Changes in Quality, Liking, and Purchase Intent of Irradiated Fresh-Cut Spinach during Storage

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Abstract: The use of ionizing radiation to enhance microbial safety of fresh spinach at a maximum dose of 4 kGy has been approved by the U.S. Food and Drug Administration (FDA). However, whether spinach can tolerate those high doses of radiation is unclear. Therefore, this study was conducted to investigate the effects of irradiation and storage on quality, liking, and purchase intent of fresh-cut spinach. The oxygen radical absorbance capacity values and total phenolic content were not consistently affected by irradiation. However, the ascorbic acid content of irradiated sample decreased rapidly during storage, resulting in these samples being lower in ascorbic acid content than controls after 7 and 14 d of storage at 4 °C. Sensory evaluation by a 50-member panel revealed that purchase intent and ratings for liking of appearance, aroma, texture, flavor, and overall were not affected by irradiation at doses up to 2 kGy. Therefore, irradiation at doses up to 2 kGy may be used to enhance microbial safety without affecting consumer acceptance or overall antioxidant values of irradiated spinach.

Keywords: antioxidant, ascorbic acid, irradiation, sensory evaluation, spinach

Introduction

Due to their nutritional benefits, increased consumption of a variety of fresh and fresh-cut (minimally processed) fruits and vegetables is highly desirable. Unfortunately, as produce consumption has increased in the United States in recent years, so has the number of produce-related outbreaks of foodborne illness. Produce-related outbreaks accounted for 22.8% of foodborne illnesses from 1998 to 2007 (CSPI 2009; AFF 2010). Leafy greens such as lettuce and spinach are one of the major groups of fresh produce linked to these outbreaks due to contamination of human pathogens such as *Escherichia coli* O157:H7 (Gravani 2009; Mandrell 2009). Washing fresh-cut produce before and after cutting and prior to packaging are important steps in reducing microbial populations. Different chemical agents such as chlorine and peroxyacetic acid-based sanitizers have been studied to determine their efficacy in inactivating pathogenic bacteria on vegetables (Herdt and Feng 2009). However, their effectiveness in reducing microbial populations on fresh produce is very limited, achieving only about 1 log CFU/g reduction of common pathogens (Weissinger and others 2000; Niemira 2007). This is because pathogens are often associated with biofilms, attached in crevices and stomata on produce surfaces, or otherwise internalized within the produce interior (Ryser and others 2009).

Ionizing irradiation is effective in inactivating pathogens both on the surface and inside of fresh produce (Niemira 2007; Fan and others 2008; Gomes and others 2009; Mahmoud 2009). After irradiation at 0.7 kGy, *E. coli* O157:H7 and *Salmonella*, inoculated on the surface of spinach, were reduced by 4 logs (Neal and others 2008). Furthermore, *E. coli* O157:H7, internalized in leaves of spinach and lettuce, was inactivated by irradiation although higher doses were required compared to when the bacterium was on the surface (Niemira 2007). Recently, the Food and Drug Administration (FDA) allowed the use of ionizing radiation for the control of foodborne pathogens and extension of shelf-life in fresh iceberg lettuce and fresh spinach up to a maximum absorbed dose of 4.0 kGy (FDA 2008). There have been many studies of the effect of irradiation on quality of lettuce (Prakash and others 2000a; Fan and Sokorai 2002, 2008; Fan and others 2003). Spinach is a rich source of antioxidants and vitamins (Cao and others 1996; Proteggente and others 2000). However, studies on the effect of irradiation on spinach quality and nutrient content are limited. Fan and Sokorai (2008) found that vitamin C in spinach was reduced by 25% after 1 kGy irradiation. The appearance of spinach was not significantly affected by 1 kGy irradiation. Similarly, Gomes and others (2009) showed that the chlorophyll content and overall visual quality were not affected by irradiation at doses up to 1 kGy. Firmness was reduced by irradiation after 7 d of storage at 4 °C. Lester and others (2010) studied the effect of irradiation at doses up to 2 kGy on many nutrients of spinach, and found that vitamin C, lutein/zeaxanthin, violaxanthin, and β-carotene were significantly reduced by irradiation at 2 kGy. However, overall antioxidant capacity and vitamin C content of irradiated spinach have not been studied during storage or at higher doses. Furthermore, it is unclear whether fresh-cut spinach will tolerate 4 kGy irradiation without damage to quality. Therefore, the objective of this study was to investigate the effects of gamma radiation at doses up to 4 kGy on texture, nutritional quality, and acceptance of fresh-cut spinach after treatment and during postirradiation storage.

