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Research Article

The effect of seed priming with UV and gamma rays on the growth, production, and storage ability of cauliflower heads

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Abstract

The goal of the current study was to evaluate the effects of gamma ray, UV-C, UV-A (ultraviolet) treatments as seed priming on the growth, yield, quality, and the storage ability of cauliflower heads. The seeds were exposed to the following treatments: 50 and 75 kGy (gamma ray), UV-C for 15, 30, 45 minutes, and UV-A for 15, 30, 45 minutes. Plant growth and yield parameters were evaluated at the harvest time. The cauliflower heads from previous treatments were stored at 5° C for 16 days to evaluate their shelf-life traits. The results indicated that gamma ray, UV-C, and UV-A treatments enhanced the plant growth characteristics including plant height, leaf length, number of leaves, plant fresh weight, SPAD reading, and plant dry weight. Additionally, the cauliflower seeds treated with different treatments showed higher total yield, head diameter, and head weight than the control plants. The storage ability including weight loss, total soluble solids, and antioxidant capacity during refrigerated storage of cauliflower heads was not affected by the different treatments, however UVA treatment enhanced vitamin C and phenolic compounds compared to the control.

Keywords: gamma rays; growth; seed priming; storage; quality; UV-A; UV-C

Introduction

A popular vegetable from the Brassica family is cauliflower that contains many important phytochemicals such as minerals, fibers, phenolic compounds, carotenoids, and glucosinolates (Aly *et al*., 2021; El-Bauome *et al*., 2022). Prior substances have demonstrated efficacy in preventing a variety of chronic diseases, including various forms of cancer (Kapusta-Duch *et al*., 2019). However, because its high-water loss and high respiration rate, it is highly perishable after harvest (Nasrin *et al*., 2022). The decline in the shelf-life, marketing

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value, and nutritional value of cauliflower curds after harvest is due to many factors such as yellowing and browning of curd, losing of compactness, opening of florets, development of an undesirable brown spots, and increasing microbial risk (Zhan *et al*., 2014). To increase the shelf-life of cauliflower curds, after harvest, a variety of techniques have been utilized, including storage in modified atmosphere packaging and exposure) to light at a dosage of 24 mol $m^2.s^{-1}$ (Nasrin *et al*., 2022). Moreover, various pre-harvest treatments, including spraying with methyl jasmonate (500 M) before 4 days of harvest, have been studied to improve the quality and shelf-life of cauliflower curds (Ku *et al*., 2013).

It has been established that gamma rays are a quick and effective way to change morphological, physiological as well as biochemical processes in most plants. Because they produce free radicals in cells, gamma rays as, an ionizing radiation, have an impact on plant growth and development by causing several biological changes in cells and tissues (Wi *et al*., 2005). The primary biological effects of irradiation is the production of free radicals from the hydrolysis of water, which can alter an anti-oxidation mechanism and lead to the buildup of phenolics and most pigments of the chlorophyll (Wi *et al*., 2007). According to previous report, higher doses of Gy were inhibitory, whilst lower levels might have been stimulatory. Low levels of radiation may accelerate the young embryo's enzymatic activation and awakening, which speeds up cell division and influences not only germination but also vegetative growth (Piri *et al*., 2011; Aly *et al*., 2023a,b).

According to previous studies, large exposure time of gamma-irradiation inhibit plant growth whereas low doses promote plant development, including seed germination, growth of plant, the activity of several enzymes, and plant production (Beyaz *et al*., 2016; Kim *et al*., 2005). Low doses are those that are less than 1 KGy of γ-rays (Zaka and Chenal, 2004). Low doses were found to improve the growth and germination rates of cucumber and okra plants (Jaipo *et al*., 2019) total yield and fruits number of tomatoes (Wiendl *et al*., 2013) and photosynthetic pigment concentration in lettuce (Marcu *et al*., 2013).

The influence of γ-rays on plants development is varied depends on several factors such as phenotypes, treated organs, age at treatment, and the morphology of the plant (Gudkov *et al*., 2019). Treated seeds with low dose of gamma-rays (below 100 Gy) were effective for increasing plant growth of some crops such as okra (Asare *et al*., 2017) and lettuce (Marcu *et al*., 2013). However, the influence of gamma irradiation as seed treatments, on the storage ability of vegetable crops including cauliflower remains unknown. The application of different types of radiation such as UV and gamma rays is considering non-invasive methods that are eco-friendly and enhance the germination rate and the growth of seeds (Thakur *et al*., 2022).

