordant titres. Using the equation of the titration (Ascorbic acid $+I_2 \rightarrow 2I^-$ + dehydroascorbic acid), the amount of ascorbic acid reacted with iodine was calculated. The concentration in mol L^{-1} of ascorbic acid in the solution obtained from vegetable was also calculated in mg/100 g of ascorbic acid in the sample.

Total antioxidant activity analysis using 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method

The DPPH assay was done according to the method of Brand-Williams et al. [5]. The stock solution was prepared by dissolving 24 mg DPPH with 100 mL methanol and then stored at -20°C until needed. The working solution was obtained by mixing 10 mL stock solution with 45 mL methanol and an absorbance obtained using the spectrophotometer. Aliquot of 100 microliters was allowed to react with 3900 µL of the DPPH solution for 30 minutes in the dark. Then the absorbance was taken at 517 nm. The standards curves were between 0.2 to 1.0 µL according to the method reported by Blois [6]. The experiment was carried out in triplicate. Radical scavenging activity was calculated as follows:

% reduction of absorbance = [(AB –AA) / AB] ×100

Where: AB - absorbance of blank sample (time=0 min); AA – absorbance of the cabbage extract solution (t=30 min).

Total phenolic determination using folin-ciocalteu method

The FC analysis was carried out according to the procedure in Singleton et al. [7]. The content of total phenolic compounds in the cabbage aqueous and methanolic extracts was determined by the Folin-Ciocalteu method. For the preparation of the calibration curve 1 mL aliquots of 0, 0.2, 0.4, 0.6, 0.8 and 1.0mg/ml Gallic acid solutions in methanol were mixed with 5 ml of Folin-Ciocalteu reagent (diluted ten-fold) and 4 ml of sodium carbonate solution. Absorbance readings using spectrophotometer were taken at 760 nm after incubating for 30 minutes at ambient temperature and calibration curve constructed. One ml of the methanol cabbage extract (10 g/l) was mixed with the same reagents as described above, and after 1 hour the absorbance was measured for the determination of total cabbage phenolics. All determinations were performed in triplicate. Total content of phenolic compounds in cabbage methanol extracts in gallic acid equivalents (GAE) was calculated by the following formula:

C = cV/m

Where: C=total content of phenolic compounds in mg/g cabbage extract, in GAE; c=the concentration of gallic acid established from the calibration curve in mg/ml; v=the volume of extract in ml; m=the weight of cabbage methanolic extract in gram.

Total flavonoid using aluminium chloride colorimetric method

Total soluble flavonoids were expressed as quercetin equivalent (QE). Quercetin was used to make the calibration curve (standard solutions of 6.25, 12.5, 50.0, 75.0, 100.0 µg/ml in 80% ethanol (v/v), 0.5 mL of a product (ethanolic solutions of extracts) was mixed with 1.5 mL 95% ethanol (v/v), 0.1 mL 10% aluminium chloride ($AlCl_3$) (m/v), 0.1 mL of 1 mol/L potassium acetate and 2.8 mL water. A volume of 10% (m/v) $AlCl_3$ was substituted by the same volume of distilled water in blank. After incubation at room temperature for 30minutes, the absorbance of the reaction mixture was measured at 415 nm. The total flavonoids content in the fractions was determined as µg quercetin equivalent by using the standard quercetin graph. The flavonoid content was expressed as mg QE/100 g FW with $R^2 = 0.9372$ and equation of y = 0.0025x + 0.029. Where: FW=fresh weight, X=absorbance of cabbage.

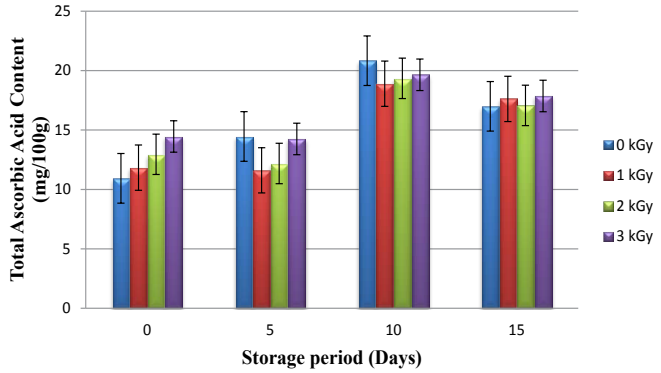

Figure 1: Total ascorbic acid content of control and irradiated samples of cut cabbage stored for 15 days at 8 ± 2°C. (Values are expressed as mean ± SD (n=3)).

