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UV-C Irradiation as a Sustainable Alternative to Fungicides for Managing Botrytis Decay and Extending the Shelf Life of Strawberry Fruit

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Abstract

Botrytis cinerea, the causal agent of gray mold or Botrytis rot on many vegetable and fruit crops worldwide, is ranked among the main limiting factors for strawberry production, being able to strongly compromise the quality, shelf life, and commercial value of fruit. UV-C is considered an environmentally friendly strategy for postharvest protection for several commodities. In this regard, this research evaluated the performance of short-wavelength UV-C radiation in reducing postharvest Botrytis decay, extending or maintaining the shelf life and quality of strawberry fruit, and detecting possible negative effects. The topic is of growing interest, as it falls within the strategic priorities of so-called "Green Technologies" to pursue a sustainable agriculture and safe food supply by minimizing fungicide use as much as possible. UV-C exposure (at a rate of 1428 J m^{-2}) by means of a UV-C lamp (15 W) at a source distance of 25 cm for just 1 min provided significant reductions (from 41 up to almost 80%) depending on the artificial or natural decay pressure of gray mold caused by *B. cinerea* on strawberry fruit without phytotoxic effects. Analyses performed under both refrigerated and room-temperature storage conditions at different day intervals showed that postharvest UV-C does not significantly affect key chemical parameters, including the ascorbic acid content, total sugars, pH, and titratable acidity of strawberry fruit. Thus, UV-C exposure for a brief time, especially if combined with a low temperature, can be effectively considered for sustainable protection of strawberry fruit at the postharvest stage, providing a theoretical basis for further elucidation of the action modes for this and other targets, and potential large-scale application.

Keywords: ultraviolet irradiation; *Botrytis cinerea*; fungal fruit rot; fruit storage; Green Technologies

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1. Introduction

Strawberry (*Fragaria* × *ananassa*) is a popular non-climacteric fruit, belonging to the Rosaceae family [1], with a high nutritional content [2]. Strawberries are a considerable

source of polyphenolic compounds, with significant amounts of anthocyanins, flavonoids and tannins [3–5], and ascorbic acid (vitamin C) [6]. Considering their beneficial effects, such as anti-inflammatory, antimicrobial, anti-carcinogenic and neuro-protective properties, the consumption of strawberries is highly recommended [7]. Strawberry fruit are characterized by a very short postharvest life due to their high metabolic activity and susceptibility to fungal decays [8]. Like other horticultural commodities [9], strawberry fruit are susceptible to water loss, bruising and mechanical injury due to their soft texture and lack of a protective rind [10]. Due to their perishability and the way they are handled, strawberries are among the most wasted fruits in the agri-food chain [11]. One of the most important quality characteristics of strawberries is their attractive red color, which is due to anthocyanins, a group of water-soluble pigments with antioxidant activity. As the spoilage index increases, the product becomes less attractive, reducing consumer acceptability [12–15]. The main limiting factor of strawberries at postharvest is represented by *Botrytis cinerea* Pers. This ascomycete is responsible for the well-known gray mold decay, also called Botrytis rot, and it is considered one of the most damaging fungal pathogens, affecting many vegetable and fruit crops worldwide [16–18]. Furthermore, the pathogen significantly compromises the quality, shelf life, and commercial value of fruit at the postharvest stage, including of strawberries. *Botrytis cinerea* is a necrotrophic generalist that infects flowers and ripening fruit, usually entering through senescing floral tissues, wounds or injuries. Symptoms include rapid softening, which leads to rapid fruit decay under humid conditions. The fungus infects strawberry fruit at both the pre- and postharvest stages, causing water-soaked lesions or soft decay. Under humid conditions, these lesions become covered with the characteristic gray conidial masses. This disease is responsible for significant economic losses [19,20]. Traditionally, management approaches have relied both on cultural sanitation practices and chemicals. However, the overuse of fungicides often induces widespread resistance phenomena, raising concerns about residues and environmental impact. Thus, combined strategies that include suitable agronomic practices, resistant cultivars, biological control agents, postharvest treatments, and novel approaches that exploit induced host resistance are being investigated more and more, and are attracting the most interest. Unfortunately, their performance is variable and depends on many factors [21,22]. Consequently, consumers are increasingly demanding sustainable and eco-friendly alternatives for managing postharvest diseases [19,23]. One of these promising methods is the application of ultraviolet (UV) light, which has emerged as a non-chemical strategy capable of inhibiting fungal growth and extending fruit shelf life [24–26].

In light of the above, this research aims to (i) investigate the performance of UV-C in reducing postharvest decay of strawberry fruit caused by *B. cinerea*; (ii) exclude any detrimental (phytotoxicity) implications of UV-C application on the commodity during the postharvest stage; and (iii) evaluate the impact of short-wavelength UV-C radiation on extending shelf life and maintaining the postharvest quality of fresh strawberry fruit.

