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The Effect of Treating String Bean Pods with Modified Atmosphere Packaging and UV-C Irradiation on Their Storage Life

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Abstract: The aim of the experiment was to determine the optimal treatment of string bean pods, prolonging their storage life. To this end, the effect of modified atmosphere packaging in Xtend® bags (CH-49) and UV-C radiation on the quality of string beans 'Unidor' in cold storage was studied. Observations of the pods and their measurements were made after 14 and 28 days and chemical analyses 14 days after irradiation exposure and storage at 2–4 °C. The tests were conducted in laboratory conditions in a completely randomized design. Storing bean pods in Xtend® bags significantly increased the weight and umber of pods fit for consumption, compared to those stored in bulk. However, the content of dry matter, total sugars, and protein in pods stored in Xtend® bags decreased. Irradiation, regardless of the exposure time and the distance of lamps from the surface, contributed to an increase in the weight and number of pods suitable for consumption after 14 and 28 days. After 14 days irradiated pods contained more dry matter, L-ascorbic acid, polyphenols and flavonoids. After UV-C irradiation for 600 s with lamps at a height of 40 cm pods in Xtend® bags responded with the most favorable protein content.

Keywords: UV-C; MAP; *Phaseolus vulgaris* L.; pods quality; nutritional value; antioxidants

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1. Introduction

To prolong the shelf life of vegetables, conventional chemical treatments are usually applied, using solutions of chemicals with fungicidal and bactericidal properties: chlo-rine, peracetic acid, electrolyzed water, hydrogen peroxide, etc. [1]. Due to some disadvantages of using these chemicals, more ecological methods of post-harvest treatment of fruits and vegetables are investigated. These methods include ozonation [2,3], UV-C irradiation [4,5], gamma radiation [6,7], essential oil nanoemulsions [4,8,9], controlled atmosphere storage (CA), and modified atmosphere packaging (MAP) [5,7]. As a method of eliminating viruses, bacteria, and fungi, UV-C irradiation is often used to disinfect materials that are sensitive to high temperature and those that cannot be treated with chemicals [10]. According to Tomaszewska-Sowa et al. [11], a high degree of sterilization of plant material can be achieved by UV-C irradiation with a wavelength of 100 to 280 nm. Such irradiation is successfully used for surface sterilization in agriculture and horticulture to protect plant raw material after harvesting from being infected by fungi and bacteria [12]. UV-C irradiation can both increase the resistance of harvested fruit and vegetables to rot [13] and delay the process of their post-harvest maturation, prolonging their durability [14,15] and their storage period [16]. UV-C irradiation brings many benefits to food manufacturers, i.e., it does not leave any residue in treated food, and it is cheap and easy to use and effective in removing most microorganisms [17]. Microbial inactivation can be achieved in a period of several seconds to several minutes, depending on the type of food products and microbes [18]. In addition to the bactericidal effect, UV irradiation was found to cause desired changes in health-promoting components of fruits and vegetables [16]. Exposure to UV-C light and pulsed light (PL) causes stress in plant tissues, stimulating the biosynthesis of secondary metabolites with antioxidant effects, among others, carotenoids and phenolic compounds [19]. According to Ribeiro et al. [20], exposure of fresh products, such as mangoes, edible mushrooms, strawberries, berries and grapes, to low wavelength UV-C irradiation (200–280 nm) at low doses (<1 J·cm^{-2}) resulted in an increase in anti-oxidative abilities and in the content of phenol compounds, anthocyanins, and vitamin D2.

Another method of reducing the number of microorganisms on the surface of fresh fruit and vegetables and of extending their shelf life is the use of modified atmosphere packaging [21–23]. The storage of fruit and vegetables in modified atmosphere inhibits the development of microorganisms causing spoilage of the packed product, delays the processes associated with ripening, contributes to the reduction of water loss and in consequence slows down shrinking and withering of the texture. The effectiveness of modified atmosphere depends on a number of factors, i.e., product type, weight, temperature, and characteristics of the packaging material [24,25].

The aim of the experiment was to determine the optimal way of treating string bean pods to extend their shelf life between harvesting and consumption. To this end, the effect of UV-C irradiation with varying time and distance of lamps from the surface of pods and the effect of their cold storage in Xtend® bags on their suitability for consumption and the content of selected nutrients were studied. Pods treated and stored like that were compared to those not irradiated with UV-C and to those stored in bulk.

2. Materials and Methods

2.1. Plant Material

The experiment was conducted on the 'Unidor' variety of string bean pods (*Phaseolus vulgaris* L.) harvested on 3 August 2018 and grown as a commodity crop on a vegetable farm located in central-eastern Poland (52°14′11″ N, 22°10′19″ E). All pods used in the experiment were from the same location, harvested in full fruiting on the same day. This ensured the homogeneity of the plant material, so the results were affected by the factors tested in the experiment without influence of different harvest dates or different growing places. Each test was repeated three times.