Materials and Methods

Sample preparation

Organic, ready-to-eat spinach in 1.16 kg bags as obtained from a California Farm through the Philadelphia wholesale market.

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Whole spinach leaves from 2 bags were randomized and treated as a replicate. Leaves (100 g for instrumental texture and nutrient analyses, 1 kg for sensory evaluation) were placed into perforated polyethylene film bags. Because a part of the spinach samples was used for taste tests, strict sanitization practice was followed to avoid any contamination. All potential contact surfaces during irradiation were sanitized using 70% ethanol or 300 ppm bleach. Gloves were worn and the product was maintained at 4 °C at all times. All products were treated with 0 (nonirradiated), 1, 2, 3, and 4 kGy gamma radiation. Each replicate was irradiated separately. After irradiation, samples were stored at 4 °C for 14 d.

Irradiation and dosimetry

Irradiation was conducted using a self-contained, Lockheed Corp. ^{137}Cs gamma radiation source (Marietta, Ga., U.S.A.). The unit has 23 ^{137}Cs pencils placed in an annular array around a 63.5 cm high stainless steel cylindrical chamber with a 22.9-cm internal diameter. The dose rate was 0.09 kGy/min. The dose rate was established using alanine transfer dosimeters from the Natl. Inst. of Standards and Technology (Gaithersburg, Md., U.S.A.). Corrections for source decay were made monthly. Variations in radiation dose absorption were minimized by placing the samples within a uniform area of the radiation field, and by using the same geometry for sample irradiation during the entire study. Routine dosimetry was performed in accordance with Intl. Organization for Standardization/American Society for Testing and Materials standards. The 5-mm diameter alanine dosimeters were placed into 1.2 mL cryogenic vials (Nalgene, Rochester, N.Y., U.S.A.), and the cryogenic vials were taped onto the samples prior to irradiation. After irradiation, the free-radical signals in the dosimeters were measured using a Bruker EMS 104 EPR Analyzer (Bruker Instruments, Rjeomstettem, Germany). The temperature in the radiation chamber was maintained at 4 °C by injecting the gas phase from a liquid nitrogen tank into the radiation chamber. Measured doses were within 10% of the target doses.

Ascorbic acid analysis

Ascorbic acid was analyzed as described earlier (Fan and Sokorai 2008). Samples (10 g) were homogenized with 20 mL 5% (62.5 mM) metaphosphoric acid using a homogenizer (Virtishear, Virtis, Gardiner, N.Y., U.S.A.) at a speed setting of 70 for 1 min. The homogenate was filtered through 4 layers of cheesecloth, and then the filtrate was centrifuged at 10000 *g* for 10 min at 4 °C in a Sorvall RC2-B refrigerated centrifuge (Kendro Laboratory Products, Newtown, Conn., U.S.A.). The supernatant was filtered through a 0.45 μm PVDF Durapore Millex-HV syringe filter (Millipore Corp., Bedford, Mass., U.S.A.). The filtered samples were placed into 2-mL vials, and analyzed using a Hewlett Packard Ti-series 1050 HPLC system (Agilent Technologies, Palo Alto, Calif., U.S.A.) consisting of an autosampler, an integral photodiode array detector, an autoinjector, and Hewlett–Packard Rev. A02.05 Chemstation. Injection volume was 20 μL. Separation of compounds was achieved with an Aminex HPX-87H organic acids column (300 (7.8 mm), fitted with a microguard cation H^+ cartridge, by elution with a mobile phase of 5 mM sulfuric acid at a flow rate of 0.5 mL/min. Column temperature was maintained at 30 °C using a column heater (Bio-Rad Laboratories, Hercules, Calif., U.S.A.). Ascorbic acid was monitored at 245 nm, and the sample ascorbic acid content was calculated from an ascorbic acid standard and expressed as μg/g fresh weight (FW).

