# Quality of Irradiated Alfalfa Sprouts†

XUETONG FAN* AND DONALD W. THAYER

*U.S. Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, 600 East Mermaid Lane, Wyndmoor, Pennsylvania 19038, USA*

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## ABSTRACT

Alfalfa (*Medicago sativa* L.) sprouts were irradiated with gamma rays at doses of 0, 0.85, 1.71, and 2.57 kGy at 5°C, then stored at 6°C for 14 days. Antioxidant power, total ascorbic acid (TAA) (ascorbic acid plus dehydroascorbic acid), carotenoid, chlorophyll, and color were measured at 1, 7, and 14 days of storage. Antioxidant power increased linearly with radiation dose at both 1 and 7 days of storage. Irradiation had minimal effect on TAA content when compared with the decrease in TAA content during storage. Carotenoid content of sprouts irradiated at 1.71 and 2.57 kGy was higher than that of control at 7 days of storage. Irradiation did not have a consistent effect on chlorophyll content or color.

Consumption of raw sprouts has been implicated in several outbreaks of foodborne illness *(24)*. Approaches to inactivate human pathogens on sprouts are being investigated. One approach is ionizing irradiation, which is very effective in reducing foodborne pathogens *(27)*; however, the effect of irradiation on quality, especially the nutritional quality of alfalfa sprouts, is unknown.

Alfalfa sprouts are considered highly nutritional foods, containing many vitamins and antioxidants *(2)*. Consumption of fresh vegetables has been associated with lower incidence and lower mortality rates of cancers and cardio- and cerebrovascular diseases *(20, 34)*. The protection that vegetables provide against these diseases has been attributed to endogenous antioxidants. Antioxidant activity of alfalfa sprouts is one of the highest among the tested vegetables *(5)*. Therefore, the effect of irradiation on antioxidant activity of alfalfa sprouts is an important issue with respect to quality.

Alfalfa sprouts contain a significant amount of ascorbic acid (AA) *(12)*, an important antioxidant in plants. There are some conflicting reports on the effect of irradiation on AA content in fruits and vegetables *(30, 31)*. Either no effect or a decrease in AA content has been reported. Although irradiation reduces the amount of AA immediately after treatment, no significant difference between irradiated and nonirradiated potatoes is found after prolonged storage *(30)*. Graham and Stevenson *(11)* have shown that irradiation at doses of 1, 2, and 3 kGy reduces AA and total AA (TAA: AA plus dehydroascorbic acid) content of potatoes, but the reduction is small compared with the variation among cultivars. Loss of 64 to 92% AA has been observed in asparagus, broccoli, green beans, and spinach in response to irradiation *(25)*. In general, irradiation treatment reduces AA content in strawberries *(11, 21)* and tomato fruits *(1)*. Many factors influence the impact of radiation on AA, such as cultivar, developmental stage, and storage time *(30)*. In many earlier studies, only AA was analyzed, but the oxidized form of AA—dehydroascorbic acid—is also biological active. Therefore, it is essential to determine the TAA to actually evaluate vitamin C content.

Although AA contributes to the total antioxidant activity, the majority of the antioxidant activity of many vegetables comes from compounds other than AA *(32)*, such as carotenoids and flavonoids *(5, 15, 23)*. Alfalfa sprouts contain the highest amount of carotenes among several sprouts *(2)*; however, up to 95% of carotenoids can be degraded with irradiation at a dose of 10 kGy *(9, 19)*.

The greenness of leaf vegetables depends on chlorophyll content in the tissue. Senescence of green plant tissues involves breakdown of chlorophyll. Chlorophyll is sensitive to irradiation *(28, 36)*. A linear decrease in chlorophyll content of green beans and broccoli was directly related to the absorbed dose over the range of 4.9 to 92.9 kGy *(36)*. Irradiation temperature, type of vegetable, and headspace atmosphere have an influence on degradation of carotenoids and chlorophyll *(9)*. Many earlier studies on degradation of carotenoids and chlorophyll due to irradiation have been conducted on frozen or canned vegetables and at high doses *(9, 19, 25, 36)*. Effect of low-dose gamma radiation on degradation of chlorophyll and carotenoids in many fresh vegetables has not been reported.

The objective of this study was to investigate the impact of gamma radiation at doses that inactivate common foodborne pathogens on the quality of alfalfa sprouts during subsequent storage at 6°C.