2.2. Experimental Factors, Sample Preparation

The laboratory experiment (Laboratory of Structural Research and Natural Analysis in Siedlce University of Natural Sciences and Humanities) was a completely randomized design with three replicates. The effect of the following physical factors was examined: (A) storing method: (A1) pods packed in Xtend® bags, (A2) pods stored without bags, in bulk in boxes; (B) UV-C irradiation method [irradiation time in seconds/distance of lamps from the sample surface (cm)]: (B1) without UV-C irradiation, (B2) UV-C 300/20, (B3) UV-C 300/40, (B4) UV-C 300/60, (B5) UVC 600/20, (B6) UV-C 600/40, (B7) UV-C 600/60.

Two series, with 42 samples in each, were prepared, with fresh, fully grown, and mechanically undamaged pods. Each sample with an average of 20 pods, weighed on average, 134 g. Of each series, 21 samples were placed in Xtend® bags and 21 others in polyethylene containers of 17 × 12 × 10 cm. Those pods were subjected to UV-C light for 300 s or 600 s, by placing them at a distance of 20, 40 or 60 cm from the lamps. From each series, three samples in Xtend® bags and three samples in flat polyethylene containers were left without exposure as control. All samples were stored in a cold room. The storage temperature after harvest and during their processing affects the quality of the green bean pods, including not only their visual characteristics such as colour, appearance and freshness, but also their nutrient content. According to Cantwell and Suslow [26], the optimal storage conditions for green bean pods are 5–7.5 °C and 95−100% of relative humidity. According to Sánchez-Mata et al. [27], when stored in such conditions, pods can retain their natural appearance for up to 12 days. The maximum shelf life of bean pods is four weeks. At the start of the experiment, the content of selected nutrients in freshly harvested pods was determined.

2.3. Xtend® Bags

Bean pods were stored in Xtend® modified atmosphere bags (CH-49) manufactured by StePac L.A. Ltd. headquartered in Tefen, Israel. According to the manufacturer, Xtend® bags modify the micro-atmosphere around the produce packed in them, thus contributing to a decline in oxygen content, an increase in carbon dioxide content, and an increase in humidity, making it possible to control water vapor condensation. Modified atmosphere with its relative humidity of 90–95%, as a result of respiration of the plant material stored in Xtend® bags, reduces dehydration and weight loss to a minimum and ensures that the produce is firm. At the same time, Xtend® bags remove excessive moisture, which results in the produce preserving its fresh, healthy appearance, and prevent physiological disturbances. While storing the beans, the humidity inside 10 randomly selected Xtend® bags containing samples was measured three times using a Benetech GM1361 thermo hygrometer. It varied from 92.5% to 93.8% and was within the range specified by the manufacturer.

2.4. UV-C Irradiation

Irradiation of the pods was achieved by using two lamps (TUV 36W/G36 T8 Philips Eindhoven, The Netherlands), with the wavelength of 256 nm. Both the lamps were installed in a casing with a reflector made of stainless steel. Exposure time to UV-C consisted of two cycles 150 s each (in total 300 s), or two cycles 300 s each (in total 600 s). Bean pods were placed at a distance of 20, 40 or 60 cm from the irradiation source. After the first treatment, the pods were shuffled to increase the area of exposure to the ultraviolet radiation.

Bean pods were irradiated after they were packed in Xtend® bags. UV-C irradiation intensity was measured by means of UV LightMeter SENTRY® ST512 (Sentry Optronics Corp., Taiwan). UV-C doses for pods irradiated for 300 s and 600 s with lamps located at a height of 20 cm, 40 cm and 60 cm from the surface and stored in Xtend® bags and in containers are presented in Table 1.

Table 1. UV-C radiation dose (kJ·m^{-2}).

UV-C Irradiation Exposure Time (s)/Distance of Lamps from the Surface (cm)	Packing	
	Xtend® Bags	No Bags
UV-C 300/20	4.36	5.12
UV-C 300/40	2.12	2.69
UV-C 300/60	1.25	1.55
UV-C 600/20	8.72	10.24
UV-C 600/40	4.24	5.38
UV-C 600/60	2.51	3.11

2.5. Storage Conditions of Bean Pods

The pods were stored in cold storage at 2–4 °C and 90–95% humidity.

2.6. Chemical Observations, Measurements and Analyses

Observations and measurements of the first series of pods were made 14 and 28 days after irradiation. During that time, the number and weight of the pods fit for consumption, i.e., the number of pods with no symptoms of rotting or molding, were determined. After 14 days of storage, the number of pods with brown discolorations on the surface, associated with the effects of UV-C on the tissue, was also determined. Such changes can affect the attractiveness of pods for buyers although they do not affect their quality.