Antioxidant analysis

Spinach leaves (10 g) after removal of leaf stalk were homogenized with 20 mL 70% methanol using a homogenizer (Virtishear) at a speed setting of 70 for 1 min. The homogenate was filtered through 4 layers of cheesecloth and then centrifuged at approximately 10000 *g* for 10 min at 5 °C in a Sorvall RC2-B refrigerated centrifuge (Kendro Laboratory Products). The supernatants were analyzed for antioxidant capacity and phenolic content. Antioxidant capacity was determined using the oxygen radical absorbance capacity (ORAC) method (Cao and others 1996; Ou and others 2001). For the ORAC assay, a BioTek Synergy HT Multi-mode Microplate Reader (Winooski, Vt., U.S.A.) was used. After 25 μL samples (diluted with phosphate buffer, pH 7.4 if necessary) were loaded into the wells of a microplate, the reaction mode of the instrument automatically pipetted and transferred fluorescein (150 μL, 40 nM) into the wells. The plate was incubated at 37 °C for 30 min before 2,2′-azobis(2-amidinopropane) dihydrochloride (25 μL, 153 mM) was injected into each well to start the reaction. Fluorescent filters were set to pass the light with an excitation wavelength of 485 nm and an emission wavelength of 528 nm. Readings were taken every minute for a duration of 30 min. Trolox, was used as a standard and phosphate buffer (25 μL, 75 mM, pH. 7.4) as a blank. The final results were calculated by comparison with Trolox standard curve using the differences of areas under the decay curves between the blank and a sample and were expressed as micromole Trolox equivalents (TE) per gram (μmol TE/g).

Determination of total phenolic content

Total phenolic content was measured using the Folin–Ciocalteu colorimetric method. After proper dilution, the diluted extract (0.1 mL) used for the ORAC assay was mixed with 0.2 mL of Folin–Ciocalteu reagent (Sigma Chemical Co., St. Lois, Mo., U.S.A.), and incubated for 1 min at 23 °C. Then, 3 mL of 5% Na_2CO_3 was added. Absorbances at 760 nm were recorded for the mixtures after 2 h incubation at 23 °C. Phenolic content was expressed as μmol/g gallic acid (GA) equivalent.

Instrumental texture

Texture was determined using the TA-XT2i Texture Analyzer (Texture Technology Corp., Scarsdale, N.Y., U.S.A.). Spinach samples without stems (15 g) were placed into a Kramer Shear press with 5 blades. The 5-flat plunger of the press was set at 70 mm from the bottom of the rectangular sample holding box, moved down to the sample at a speed of 2 mm/s, compressed the samples through the 5 slots, and stopped when it reached 5 mm below the bottom of the holding box. Forces over time were recorded using the Texture Expert software (version 1.22, Texture Technology). The maximum shear force and the area under the force-distance curve were then calculated.