## MATERIALS AND METHODS

**Plant source.** Six-day-old alfalfa sprouts (*Medicago sativa* L.) grown from mixed seeds of three cultivars (Dawson, Buffalo, and Timeron) were obtained from a local commercial sprout grower and transported to the laboratory on ice in insulated chests. Sprouts (approximately 100 g) were placed into 15- by 15-cm Ziplock bags perforated with four holes (6 mm in diameter each

* Author for correspondence. Tel: 215-836-3785; Fax: 215-233-6406; E-mail: xfan@arserrc.gov.

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hole). The packages containing sprouts were randomly assigned to each treatment. There were four packages per treatment, and each package was considered as a replicate.

**Irradiation and storage.** The sprouts in packages were treated with 0-, 0.85-, 1.71-, or 2.57-kGy gamma radiation at 5 ± 2°C using a $^{137}Cs$ source. The custom-made, self-contained gamma-radiation source (Lockheed Georgia Company) 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 source strength at the time of this study was ca. 109,159 Ci (4.039 PBq) with a dose rate of 0.10 kGy $min^{-1}$. The dose rate was established using alanine transfer dosimeters from the National Institutes of Standards and Technology, Gaithersburg, Md. 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, by irradiating them within a polypropylene container (4-mm wall) to absorb Compton electrons, and by using the same geometry for sample irradiation during the entire study. Radiochromic film dosimeters (Far West Technologies, Inc., Goleta, Calif.) were used to establish doses absorbed by the sprouts. The doses were calculated from a calibration curve. Maximum/minimum dose ratio was 1.11. More detailed description of the dosimetry techniques has been reported previously *(29)*. Control samples were handled similarly without irradiation treatment. After irradiation, samples were stored in air at 6°C for 14 days. Color, TAA, antioxidant power, carotenoid, and chlorophyll were measured at 1, 7, and 14 days of storage.

**Color measurement.** Color was measured with a color meter (HunterLab MiniScan XE, Hunter Associates Laboratory, Reston, Va.) using a 36-mm measuring aperture. The color meter was calibrated using the standard white and black plates. D65/0° was the illuminant and viewing geometry. Five readings were made on alfalfa sprouts of each package. The reading was made on approximately 20-g samples. After color measurement, samples of sprouts were rapidly frozen using liquid nitrogen, then stored at −76°C until TAA, pigments, and antioxidant power were analyzed.

**TAA measurement.** Analysis of TAA was measured according to Graham and Annette *(10)*. Samples (15 g) were homogenized with 15 g of 5% (62.5 mM) metaphosphoric acid using a homogenizer (Virtishear, Virtis, Gardiner, N.Y.) at a speed setting of 70 for 2 min. The homogenate was filtered through Whatman no. 2 paper filter (Maidstone, Kent, UK), then the filtrate was centrifuged at 1,300 × *g* for 10 min at 5°C in a Sorvall RT6000B refrigerated centrifuge (DuPont Co., Wilmington, Del.). Supernatant was then used for analysis of TAA. Dehydroascorbic acid in the supernatant was reduced to AA using a method of Hughes *(13)*. A 0.3-ml sample of supernatant was added to 0.05 ml of 30 mM DL-homocysteine solution, and the pH was adjusted to 6.5 to 7.0 by slow addition of 0.1 ml of 2.6 M dipotassium hydrogen phosphate. After 30 min at 23°C, the reaction was stopped by addition of 0.15 ml of 3% (wt/vol) metaphosphoric acid. The mixture was filtered through a 0.2-μm Acrodisc LC 13 PVDF syringe filter (Gelman Sciences, Ann Arbor, Mich.), and a 20-μl filtrate aliquot was analyzed using high-performance liquid chromatography. The high-performance liquid chromatography system consisted of a Beckman model 1A pump (Beckman Instruments Inc., Fullerton, Calif.), an Autochrom sample injector (Rheodyne Inc., Cotati, Calif.), a Bio-Rad model 1790 UV/VIS detector (Bio-Rad Laboratories, Hercules, Calif.) with wavelength set at 245 nm, and an HP3390A integrator (Hewlett Packard, Palo Alto, Calif.). Separation of compounds was achieved with an Aminex HPX-87H organic acids column (300 by 7.8 mm) fitted with a microguard cation H+ cartridge (Bio-Rad) eluted with a mobile phase of 5 mM sulfuric acid at a flow rate of 0.5 ml $min^{-1}$. Column temperature was maintained at 30°C using a column heater (Bio-Rad).