Storage period (days)	Antioxidant activity (%)	Ascorbic acid content (mg/100 g FW)	Total phenolic content (mg GAE/100 g FW)	T content (mg QE/100 g FW)
0	16.808 ± 3.27^a	12.545 ± 1.08^a	1.331 ± 0.24^a	39.746 ± 5.15^a
5	14.395 ± 3.27^a	13.123 ± 1.08^a	1.484 ± 0.24^a	30.660 ± 5.15^{ab}
10	28.099 ± 3.27^b	19.686 ± 1.08^b	1.679 ± 0.24^a	21.555 ± 5.15^{bc}
15	37.701 ± 3.27^b	17.389 ± 1.08^b	2.662 ± 0.24^b	15.453 ± 5.15^c

Values are pooled means ± standard error.

Different uppercase superscripts in a column are significantly different (p>0.05). GAE=garlic acid equivalent. QE=quercetin equivalent. FW=fresh weight.

Table 1: Pooled mean values of phytochemical analysis of cut cabbage sample stored for 15 days.

Sensory evaluation

Two set of sensory evaluation were conducted to assess the quality attributes of irradiated cut-vegetable. In the descriptive sensory evaluation, three attributes (colour, texture, and smell) were examined. Hedonic scale was used for the preference test. The following interpretations were given to the hedonic scale; 9.00 to 9.99 – like extremely; 8.00 to 8.99 – like very much; 7.00 to 7.99 – like moderately; 6.00 to 6.99 – like slightly; 5.00 to 5.99 – neither like nor dislike; 4.00 to 4.99 – dislike slightly; 3.00 to 3.99 – dislike moderately; 2.00 to 2.99 – dislike very much; 1.00 to 1.99 – dislike extremely.

Fifty untrained panelists (all workers of Ghana Atomic Energy Commission) were presented with three coded irradiated cut-cabbages and were asked to indicate their levels of acceptance by scoring and describing other attributes (smell, colour and texture).

Results and Discussion

Phytochemical analysis

Total ascorbic acid content: The result of Total Ascorbic Acid content (TAAC) is presented in (Figure 1). The initial TAAC for unirradiated cut cabbage samples ranged from 8.44 to 13.25 mg/100 g and that of 1-3kGy irradiated samples at 0 day ranged between 11.84 and 14.46 mg/100 g. The highest total ascorbic acid content among all samples studied was 20.85 mg/100 g for unirradiated sample stored for 10 days, while the lowest total ascorbic acid content of 10.98 mg/100 g was detected in unirradiated cut cabbage samples examined immediately after processing (Figure 1).

Although TAAC values of irradiated cut cabbage samples were different from the unirradiated samples, these differences in TAAC

values were not statistically significant ($p>0.05$) within irradiated samples or between irradiated and unirradiated samples. However, the effect of storage period in TAAC on cut-cabbage samples was highly significant ($p \leq 0.01$). There was no significant difference ($p>0.05$) in interaction between radiation and storage time (Table 1).

Generally, irradiation caused statistically insignificant reduction in TAAC especially during the first five days of storage but the decrease was short lived as natural synthesis of ascorbic acid caused increases in TAAC. These reductions in TAAC may have been caused by free radicals generated partial by storage stress and irradiation potentially converting ascorbic acid (AA) to dehydroascorbic acid (DHAA). Halliwell reported that during storage, fruits and vegetables undergo several stress conditions including wounding, chilling, heat, pathogens, and senescence [8]. These changes generate reactive oxygen species (ROS), such as singlet oxygen ($1O_2$), hydroxyl (OH), peroxyl radicals (O_2) and superoxide anion (O_2^-), which result in cellular deterioration including lipid peroxidation, enzyme inactivation, and mutation. Free radicals generated by mostly irradiation convert's ascorbic acid to dehydroascorbic acid, both of which exhibit biological activity and are readily interconvertible [9]. Graham and Stevenson have shown that irradiation at doses of 1, 2 and 3 kGy reduced the ascorbic acid (AA) content of strawberries and potatoes [10]. Kilcast reported that ionizing radiation can cause a partial conversion of AA to DHAA [11].