2. Materials and Methods

2.1. UV-C Application, Procedure and Experimental Scheme

The strawberry fruit were irradiated using a UV-C lamp (Osram Puritec, HNS 36NG13, Osram, Treviso, Italy) with power output of 15 W (200–280 nm). The source–detector distance was 25 cm. A spectroradiometer (Hopoocolor, OHSP-350 series, Hangzhou Hopoo Light and Colour Technology Co., Ltd.-RPC, Hangzhou, China) was placed under the UV

lamp to determine its irradiation capacity. The emission spectrum, method and UV-C dose were calculated according to previous papers [26,27].

$$\text{UV dose}(\text{J m}^{-2}) \text{ irradiance}(\text{W m}^{-2}) \times \text{exposure time}(\text{s})$$

The UV-C irradiance, normalized to the distance of the samples undergoing treatment (25 cm), was equal to 23.8 W m^{-2}. Fruits were irradiated for 1 min with a dose of 1428 J m^{-2}. Both exposure time and rate for THE fruit were selected based on bibliographic research and a comparative data analysis [15,24]. To ensure the standardization of the irradiance value, the UV-C mercury lamp was switched on at least 3 min before irradiation to allow the filament to reach its steady-state emission level. Strawberry fruit were exposed to irradiation by positioning them beneath a reflective surface composed of aluminum foil, a material commonly employed in food preservation. It was ensured that the surface in contact with the fruit was the shiny one, characterized by a total reflectivity for UV radiation that exceeded 80% (in the absence of additional data, precautionary values were obtained) and that the incident radiation could reach the surface of the reflective foil unobstructed. All fruit were positioned with the inoculated surfaces facing upwards and towards the UV-C lamp so that the inoculated areas on fruit surface received full UV exposure.

Strawberry fruit (cultivar Portola®) were obtained from a commercial 2-year-old planting located at Maletto municipality, Catania province, Italy (37°49′43.8″ N 14°50′47.6″ E). "Maletto" strawberry refers to a recognized production area in Italy, including many everbearing strawberry (*Fragaria* × *ananassa* Duch.) varieties such as Portola, cultivated in the volcanic soil of Mount Etna, Sicily, and appreciated for its intense aroma, vibrant color, and extended flowering and fruiting period. Recently, the cultivar Portola has been able to reflect both the microclimate of Maletto and its long-standing tradition of high-quality strawberry production. In detail, fungicide-free fruits were chosen at commercial maturity and used for consumer's expectations. Fungicide-free (for at least 2 weeks) strawberry fruit, healthy and free of any microbial contamination or mechanical defects, were uniformly selected in terms of size and surface sanitized with an aqueous solution of sodium bicarbonate (2% of $NaHCO_3$) (Sanitec Natural, Italchimica S.r.l., Padova, Italy) for 2 min. Samples were packaged in commercial polypropylene (PP) trays for take-away purposes with a hermetic lid, measuring 12.5 × 11.5 × 5 cm (ILIP S.r.l., Valsamoggia, Bologna, Italy).

The packaged strawberry fruit were divided into 4 groups: 1—not inoculated (NI); 2—inoculated with *B. cinerea* (I); 3—not inoculated and treated with UV-C (NI + UV-C); 4—inoculated with *B. cinerea* and treated with UV-C (I + UV-C). Each treatment consisted of 4 replicates each formed by 4 fruits. Strawberry fruit were selected according to an average weight of 30–35 g.

Following inoculation and irradiation, all packaged strawberry fruit were stored at 20 ± 1 °C for 7 days (growth chamber) at about 85% relative humidity (RH) for evaluation of gray mold decay and at 4 ± 1 °C (refrigerated conditions) at 90% RH for 17 days for the assessment of shelf-life parameters.

2.2. Performance of UV-C Irradiation in Reducing Gray Mold on Strawberry

The UV-C effects were evaluated in two in vivo experiments on the strawberry cultivar Portola® against both gray mold decay onset (under natural infections) and artificial inoculation of *B. cinerea*, separately. The assessment of UV-C effectiveness in reducing gray mold rot caused by *B. cinerea* was performed in both experiments in hermetically sealed lidded trays containing fruit. The trays were incubated in a growth chamber during a 12 h photoperiod, at 20 ± 1 °C and about 85% RH. For the artificial inoculation experiment, the fruit were previously surface disinfected as described above and inoculated with a *B. cinerea*

conidial suspension approximately 5 min later. An aggressive isolate (Di3A Bc.1a) was previously recovered from infected strawberry Sicilian plantations, identified and stored in Di3A culture collection (Dipartimento di Agricoltura, Alimentazione e Ambiente i.e., Department of Agriculture, Food and Environment), University of Catania, Italy. A conidial suspension of *B. cinerea* recovered from an 8-day-old colony grown on potato dextrose agar (PDA, Lickson, Vicari, Italy) was used for the inoculation. By means of a microscope hemocytometer or Bürker chamber (BRAND GMBH + CO KG, Wertheim, Germany), the propagule concentration was set up to about 1.3×10^5 CFU (colonies forming units)/mL. Therefore, the conidial suspension was dispersed by means of a sprayer (droplet size of about 50–100 µm) on strawberry fruit until run off (approximately 250 µL/fruit). Under natural infection (NI) conditions, no inoculation was performed, but only spraying with the same amount of sterile distilled water (SDW, about 250 µL/fruit) as mentioned above. Both treated strawberry fruit were air-dried at 28–30 °C for approximately 3 min prior to UV-C exposure. Therefore, strawberry fruit were sealed in the PP trays with humidity conditions of about 90% RH. The experimental scheme included (i) untreated and (ii) UV-C-treated fruit. Four replicates (trays), each consisting of four strawberry fruit, were used. Single fruit had an approximate weight of 30–35 g. Both experiments (under natural and artificial decay pressure) were carried out twice.