The effect of ultraviolet light including UVA (320 nm to 400 nm), UVB (280 nm to 320 nm), and UVC (200nm to 280 nm) on the storage ability of horticultural crops after harvest has recently received increased attention (Urban *et al*., 2016). There have been numerous reports of the use of radiation processing to improve the quality and extend the shelf life of minimally processed vegetables such as cabbage (Ahn *et al.,* 2005), potatoes (Lin *et al*., 2017), and French beans (Gupta *et al*., 2012). Some previous studies showed that exogenous ultraviolet application can increase the quality of crops. For example, Liao *et al*. (2016) recorded that treating spinach, leek, and cabbage with 2.46 kJ/m2 UVC after harvest maintained total soluble protein, vit. C, and the content of chlorophyll through refrigerated storage compared with untreated samples. Additionally, bioactive compounds including total phenolics and glucoraphanin of broccoli florets were increased by 9 kJ/m2 UV-Cexogenous application (Formica-Oliveira *et al*., 2017). Other works that evaluated the influence of UVA on plant growth are limited. For example, it has been reported that UVA application enhancing photosynthesis and biomass accumulation of some plants (Verdaguer *et al.*, 2017). The irradiated seeds of vegetables by either UVA or UVC lights to improve growth and production of some fruits and vegetables were studied. To the best of our current knowledge, this is the first study to evaluate the effect of radiation on cauliflower seeds. Additionally, the effect of seed radiation on storage ability of cauliflower were not studied before. Therefore, the aims of this study were to evaluate the individual effects of Gy, UVA and UVC on cauliflower yield, quality, chemical composition, and shelf-life at various doses.

Materials and Methods

Irradiation by gamma rays

Cauliflower seeds (*Brassica oleracea var. botrytis* L.) cv. 'AD6033' was used in this experiment. This is a method developed by preliminary studied. Cauliflower seeds were exposed to gamma-rays from ^{60}Co at the laboratory of the National Center for Radiation Research and Technology, Atomic Energy Authority (NCRRT), Egypt, applying dosages of 0, 50, and 75 Gy. The application with gamma irridation seeds were irradiated with a dose rate of 7.775 Gy/ h. The irradiations were carried out at room conditions. Alcoholic chlorobenzene dosimetry was used to calculate the absorbed dose.

Ultraviolet irradiation

The seeds used in this experiment were counted and placed in transparent petri dishes as 50 seeds for each control group. Three samples of cauliflower seeds were exposure by UV-A radiation with wavelength range 365 nm at three times (15, 30 and 45 min). Another three samples of cauliflower seeds were exposure by UVC radiation with wavelength range (253.7 nm) at three exposure durations (15, 30 and 45 min) and constructed the system and irradiation by ultraviolet (UVA and UVC).

Ultraviolet unit was consisting of UVC lamps, box, timer (time controller), electrical wire and tray. The box of Unit: was constructed from Aluminum metal (90 x 45 x 45 cm). UVC light treatment was conducted on a lab-scale by using two lamps producing UVA and UVC at 365nm and 253.7 nm and 2.5 cm diameter were put on top of Aluminum box. Each lamp (60 cm), had a nominal power output of 18W. A stainless-steel sample holding tray with dimensions (70 x 30 cm), it was used to place the samples at 30 cm from the lamps. Cauliflower seeds were exposed by UV-A light (15, 30 and 45 min). The total treatments of ten samples of cauliflower after irradiated by two methods were measured its characteristics (each treatment has three replicates).

Filed experiment and experiment design

The treated seeds were sowing in 84 plastic trays on October in 2020 and 2021. The growing media was peat-moss plus vermiculite (1:1/v:v). The trays were kept under plastic greenhouses condition at Vegetable Crops Department, Cairo University, Giza, Egypt. After 45 days from sowing seeds, the transplants were translated to the field. The soil of the experiment was clay loam. Every treatment received 92 kg N (urea), 96 kg P_2O_5 (super phosphate), and 90 kg K (potassium sulphate)/hectare. Four replicates of each treatment were used in a randomized complete block design.

Irrigation and pest control

After transplanting, the irrigation periods are rounded so that they range from 2-4 days, and then after 7 days, in order to form a strong root system and install the plant in the ground, then irrigation is done after 10 to 15 days. The cotton leafworm is the most dangerous insect pest and is controlled with (Tavapan) pesticides. As for aphids and whiteflies, they are controlled with (Mospilan). While the fungal diseases that affect cauliflower, such as downy mildew, are controlled with the pesticide (Tazoline), as well as powdery mildew, which is controlled with the pesticide (Baileys).

Plant growth parameters

Plant height, fresh weight of plant, leaf number, shoot fresh weight, leaf dry weight, and chlorophyll contents in leaves using a SPAD (SPAD 502 Minolta Co., Osaka, Japan) Meter were measured after 45 days from planting according to Qihua *et al.,* (2011). The heads of each plot were harvested and weighted to measure the total yield.