Sensory evaluation

A quantitative affective test was used to determine liking and attitude of irradiated spinach because it would show whether irradiation affected acceptance (liking) by consumers (in-house panel) (Meilgaard and others 1999). The test was performed at the sensory evaluation room of USDA's Eastern Regional Research Center (ERRC). Panelists consisted of ERRC employees and were recruited so that the number of panelists for each session was 50. Panelists were selected based on their availability to participate, willingness to eat irradiated foods, and experience of consuming fresh spinach. Panelists were not compensated. Each panelist evaluated 5 samples (0 to 4 kGy) during each session. Samples were presented monadically in a random sequence, that is, a sample was presented, scored, and removed before the 2nd sample was given. Each replicate of samples were evaluated by 12 to 13 panelists. Samples were evaluated in environmentally controlled booths illuminated with indoor halogen PAR 30 1100 lumens, 75 W, narrow floodlight lamps (Osram Sylvania Products Inc., Winchester, Ky., U.S.A.). Prior to the taste test, a consent form with information about the purpose, nature, and procedure of the study was signed by panelists. Panelists were also asked to provide their age range, gender, and frequency of consuming spinach. On the day of taste testing, 4 spinach leaves were placed into 96 mL (3.25 oz**)** plastic portion cups labeled with a 3-digit code, covered with snap-on lids, and refrigerated for 1 to 1.5 h before being served to panelists. Panelists were asked to open the container, sniff the product, and give a rating for aroma liking. Then, the panelists gave a rating for appearance liking, and tasted the sample and gave ratings for texture, flavor, and overall liking. The traditional 9-point hedonic scale with the original categories (word only) was used (Peryam and Pilgrim 1957). The verbal scale consisted of 9 brief statements lining up horizontally with "dislike extremely" on the left and "like extremely" on the right. Panelists were asked to check a small square below the appropriate statement. Water and unsalted crackers were provided for cleansing the palate between samples. At the end of the session, panelists were asked to indicate their purchase intent. Numbers (1 to 9) were added to the liking categories and purchase intent after the sensory tests for statistical analysis. For likings, 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely. The assigned numbers for purchase intent were: 1 = definitely would buy, 2 = probably would buy, 3 = maybe/maybe not, 4 = probably would not buy, and 5 = definitely not buy.

Experimental design and statistical analysis

The experiments were performed as a completely randomized design. For quality analysis (texture, antioxidant, phenolic, and vitamin C), the treatments were repeated 6 times. For sensory evaluation, the number of replications was 4. The categorical data (9-point scale for the sensory evaluation and 5-point scale for purchase intent) were treated as on the continuum even though the scales only yield interval data (Lim and others 2009). Data were analyzed using statistical software (SAS, Version 9.2, SAS Inst. Inc., Raleigh, N.C., U.S.A.). The effects of storage, dose, and their interaction were analyzed using a generalized linear model performing a logistic regression analysis addressing the multinomial nature of the response. The least significant difference analysis was used to separate the means among irradiation doses and storage times.

Results and Discussion

Ascorbic acid content

There was no significant difference in ascorbic acid content between nonirradiated samples and those irradiated at doses lower than 4 kGy after 1 d of storage (Table 1). During storage, ascorbic acid content of both irradiated and nonirradiated samples decreased linearly ($P < 0.05$) during storage. However, the losses in ascorbic acid content in irradiated samples were much higher in irradiated samples compared to nonirradiated ones, and increased with increasing radiation dose.

The losses in ascorbic acid occurred during the 14 d storage were 33.0, 73.7, 82.5, 89.5, and 92.3% for 0, 1, 2, 3, and 4 kGy samples. As a result, the ascorbic acid content in irradiated samples was significantly lower than nonirradiated ones after 7 and 14 d of storage. For example, after 14 d of storage, ascorbic acid content in the 1, 2, 3, and 4 kGy samples were 40.6, 23.3, 14.5, and 9.5%, respectively, of that of nonirradiated samples.

Irradiation exerts its effect mostly through radiolysis of water in foods such as spinach in which water is the dominant component. Hydroxyl radicals and other radicals generated from water attack other food components, particularly those in proximity to water (water soluble), such as ascorbic acid. It is known that ascorbic acid can be converted to dehydroascorbic acid upon irradiation (Fan and Sokorai 2002; Fan and others 2002; Lester and others 2010). Although dehydroascorbic acid has vitamin C activity and its utilization in humans is the same as ascorbic acid, it is not as stable as ascorbic acid. Dehydroascorbic acid rapidly hydrolyzes to diketogulonate, which is very unstable and degrades further (Tannenbaum and others 1985; Bode and others 1990). Consequently, the ascorbic acid content of irradiated samples decreases during storage.