The slight increase in TAAC after the fifth day of storage was terminated by the decrease recorded on the fifteenth day of storage. This observation is in agreement with Swailam et al., who reported that ascorbic acid in all un-irradiated and irradiated fresh cut pear samples showed significant reduction upon refrigeration storage and the reduction increased with increasingly storage time [12]. On the other hand, El-Samahy et al., attributed loses in ascorbic acid of mango fruits during storage to the ripening processes [13]. Sanusi et al. also reported variable losses in Ascorbic acid (vitamin C) content of sixteen different whole fruits in Nigeria assessed initially and after different lengths of storage time ranging from 3 to 8 months [14].

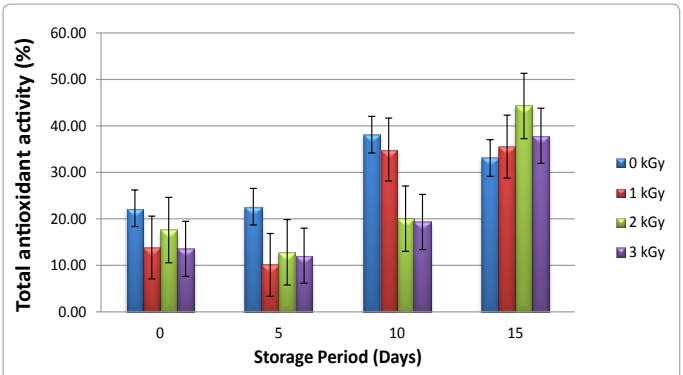

Figure 2: Total antioxidant scavenging activity of control and irradiated cut cabbage samples stored for 15 days at 8 ± 2ºC. (Values are expressed as mean ± SD (n=3)).

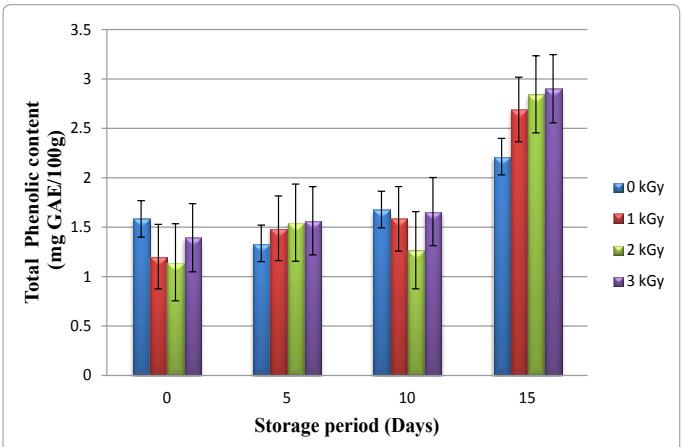

Figure 3: Total Phenolics of control and irradiated samples of cut cabbage stored for 15 days at 8 ± 2ºC. (Values are expressed as mean ± SD (n=3)).

Total phenolic content

Total phenolic content (TPC) registered the lowest values among all the phytochemical studied in this research. Immediately after irradiation (at day 0) there was insignificant reduction in TPC, however after 15 days of storage there were increases in radiated samples compared to the unirradiated. (Figure 2) shows that TPC of cut cabbage samples ranged from 1.2 to 2.9 mg GAE/100 g of fresh cabbage. Samples treated with 3 kGy stored for 15 days had the highest TPC of 2.90 mg GAE/100 g and 2 kGy treated samples initially had lowest value of 1.20 mg GAE/100 g. Even though irradiation doses were seen to have caused variations in TPC of cut cabbage these increases were not statistically significant ($p>0.05$) (Figure 3).

On the other hand, the effect of storage period on TPC of the cut cabbage was highly significant ($p<0.01$). Increasing total phenolic content on cut cabbage was independent of irradiation dose.

The effect of irradiation on cut leafy vegetables has been studied by other researchers. Ahn et al. reported that a gamma irradiation of 1 kGy or above significantly reduced the phenolic content in cut Chinese cabbage [15]. However, Fan et al., reported that phenolics synthesis (increase) in fresh-cut iceberg lettuce was induced by warm water dipping rather than gamma irradiation [16,17].