Head quality

Ten mature heads per experimental plot were randomly chosen at harvest time to measure the following:

Total soluble solids percentage (TSS %) and Ascorbic acid (AA)

The TSS was measured in heads by using digital refractometer (PAL-BX/ACID2, Atago Co. Ltd., Tokyo, Japan). Titrimetric determination of ascorbic acid contents in plant samples by 2, 6-Dichlorophenolindophenol method was used according to Behrouz Vahid (2012).

Firmness of heads and color of head

Five heads were chosen in each replication to measure their firmness by using a Force Gauge Mode M4-200 (ELECTROMATIC Equipment Co., Inc. Cedarhurst, NY 11516 USA) by flat probe (1 mm diameter). The readings for firmness were given in newton. A chromametre was used to measure the colour of the head's surface (CR-400, Konica Minolta, Tokyo, Japan). For each replication, the surface colour of 10 heads was evaluated for L* (lightness), chroma, and hue angle (h°). Three measurements were taken for every individual head.

Phenolic compounds and total antioxidant

The method of (Singleton and Rossi, 1965) was utilized to measure the total phenolic contents (TPC) using the Folin-Ciocalteu colourimetric method. One gram of the sample was homogenised with 10 mL of methanol (80%) and centrifuged at for 15 min under cool condition at 4 °C to prepare the methanolic extract. The DPPH technique was used to calculate antioxidant. This assay measures by spectrophotometer the ability of antioxidants to reduce 2,2- diphenylpicrylhydrazyl (DPPH), another radical not commonly found in biological systems.

Storage experiment

Within two hours, the healthy cauliflower heads were harvested and transferred to the postharvest lab. Each head was shrink-wrapped and packaged in a cardboard box and kept in a refrigerator room at 5 °C and 95% RH for 16 days. The following measurements were taken every 4 days:

Weight loss

Reported as a percentage of weight reduction. The heads were weighted immediately before storage and at every storage time.

Browning degree

The browning of cauliflower heads was measured as described before (El-Mogy *et al.,* 2020) Color measurements of the samples were carried out by using color Spectrophotometer (Hunter Lab, Model: Colour Flex EZ), which expresses as three-color parameters (L, a and b) were recorded. The L* value represented the brightness and varied from 0 (black) to 100 (white). The chromaticity coordinates indicated for a the redness (+)/greenness (-) and for b* the yellowness (+)/blueness (-). Value of L, a, b with the positive value of a, b indicating red and yellow color and negative quality of raisins depends upon the color value. Three readings of three different replications were conducted for each sample. The positive values of b indicate the yellow color. So the sample which has greater value of b indicated good quality.

$BI = (100 (x-0.31)) / (0.17)$

Where $x = (a^* + 1.75 L^*) / (5.645 L^* + a^* - 3.012 b^*)$

Statistical analysis

The SPSS software was used to conduct an analysis of variance and Tukey's multiple range tests with significance set at $p < 0.05$. Data (n=4) were presented as means.

Results

Plant growth parameters

The cuurent results in Figure 1A indicate that the height of the cauliflower plant was significantly ($p<0.05$) affected by all irradiation treatments. The results show that the taller plants length was observed in 50-Gy, 30-UVA, and all UVC doses compared with the control plants (non-treated). The greater number of leaves obtained from cauliflower plants which their seeds treated with 30-UVA while the control plants had the lowest number of leaves compared with all other treatments (Figure 1B). Additionally, the difference between treatment in number of leaves parameter was not significant. The treatments of cauliflower seeds with 50-Gy, 30-UVA, all UVC doses significantly increased the leaf length compared with the other treatments and with the control (Figure 1C). The results in Figure 1D&E show that all irradiation treatments significantly increased plant fresh weight and plant dry weight compared with the control treatment. Also, 30-UVA and 15 UVC showed the high plant weight than other treatments followed by 50-Gy treatment. The provided results in Figure 1F show that SPAD was affected significantly by irradiation treatments. The highest SPAD values were recorded from plants that treated with 15-UVC followed by 30-UVA and 50-Gy. Additionally, the control plants recorded the lowest SPAD values compared with all other treatments. The Pearson correlation (Table 1) and heat-map (Figure 2) show the correlation between the measured parameters. The data indicated that there is a strong positive correlation between head diameter and other parameters (head weight, total yield, and head dry weight).