Seven days following UV-C irradiation, the treatment efficacies were analyzed and related to the reduction in the incidence (DI), severity (DS) and McKinney index (IMcK) of gray mold decay. Data were definitively adjusted according to the following re-isolation of the fungal causal agent. DI was determined for each tray as the number of decayed fruit expressed as a percentage of the total number of fruit:

$$\mathrm{DI} = \frac{\text{n° of infected fruits}}{\text{n° total fruit}} \times 100$$

whereas DS referred to a practical 6-class scale taking into account increasing Botrytis fruit rot amount (Table 1, Figure 1) and was determined as follows:

$$\mathbf{DS} = \frac{\sum_{i=0,1\ldots5}^{n}(\mathbf{C}i \times \mathbf{n})}{N}$$

where DS is the mean index of disease severity, Ci is each class detected, n is the number of infected fruit in each class, i represents numerical values ranging from 0 to 5, and N is the total number of examined fruit [28].

Table 1. Empirical scale including 6 classes adopted for the assessment of gray mold decay caused by *Botrytis cinerea* on strawberry fruit cultivar Portola.

Score	Gray Mold Decay (*Botrytis cinerea*)
Class 0	Fruit apparently healthy
Class 1	Water-soaked rot without fungal sporulation
Class 2	Gray mold up to 20% of the fruit surface
Class 3	Gray mold from 20.1 to 45% of the fruit surface
Class 4	Gray mold from 45.1 to 70% of the fruit surface
Class 5	Gray mold from 70.1 to 100% of the fruit surface

Moreover, McKinney's index (IMcK), which combines both the decay incidence and severity of gray mold infections, was calculated as follows:

$$\mathbf{I_{McK}} = \frac{\sum(Ci \times n)}{N \times D} \times \mathbf{100}$$

where, beside the parameters reported above, D is the highest class appearing on the scale [29].

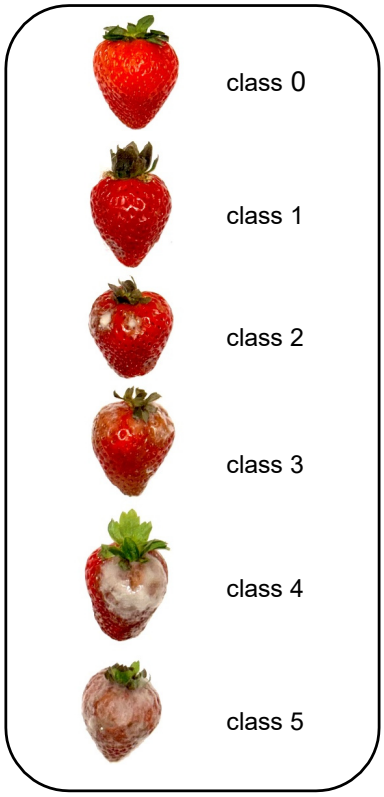

Figure 1. Color disease scale.

Deleterious phenomena or negative effects induced by UV-C irradiation versus the host were directly detected by analyzing the strawberry fruit surface.

2.3. Package Weight Loss and Headspace Gas Composition

The percentage of weight loss in fresh strawberry fruit was calculated at different storage intervals (0, 3, 7, 13, and 17 days under refrigeration, and 3, 5, and 7 days at room temperature), using the following equation:

$$WL\ (\%) = \left[\frac{W0 - Wt}{W0}\right] \times 100$$

where:

WL represents the percentage weight loss at time t;

W0 is the initial sample weight;

Wt is the sample weight at time t.

Headspace gas composition was determined using a CheckPoint portable gas analyzer (MO-CON EuropeA/S (Dansensor, Ringsted, Denmark), to measure CO_2 and O_2 concentrations. Analysis was performed for a single experiment on 4 replicates for each sampling time, both during refrigerated and room-temperature storage conditions.

2.4. Determination of Chromatic Parameters and Compositional Traits

All fruit from the four replicates of each tray were scanned in a dark room using a digital scanner (CanoScan LiDE 220, Canon Inc., Tokyo, Japan) to 600 × 600 dpi to determine chromatic coordinates and browning. The space used for the color evaluation referred to RGB (R = red; G = green; B = blue), whereas browning evaluation referred to the

HSI color model (H = hue; S = saturation; I = intensity) using Image-Pro® Plus software vers. 7.1 (Media Cybernetics Inc., Rockville, MD, USA).

The soluble solids (SS) were determined by squeezing the samples. The juice was dropped into a digital refractometer (DBR 95, P.R.C, Modena, Italia). Each measure was repeated three times, and the final data are expressed as percentage average (%).

Ascorbic acid (ASA, ppm) content was quantified using the HI 3850 Test Kit (Hanna Instruments Italia Srl, Padova, Italy), following the manufacturer's instruction.

Titratable acidity (TA) and pH were determined on fruit juice. In detail, 10 mL of juice was dissolved in 50 mL of distilled water, and the solution was titrated with NaOH 0.1 N. TA is expressed as g/100 g of citric acid as follows [30]:

$$TA\ (\%) = \left[\frac{\text{mL}\ NaOH \times 0.0064}{10}\right] \times 100$$

pH was determined at room temperature on strawberry juice diluted 1:10 with SDW with a pH meter (XS pH 7 Vio, Xs instruments, Modena, Italy).