The second sample series was used to carry out chemical analyses after 14 days of storage. The content of dry matter, total sugars, proteins, L-ascorbic acid, polyphenols and flavonoids in pods was determined. Dry matter determination was made by the drying method according to AOAC [28], while the content of total sugars was determined by the Luff-Schoorl method [29]. The determination of L-ascorbic acid content was made by Tillman's method [30] and total phenolic content with the Folin-Ciocalteu reagent [31].

2.7. Statistical Analysis

The results of the research were processed statistically using analysis of variance (ANOVA) for a completely randomized design according to the following mathematical model:

$$Y_{ijl} = \mu + A_i + B_j + AB_{ij} + e_{ijl} \quad (1)$$

where:

Y_{ijl}—the value of the characteristic, μ—population mean, A_i—the effect of the i-th level of factor A (pcking method), B_j—the effect of the j-th level of factor B (UV-C irradiation), AB_{ij}—the effect of the interaction of the i-th level of factor A with the j-th level of factor B, e_{ijl}—random error [32].

The significance of differences was determined using Tukey's test at the significance level of $p = 0.05$. The calculations were performed with Statistica® version 10.0 (Statsoft, Tulsa, OK, USA) and Excel software.

3. Results and Discussion

After 14 days of storage on average 72.2% of the initial mass and 76.2% of the initial number of pods were fit for consumption, while after 28 days these values were 28.8 and 32.2%, respectively (Table 2). Both after 14 and 28 days the weight and number of pods fit for consumption in Xtend® bags were significantly higher than among those stored without bags.

Studying the effectiveness of cherry storage methods, Guler et al. [33] found that Xtend® modified atmosphere (MAP) significantly reduced the loss of their mass. After 7 days of storage, the mass loss was 0.78% lower than that of bulk-stored fruit, with those values reaching 1.52 and 3.50% after 14 and 21 days.

In the present experiment, after 14 and 28 days of storage it turned out that UV-C irradiation had a beneficial effect on the mass and number of pods fit for consumption. Following 600 s irradiation, after 14 and 28 days of storage the mass of good-quality pods stored in Xtend® bags was significantly higher than those without irradiation, regardless of the height of the lamp. Moreover, pods responded in the same way to UV-C 300/20 light. After 28 days of storage, a beneficial effect was also found for UV-C 300/40 irradiation.

For beans without bags in cold storage for 14 days, the largest mass of good-quality pods was when they were exposed to UV-C 300/20, UV-C 300/40 or UV-C 600/60 light. After 28 days of bulk storage, only single pods showed no signs of rotting or withering, with their condition good enough to be qualified as fit for consumption. No significant effect of irradiation on the mass of edible pods was found at that time.

After 14 days of storage in Xtend® bags, there were almost five more pods fit for consumption and 10 more after 28 days than among those stored without bags. After 14 days of storage, there was a significantly higher number of irradiated pods suitable for eating than irradiated ones, regardless of the UV-C dose. After 28 days of storage in Xtend® bags, significant quality improvement was recorded in pods irradiated with UV-C 300/40 and UV-C 600/40 and UV-C 600/60 light. The irradiation of pods stored without bags did not result in significant changes in the number of pods fit for consumption after 28 days of storage.

Pan et al. [34] found that UV-C irradiation reduced the mass of strawberry fruit after 6 days of storage at 20 °C compared to the mass loss of unexposed fruit. Manzocco et al. [35] reported that UV-C irradiation increased the storage time of pineapple.

After 14 and 28 days of storage, the loss of pod mass due to transpiration averaged 9.3 and 16.3 g (Table 2), which represented 6.9 and 12.1%, respectively, of their initial mass. Both after 14 and 28 days, the mass loss of pods stored in Xtend® bags was significantly smaller than of those stored without bags.

Table 2. Mass and number of good-quality pods and mass loss of pods after 14 and 28 days of storage.