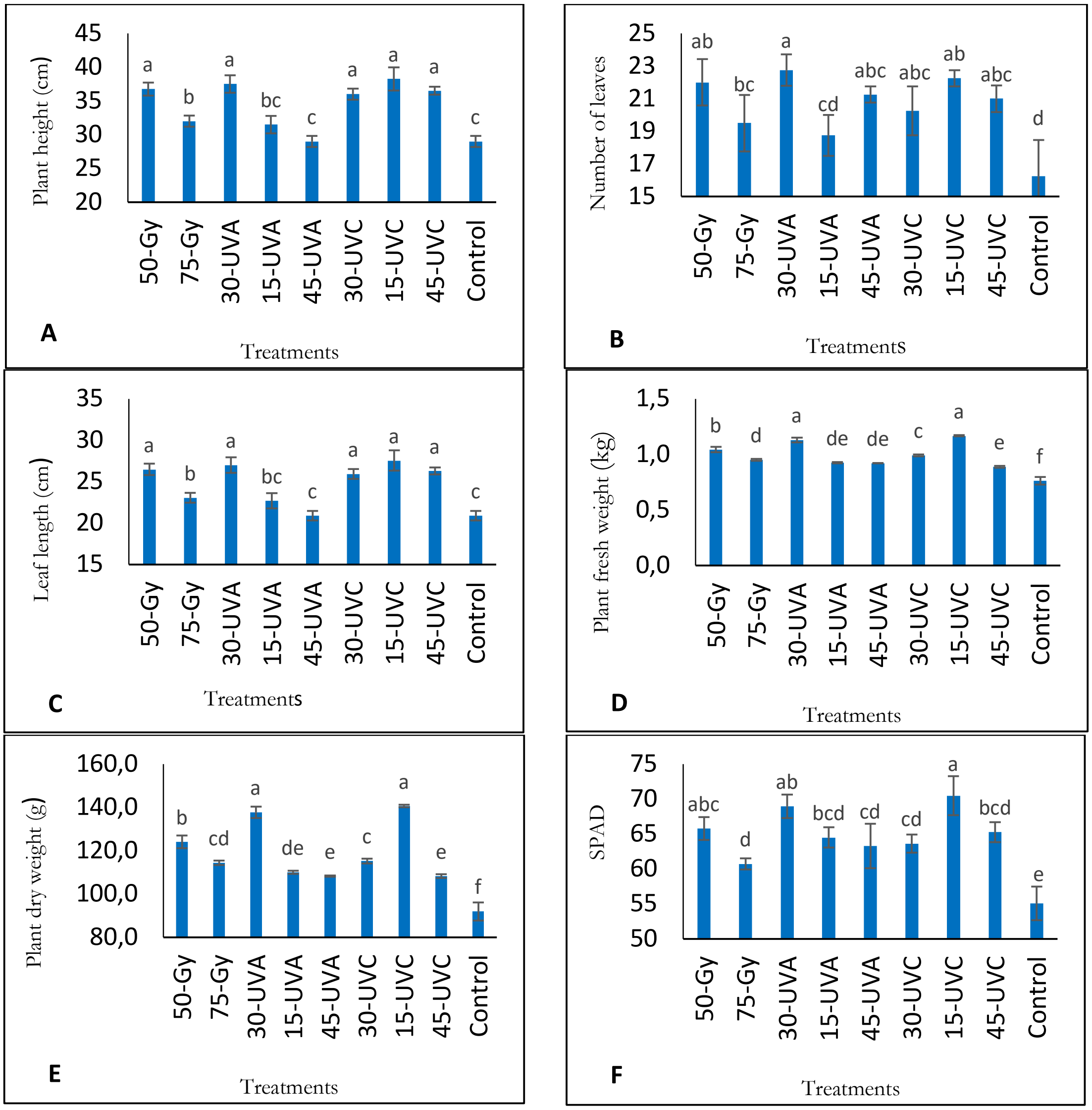

Figure 1. Effect of different doses of gamma ray (50 and 75), UVA (15, 30, and 45 min), and UVC (15, 30, and 45 min) on (A) plant height, (B) number of leaves, (C) leaf length, (D) plant fresh weight, (E) plant dry weight, and (F) SPAD reading of cauliflower

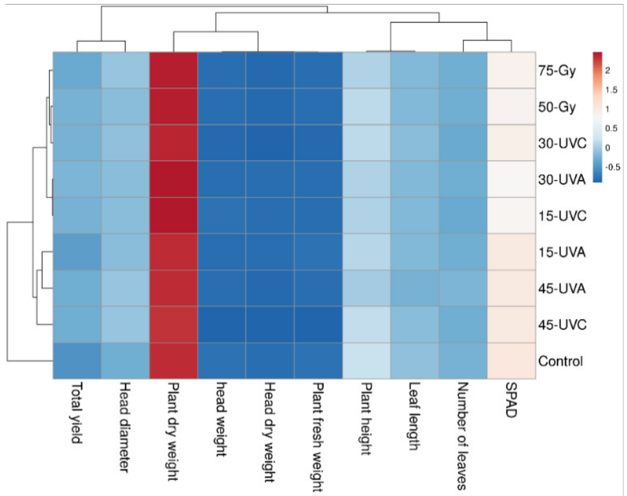

Figure 2. Visualization heat-map diagram of the tested parameters of cauliflower samples. Columns represent the individual tested variables, while rows show the treatments. The blue colour present the lower numerical values, whereas red colour present the higher numerical values