2.5. Statistical Analyses

The Statistica software package (vers. 10; Statsoft Inc., Tulsa, OK, USA) was employed for the data analysis. Regarding in vivo UV-C effects in reducing fruit decay parameters, an analysis of variance (ANOVA) was performed on raw data. First, F and *p* values were calculated to establish whether the effects of single factors and their interactions were significant (three- and two-way ANOVA). Before the statistical analysis, DI percent values were transformed into angular values using arcsine ($\sin^{-1}$ square root x) to improve the homogeneity of variances. The means were always separated in the post hoc analyses (main effect) using Fisher's least significance difference test ($\alpha = 0.05$) [31].

Two-way ANOVA was used for compositional and chromatic variables by considering treatment and storage time as factors. Otherwise, one-way ANOVA was adopted considering treatment as the main factor. To determine post hoc differences, the aforementioned test was used with the same significance level ($\alpha = 0.05$).

3. Results

3.1. Performance of UV-C Irradiation in Reducing Gray Mold Decay of Strawberry

In the three-way ANOVA, treatment and decay pressure factors consistently had a significant effect on each gray mold decay parameter caused by *B. cinerea*. In contrast, trial and all interactions did not have a significant effect on strawberry decay parameters, thus suggesting a high reproducibility of experiments (Table 2).

Table 2. Analysis of variance for treatment, trial and disease pressure (natural or artificial) and relative interactions on incidence, severity and McKinney index of gray mold decay of strawberry fruit caused by *Botrytis cinerea*.

Factor		Decay Incidence		Decay Severity		McKinney Index	
	df	F	*p*-Value	F	*p*-Value	F	*p*-Value
Treatment	1	*19.267*	*0.0002* ***	*53.797*	*<0.0001* ****	*53.797*	*<0.0001* ****
Trial	1	0.600	0.446 ^{ns}	0.102	0.753 ^{ns}	0.1017	0.753 ^{ns}
Disease pressure	1	*41.667*	*<0.0001* ****	*26.034*	*<0.0001* ****	*26.034*	*<0.0001* ****
Treatment × trial	1	0.600	0.446 ^{ns}	0.915	0.348 ^{ns}	0.915	0.348 ^{ns}
Treat. × disease pressure	1	0.600	0.446 ^{ns}	1.627	0.214 ^{ns}	1.627	0.214 ^{ns}

Table 2. *Cont.*

Factor	df	Decay Incidence		Decay Severity		McKinney Index	
		F	*p*-Value	F	*p*-Value	F	*p*-Value
Trial × disease pressure	1	0.067	0.798 ^{ns}	0.000	1.000 ^{ns}	0.000	1.000 ^{ns}
Treat. × dis. press. × trial	1	0.067	0.798 ^{ns}	0.000	1.000 ^{ns}	0.000	1.000 ^{ns}

df = degree of freedom; *p*-value of fixed effects associated with F (Fisher) test. ^{ns} = not significant data; * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; **** = *p*-value < 0.0001.

The UV-C rays provided a higher significant effect in reducing decay parameters under artificial inoculation than those relative to and detected under natural decay pressure (Tables 3 and 4).

Table 3. Analysis of variance for single factors, treatment and trial and relative interaction on decay incidence, severity and McKinney index caused by *Botrytis cinerea* on strawberry fruit under natural decay pressure.

Factor	df	Fruit Decay Incidence (DI)		Fruit Decay Severity (DS)		McKinney Index	
		F	*p*-Value	F	*p*-Value	F	*p*-Value
Treatment	1	*8.333*	*0.014* *	*11.645*	*0.005* **	*11.645*	*0.005* **
Trial	1	0.333	0.574	0.032 ^{ns}	0.860 ^{ns}	0.032 ^{ns}	0.860 ^{ns}
Treatment × trial	1	0.333	0.574	0.290 ^{ns}	0.600 ^{ns}	0.290 ^{ns}	0.600 ^{ns}

df = degree of freedom; *p*-value of fixed effects associated to F (Fisher) test. ns = not significant data; * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; **** = *p*-value < 0.0001.

Table 4. Analysis of variance for single factors, treatment and trial and their interactions on decay incidence, severity and McKinney index caused by *Botrytis cinerea* on strawberry fruit under artificial decay pressure.

Factor	df	Fruit Decay Incidence (DI)		Fruit Decay Severity (DS)		McKinney Index	
		F	*p*-Value	F	*p*-Value	F	*p*-Value
Treatment	1	*16.333*	*0.0016* **	*87.480*	*<0.0001* ****	*87.480*	*<0.0001* ****
Trial	1	0.333	0.574 ^{ns}	0.120	0.735	0.120	0.735
Treatment × trial	1	0.333	0.5744 ^{ns}	1.080	0.319	1.080	0.319

df = degree of freedom; *p*-value of fixed effects associated to F (Fisher) test. ns = not significant data; * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; **** = *p*-value < 0.0001.

Thus, the main post hoc effects tests always confirmed the differences between UV-C-treated and untreated fruit for all decay parameters in all conditions (Table 5, Figure 2).

Table 5. Post hoc main effects of UV-C on decay incidence, severity and McKinney index on strawberry fruit cv Portola® caused by *Botrytis cinerea*.

	Natural Infections (*Botrytis cinerea*)				Artificial Inoculation (*Botrytis cinerea*)			
	DI (%)	DI (av)	DS (6-Class Scale)	McKinney	DI (%)	DI (av)	DS (6-Class Scale)	McKinney
Untreated	21.88 ± 2.55 a	26.25	0.75 ± 0.05 a	12.50 ± 0.85 a	53.13 ± 2.55 a	46.87	1.38 ± 0.05 a	22.92 ± 0.85 a
UV-C	6.25 ± 0.03 b	7.50	0.16 ± 0.03 b	2.61 ± 0.43 b	31.25 ± 0.05 b	33.75	0.53 ± 0.05 b	8.85 ± 0.43 b

Data from two trials ± SEM (standard error of the mean). Means for each parameter were obtained from 4 replicates, each formed by 4 fruits. Before analysis, DI percent values were previously transformed as arcsine square root (into angular values—av) to improve homogeneity of variance. According to Fisher's least significance differences test, values followed by different letters within the column are significantly different ($\alpha = 0.05$).