**Analysis of antioxidant power.** Samples (10 g) were extracted with 15 ml cold ethanol using a homogenizer (Virtishear, Virtis) at a speed setting of 70 for 2 min. The homogenate was filtered through a glass-fiber filter (GF/A, Whatman, Maidstone) under vacuum, and the filtrate was transferred into a 25-ml volumetric flask and adjusted to a 25-ml value using ethanol. Antioxidant power in the crude extract was determined using the ferric reducing antioxidant power (FRAP) assay *(3, 4)*. The FRAP reagent was prepared daily by combining 300 mM acetate buffer (pH 3.6), 10 mM 2,4,5,-tripyridyl-s-triazine in 40 mM HCL, and 20 mM $FeCl_3$ in the ratio of 10/1/1 (vol/vol/vol). Three milliliters of FRAP reagent was added to 100 μl extract. The mixture was incubated at 23°C for 30 min before absorbance at 593 nm was measured with a Sargent-Welch 6-550 UV/VIS spectrophotometer (Pye Unicam Ltd., Cambridge, UK). FRAP values were calculated from an AA standard curve. One micromole AA equals 2 μmol FRAP value *(3)*.

**Measurement of carotenoids and chlorophyll.** Samples (5 g) were homogenized on ice with 20 ml cold acetone using a homogenizer (Virtis) at a speed setting of 70 for 2 min. The homogenate was filtered through glass-fiber filters (GF/A, Whatman, Maidstone) under vacuum, and the residue (the filter cake layer) was washed twice with two 5-ml washings of cold acetone. The filtrate was evaporated under vacuum to approximate 20 ml, then transferred to a 25-ml volumetric flask and adjusted to 25 ml with acetone. After overnight storage at −20°C, 2 ml acetone extract was added to a 15-ml centrifuge tube; then, 0.8 ml deionized water and 3 ml of diethyl ether were added. The tube was sealed with a cap and shaken vigorously, and diethyl ether phase containing chlorophyll and carotenoids was transferred to a fresh tube containing 2 ml deionized water. The tube was sealed and vortexed for 15 s, and chlorophyll and carotenoids in the water-saturated diethyl ether phase were measured using a Shimadzu UV-1601 spectrophotometer (Shimadzu Scientific Instruments, Columbia, Md.). The content of chlorophyll *a*, chlorophyll *b*, and carotenoid was calculated using equations developed by Lichtenthaler *(18)*. Total chlorophyll was the sum of chlorophyll *a* and *b*.

**Statistical analysis.** There were four replicates each treatment. Each package (100 g) of sprouts was regarded as a replicate. Data were subjected to statistical analysis using SAS version 6.12 (SAS Institute, Raleigh, N.C.). Various quality parameters as function of radiation dose and storage time were analyzed by the least significant difference analysis using the general linear model procedure. The linearity effect of radiation dose and storage time was analyzed using orthogonal comparisons, and significance of polynomials was calculated using the Contrast statement of the general linear model procedure.

## RESULTS AND DISCUSSION

TAA content of both nonirradiated and irradiated alfalfa sprouts decreased rapidly during storage at 6°C. Compared to the sprouts at day 1, nonirradiated sprouts lost 65.1 and 88.3% of TAA after storage at 6°C for 7 and 14 days, respectively (Table 1). At 1 day of storage, the TAA content of irradiated sprouts was similar to that of nonirradiated samples. At 7 days of storage, sprouts irradiated at 2.57 kGy had less TAA content than nonirradiated ones, and the

TABLE 1. *Total ascorbic acid content (μg $g^{-1}$ fresh wt) of irradiated and nonirradiated sprouts during storage at 6°C; sprouts were irradiated with 0-, 0.85-, 1.71-, and 2.57-kGy gamma radiation at 5°C, then stored in air at 6°C; total ascorbic acid was measured at 1, 7, and 14 days of storage; values were means of four replicates*

| Irradiation dose (kGy) | Storage time (day) 1 | 7 | 14 | $LSD_{0.05}$[a] | Linear | Quadratic |
|---|---|---|---|---|---|---|
| 0 | 42.5 | 14.8 | 5.0 | 4.0 | ***[b] | *** |
| 0.85 | 37.0 | 14.6 | 3.9 | 6.2 | *** | * |
| 1.71 | 39.5 | 12.4 | 4.8 | 10.3 | *** | ** |
| 2.57 | 38.1 | 10.0 | 5.3 | 4.1 | *** | *** |
| $LSD_{0.05}$ | 10.6 | 3.3 | 1.0 | | | |
| Linear | NS | ** | NS | | | |
| Quadratic | NS | NS | * | | | |
| Cubic | NS | NS | NS | | | |