The rapid decrease in ascorbic acid in the irradiated samples during storage may be a stress response to irradiation (Reyes and others 2007). High CO_2 concentration during storage of fruits and vegetables was also found promoting the loss of ascorbic acid in spinach, due to stimulation of the oxidation of ascorbic acid and inhibition of dehydroascorbic acid reduction (Kader 2009). It would be interesting to study whether irradiation impacts glutathione, ascorbic acid peroxidase, and other enzymes that are involved in the catabolism of ascorbic acid.

Antioxidant and phenolic contents

In general, ORAC values were not significantly affected by irradiation even though the highest ORAC value was observed in the nonirradiated control sample on days 1 and 7 of storage (Table 2). Similar to ORAC values, phenolic content was not affected by irradiation at any dose (Table 2). During storage, phenolic content decreased linearly ($P < 0.05$) for all samples except the 4 kGy sample. No change in phenolic content and ORAC values of 4 kGy samples during storage may be due to *de nova* syntheses of phytochemicals induced by irradiation. For example, Fan (2005) found that irradiation (2 kGy) increased phenolic and antioxidant contents of lettuce and endive. Enhanced antioxidant content of plant tissues after irradiation is mainly attributed either to increased enzyme activity (for example, phenylalanine ammonia-lyase) or to the increased extractability from the tissues (Tomas-Barberan and Espin 2001; Bhat and others 2007). Spinach is a nutritive vegetable. The ORAC value of spinach was one of the highest among fresh vegetables (Cao and others 1996; Ou and

Table 1–Effect of irradiation and storage on ascorbic acid content (μg/g FW) of fresh-cut spinach.

	Storage time (d)		
Dose (kGy)	1	7	14
0	645 ± 94 aA[a]	557 ± 111 aAB	432 ± 42 aB
1	666 ± 91 aA	341 ± 120 bB	175 ± 78 bC
2	606 ± 92 abA	226 ± 114 bcB	106 ± 71 cC
3	596 ± 52 abA	189 ± 57 cB	63 ± 28 cdC
4	531 ± 94 bA	170 ± 58 cB	41 ± 13 dC

[a]The numbers are means followed by standard deviations ($n = 6$). Data in the same column followed by the same lower case letters and in the same row followed by the same upper case letters are not significantly ($P > 0.05$) different.

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others 2002). Irradiation did not have any effect on ORAC or the phenolic content, suggesting that irradiation would not affect the antioxidant properties of spinach.

Instrumental texture

The texture of spinach was expressed as the maximum force and the area under the curve of force over distance (time) (Table 3). The force and the area under the curve are the highest shear force and the work, respectively, required to cut through the samples. The 2 parameters represent hardness and toughness of samples as related to the process of mastication. In general, as dose increased, both maximum force and the area decreased linearly ($P < 0.01$) regardless of storage time, indicating tissue softening induced by irradiation. One day after irradiation, the maximum force and the area under the curve of spinach irradiated at 3 and 4 kGy were significantly lower ($P < 0.05$) than the nonirradiated ones. Seven days after irradiation, significant softening due to irradiation was observed only in 4 kGy samples. After 14 d of storage, all irradiated samples were softer than the nonirradiated controls. During storage, the texture of nonirradiated samples and most of the irradiated samples did not change. Tissue softening due to irradiation has been observed on lettuce (Prakash and others 2000a), strawberries (Yu and others 1996), papaya (Zhao and others 1996), cantaloupe (Boynton and others 2006), and apples (Fan and others 2005). Irradiation-induced softening may be due to the breakdown of cellular constituents such as pectin, cellulose, and hemicellulose, and loss of cell turgor. Irradiation-induced changes in water-soluble and oxalate-soluble pectins have been observed (Yu and others 1996; Prakash and others 2000a).

Table 2–Effect of irradiation and storage on antioxidant capacity and phenolic content of fresh-cut spinach.