The increase in TPC during storage may be due to fact that the fresh cut cabbage is a biological non-climacteric material which is still living hence carries out biosynthesis of phenolic compounds. On the other hand, increases due to irradiation are as a result of increase or activation of phenylalanine ammonia-lyase (PAL) enzymes activity which has positive correlation with production of phenolic compounds in fruits and vegetables [18]. Polyphenols also play a role in mitigating the oxidative stress during postharvest storage and handling, and thus contribute to extending the shelf life of fruits. Polyphenols such as lignins contribute to the firmness of fruits, protecting the fruits and vegetable against mechanical injuries during postharvest handling hence the increase in phenolic content during storage. Gon-calves et al reported that the total phenolic content increased in sweet cherry during storage at both 1–2ºC and 15 ± 5ºC [19,20]. It has also been observed that the content of total phenolics were higher in cherries kept at room temperature than cold storage (1–2ºC). There was variation in the levels of individual phenolics but these variations were lower in cold storage than room temperature [19,20].

The identification of post-harvest abiotic factors that trigger a stress response is a key component in designing strategies to increase nutriceutical content of fresh fruits and vegetables. It was found that selected abiotic stress treatments such as wounds, phytohormones, temperature, ultraviolet light, altered gas composition, heat shock, among others affect the secondary metabolism of fresh produce and increase the synthesis of phytochemicals with functional activity [21].

The significant increase in flavonol composition observed during

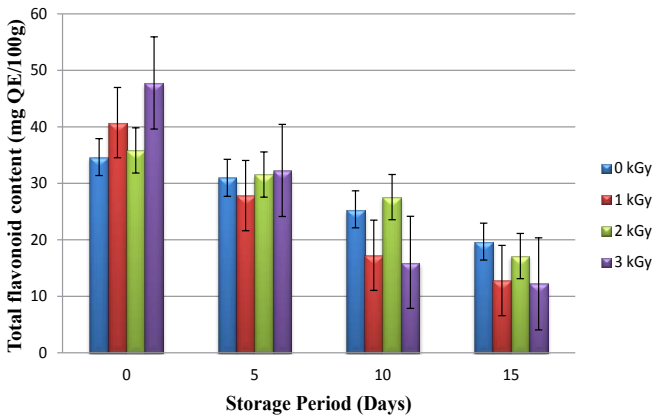

Figure 4: Total flavonoids of cut cabbage control and irradiated samples stored for 15 days at 8 ± 2ºC. (Values are expressed as mean ± SD (n=3)).

storage could be due to the action of ethylene. Ethylene can stimulate activity of phenylalanine ammonia-lyase (PAL), a key enzyme in biosynthesis of phenolic compounds and accumulation of phenolics constituents [22,23]. Benkeblia reported a positive relationship between PAL activity and total phenolics variations in long-term stored onion bulbs [22].

Total flavonoid content

There were general decreases in total flavonoids content in the cut cabbage with increasing storage period but with variations in TFC as a result of irradiation were not consistent. The effect of storage period was significantly different from one another ($p<0.05$). Apart from TFC for 5 day of 30.660 mg QE/100 g, 39.746 mg QE/100 g (0 day) was significantly different from TFC for the rest of the storage periods. Accordingly TFC for 5 day was not significant from that of 10day but was significantly different ($p<0.05$) from 15 day. However TFC for 10 day was neither different ($p<0.05$) from 5 day nor 15 day.The interaction of storage period and irradiation doses was not significantly different ($p>0.05$), i.e., the effect of storage period on TFC was independent of irradiation treatment.

The decrease in flavonoid content of cut cabbage cannot be attributed to irradiation but rather the length of storage, as percentage decrease in 0, 1, 2 and 3 kGy for the 15 days storage period are represented as 43.2, 68.6, 52.2 and 74.5% respectively (Figure 4).

Reduction in total flavonoids compound in storage observed in this study has been reported by different authors such as Gennaro et al who observed a decrease of 73-64% in total anthocyanins in onions stored under room temperature [24]. Thanajiruschaya et al., reported flavonoids content in milled rice decreased from 13.263 to 6.446 mg/g during storage at 37°C for 0-7 months [25]. Wiley also reported that among the flavonols studied only the rutin could be detected and quantified in white wine and its content also diminishes and could not be detected after 6 months of storage [26].