UV-C irradiation Exposure Time (s)/Distance of Lamps from the Surface (cm)		Mass of Good-Quality Pods (g)			Number of Good-Quality Pods			Mass Loss of Pods (g)		
		Xtend® Bags	No Bags	Means	Xtend® Bags	No Bags	Means	Xtend® Bags	No Bags	Means
After 14 days										
Without irradiation		90.7 ± 14.0a	61.0 ± 11.0a	75.8 ± 19.8a	14.0 ± 2.0	10.0 ± 2.0	12.0 ± 2.8a	5.0 ± 3.0	12.3 ± 6.1	8.7 ± 5.9
UV-C 300/20		118.7 ± 7.6b	92.0 ± 3.6b	105.3 ± 15.5b	18.3 ± 1.2	14.7 ± 0.6	16.5 ± 2.2b	4.8 ± 2.6	13.3 ± 4.2	9.1 ± 5.6
UV-C 300/40		109.7 ± 10.7ab	86.3 ± 12.5b	98.0 ± 16.5b	17.0 ± 1.7	14.0 ± 2.0	15.5 ± 2.3b	4.7 ± 0.6	16.7 ± 2.3	10.7 ± 6.7
UV-C 300/60		112.3 ± 7.2ab	70.7 ± 2.1ab	91.5 ± 23.3ab	17.3 ± 1.2	11.3 ± 0.6	14.3 ± 3.4b	5.7 ± 0.6	13.3 ± 5.3	9.3 ± 5.2
UV-C 600/20		122.3 ± 6.5b	69.7 ± 8.4ab	96.0 ± 29.6b	19.0 ± 1.0	11.3 ± 1.2	15.2 ± 4.3b	5.8 ± 2.6	11.3 ± 2.9	8.6 ± 3.9
UV-C 600/40		122.7 ± 6.8b	83.3 ± 11.2ab	103.0 ± 23.1b	19.0 ± 1.0	13.3 ± 2.1	16.2 ± 3.4b	3.7 ± 0.6	12.3 ± 3.8	8.0 ± 5.2
UV-C 600/60		125.0 ± 6.2b	90.3 ± 10.6b	107.7 ± 20.5b	19.3 ± 1.2	14.7 ± 1.5	17.0 ± 2.8b	3.3 ± 1.5	17.7 ± 10.3	10.5 ± 10.2
Means		114.5 ± 13.5B	79.1 ± 13.7A	96.8 ± 22.4	17.7 ± 2.1B	12.8 ± 2.2A	15.2 ± 3.3	4.7 ± 1.8A	13.8 ± 5.2B	9.3 ± 6.0
Source of variation	df	*F*	*P*	$LSD_{0.05}$	*F*	*P*	$LSD_{0.05}$	*F*	*P*	$LSD_{0.05}$
Packaging method	1	47.67	0.020	23.83	37.04	0.026	3.78	172.90	0.006	3.21
UV-C irradiation	6	10.48	<0.001	16.20	11.06	<0.001	2.30	0.29	>0.05	NS
Interaction	6	3.17	0.042	23.80	1.98	>0.05	NS	0.78	>0.05	NS
After 28 days										
Without irradiation		50.7 ± 6.7a	0.0	25.3 ± 28.1a	8.3 ± 1.2a	0.0	4.2 ± 4.6a	10.3 ± 2.3	17.3 ± 5.0	13.8 ± 5.0
UV-C 300/20		72.3 ± 6.5bc	3.3 ± 2.9	37.8 ± 38.1abc	12.0 ± 1.0bc	0.7 ± 0.6	6.3 ± 6.3abc	14.7 ± 10.8	21.0 ± 11.3	17.8 ± 11.3
UV-C 300/40		85.7 ± 6.1c	7.7 ± 2.9	46.7 ± 42.9c	14.0 ± 1.0c	1.3 ± 0.6	7.7 ± 7.0c	10.7 ± 1.2	22.3 ± 6.7	16.5 ± 6.7
UV-C 300/60		57.7 ± 7.2ab	0.0	28.8 ± 31.9ab	9.7 ± 1.2ab	0.0	4.8 ± 5.3ab	12.8 ± 13.1	20.7 ± 9.1	16.8 ± 9.1
UV-C 600/20		73.0 ± 20.8bc	7.7 ± 2.9	40.3 ± 38.2bc	12.0 ± 3.5bc	1.3 ± 0.6	6.7 ± 6.3abc	13.5 ± 2.2	17.0 ± 2.7	15.3 ± 2.7
UV-C 600/40		84.3 ± 13.1c	13.3 ± 2.9	48.8 ± 39.8c	13.7 ± 2.1c	2.7 ± 0.6	8.2 ± 6.2c	9.3 ± 1.5	23.0 ± 8.5	16.2 ± 8.5
UV-C 600/60		78.7 ± 15.5c	6.7 ± 5.8	42.7 ± 40.8c	13.0 ± 2.6c	1.3 ± 1.2	7.2 ± 6.6bc	10.7 ± 0.6	24.3 ± 9.0	17.5 ± 9.0
Means		71.8 ± 16.1B	5.5 ± 5.2A	38.6 ± 35.5	11.8 ± 2.6B	1.1 ± 1.0 A	6.4 ± 5.8	11.7 ± 7.6A	20.8 ± 4.9B	16.3 ± 7.8
Source of variation	df	*F*	*P*	$LSD_{0.05}$	*F*	*P*	$LSD_{0.05}$	*F*	*P*	$LSD_{0.05}$
Packaging method	1	205.12	0.005	21.48	209.33	0.005	3.45	189.02	0.005	3.07
UV-C irradiation	6	8.38	0.001	14.89	7.84	0.001	2.56	1.16	>0.05	NS
Interaction	6	3.61	0.028	17.29	3.15	0.043	2.94	1.82	>0.05	NS