In detail, the strawberry infection reductions due to UV-C treatment were more evident under low natural decay pressure (ranging from 70.8 up to 79.4%) than those detected under high artificial decay conditions (from 41.0 up to 61.5%), as shown in Figure 3. These differences are probably due to the high virulence degree of the *B. cinerea* isolate used for

the artificial inoculation, besides high disease pressure conditions. Moreover, no deleterious effects were investigated in the UV-C-treated fruit through all trials.

Figure 2. Exemplificative image showing the ranking of in vivo UV-C performance in managing gray mold decay of strawberry cv Portola for approximately two-thirds of the survey. Data refer to natural infection (**on the left**) and artificial inoculations (**on the right**); Ctrl = untreated control; UV-C = radiated fruit.

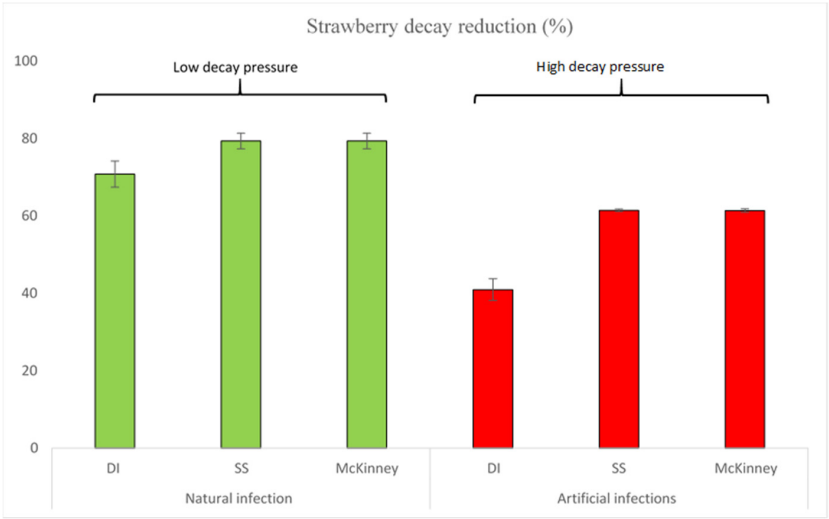

Figure 3. Comparison of UV-C performance in reducing gray mold decay under natural (low) and medium-high decay pressure. Percentage data reduction for each decay parameter refers to two trials ± SEM (standard error of the mean) performed for both operative conditions.

3.2. Package Weight Loss and Headspace Gas Composition

One-way ANOVA data of weight loss (WL%) and headspace gas composition during the observation period at room temperature are reported in Table 6. Likewise, the two-way ANOVA output is reported in Table 7. An increase in weight loss of all samples (untreated and UV-C treated) was observed. After 5 days of storage at 20 °C, no differences were found between control and treated strawberry fruit. In contrast, after 7 days, fruit irradiated with UV-C showed higher weight loss than the control, reaching 7.33 ± 0.00 (+14.28%) for NI + UV-C samples and 7.40 ± 0.00 (+9.25%) for I + UV-C samples (Table 6).

Table 6. One-way ANOVA output of the treatment effect on weight loss and headspace gas composition during storage at room temperature (20 °C) of strawberry fruit.

	Days	WL (%)	O_2 (%)	CO_2 (%)
NI	0	-	20.30 ± 0.07 ab	0.60 ± 0.07 ab
I		-	20.10 ± 0.00 ab	0.65 ± 0.04 ab
NI + UV-C		-	19.95 ± 0.04 b	1.00 ± 0.07 a
I + UV-C		-	20.55 ± 0.11 a	0.45 ± 0.04 b
		***	*	*
NI	3	0.49 ± 0.00 c	16.95 ± 0.32	4.60 ± 0.21
I		0.80 ± 0.00 a	17.45 ± 0.18	4.20 ± 0.00
NI + UV-C		0.60 ± 0.00 b	17.60 ± 0.28	4.20 ± 0.28
I + UV-C		0.72 ± 0.00 a	18.30 ± 0.49	3.70 ± 0.57
		***	ns	ns
NI	5	1.79 ± 0.00	16.65 ± 0.04	5.60 ± 0.35
I		2.28 ± 0.00	17.60 ± 0.64	4.50 ± 0.57
NI + UV-C		2.17 ± 0.00	17.60 ± 0.00	4.75 ± 0.25
I + UV-C		2.40 ± 0.00	18.60 ± 0.07	3.10 ± 0.28
		ns	ns	ns
NI	7	5.36 ± 0.00 b	16.20 ± 0.00	6.90 ± 0.00
I		6.44 ± 0.00 ab	16.35 ± 0.04	5.60 ± 0.07
NI + UV-C		7.33 ± 0.00 a	17.10 ± 0.04	4.95 ± 0.04
I + UV-C		7.40 ± 0.00 a	18.65 ± 0.04	2.95 ± 0.04
		*	ns	ns

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns: not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; WL%: percent of weight loss; O_2 and CO_2%: percent of partial pressures of oxygen and carbon dioxide in the headspace of the packages.