Table 1. Pearson's correlation analysis among the measured parameters of cauliflower plants

Name	Head diameter	Head weight/plant	Number of leaves	Plant height	Leaf length	Total yield	Head dry weight	SPAD	Plant fresh weight	Plant dry weight
Head diameter	1	.802**	.781**	.680**	.680**	.803**	.806**	.731**	.775**	.760**
Head weight/plant	.802**	1	.704**	.725**	.725**	1.000**	.999**	.727**	.788**	.784**
Number of leaves	.781**	.704**	1	.591**	.591**	.705**	.704**	.675**	.708**	.705**
Plant height	.680**	.725**	.591**	1	1.000**	.724**	.728**	.708**	.754**	.767**
Leaf length	.680**	.725**	.591**	1.000**	1	.724**	.728**	.708**	.754**	.767**
Total yield	.803**	1.000**	.705**	.724**	.724**	1	.999**	.727**	.789**	.784**
Head dry weight	.806**	.999**	.704**	.728**	.728**	.999**	1	.736**	.793**	.789**
SPAD	.731**	.727**	.675**	.708**	.708**	.727**	.736**	1	.828**	.829**
Plant fresh weight	.775**	.788**	.708**	.754**	.754**	.789**	.793**	.828**	1	.993**
Plant dry weight	.760**	.784**	.705**	.767**	.767**	.784**	.789**	.829**	.993**	1

** Correlation is significant at the 0.01 level (2-tailed).

Yield and head quality

In the present investigation, 50-Gy, 30-UVA, 30-UVC, and 15-UVC treatments showed the highest head weight values compared with other treatments while the control showed the lowest values (Figure 3A). The results in Figure 3B shows that all treatments had a significant positive effect on increasing the head diameter of cauliflower plants compared with the control treatment. All irradiation treatments (except 15-UVA) also significantly increased head dry weight compared with the control heads (Figure 3C). According to the results in Figure 3D, all irradiation treatments, except 15-UVA, significantly increased total yield compared with the control treatment.

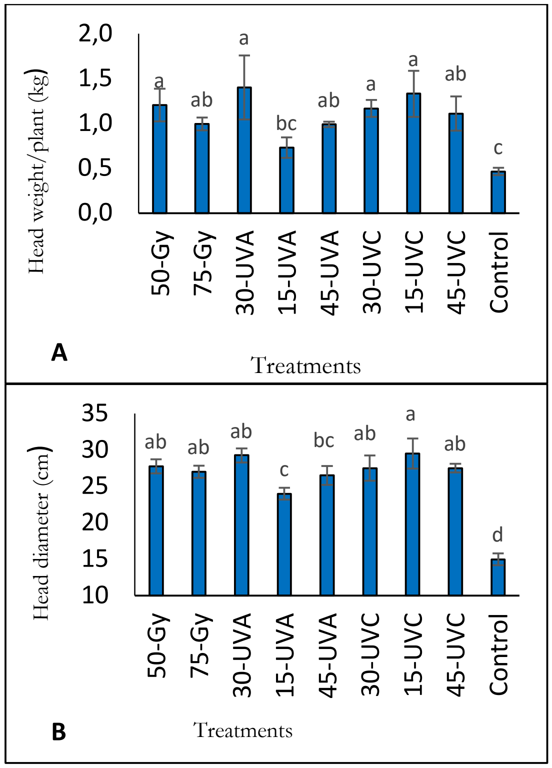

Figure 3. Effect of different doses of gamma ray (50 and 75), UVA (15, 30, and 45 min), and UVC (15, 30, and 45 min) on (A) head weight/plant, (B) head diameter, (C) head dry weight, and (D) total yield/ha of cauliflower

Storage behavior

Table 2 shows the weight loss and TSS of cauliflower heads that stored for 16 days under cold condition (5 °C). As expected, weight loss of all samples increased with increasing the storage period. After 4 days from storage, the lowest weight loss was recorded from samples that treated previously by 45-UVC treatment. However, the difference between treatments were not significant. Additionally, there were no significant differences between treatments during the remaining of storage period. The TSS values for all treatments were not changed over the storage periods and ranged between 4 and 5%.

Table 3 shows the influence of irradiation treatments on total phenolic compounds and antioxidant capacity of cauliflower heads that stored at 5 °C for 16 days. Antioxidant capacity increased by increasing the storage periods in all treatments except for 50-Gy that was decreased and then increased. However, after 4 days of storage, the highest antioxidant capacity was recorded by 50-Gy treatment followed by 75-Gy. Additionally, the different between the other treatments and the control was not significant. After 8 days, 75-Gy treatment showed the highest antioxidant capacity while 30-UVC treatment showed the highest levels after 12 days from storage. At the end of storage, 50-Gy treatment showed the highest antioxidant capacity.