Mean ± SD (n = 3) followed by different lowercase letters in columns and different uppercase letters in rows differ significantly at $p \leq 0.05$; NS—not significant, df—degrees of freedom, *F*—F-distribution, *P*—probability, $LSD_{0.05}$—least significant difference.

According to the literature the high mass loss of beans stored at any temperature indicates that the use of a film wrap may help create high relative humidity and therefore reduce water loss, maintaining better overall quality and extending the shelf life of snap beans [36]. Additionally, Guler et al. [33] found that storing cherries in modified atmosphere (MAP) in cold storage significantly delayed the mass loss of fruit compared to control because MAP slowed down breathing and reduced water loss.

UV-C irradiation contributed to the formation of brown discolorations on the pods, reducing their commercial value. The highest number of discolored pods was found after 600 s irradiation, regardless of the height of the lamp, but the spots were less numerous after UV-C 300/60 and UV-C 300/40 irradiation (Table 3 and Figure 1). According to Ben-Yehoshua et al. [37], UV-C radiation beyond a certain threshold dose caused visible damage to the peels of citrus fruits.

Table 3. Number of string beans with discolorations.

UV-C Irradiation: Exposure Time (s)/Distance of Lamps from the Surface (cm)		Packing Method: Xtend® Bags	No Bags	Means
Without irradiation		0.0a	0.0a	0.0 a
UV-C 300/20		4.0 ± 2.6ab	8.7 ± 1.2bc	6.3 ± 3.1b
UV-C 300/40		1.7 ± 1.5ab	2.7 ± 1.2ab	2.2 ± 1.3a
UV-C 300/60		0.0a	0.7 ± 0.6a	0.3 ± 0.5a
UV-C 600/20		6.7 ± 5.1ab	17.3 ± 2.9d	12.0 ± 6.9c
UV-C 600/40		8.7 ± 2.5b	14.7 ± 3.1cd	11.7 ± 4.1c
UV-C 600/60		6.7 ± 3.2ab	15.3 ± 0.6cd	11.0 ± 5.2c
Means		4.0 ± 4.0	8.5 ± 7.2	6.2 ± 6.2
Source of variation	df	*F*	*P*	$LSD_{0.05}$
Packaging method	1	14.94	>0.05	NS
UV-C irradiation	6	64.64	<0.001	3.33
Interaction	6	3.74	0.024	7.54

Mean ± SD (n = 3) followed by different lowercase letters in columns and different uppercase letters in rows differ significantly at $p \leq 0.05$; NS—not significant, df—degrees of freedom, *F*—F-distribution, *P*—probability, $LSD_{0.05}$—least significant difference.

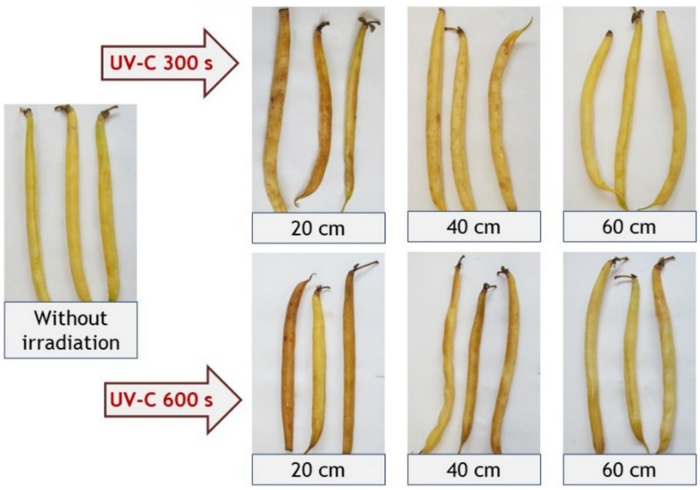

Figure 1. Discolorations of pods after UV-C irradiation.

On pods in Xtend® bags the largest number of discolorations was recorded after UV-C 600/40 irradiation. No spots were observed on pods irradiated with UV-C 300/60 light or on non-irradiated ones. For bulk pods in containers, the largest number of pods with discolorations was recorded after 600 s exposure, regardless of the height of the lamp, and after the irradiation of UV-C 300/20.