Dose (kGy)	Storage time (d) 1	7	14
	ORAC value (μmol TE/g)		
0	102 ± 24 aA[a]	100 ± 17 aAB	84 ± 22 bcB
1	83 ± 7 bA	90 ± 9 aA	74 ± 11 cB
2	95 ± 22 abA	91 ± 26 aA	97 ± 7 aA
3	99 ± 22 abA	95 ± 8 aAB	85 ± 13 bcB
4	97 ± 24 abA	88 ± 11 aA	87 ± 12 abA
	Phenolic content (mg GA/g)		
0	118 ± 13 aA	107 ± 9 aB	105 ± 4 aB
1	111 ± 5 aA	101 ± 8 aB	101 ± 6 aB
2	118 ± 7 aA	97 ± 8 aB	105 ± 2 aB
3	119 ± 6 aA	106 ± 9 aB	102 ± 7 aB
4	116 ± 8 aA	106 ± 7 aA	107 ± 10 aA

[a]The numbers are means followed by standard deviations ($n = 6$). Data in the same column followed by the same lower case letters and in the same row followed by the same upper case letters are not significantly ($P > 0.05$) different.

Table 3–Effect of irradiation and storage on texture of fresh-cut spinach.

Dose (kGy)	Storage time (d) 1	7	14
	Maximum force (kg)		
0	32.0 ± 2.8 aA[a]	30.4 ± 4.8 aA	32.4 ± 2.6 aA
1	31.0 ± 3.1 aA	30.6 ± 3.4 aA	28.9 ± 3.8 bA
2	31.2 ± 3.4 aA	28.3 ± 2.9aB	27.5 ± 3.6 bcB
3	27.6 ± 4.7 bAB	29.0 ± 2.3aA	25.5 ± 3.4 cB
4	26.6 ± 4.1 bA	25.2 ± 3.0bA	25.0 ± 3.6 cA
	Area under the curve		
0	163 ± 19 aA	154 ± 26 aA	161 ± 16 aA
1	147 ± 14 bAB	152 ± 13 aA	138 ± 16 bB
2	153 ± 13 abA	144 ± 13 aAB	133 ± 19 bcB
3	141 ± 22 bcA	140 ± 14 aA	122 ± 15 bcB
4	134 ± 14 cA	123 ± 11 bB	129 ± 11 cAB

[a]The numbers are means followed by standard deviations ($n = 6$). Data in the same column followed by the same lower case letters and in the same row followed by the same upper case letters are not significantly ($P > 0.05$) different.

Sensory evaluation

The gender of panelists was about equal between male and female with males making up 51% of the panels. A wide range of panelists from each age group participated in the study among which 94% of panelists were aged from 21 to 70 y old. Two-thirds (76%) of panelists claimed consuming spinach at least once a month.

The average ratings on liking of aroma, appearance, flavor, texture, and overall are shown in Table 4. The degree of aroma liking was found to be significantly lower in 4 kGy sample compared to the nonirradiated sample 1 and 7 d after irradiation (Table 4). The aroma liking of other irradiated samples was ranked similarly as the nonirradiated control on the 2 sampling days. Lower aroma ranking was observed for the 2 and 3 kGy samples after 14 d of storage. During storage, the liking of aroma decreased linearly for all samples except 4 kGy samples. At day 1, 4 kGy sample had the lowest score of aroma liking and did not further deteriorate during storage. Irradiation at any dose did not significantly affect appearance liking of the spinach at any sampling day (Table 4) even though the appearance liking decreased during storage.

The flavor liking of spinach decreased linearly as dose increased regardless of storage time (Table 4). However, significant lower ranking of flavor liking was observed only for the 4 kGy samples compared to the nonirradiated control. The flavor liking of spinach did not change significantly during 14 d of storage at 4 °C.

The texture liking of spinach decreased linearly with increasing radiation dose 1 and 7 d after irradiation (Table 4). Similar to flavor ranking, significant changes in texture liking were observed only at doses of 3 and 4 kGy. Irradiation did not have any significant effect on the texture liking after 14 d of storage.