Table 2. Effect of seed applications by different rates of gamma ray (50 and 75 Gy), UVA (15, 30, and 45 min), and UVC (15, 30, and 45 min) on weight loss and TSS of cauliflower heads stored for 16 days at 5 °C

	Weight loss (%)				TSS (%)			
	4 d	8 d	12 d	16 d	4 d	8 d	12 d	16 d
50-Gy	1.44 ab*	2.45 ns	3.61 ns	4.56 ns	4.15 d	4.22 b	4.25 bc	4.30 cd
75-Gy	1.49 ab	2.46	3.57	4.43	4.42 cd	4.32 ab	4.30 bc	4.30 cd
30-UVA	1.66 a	2.65	3.81	4.76	4.22 d	4.62 ab	4.57 b	4.42 bcd
15-UVA	1.67 a	2.82	4.10	5.14	5.25 ab	4.60 ab	4.35 bc	4.57 bcd
45-UVA	1.54 ab	2.60	3.94	4.96	4.77 bc	4.57 ab	4.10 bc	4.22 d
30-UVC	1.59 ab	2.71	3.93	4.95	5.65 a	4.97 ab	5.20 a	5.47 a
15-UVC	1.41 ab	2.37	3.48	4.35	4.57 cd	4.87 ab	4.60 ab	4.80 bc
45-UVC	1.12 b	3.97	3.13	4.37	4.50 cd	4.82 ab	3.95 c	4.52 bcd
Control	1.48 ab	2.97	3.91	4.89	4.47 cd	5.00 a	4.67 ab	4.90 b

* Means followed by a letter in common in the same column are not significantly different at 0.05 level of probability according to Tukey's multiple range test (n= 4).

Table 3. Effect of seed applications by different rates of gamma ray (50 and 75 Gy), UVA (15, 30, and 45 min), and UVC (15, 30, and 45 min) on antioxidant capacity and total phenolic compounds of cauliflower heads stored for 16 days at 5 °C

	Antioxidant capacity (%)				Total phenolic compounds			
	4 d	8 d	12 d	16 d	4 d	8 d	12 d	16 d
50-Gy	34.83 a*	16.66 bc	10.21 c	66.81 a	149.16 bc	185.32 ns	111.99 ns	218.80 ns
75-Gy	19.98 b	35.71 a	33.09 ab	51.48 ab	187.83 abc	201.23	143.31	238.73
30-UVA	7.79 c	15.30 bc	18.98 abc	34.29 b	270.87 a	151.01	128.74	197.38
15-UVA	16.34 bc	24.01 abc	28.11 ab	33.51 b	244.42 ab	198.72	121.88	150.67
45-UVA	15.51 bc	28.95 ab	34.20 ab	58.43 ab	179.79 abc	118.86	161.05	174.44
30-UVC	8.66 c	10.83 c	36.52 a	56.09 ab	139.62 bc	169.92	114.34	193.53
15-UVC	6.95 c	14.85 bc	16.72 bc	49.96 ab	157.86 bc	149.00	132.93	180.47
45-UVC	6.80 c	11.10 c	18.26 bc	51.72 ab	153.85 bc	166.74	125.89	261.33
Control	7.14 c	18.65 bc	23.42 abc	41.64 ab	102.84 c	166.57	96.59	173.94

* Means followed by a letter in common in the same column are not significantly different at 0.05 level of probability according to Tukey's multiple range test (n= 4).

The data in Table 4 shows the influence of the radiation treatments on browning index and vitamin C content of cauliflower heads under cold storage condition. As expected, browning index increased by increasing storage periods in all treatments (Table 4). No clear trend in browning index was observed after 4, 8, 12, and 16 days of storage (Figure 4). Also, vitamin C in cauliflower heads was decreased by increasing storage time in all treatments. The difference between treatments was not significant after 4 days from storage. After 8 and 12 days from storage, 30-UVC and 45-UVA treatment showed the highest vitamin C content in cauliflower heads compared with the control, respectively. At the end of storage period, the highest vitamin C content was recorded by 45-UVA treatment followed by 50-Gy.

Table 4. Effect of seed applications by different rates of gamma ray (50 and 75 Gy), UVA (15, 30, and 45 min), and UVC (15, 30, and 45 min) on browning index (BI) and Vitamin C of cauliflower heads stored for 16 days at 5 °C