Total antioxidant scavenging activity

The antioxidant activity is a very important nutritional factor since every individual phytochemical contributes in one way or the other to the overall antioxidant activity of the cut cabbage. (Figure 4) shows that total antioxidant activity (TAA) range of unirradiated cut cabbage was from 19.70 to 23.81% and that of irradiated samples were between 13.54 and 17.59%. The increases in TAA percentage caused by storage period were statistically significant ($p \leq 0.01$) both control and irradiated cut cabbage samples. For instance, 16.808 and 14.395% for days 0 and 5 respectively were significantly different from 10 and 15 days of 28.099 and 37.701%. It is worth noting however that there were no differences between TAA for day 0 and 5 as well as 10 and 15 day. Again increase of 21.71, 26.69 and 24.34% TAA for 1, 2 and 3 kGy treated samples respectively for the 15 days storage period. The unirradiated sample also had 15% increases in TAA for the first 10days of storage. There was no significant difference ($p \leq 0.05$) of interaction between radiation and storage time. This means the effect of storage time on TAA was independent on irradiation dose. For example in (Figure 2), between 10-15 days, unirradiated sample decreased in TAA while irradiated samples decreased in TAA. Again, there were general increases in TAA of unirradiated but decrease in TAA of irradiated cut cabbage during 0 to 5 days of storage. (Figure 2)

The variations as a result of irradiation were insignificant in DPPH radical-scavenging activity of cut cabbage aqueous extracts, mainly in the first five days after irradiation. Observed differences were gradually disappeared during the storage due effect of storage on the irradiated samples. This increase of cut cabbage radical-scavenging activity may be due to the increases in contributory phytochemical such as ascorbic acid and polyphenol compounds during the storage of this vegetable under refrigeration condition as can be seen in (Figures 3 and 4).

	Antioxidant Activity	Ascorbic Acid	Phenolic Content	Flavonoid Content
Antioxidant Activity		0.2324	0.5557	-0.2926
		(48)	(48)	(48)
		0.1119	**0.0000**	**0.0436**
Ascorbic Acid	0.2324		0.1602	-0.2382
	(48)		(48)	(48)
	0.1119		0.2769	0.1030
Phenolic Content	0.5557	0.1602		-0.4485
	(48)	(48)		(48)
	0.0000	0.2769		**0.0014**
Flavonoid Content	-0.2926	-0.2382	-0.4485	
	(48)	(48)	(48)	
	0.0436	0.1030	**0.0014**	

Correlation
(Sample Size)
P-Value.

Table 2: The correlation of antioxidant activity with ascorbic acid, phenolic and flavonoid content of cut cabbage.

DAYS/DOSES	0 kGy	1 kGy	2 kGy	3 kGy
1	7.080 ± 0.05Aa	6.680 ± 0.05Aa	6.480 ± 0.04Aa	5.920 ± 0.05Ab
8	6.680 ± 0.05Aa	6.600 ± 0.05Aa	6.000 ± 0.04Bb	5.720 ± 0.05Ab
15	6.600 ± 0.05Aa	5.880 ± 0.06Bb	5.840 ± 0.05Bb	5.680 ± 0.05Ab

Different letters in the column represent significant differences ($p \leq 0.05$) between storage days. Different letters in a row represent significant differences ($p \leq 0.05$) for irradiation doses. Mean ± standard error.

Table 3: Mean values of panelists' scores for texture of un-irradiated and irradiated cut-cabbage stored at 8 ± 2ºC for 15 days.

DAYS/DOSES	0 kGy	1 kGy	2 kGy	3 kGy
1	7.520 ± 0.04a	7.160 ± 0.04a	6.680 ± 0.05b	6.520 ± 0.04b
8	7.520 ± 0.04a	7.080 ± 0.04b	6.640 ± 0.04b	5.680 ± 0.06c
15	7.400 ± 0.04a	7.040 ± 0.05a	6.400 ± 0.06b	6.040 ± 0.05b

Different letters in a row represent significant differences ($P \leq 0.05$). Mean ± standard error.

Table 4: Mean values of panelists' scores for colour of un-irradiated and irradiated cut-cabbage stored at 8 ± 2ºC for 15 days.

Phenolic contents are very important plant constituents because of their scavenging ability due to their hydroxyl groups [27]. Ascorbic acid acts as a chain breaking antioxidant impairs the formation of free radicals in the normal body processes such as formation of intercellular substances, including collagen, bone matrix and tooth dentine [28]. (Table 2)

The positive correlation of ascorbic acid and phenolics with total antioxidant activity (TAC) as well as negative correlation of total flavonoid content of both control and irradiated cut cabbage samples can be seen from (Table 2).