Strawberry respiration rate increased during storage at room temperature. In detail, for all samples through the observation period, a decreasing trend for O_2% followed by an increase in partial pressure of CO_2 (CO_2%) was registered. After 7 days, control fruit showed higher values than UV-C-irradiated fruit, in NI samples reaching 16.20 ± 0.00 O_2% and 6.90 ± 0.00 CO_2%, while the lowest respiration rate was detected in I + UV-C samples (O2% 18.65 ± 0.04 and CO_2% 2.95 ± 0.04) (Table 6).

Considering refrigerated storage, one-way ANOVA showed no statistical differences for headspace gas composition until the end of the survey period (Table 8). The greatest increase in WL% was registered in NI + UVC samples (4.24 ± 0.00) up to the 13th day of storage. At 17 days, in all samples similar values were found regardless of treatment and inoculation (Table 8).

Two-way ANOVA showed significant differences for weight loss and headspace gas composition until the end of storage (Table 9). Higher weight loss values were found in the irradiated samples. Table 9 shows the trend in gas concentration up to day 17. For all samples, a decrease in oxygen concentration was detected in the headspace, with

a consequent increase in carbon dioxide concentration. I + UVC exhibited the greatest decrease in O_2 concentration compared to all other treatments, reaching 19.77 ± 0.02 O_2%. The sample showing the highest increase in CO_2 was I + UVC (1.36 ± 0.03 CO_2%).

Table 7. Two-way ANOVA output on the effect of treatment and storage time on weight loss and headspace gas composition at room temperature (20 °C) of strawberry fruit.

Main Factor	Parameters		
	WL (%)	O_2 (%)	CO_2 (%)
NI	2.54 ± 0.00 b	17.53 ± 0.22 b	4.43 ± 0.32 a
I	3.18 ± 0.00 a	17.88 ± 0.19 b	3.74 ± 0.25 a
NI + UV-C	3.36 ± 0.01 a	18.06 ± 0.15 b	3.73 ± 0.22 a
I + UV-C	3.50 ± 0.01 a	19.03 ± 0.13 a	2.55 ± 0.18 b
Treatment (T)	***	***	***
0	-	20.23 ± 0.03 a	0.68 ± 0.03 c
3	0.65 ± 0.00 c	17.58 ± 0.08 b	4.18 ± 0.08 b
5	2.16 ± 0.00 b	17.61 ± 0.14 b	4.49 ± 0.14 ab
7	6.63 ± 0.00 a	17.08 ± 0.19 b	5.10 ± 0.19 a
Storage time (days) (ST)	***	***	***
Treat. × storage time	**	ns	**

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns: not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; WL%: percent of weight loss; O_2 and CO_2%: percent of partial pressures of oxygen and carbon dioxide in the headspace of the packages.

Table 8. One-way ANOVA output on the effect of treatment on chemical–physical quality parameters tested during the refrigerated storage (days) of strawberry fruit.

Main Factor	Days	WL (%)	O_2 (%)	CO_2 (%)
NI	0	-	20.30 ± 0.03 b	0.63 ± 0.02 b
I		-	20.13 ± 0.02 bc	0.63 ± 0.06 b
NI + UV-C		-	20.00 ± 0.03 c	1.00 ± 0.03 a
I + UV-C		-	20.57 ± 0.05 a	0.37 ± 0.05 b
			***	***
NI	3	0.94 ± 0.00 a	20.47 ± 0.05 a	0.27 ± 0.02 b
I		0.11 ± 0.00 b	19.80 ± 0.12 b	1.17 ± 0.11 a
NI + UV-C		1.12 ± 0.00 a	19.77 ± 0.04 b	1.43 ± 0.08 a
I + UV-C		0.09 ± 0.00 b	19.63 ± 0.08 b	1.53 ± 0.10 a
		***	*	***
NI	7	1.84 ± 0.00 a	19.63 ± 0.02	1.47 ± 0.05
I		1.00 ± 0.00 b	19.50 ± 0.12	1.67 ± 0.13
NI + UV-C		2.22 ± 0.00 a	19.67 ± 0.02	1.33 ± 0.04
I + UV-C		1.07 ± 0.00 b	19.67 ± 0.10	1.33 ± 0.10
		**	ns	ns
NI	10	2.48 ± 0.00 ab	20.17 ± 0.22	1.20 ± 0.09
I		1.65 ± 0.00 b	19.70 ± 0.09	1.43 ± 0.13
NI + UV-C		3.05 ± 0.00 a	19.63 ± 0.08	1.43 ± 0.08
I + UV-C		1.99 ± 0.00 b	19.63 ± 0.05	1.47 ± 0.08
		*	ns	ns
NI	13	3.41 ± 0.00 ab	19.77 ± 0.10	1.40 ± 0.15
I		2.53 ± 0.00 b	19.77 ± 0.02	1.47 ± 0.08
NI + UV-C		4.24 ± 0.00 a	19.70 ± 0.09	1.43 ± 0.13
I + UV-C		2.99 ± 0.00 ab	19.87 ± 0.15	1.20 ± 0.19
		*	ns	ns

Table 8. *Cont.*

Main Factor	Days	WL (%)	O_2 (%)	CO_2 (%)
NI	17	4.67 ± 0.00	20.07 ± 0.10	1.20 ± 0.12
I		3.69 ± 0.00	20.03 ± 0.05	1.30 ± 0.09
NI + UV-C		5.65 ± 0.00	19.83 ± 0.11	1.50 ± 0.15
I + UV-C		4.53 ± 0.00	19.97 ± 0.07	1.37 ± 0.11
		ns	ns	ns

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns: not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; WL%: percent of weight loss; O_2 and CO_2%: percent of partial pressures of oxygen and carbon dioxide in the headspace of the packages.