	BI				Vitamin C (mg/100 g fw)			
	4 d	8 d	12 d	16 d	4 d	8 d	12 d	16 d
50-Gy	3.37 b*	3.27 c	3.77 c	4.00 ab	69.29 a	42.06 bcd	25.74 ab	22.33 ab
75-Gy	3.31 b	3.24 c	3.71 c	3.82 b	43.55 b	49.98 b	19.30 bc	17.44 bc
30-UVA	3.37 b	3.44 bc	3.90 c	3.89 b	57.90 ab	31.18 d	13.36 cd	11.80 c
15-UVA	3.79 b	3.92 b	4.41 bc	4.38 ab	61.86 ab	52.95 b	11.88 d	11.88 c
45-UVA	4.80 a	5.24 a	5.3 a	5.04 a	70.28 a	35.63 cd	27.22 a	24.36 a
30-UVC	3.95 ab	3.75 bc	4.70 ab	4.19 ab	63.35 ab	69.29 a	16.83 cd	14.37 c
15-UVC	3.25 b	3.44 bc	3.85 c	3.72 b	62.36 ab	36.12 cd	15.34 cd	13.16 c
45-UVC	3.86 b	3.83 bc	4.21 bc	4.28 ab	74.73 a	48.00 bc	15.84 cd	13.99 c
Control	3.82 b	3.70 bc	4.00 bc	4.10 ab	43.55 b	29.70 d	13.36 cd	11.42 c

* Means followed by a letter in common in the same column are not significantly different at 0.05 level of probability according to Tukey's multiple range test (n= 4).

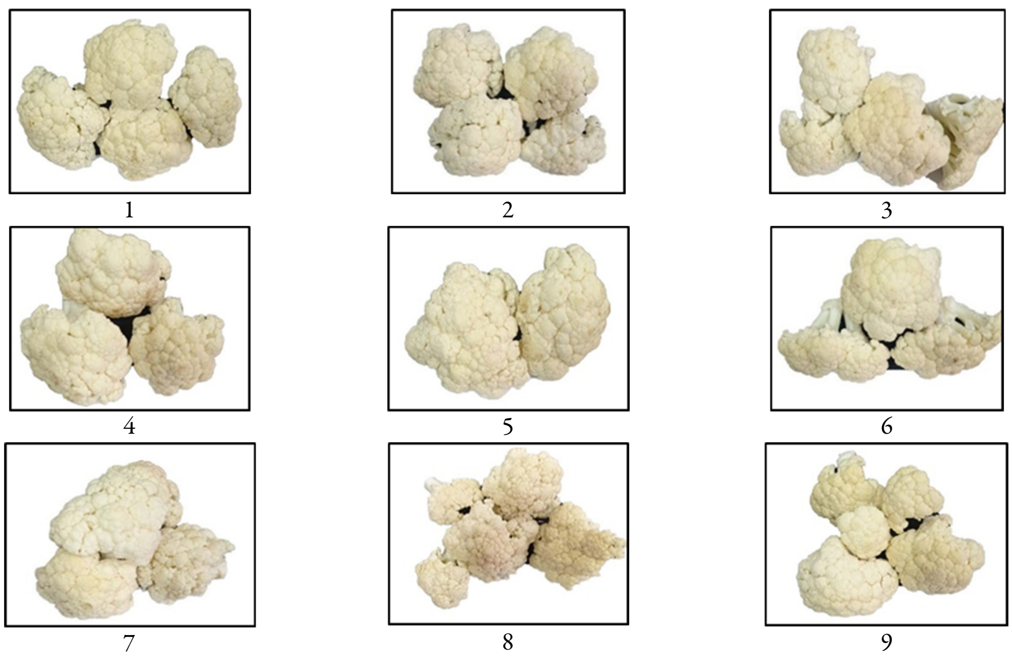

Figure 4. Effect of seed applications by different rates of radiation as follow: 1= 50 Gy, 2= 75Gy, 3= 15-UVA, 4= 30-UVA, 5= 45-UVA, 6= 15-UVC, 7= 30-UVC 30, 8= 45-UVC, and 9= control on browning index of cauliflower heads after 12 days from storage at 5 °C

Discussion

Increasing the plant growth and production of high-value crops through seed priming technology is a promising technology (McDonald and Basis, 2000) as irradiated seeds exhibited an increase rate and time with uniform of germination, improved the growth and its characteristics, and quicker emergence of crop stand because they are physiologically near to the stage of germination (Farooq *et al*., 2006).

In this experiment, the seed priming with UVA (for 15 and 30 min) and UVC (for 15, 30, and 45 min) improved cauliflower plant growth compared to the untreated plants (Figure 1). Our results and previous study done by Thomas *et al*. (2017) indicated that low dose of UV rays improved seed germination rate and the accumulation of cowpea biomass. Additionally, in accordance with this results in Figure 1F, UV application on the seeds of eggplants, beet, and cabbage crops improved chlorophyll content in the shoots (Kacharava *et al*., 2009). According to Hamid and Jawaid (2011), the effects of UVA radiation on beans seeds were effective, and they demonstrated that seed treatment before sowing with UVA resulted in enhancing germination and growth of the seedling including mean of leaf area, root length, foliage length, and dry weight. Some previous work indicates the role of UVC in seed priming as an antibacterial (Brown *et al.,* 2001). However, the literature about the effect of the treatment of seeds with UVC and its effect on growth and productivity is rare, and further studies are required. In our study, UVC treatment improved cauliflower plant growth compared with the control plants. It has been reported that exposed seeds (as priming application) to low levels of UVC, plants have been discovered to activate both enzymatic and non-enzymatic antioxidant mechanisms to mitigate various stress conditions and improve their growth (Katerova *et al.*, 2011; Rai *et al*., 2011; El-Beltagi *et al.,* 2023 a,b).