Trinidad et al. indicated that there was strong positive correlation between total phenolic compounds to total antioxidant activity for Andean root and tuber crops [29]. This is due to the fact that phenolic compounds greatly contribute to antioxidant capacity in food crops.

Sensory analysis

Colour: Panelists' scores for colour of the cut cabbage ranged between 5.68 and 7.52 being neither like nor dislike and like moderately for all the storage materials tested (Table 3). The unirradiated samples scored between 7.40 and 7.52 being liked moderately while the irradiated cut cabbage scores ranged from 5.68 to 7.16 also being neither liked nor disliked and liked moderately. The lowest colour score of 5.68 was for the 3kGy treated sample stored for 8 days and 7.52 was the highest score for unirradiated samples on the first and eighth day of storage (Table 4).

Colour scores of the cut-cabbage generally decreased implying that consumer preference for samples' colour declined with increased doses. The effect of irradiation doses on colour of the cut cabbage was highly significant ($p \leq 0.01$), i.e., the light green colour of the cut-cabbage decreased with increasing irradiation doses. The panelists' scored 6.08 (unirradiated samples) was statistically different from 7.09, 7.48 and 6.57 for 1, 2 and 3 kGy samples respectively. There were variations of colour in both irradiated and unirradiated by the end of 15 days storage. However, the colour change could not be attributed to storage time since the effect of storage time on colour of unirradiated was not statistically different ($p>0.05$) from irradiated samples. The decrease in light green colour to brown may be due to synthesis of polyphenol compounds due to the activation of phenylalanine ammonia-lyase (PAL) activity by irradiation causing the browning in the irradiated cut-cabbage [30,22].

On the first day, increased colour in 2 and 3 kGy irradiated samples were significantly different from that of control and 1 kGy. By the eighth day of storage, all samples were significantly different from each except 1 and 2 kGy samples. However on the fifteenth, the pattern was similar to that of the first day. The effect of irradiation doses on browning of cut cabbage samples was independent of storage time. That is the interaction effect of storage period and irradiation doses were not significantly different ($p>0.05$). The panelists' scores gradually increased dislike for the colour may be as a result of the increase in total phenolic content of the cut cabbage.

This result on panelists' scores on the colour of the cut cabbage is consistent with what was reported by Breitfeliner et al., that using dose up to 10 kGy of irradiation mainly increased the content of 4-hydroxybenzoic acid among the phenolic in fresh strawberry fruit [30]. Furthermore, phenolic compounds are responsible for the browning reactions in vegetables, making their increase undesirable in cut vegetable. Similar results were shown by Youssef et al., who found that polyphenol oxidase activity was increased in fresh cut pears by irradiation doses which have positive correlation with phenolic content [31]. Swailam et al. also reported similar observation in fresh cut mangoes [31].

DAYS/DOSES	0 kGy	1 kGy	2 kGy	3 kGy
1	5.520 ± 0.05b	5.360 ± 0.05b	6.360 ± 0.05a	6.520 ± 0.04a
8	6.520 ± 0.04a	6.240 ± 0.05a	6.360 ± 0.05a	6.240 ± 0.05a
15	6.800 ± 0.05a	5.320 ± 0.06b	6.360 ± 0.05a	6.320 ± 0.05a

Different letters in a row represent significant differences ($P \leq 0.05$). Mean ± standard error.

Table 5: Mean values of panelists' scores for aroma of un-irradiated and irradiated cut-cabbage stored at 8 ± 2ºC.

Texture of cut cabbage: Influence of both irradiation doses and storage period had significant effect on the texture of cut-cabbage. Panelists' scores for texture unirradiated samples ranged from 6.60 and 7.52 interpreted as like slightly to like moderately and the irradiated cut cabbage scores ranged between 5.68 and 6.68. Unirradiated sample stored just for a day was most preferred for its firmness while the least preferred texture was 3 kGy treated samples stored for 15 days. Generally, softness increased with both increase in irradiation dose and length of storage time. Effect of irradiation on texture of the samples was significantly different ($p \leq 0.1$). For instance, 5.77 (3 kGy treated samples) was statistically different from 6.79, 6.39 for 0 and 1 kGy but not 6.11 for 2 kGy. Texture for all irradiated samples except 1 kGy samples was significantly different from the unirradiated sample. The texture of 2 and 3 kGy samples were significantly different from 0 and 1 kGy treated cut-cabbage. The effect of storage period on texture of the cut cabbage was also significantly different ($p \leq 0.05$). Comparing scores for days 1 and 15 (6.56 and 6.0) of the samples, these scores indicated significant differences between the two samples but scores for both days were not significant from scores (6.25) for the 8 day storage period. The interaction of storage period and irradiation doses was not significantly different ($p \leq 0.05$), i.e., the effect of storage period on the firmness of the cut cabbage was independent of irradiation treatment.