The average dry matter and selected nutrient content in freshly harvested string bean pods are presented in Table 4. After 14 days in cold storage, regardless of the method of post-harvest treatment, average dry matter content in pods increased by 1.80%. Compared to the initial values, total sugar content in fresh matter increased by 0.66 g·100 g^{-1}, protein by 0.42 g·100 g^{-1}, L-ascorbic acid by 1.3 mg·100 g^{-1}, polyphenols by 14.17 mg·100 g^{-1}, and flavonoids by 1.12 mg·100 g^{-1} (Tables 5 and 6).

Table 4. Average dry matter and selected nutrient content in fresh bean pods immediately after harvesting.

	Unit	Quantity
Dry matter	%	8.15 ± 0.32
Total sugars	g·100 g^{-1}	2.61 ± 0.10
Protein	g·100 g^{-1}	2.62 ± 0.13
Ascorbic acid	mg·100 g^{-1}	18.29 ± 0.22
Phenolics	mg·100 g^{-1}	20.93 ± 1.21
Flavonoids	mg·100 g^{-1}	6.63 ± 0.09

Each value consists of mean ± standard deviation (SD), n = 3.

After 14 days, the content of dry matter and total sugars was significantly higher in pods stored in bulk than in packed ones, with significantly lower amounts of protein (Table 5). The method of packaging, on the other hand, had no effect on the content of L-ascorbic acid, polyphenols and flavonoids (Table 6).

Chaudhary et al. [38] did not find any effect of modified atmosphere on the content of ascorbic acid in grapefruit fruit. After 7 and 14 days of storing cherries in Xtend® bags at 0 ± 0.5 °C with the humidity of 90 ± 5%, Guler et al. [33] recorded significantly higher vitamin C content of 2.00 and 0.76 mg·100 g^{-1} in fresh matter, respectively, than in those stored without bags. An increase in flavonoid content of grapefruit stored in bags with modified atmosphere compared to those stored without bags was reported by Chaudhary et al. [38]. Storage in bags reduced water loss from pod tissues but increased the consumption of assimilates by speeding up the breathing process. Sánchez-Mata et al. [27] reported that total sugar content of green bean pods generally increased beginning with the first day of storage and decreased toward the end of storage. The decrease of total sugar at the end of the storage period could have been due to the consumption of simple sugars during respiration.

In the present experiment UV-C irradiation increased pod dry matter content. Its significantly highest content was found in pods irradiated with UV-C 300/40. The lowest dry matter content was in unexposed pods. However, irradiation did not have a significant impact on the amounts of total sugars in bean pods (Table 5). Erkan et al. [39] noted opposite results. In the fruits of pumpkin (*Cucurbita pepo* L.) exposed to UV-C for 300 s and 600 s and then stored at 5 °C or 10 °C for 18 days, they found significantly lower sugar content than in non-exposed fruit. According to Pan et al. [34], sugar content in UV-C exposed strawberries after storing them at 20 °C decreased. This decrease was greater than in unexposed fruit.

The protein content of pods packed in Xtend® bags exposed to UV-C 600/40 and UV-C 600/60 was significantly higher than that found in those without irradiation and after UV-C 300/40 irradiation (Table 5). Compared to untreated pods, a higher content of L-ascorbic acid was found in those irradiated with UV-C (Table 6). UV-C 300/40 irradiated pods contained a larger amount of this acid than unexposed ones or irradiated with UV-C 600/60. Contrary to that, Artés-Hernández et al. [40] did not record significant changes in vitamin C content of watermelon fruit after UV-C irradiation.

Table 5. Dry matter, total sugar and protein content of bean pods after 14 days of storage.