The overall liking of samples decreased linearly with increasing doses in all sampling days (Table 4). However, irradiation at 1 and 2 kGy did not significantly affect the overall liking of the samples by the panels. Differences in overall liking between irradiated and nonirradiated samples were significant at 4 kGy throughout the 14-d storage.

Irradiation affected consumer's purchase intent (Table 5). Purchase intent was ranked from definitely would buy as 1 to definitely not buy as 5. As doses increased, the number of people who would buy irradiated samples decreased and people who would not buy increased. Generally doses up to 2 kGy did not affect consumer purchase intent of irradiated spinach. But irradiation at doses of 3 and 4 kGy significantly decreased consumer's intent to purchase irradiated samples.

This is the 1st sensory evaluation of irradiated fresh-cut produce involving large panels (50 members). In earlier studies, only 3- to 15-member panels were used (Prakash and others 2000a, b; Fan and others 2003; Gomes and others 2009). Furthermore, only appearance and aroma were determined, and a taste test was not conducted in most of the previous studies. In addition, earlier studies only examined fresh produce irradiated at doses not exceeding 1 kGy. Earlier studies using small panels have demonstrated that irradiation at doses up to 1 kGy did not affect appearance and aroma of most fresh-cut fruits and vegetables (Fan and Sokorai 2008). In some cases, irradiated samples were preferred over nontreated or chlorinated counterparts (Prakash and others 2000b). Our results suggest that the liking of irradiated spinach was not significantly

Table 4–Effect of irradiation and storage on the degree of liking in aroma, appearance, flavor, texture, and overall of fresh-cut spinach. The scale was: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely.

Dose	Storage time (d)														
	Aroma			Appearance			Flavor			Texture			Overall		
(kGy)	1	7	14	1	7	14	1	7	14	1	7	14	1	7	14
0	6.5 ± 1.4 aA[a]	6.0 ± 1.3 aAB	5.9 ± 1.4 aB	6.8 ± 1.5 aA	6.1 ± 1.4 abB	6.1 ± 1.6 aB	6.5 ± 1.5 aA	6.3 ± 1.3 abA	6.4 ± 1.7 aA	7.0 ± 1.4 aA	6.6 ± 1.2 aA	6.5 ± 1.6 aA	6.7 ± 1.5 aA	6.3 ± 1.1 aA	6.3 ± 1.6 aA
1	6.6 ± 1.4 aA	5.9 ± 1.5 aB	5.6 ± 1.7 abB	6.8 ± 1.7 aA	6.4 ± 1.4 aAB	6.1 ± 1.7 aB	6.4 ± 1.9 abA	6.5 ± 1.3 aA	5.9 ± 1.7 abA	7.0 ± 1.6 aA	6.4 ± 1.4 abB	6.4 ± 1.6 aB	6.7 ± 1.6 aA	6.4 ± 1.3 aA	5.9 ± 1.7 abB
2	6.6 ± 1.9 aA	6.0 ± 1.5 aB	5.2 ± 1.5 bC	6.8 ± 1.5 aA	6.2 ± 1.6 abAB	5.9 ± 1.5 aB	6.2 ± 1.7 abA	6.0 ± 1.6 abcA	5.8 ± 1.7 abA	6.8 ± 1.4 abA	6.2 ± 1.6 abcAB	6.0 ± 1.6 aB	6.5 ± 1.4 aA	6.1 ± 1.5 abAB	5.8 ± 1.5 abB
3	6.4 ± 1.9 abA	5.5 ± 1.5 abB	5.2 ± 1.5 bB	6.8 ± 1.5 aA	5.7 ± 1.6 bB	5.9 ± 1.7 aB	5.9 ± 1.8 abA	5.9 ± 1.7bcA	5.8 ± 1.9 abA	6.3 ± 1.7 bA	5.8 ± 1.7 cA	6.1 ± 1.8 aA	6.2 ± 1.7 abA	5.7 ± 1.7 bA	5.8 ± 1.8 abA
4	5.8 ± 1.9 bA	5.3 ± 1.5 bAB	5.4 ± 1.8 abAB	6.4 ± 1.6 aA	6.1 ± 1.3 abA	5.8 ± 1.6 aA	5.8 ± 2.1 bA	5.5 ± 1.5 cA	5.5 ± 1.8 bA	6.2 ± 1.9 bA	6.0 ± 1.3 bcA	6.0 ± 1.8 aA	5.9 ± 2.0 bA	5.7 ± 1.4 bA	5.4 ± 1.8 bA