Table 9. Two-way ANOVA output on the effect of treatment and storage time on chemical–physical quality parameters tested during the refrigerated storage (days) of strawberry fruit.

Main Factor	Parameters		
	WL (%)	O_2 (%)	CO_2 (%)
NI	2.13 ± 0.00 c	20.07 ± 0.02 a	1.02 ± 0.03 b
I	1.79 ± 0.00 c	19.82 ± 0.02 ab	1.28 ± 0.02 ab
NI + UV-C	3.25 ± 0.00 a	19.89 ± 0.01 ab	1.21 ± 0.02 ab
I + UV-C	2.67 ± 0.00 b	19.77 ± 0.02 b	1.36 ± 0.03 a
Treatment (T)	***	**	**
0	-	20.25 ± 0.02 a	0.65 ± 0.02 b
3	0.56 ± 0.00 e	19.91 ± 0.03 ab	1.10 ± 0.05 a
7	1.53 ± 0.00 d	19.96 ± 0.02 ab	1.35 ± 0.02 a
10	2.90 ± 0.00 c	19.78 ± 0.03 b	1.38 ± 0.02 a
13	3.29 ± 0.00 b	19.77 ± 0.02 b	1.37 ± 0.03 a
17	4.63 ± 0.00 a	19.62 ± 0.02 b	1.45 ± 0.03 a
Storage Time (days) (ST)	***	***	***
Treat. × Storage Time	ns	ns	**

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns: not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; WL%: percent of weight loss; O_2 and CO_2%: percent of partial pressures of oxygen and carbon dioxide in the headspace of the packages.

3.3. Chromatic Parameters and Compositional Traits

One-way ANOVA results of color parameters during refrigerated storage are shown in Table 10, while Table 11 reports two-way ANOVA results on color parameters during refrigerated storage. For red (R) and green (G) parameters, minimal variations among samples were found. Blue (B) showed a decreasing trend for the I + UVC sample, when compared to other samples during the observation period. For the color parameters hue (H) and saturation (S), higher values were observed for all samples except for the inoculated one, whose values were lower at the end of storage. Finally, at the end of storage, the intensity (I) parameter showed lower values for samples treated with UV-C radiation, probably due to exposure time or radiation itself.

During refrigerated storage, solid soluble content (SS%) and pH showed no statistical differences between samples at different sampling times.

Titratable acidity was reduced in samples regardless of UV-C treatment (Table 12). After 17 days of refrigerated storage, the highest TA (% of citric acid) was registered in NI + UV-C samples (0.15 ± 0.00% of citric acid) and I + UV-C samples (0.15 ± 0.00% of citric acid).

Table 10. Two-way ANOVA output on the effect of treatment and storage time on color and browning of strawberry fruit.

Main Factor	Parameters					
	Red	Green	Blue	Hue	Saturation	Intensity
NI	111.97 ± 0.17	36.71 ± 0.14 ab	40.36 ± 0.11 ab	175.54 ± 0.96	119.42 ± 0.28 a	63.33 ± 0.13 ab
I	112.48 ± 0.18	36.50 ± 0.18 ab	40.44 ± 0.16 ab	172.00 ± 1.14	120.40 ± 0.47 a	63.04 ± 0.15 ab
NI + UV-C	112.81 ± 0.22	34.70 ± 0.18 b	38.95 ± 0.16 b	169.79 ± 0.89	123.92 ± 0.39 a	62.10 ± 0.17 b
I + UV-C	113.47 ± 0.21	40.06 ± 0.18 a	43.39± 0.14 a	149.51 ± 1.41	110.54 ± 0.39 b	65.67 ± 0.15 a
Treatment (T)	ns	*	**	ns	***	*
0	114.86 ± 0.37 a	34.80 ± 0.38 b	37.53 ± 0.30 c	132.29 ± 2.08 b	126.87 ± 0.93 a	62.54 ± 0.31 bc
3	109.88 ± 0.27 ab	35.03 ± 0.25 b	38.61 ± 0.16 bc	167.91 ± 1.62 a	122.28 ± 0.43 a	61.50 ± 0.21 bc
7	114.63 ± 0.22 a	41.87 ± 0.22 a	45.32 ± 0.18 a	162.61 ± 1.76 ab	107.58 ± 0.45 b	67.21 ± 0.18 a
10	114.47 ± 0.26 a	38.26 ± 0.24 ab	42.72 ± 0.19 ab	175.61 ± 1.31 a	116.54 ± 0.46 ab	65.16 ± 0.22 ab
13	106.92 ± 0.28 b	34.06 ± 0.19 b	38.92 ± 0.19 bc	189.59 ± 1.18 a	120.64 ± 0.53 a	59.86 ± 0.17 c
17	115.35 ± 0.23 a	37.92 ± 0.21 ab	41.59 ± 0.18 abc	162.88 ± 1.94 ab	117.51 ± 0.52 ab	64.97 ± 0.18 ab
Storage time (ST)	***	***	***	***	***	***
T × S	**	***	***	***	***	***

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated.