UV-C Irradiation Exposure Time (s)/Distance of Lamps from the Surface (cm)	Packing Method: Xtend® Bags	Packing Method: No Bags	Means
	Dry matter (%)		
Without irradiation	8.34 ± 0.17	9.97 ± 0.58	9.16 ± 0.97a
UV-C 300/20	8.44 ± 0.93	10.92 ± 2.06	9.68 ± 1.97abc
UV-C 300/40	10.30 ± 1.90	13.00 ± 0.66	11.65 ± 1.95d
UV-C 300/60	9.47 ± 0.43	10.61 ± 0.81	10.04 ± 0.85bc
UV-C 600/20	8.86 ± 0.80	9.97 ± 1.15	9.42 ± 1.07ab
UV-C 600/40	8.85 ± 1.06	10.10 ± 0.31	9.47 ± 0.98abc
UV-C 600/60	9.05 ± 1.78	11.37 ± 1.28	10.21 ± 1.88c
Means	9.05 ± 1.17A	10.85 ± 1.39B	9.95 ± 1.56
	Total sugars (g·100 g^{-1} f.m.)		
Without irradiation	2.93 ± 0.10	3.25 ± 0.08	3.09 ± 0.20
UV-C 300/20	3.19 ± 0.41	3.47 ± 0.22	3.33 ± 0.33
UV-C 300/40	3.11 ± 0.31	3.54 ± 0.26	3.33 ± 0.35
UV-C 300/60	3.40 ± 0.26	3.31 ± 0.01	3.36 ± 0.17
UV-C 600/20	3.17 ± 0.13	3.38 ± 0.46	3.27 ± 0.32
UV-C 600/40	2.89 ± 0.32	3.33 ± 0.16	3.11 ± 0.33
UV-C 600/60	3.35 ± 0.47	3.47 ± 0.22	3.41 ± 0.34
Means	3.15 ± 0.32A	3.39 ± 0.23B	3.27 ± 0.30
	Protein (g·100 g^{-1} f.m.)		
Without irradiation	2.92 ± 0.12ab	3.36 ± 0.05	3.14 ± 0.25
UV-C 300/20	3.10 ± 0.12abc	3.15 ± 0.09	3.13 ± 0.10
UV-C 300/40	2.87 ± 0.30a	3.28 ± 0.09	3.08 ± 0.30
UV-C 300/60	3.25 ± 0.32abc	3.16 ± 0.09	3.21 ± 0.21
UV-C 600/20	3.01 ± 0.06abc	3.14 ± 0.16	3.08 ± 0.13
UV-C 600/40	3.47 ± 0.19c	3.26 ± 0.49	3.37 ± 0.35
UV-C 600/60	3.36 ± 0.04bc	3.48 ± 0.08	3.42 ± 0.08
Means	3.14 ± 0.27A	3.26 ± 0.21B	3.20 ± 0.24

Source of variation	df	Dry matter *F*	Dry matter *P*	Dry matter $LSD_{0.05}$	Total sugars *F*	Total sugars *P*	Total sugars $LSD_{0.05}$	Protein *F*	Protein *P*	Protein $LSD_{0.05}$
Packaging method	1	123.17	0.008	0.754	40.56	0.024	0.179	23.32	0.040	0.116
UV-C irradiation	6	12.66	<0.001	1.162	0.82	>0.05	NS	2.21	>0.05	NS
Interaction	6	0.38	>0.05	NS	0.86	>0.05	NS	3.13	0.044	0.470

Mean ± SD (n = 3) followed by different lowercase letters in columns and different uppercase letters in rows differ significantly at $p \leq 0.05$; NS—not significant, df—degrees of freedom, *F*—F-distribution, *P*—probability, $LSD_{0.05}$—least significant difference.

Unlike in the case of unexposed pods, UV-C irradiation contributed to an increase in the content of polyphenols and flavonoids after 14 days of storage (Table 6). For pods stored in bags, the highest polyphenol content was after exposure to UV-C 600/20 irradiation and flavonoids after UV-C 300/20 and UV-C 300/40 treatment. For pods stored without bags, the highest amount of polyphenols was found after UV-C 600/40 irradiation, and flavonoids after UV-C 300/20 and UV-C 600/60 treatment.

An increase in the flavonoid content of blueberries (*Vaccinium corymbosum* L.) after UV-C exposure was also recorded by Wang et al. [16]. After 4 days of storing broccoli irradiated with 10 kJ·m^{-2} UV-C, Costa et al. [41] found an increase in the content of phenols compared to non-exposed plants. Artes-Hernandez et al. [42] observed a decrease in phenol content of spinach leaves as a result of the dose of 4.54, 7.94, and 11.35 kJ·m^{-2} UV-C, regardless of storage temperature. In other studies, Artés-Hernández et al. [40] did not record any effect of UV-C radiation on the phenol content of watermelon fruit. Instead, they noted a growing decrease in that content of cube-cut watermelon during storage, regardless of whether it was exposed to different doses of UV-C or not. Similarly, Perkins-Veazie et al. [43] did not find a clear effect in total phenolic content of blueberries irradiated with UV-C after 7 days of storage at 5 °C, followed by 2 days at 20 °C. According to Cisneros-Zevallos [44] and Martinez-Hernandez et al. [45], UV-C radiation causes abiotic stress, which can cause an increase in the content of phenolic compounds after irradiation. Consequently, the effects of UV-C on the content of phenolics have not been yet completely elucidated and more research is needed.

Table 6. Selected antioxidants content of bean pods after 14 days of storage.