[a]The numbers are means followed by standard deviations ($n = 4$). Data in the same column followed by the same lower case letters and in the same row followed by the same upper case letters are not significantly ($P > 0.05$) different.

Table 5–Effect of irradiation and storage on purchase intent of fresh-cut spinach. The scale for purchase intent was: 1 = definitely would buy; 2 = probably would buy, 3 = maybe/maybe not, 4 = probably would not buy, and 5 = definitely not buy.

	Storage time (d)		
Dose (kGy)	1	7	14
0	1.9 ± 0.8 cB[a]	2.2 ± 0.8 bA	2.3 ± 1.0 bA
1	2.1 ± 1.1 bcB	2.2 ± 0.8 bB	2.6 ± 1.1 abA
2	2.3 ± 1.0 abA	2.4 ± 1.0 abA	2.6 ± 1.1 abA
3	2.4 ± 1.0 abA	2.6 ± 0.9 aA	2.6 ± 1.2 abA
4	2.6 ± 1.3 aA	2.5 ± 0.8 aA	2.9 ± 1.2 aA

[a]The numbers are means followed by standard deviations ($n = 4$). Data in the same column followed by the same lower case letters and in the same row followed by the same upper case letters are not significantly ($P > 0.05$) different.

affected by irradiation at doses up to 2 kGy. Consequently, the changes due to irradiation at doses up to 2 kGy did not affect consumer's purchase intent.

Even though we observed a large loss in ascorbic acid of irradiated (3 and 4 kGy) spinach during storage, the ORAC values were not affected by irradiation, probably because ascorbate made only a small contribution to the total antioxidant capacity of spinach. Phenolics are a major contributor to antioxidant capacity in fresh spinach (Proteggente and others 2000; Pandjaitan and others 2005) and correlated well with ORAC values (Pandjaitan and others 2005). In addition, the solvent (70% methanol) for extraction of antioxidants and phenolics used in our present study is not the best solvent for extracting and stabilizing ascorbic acid.

Conclusions

Irradiation at any dose employed did not significantly affect the appearance liking of spinach even though the appearance deteriorated over storage. It seems that spinach is more tolerant to irradiation than many other leafy greens such as lettuce, probably due to its higher antioxidant capacity and greater ascorbic acid content. Ascorbic acid serves as the primary water soluble antioxidant in plant tissues and preferentially interacts with reactive species such as those radicals generated from radiolysis of water, thus protecting cell constituents from oxidative damage. This may explain the higher tolerance of spinach to irradiation. It has been shown that the visual quality of spinach after storage was correlated with initial ascorbic acid content (Bergquist and others 2006). Spinach with higher ascorbic acid content had longer storage life.

It appears that there is a discrepancy among instrumental texture and texture liking by the consumer panel. Based on instrumental texture, samples irradiated even at doses of 1 and 2 kGy were sometimes softer than the nonirradiated control. However, texture liking by the consumer panel was similar between the nonirradiated samples and the 2 irradiated samples. It seems that slight softening due to irradiation may not have been perceived or did not affect consumer acceptance of the irradiated samples. Samples irradiated at higher doses (3 and 4 kGy) did result in lower texture liking.

Overall, our results suggest that irradiation at doses up to 2 kGy did not significantly affect the liking of cut spinach or overall antioxidant capacity of spinach even though irradiation promoted the loss of ascorbic acid during cold storage. Future studies are needed to investigate the mechanism for the loss of ascorbic acid during postirradiation storage.

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