Previous studies mentioned the role of low gamma irradiation dose for improving plant growth in some crops (Beyaz *et al.,* 2016; Jan *et al*., 2012; Melki and Sallami, 2008; Aly, 2022). Additionally, Dubey *et al.* (2007) found that application of gamma irradiation on okra seeds improved plant length, number of leaves and branches compared with the control plants. Also, Aly *et al*. (2023a,c) and Hegazi *et al*. (2010) found that gamma irradiation application with 60 Gy improved seeds growth parameters of red radish including plant length, leaf area, number of branches, plant fresh weight, and plant dry weight as well as chlorophyll content. This effect of Gy for improving the growth of plants could be due to that gamma radiation increases the generation of reactive oxygen species, which function as signaling molecules to activate an antioxidant response (Qi *et al*., 2015). Gamma rays have also an impact on plant morphology by causing some biochemical and physiological changes in the cells and tissues by generating free radicals in cells (Kim *et al*., 2004).

In the current study, treatments of cauliflower seeds with UVA (for 30 and 45 min) and UVC (for 15, 30, and 45 min) improved the total yield and head quality (Figure 3). Similarly, to the obtained results, previous studies mentioned that treating seeds with UV radiation is an environmentally friendly way to increase crop productions (Delibaltova and Ivanova, 2006; Badridze *et al*., 2016). Also, seed priming of UVC enhanced the growth and enhanced the physiological changes in some crops such as cowpea and rice (Thomas and Puthur, 2017).

The effect of UVA application as a seed priming technology on plant growth is rare in the literatures and further studies are required in this topic. For example, Hegazi *et al.* (2010) found that seed application with 300 and 400 Gy improved total yield of okra and improved the fruits quality parameters such as pod length and pod numbers. The effect of seed priming with UV rays could be related to their role for inducing germination rate, improving seedling vigor, and accumulation of dry matter that led to an increase in the plant production (Qi *et al*., 2015). Additionally, increased yield by UV rays' application has been linked to several factors such as a significant competitive advantage over weeds (Mahajan *et al*., 2011), enhanced elements absorption, and increase dry matter content (Slaton *et al*., 2001).

In this study, seed priming with UVA, UVC, and gamma rays had little effects on preserving the quality of cauliflower heads during storage (Tables 2,3,4). For example, the total phenolic compounds increased by 30-UVA treatment compared to the control after 4 days of storage (Table 3). Also, the 45-UVA treatment conserved vitamin C in cauliflower heads after 16 days of storage. The previous studies indicated that UV treatments increased the content of chemical compositions in some crop seedlings such as increasing vitamin C in kidney bean (Kacharava *et al*., 2009) and phenol content in lettuce by UVC treatment (Ouhibi *et al*., 2014).

Conclusions

The current study found that all radiation treatments had a significant positive effect on the plant height, number of leaves, leaf length, plant weight, and SPAD values of cauliflower plants compared to the control. The treatments of 50-Gy, 30-UVA, 30-UVC, and 15-UVC showed higher head weight values and increased head diameter, dry weight, and total yield compared to the control. After 4 days of cold storage, the lowest weight loss was recorded from samples treated with 45-UVC. Antioxidant capacity increased with storage time in all treatments except for 50-Gy. 30-UVA treatment showed the highest total phenolic compounds after 4 days of storage. Vitamin C content in cauliflower heads decreased with storage time, but 45-UVA treatment showed the highest vitamin C content at the end of the storage period. Our results focused on the importance of using radiation as seed priming application for enhancement growth and yield of cauliflower plant. Further studies are required in this topic. By improving seed germination, plant growth, and production; seed priming with irradiation can lead to better crop yields and higher quality fruit. As research in this area continues, it will be interesting to see how this technique is applied in the fruit industry and how it can help growers to improve their crop production.

Authors' Contributions

Conceptualization: HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; Data curation: HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; Formal analysis: HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; Funding acquisition: HSEB; Investigation: HSEB and MME-M; Methodology: MME-M; Project administration: HSEB and MMEl-M; Resources: MME-M; Software: GAT, SAS, SRO, and OAA; Supervision: HSEB and MMEl-M; Validation: HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; Visualization HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; Writing - original draft: GAT, SAS, SRO, OAA, AAA, and MME-M; Writing - review and editing: HSE-B, GAT, SAS, SRO, OAA, AAA, and MME-M; All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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