UV-C Irradiation Exposure Time (s)/Distance of Lamps from the Surface (cm)	Packing Method: Xtend® Bags	Packing Method: No Bags	Means
	Ascorbic acid (mg·100 g^{-1} f.m.)		
Without irradiation	18.73 ± 0.09	18.81 ± 0.44	18.77 ± 0.29a
UV-C 300/20	19.80 ± 0.69	19.76 ± 0.51	19.78 ± 0.54ab
UV-C 300/40	20.67 ± 1.09	20.08 ± 0.43	20.37 ± 0.81b
UV-C 300/60	19.80 ± 0.23	19.80 ± 0.80	19.80 ± 0.53ab
UV-C 600/20	19.85 ± 0.25	19.45 ± 0.34	19.65 ± 0.35ab
UV-C 600/40	19.27 ± 0.64	19.80 ± 0.77	19.53 ± 0.70ab
UV-C 600/60	19.01 ± 0.63	19.37 ± 0.15	19.19 ± 0.45a
Means	19.59 ± 0.80	19.58 ± 0.60	19.59 ± 0.69
	Phenolics (mg·100 g^{-1} f.m.)		
Without irradiation	29.6 ± 3.2a	21.1 ± 1.5a	25.3 ± 5.2a
UV-C 300/20	43.6 ± 2.5c	37.4 ± 3.8bc	40.5 ± 4.5b
UV-C 300/40	41.0 ± 2.2bc	28.5 ± 0.7ab	34.8 ± 7.0ab
UV-C 300/60	33.0 ± 8.5ab	38.2 ± 10.7bc	35.6 ± 9.1ab
UV-C 600/20	54.7 ± 2.6d	28.4 ± 0.8ab	41.6 ± 14.5b
UV-C 600/40	32.1 ± 2.9ab	38.8 ± 1.7c	35.4 ± 4.2ab
UV-C 600/60	30.1 ± 6.2a	35.0 ± 6.1bc	32.5 ± 6.2ab
Means	37.7 ± 9.6	32.5 ± 7.6	35.1 ± 8.9
	Flavonoids (mg·100 g^{-1} f.m.)		
Without irradiation	6.58 ± 0.04a	6.62 ± 0.10a	6.60 ± 0.07a
UV-C 300/20	8.66 ± 0.72c	8.30 ± 0.75c	8.48 ± 0.68b
UV-C 300/40	8.63 ± 0.94c	7.78 ± 0.43bc	8.20 ± 0.80b
UV-C 300/60	8.16 ± 0.70bc	6.96 ± 0.51ab	7.56 ± 0.85ab
UV-C 600/20	7.54 ± 0.1b	7.64 ± 0.08bc	7.59 ± 0.13ab
UV-C 600/40	8.25 ± 0.13bc	7.67 ± 0.19bc	7.96 ± 0.35b
UV-C 600/60	7.75 ± 0.42bc	7.91 ± 0.05c	7.83 ± 0.28b
Means	7.94 ± 0.83	7.55 ± 0.63	7.75 ± 0.76

Source of variation	df	Ascorbic acid F	Ascorbic acid P	Ascorbic acid $LSD_{0.05}$	Phenolics F	Phenolics P	Phenolics $LSD_{0.05}$	Flavonoids F	Flavonoids P	Flavonoids $LSD_{0.05}$
Packaging method	1	0.02	>0.05	NS	7.48	>0.05	NS	16.57	>0.05	NS
UV-C irradiation	6	4.72	0.011	1.149	5.51	0.006	11.33	7.06	0.002	1.120
Interaction	6	0.61	>0.05	NS	17.59	<0.001	10.03	3.84	0.023	0.930

Mean ± SD (n = 3) followed by different lowercase letters in columns and different letters in rows differ significantly at $p \leq 0.05$; NS—not significant, df—degrees of freedom, F—F-distribution, P—probability, $LSD_{0.05}$—least significant difference.

4. Conclusions

In the present study it was observed that a combined method of post-harvest treatment of string bean pods significantly reduced the loss of weight and quantity of pods fit for consumption in cold storage. The method was based on irradiating pods after the harvest and storing them in Xtend® bags which modified the composition of the atmosphere around stored vegetables. The loss of the mass of the pods due to transpiration was significantly lower if they were stored in Xtend® bags. The content of dry matter, total sugars and protein of pods stored in them was also lower. The combined method of post-harvest treatment of beans resulted in a significant increase in the content of compounds with antioxidant properties, i.e., polyphenols and flavonoids. UV-C irradiation, regardless of how pods were stored, increased the content of L-ascorbic acid. For practical use, it is necessary to recommend storing bean pods in Xtend® bags and their irradiation for 600 s with lamps at a distance of 40 cm. Such treatment had the most beneficial effect on the mass and quantity of pods fit for consumption after 14 days of storage. Additionally, there was high protein content in pods treated this way. To further study the effects of combined treatment (UV-C + MAP/Xtend® bags) of bean pods, but also of other vegetable species, it is worth considering testing the method on edible parts of plants originating from various locations and harvested at various maturity stages.

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