[a] The least significant difference at $P < 0.05$.
[b] NS, *, **, or *** indicates nonsignificant or significant at $P <$ 0.05, 0.01, and 0.001, respectively.

TABLE 2. *Antioxidant power (μmol $kg^{-1}$ fresh wt) of irradiated and nonirradiated sprouts during storage at 6°C; sprouts were irradiated with 0-, 0.85-, 1.71-, and 2.57-kGy gamma radiation at 5°C, then stored in air at 6°C; antioxidant was measured using the ferric reducing antioxidant power assay at 1, 7, and 14 days of storage; the values are the means of four replicates*

| Irradiation dose (kGy) | Storage time (day) 1 | 7 | 14 | $LSD_{0.05}$[a] | Linear | Quadratic |
|---|---|---|---|---|---|---|
| 0 | 1,110 | 1,162 | 1,231 | 149 | NS[b] | NS |
| 0.85 | 1,179 | 1,171 | 1,189 | 129 | NS | NS |
| 1.71 | 1,227 | 1,215 | 1,291 | 192 | NS | NS |
| 2.57 | 1,362 | 1,289 | 1,316 | 118 | NS | NS |
| $LSD_{0.05}$ | 184 | 85 | 148 | | | |
| Linear | * | ** | NS | | | |
| Quadratic | NS | NS | NS | | | |
| Cubic | NS | NS | NS | | | |

[a] The least significant difference at $P < 0.05$.
[b] NS, *, **, or *** indicates nonsignificant or significant at $P <$ 0.05, 0.01, and 0.001, respectively.

TAA content decreased linearly with radiation dose. At 14 days of storage, sprouts irradiated with 2.57-kGy radiation had higher TAA content than those irradiated with 0.85 kGy.

Our results showed that TAA decreased rapidly during storage at 6°C. TAA content of irradiated alfalfa sprouts did not consistently differ from nonirradiated ones during the 14 days of storage at 6°C (Table 1). Storage duration had a much larger effect on TAA content than irradiation. Similar results have been observed on endive *(16)*. Nonirradiated endive lost nearly half of TAA at 2 days of storage at 0°C. Irradiation at 1 kGy promoted the loss of TAA over 2 days of storage; however, there was no difference in TAA content between irradiated and nonirradiated endive at 5 days of storage *(16)*. Techniques such as modified atmosphere storage may reduce this loss. Controlled or modified storage of fruits and vegetables generally results in better retention of AA, probably because of its ability to retard senescence *(17, 33)*.

FRAP values of alfalfa sprouts did not change much during storage (Table 2) but increased linearly ($P < 0.05$) as radiation dose increased at 1 and 7 days of storage (Table 2). At 14 days of storage, the difference became nonsignificant. TAA was not the major component of antioxidants in alfalfa sprouts, accounting for less than 6% of total antioxidant power (data not shown). Antioxidant activity of alfalfa sprouts is one of the highest among the vegetables surveyed *(5)*. It appears that there are compounds other than AA contributing to antioxidant power, as shown in many other vegetables *(5)*.

Carotenoid content did not change much during storage (Table 3). Irradiation had no significant effect on carotenoid content at 1 day of storage. Carotenoid content, however, increased with radiation dose at 7 days of storage, and the difference disappeared at 14 days.