(Table 5) shows significant effect of irradiation dose and storage time on increased softness of fresh-cut cabbage samples. Generally, texture of both irradiated and unirradiated cut cabbage slightly decreased less than 1 during the storage period. This decrease in texture may be due to the fact that biochemical and enzymatic activities in the cut-cabbage during storage period might have cause breakage of intercellular bonds leading to the decrease in texture (Table 3).

With the exception of 2 kGy samples which had significant effect by 8 day of storage, all other samples were not significantly different from each other. The observation in this research is agreement with that of Lopez et al., who reported that storage period of 7 days, had no significant effect on both irradiated and non-irradiated minimally processed cabbage [32]. This agrees with that of Lopez et al., who reported that storage period of 7 days, had no significant effect on both irradiated and non-irradiated minimally processed cabbage [27].

Panelists were sensitive to changes in texture of irradiated cut-cabbage at different dose treatments. The decrease in texture of cut-cabbage may be attributed to breakage of cellular bonds by the free radicals generated irradiation treatment. Gunes et al., found that firmness of fresh-cut apples decreased as irradiation dose increased beyond a 0.34 kGy threshold [33]. This is in conformity with the observations of Yul et al., that fruit firmness decreased as irradiation dose increased [34]. Water-soluble pectin increased and oxalate-soluble pectin decreased at 0 and 1 day after 1 and 2 kGy irradiation. Irradiation may induce softening in some fruits [33]. Irradiation-induced softening was related to partial depolymerisation of cell- wall polysaccharides, cellulose, and pectin and to changes in activity of the

cell-wall enzymes pectinmethylestarase and polygalacturonase that act on pectin substrates.

On the other hand, the rate of decrease in firmness values of irradiated samples was higher than that of non-irradiated ones. It is clear that the highest decrease in firmness was observed with fresh-cut cabbage samples exposed to 3 kGy.

Smell: Panelists' scores for smell or aroma of the cut cabbage range between 5.32 and 6.80 represented by neither like nor dislike and like slightly for all the storage materials tested. The unirradiated samples scored between 5.52 and 6.80 while the irradiated cut cabbage score ranged from 5.32 to 6.52. Interestingly, both the highest and lowest scores were from unirradiated samples. The lowest aroma score of 5.32 was at 1 and 8 days and 6.80 was the highest score for same unirradiated samples on the 15 day of storage.

Although there were some minimal variations in the scores from panelists for samples of various irradiation doses yet these minimal changes were significantly different ($p>0.05$). For example, 1 kGy treated cut cabbage samples scored 5.64 for smell which was significantly different from 6.28 (unirradiated) and 6.36 for both 2 and 3 kGy. Unlike the effect of irradiation on smell, that of storage time was by and large not statistically significant ($p>0.05$).

There was no significant difference ($p>0.05$) of interaction between radiation and storage time as the effect of irradiation in reduction of scent was independent of storage time (Table 5).

The effect of irradiation on smell was not consistent since both 2 and 3 kGy samples had the same scores as the unirradiated samples which different from scores of 1 kGy samples. These wide variations of scores for aroma over the storage time may be due to activity of spoilage micro-organisms on the unirradiated product. These results are similar to observations made by Fan and Masson which stated that 'A decrease in characteristic aroma of cilantro Fan et al., and off-flavor of bell peppers Masson have been observed at irradiation doses of greater than or equal to 3 kGy [16,35-38]. Changes in flavour and aroma of fresh vegetables are highly correlated with microbial spoilage. Thus, low irradiation doses generally inhibit or delay development of off-flavours related to growth of spoilage organisms'.

Conclusion

It was concluded that 2 kGy did not have much effect on the phytochemical and sensory quality of cut cabbage. However, it was most effective for microbial decontamination of cut cabbage for shelf-life extension.

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