Total chlorophyll content did not change much during storage (Table 4). It appears that chlorophyll content was promoted by irradiation at 1 and 7 days, but the increase was not statistically significant. Irradiation did not affect the ratio of chlorophyll *a* to chlorophyll *b*, except that at 14 days, the sprouts irradiated at 2.57 kGy had a lower ratio of chlorophyll *a* to *b* compared to the nonirradiated ones. During storage at 6°C, the chlorophyll *a/b* ratio decreased in both irradiated and nonirradiated sprouts. Based on visual observation, color of sprouts was not markedly changed during storage and was not affected by irradiation. Instrumental measurement of color, however, revealed that chroma of all sprouts increased during storage (Table 5). The increase in chroma indicated the sprouts were turning yellow during storage at 6°C. Sprouts irradiated at 0.85 and 1.71 kGy had lower chroma than nonirradiated sprouts and lower chroma than those irradiated at 2.57 kGy at 7 days of storage, suggesting sprouts irradiated at 0.85 and 1.71 kGy were greener than nonirradiated ones.

TABLE 3. *Carotenoid content (μg $g^{-1}$ fresh wt) of irradiated and nonirradiated sprouts during storage at 6°C; sprouts were irradiated with 0-, 0.85-, 1.71-, and 2.57-kGy gamma radiation at 5°C, then stored in air at 6°C; carotenoids were measured at 1, 7, and 14 days of storage; the values were means of four replicates*

| Irradiation dose (kGy) | Storage time (day) 1 | 7 | 14 | $LSD_{0.05}$[a] | Linear | Quadratic |
|---|---|---|---|---|---|---|
| 0 | 20.3 | 18.1 | 22.2 | 5.6 | NS[b] | NS |
| 0.85 | 23.3 | 20.1 | 22.6 | 8.1 | NS | NS |
| 1.71 | 23.6 | 23.8 | 26.6 | 8.5 | NS | NS |
| 2.57 | 22.8 | 24.8 | 22.6 | 8.7 | NS | NS |
| $LSD_{0.05}$ | 9.1 | 3.7 | 8.6 | | | |
| Linear | NS | *** | NS | | | |
| Quadratic | NS | NS | NS | | | |
| Cubic | NS | NS | NS | | | |

[a] The least significant difference at $P < 0.05$.
[b] NS, *, **, or *** indicates nonsignificant or significant at $P <$ 0.05, 0.01, and 0.001, respectively.

TABLE 4. *Total chlorophyll content (μg $g^{-1}$ fresh wt) and chlorophyll a/chlorophyll b ratio of irradiated and nonirradiated sprouts during storage at 6°C; sprouts were irradiated with 0-, 0.85-, 1.71-, and 2.57-kGy gamma radiation at 5°C, then stored in air at 6°C; chlorophyll was measured at 1, 7, and 14 days of storage; values were means of four replicates*

| Irradiation dose (kGy) | Storage time (day) 1 | 7 | 14 | $LSD_{0.05}$[a] | Linear | Quadratic |
|---|---|---|---|---|---|---|
| Total chlorophyll content | | | | | | |
| 0 | 91.3 | 88.8 | 116.0 | 41.0 | NS[b] | NS |
| 0.85 | 120.8 | 97.1 | 107.1 | 54.9 | NS | NS |
| 1.71 | 118.5 | 112.4 | 127.2 | 59.7 | NS | NS |
| 2.57 | 114.8 | 117.6 | 112.1 | 41.0 | NS | NS |
| $LSD_{0.05}$ | 64.1 | 30.9 | 43.0 | | | |
| Linear | NS | NS | NS | | | |
| Quadratic | NS | NS | NS | | | |
| Cubic | NS | NS | NS | | | |
| Chlorophyll *a*/chlorophyll *b* | | | | | | |
| 0 | 3.5 | 3.3 | 2.9 | 0.4 | * | NS |
| 0.85 | 3.2 | 3.2 | 2.8 | 0.3 | * | NS |
| 1.71 | 3.2 | 3.1 | 2.8 | 0.2 | ** | NS |
| 2.58 | 3.1 | 3.2 | 2.7 | 0.2 | NS | NS |
| $LSD_{0.05}$ | 0.6 | 0.3 | 0.2 | | | |
| Linear | NS | NS | NS | | | |
| Quadratic | NS | NS | NS | | | |
| Cubic | NS | NS | NS | | | |

[a] The least significant difference at $P < 0.05$.
[b] NS, *, **, or *** indicates nonsignificant or significant at $P <$ 0.05, 0.01, and 0.001, respectively.

TABLE 5. *Change in color (chroma) of irradiated and nonirradiated sprouts during storage at 6°C; sprouts were irradiated with 0-, 0.85-, 1.71-, and 2.57-kGy gamma radiation at 5°C, then stored in air at 6°C; color was measured at 1, 7, and 14 days of storage; values were means of four replicates*

| Irradiation dose (kGy) | Storage time (day) 1 | 7 | 14 | $LSD_{0.05}$[a] | Linear | Quadratic |
|---|---|---|---|---|---|---|
| 0 | 12.1 | 12.9 | 13.1 | 0.5 | ***[b] | NS |
| 0.85 | 11.6 | 12.2 | 13.2 | 0.4 | *** | NS |
| 1.71 | 12.0 | 12.3 | 13.1 | 0.4 | *** | NS |
| 2.57 | 12.3 | 12.9 | 13.4 | 0.4 | *** | NS |
| $LSD_{0.05}$ | 0.4 | 0.5 | 0.5 | | | |
| Linear | NS | NS | NS | | | |
| Quadratic | * | *** | NS | | | |
| Cubic | NS | NS | NS | | | |

[a] The least significant difference at $P < 0.05$.
[b] NS, *, **, or *** indicates nonsignificant or significant at $P <$ 0.05, 0.01, and 0.001, respectively.

The *D*-values (dose required to achieve 90% mortality) for inactivation of *Salmonella* and *Escherichia coli* O157:H7 in sprouts were 0.46 and 0.31 kGy, respectively *(27)*. A 2.3-kGy gamma radiation would be required to achieve the 5-log reduction of both pathogens recommended by the National Advisory Committee on Microbiological Criteria for Foods *(24)*. Based on our results, gamma radiation at 2.3 kGy would not affect content of TAA, chlorophyll, color, or carotenoid, but it would increase the antioxidant power. Irradiation at 1.0 kGy eliminated *Listeria monocytogenes* and *E. coli* O157:H7 and extended the shelf life of diced celery by maintaining color, texture, and aroma *(26)*.

After 17 days of storage, some nonirradiated alfalfa sprouts became brown and mushy, whereas irradiated sprouts did not develop any of these symptoms (data not shown). The preservation of sprouts by irradiation may be due to reduced spoilage microorganisms on alfalfa sprouts *(27)*. Unlike many fruits and vegetables, which develop phytotoxic injury following irradiation at doses of 1 kGy or above *(14)*, alfalfa sprouts appear to be tolerant to gamma radiation. The impact of ionizing radiation on fresh fruits and vegetables is largely due to free radicals generated during irradiation. Alfalfa sprouts are young seedlings and contain high amounts of antioxidants *(5)*. The tolerance of alfalfa sprouts to irradiation may be due to their high antioxidant power. Plants with high levels of antioxidants, either constitutive or induced, have a greater resistance to oxidative damage *(8)*. Many early studies showed AA, chlorophyll, and carotenoids were sensitive to irradiation *(9, 30, 36)*. Our results show that irradiation did not consistently promote loss of TAA, chlorophyll, or carotenoid. The high antioxidant power of alfalfa sprouts may have a protective role against irradiation-induced losses in TAA, chlorophyll, and carotenoids.

Irradiation increased antioxidant power of sprouts. Plant tissues are able to adapt to the adverse conditions through increasing in endogenous antioxidants, including AA, glutathione, carotenoids, α-tocopherol, and enzymatic antioxidants *(35)*. These antioxidants can effectively scavenge and remove the toxic products before cellular damage occurs. Free radicals generated during irradiation may act as stress signals and may trigger the same stress responses in alfalfa sprouts, resulting in higher antioxidant content. Irradiation, however, did not stimulate the increase in TAA content. Compounds other than AA may be stimulated by irradiation. Gamma radiation induces accumulation of 4-(3-methyl-2-butenoxy) isonitrosoacetophenone in citrus fruits. The compound exhibits both antioxidant and antifungal activities *(6)*. Flavonoids that have antioxidant activity can also be induced by gamma and x-ray radiation *(22)*. The increased FRAP value due to irradiation has been also observed in orange juice *(7)*.

This study demonstrates that irradiation, at doses inactivating common foodborne human pathogens such as *Salmonella* and *E. coli* O157:H7, did not consistently influence contents of TAA, carotenoids, and chlorophyll, or color. In fact, irradiation increased the antioxidant power of sprouts during the first week of postirradiation storage at 6°C. Our results further suggest that quality changes occurring during storage were much larger than those due to irradiation. Irradiation can be used to enhance safety of sprouts without loss in appearance or nutrient quality.

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