Table 11. One-way ANOVA output on the effect of treatment and storage time on color and browning of strawberry fruit.

Main Factor	Days	Parameters					
		Red	Green	Blue	Hue	Saturation	Intensity
NI	0	109.11 ± 0.44 b	34.09 ± 0.72 b	36.99 ± 0.50 b	150.62 ± 6.93 b	122.86 ± 1.96 b	60.23 ± 0.49 b
I		115.64 ± 1.33 ab	25.52 ± 0.64 b	30.26 ± 0.31 b	174.63 ± 6.56 a	156.09 ± 2.04 a	57.17 ± 0.70 b
NI + UVC		109.64 ± 1.93 b	28.52 ± 1.04 b	32.05 ± 0.83 b	151.45 ± 5.63 b	136.96 ± 2.51 ab	56.74 ± 1.19 b
I + UVC		125.05 ± 1.14 a	51.07 ± 1.09 a	50.84 ± 0.91 a	152.44 ± 5.07 b	91.57 ± 2.61 c	76.00 ± 0.67 a
		*	***	***	***	***	***
NI	3	109.89 ± 1.39	39.24 ± 1.52	39.57 ± 0.90	124.06 ± 8.29	117.00 ± 1.87	63.76 ± 1.33
I		109.39 ± 1.00	32.66 ± 0.83	37.80 ± 0.67	189.00 ± 5.99	125.30 ± 1.87	59.93 ± 0.73
NI + UVC		111.06 ± 0.80	34.55 ± 0.82	38.75 ± 0.65	173.02 ± 3.51	124.25 ± 1.91	61.46 ± 0.65
I + UVC		109.18 ± 1.23	33.67 ± 0.41	38.33 ± 0.38	185.57 ± 4.48	122.58 ± 1.29	60.84 ± 0.58
		ns	ns	ns	ns	ns	ns
NI	7	113.83 ± 0.61 ab	38.42 ± 0.97	40.92 ± 0.65 b	144.85 ± 7.84	116.53 ± 1.91	64.60 ± 0.67 b
I		110.87 ± 0.94 b	39.72 ± 0.74	44.29 ± 0.67 ab	188.42 ± 4.27	109.34 ± 1.26	64.91 ± 0.76 ab
NI + UVC		120.73 ± 0.95 a	45.60 ± 0.82	48.20 ± 0.75 a	143.48 ± 6.99	104.30 ± 1.93	71.65 ± 0.65 a
I + UVC		113.09 ± 0.38 ab	43.74 ± 0.85	47.89 ± 0.55 ab	173.69 ± 8.08	100.17 ± 1.66	67.67 ± 0.55 ab
		*	ns	*	ns	ns	*
NI	10	111.64 ± 1.26	35.06 ± 0.63 ab	40.35 ± 0.64 ab	190.31 ± 2.83 ab	120.99 ± 1.40 ab	62.78 ± 0.81 ab
I		117.21 ± 0.51	44.40 ± 0.66 a	47.25 ± 0.43 a	149.99 ± 6.18 b	104.49 ± 1.14 b	69.77 ± 0.51 a
NI + UVC		112.03 ± 1.03	32.42 ± 1.01 c	38.66 ± 0.89 b	205.73 ± 3.50 a	128.70 ± 2.00 a	60.67 ± 0.96 b
I + UVC		117.01 ± 1.19	41.16 ± 0.75 bc	44.63 ± 0.55 ab	156.41 ± 5.04 ab	112.00 ± 1.39 b	67.41 ± 0.72 ab
		ns	***	*	*	***	*
NI	13	107.56 ± 0.83	34.84 ± 0.61	40.39 ± 0.53 ab	208.38 ± 2.45 bc	119.33 ± 2.02	61.12 ± 0.55
I		104.56 ± 0.60	36.42 ± 0.97	42.07 ± 0.89 a	216.73 ± 1.73 a	112.33 ± 2.36	60.26 ± 0.67
NI + UVC		110.15 ± 1.65	29.68 ± 0.72	33.77 ± 0.76 b	159.60 ± 3.33 c	134.10 ± 2.30	58.08 ± 0.89
I + UVC		105.40 ± 1.15	35.29 ± 0.51	39.45 ± 0.57 ab	173.80 ± 6.26 ab	116.79 ± 0.67	59.98 ± 0.64
		ns	ns	*	**	ns	ns

Table 11. *Cont.*

Main Factor	Days	Parameters					
		Red	Green	Blue	Hue	Saturation	Intensity
NI	17	119.80 ± 0.82	38.58 ± 0.25	43.93 ± 0.25	197.67 ± 4.78 a	119.82 ± 1.27	67.50 ± 0.37
I		117.24 ± 1.05	40.29 ± 1.09	40.99 ± 1.02	113.22 ± 7.78 b	114.86 ± 2.53	66.23 ± 0.97
NI + UVC		113.26 ± 0.80	37.41 ± 0.54	42.28 ± 0.62	185.49 ± 3.92 ab	115.23 ± 1.01	64.01 ± 0.64
I + UVC		111.11 ± 0.66	35.40 ± 1.18	39.18 ± 0.71	155.15 ± 9.62 ab	120.14 ± 3.14	62.15 ± 0.71
		ns	ns	ns	*	ns	ns

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated.

Table 12. One-way ANOVA output on the effect of treatment on chemical quality parameters tested during the refrigerated storage (days) of strawberry fruit.

Main Factor	Days	TA (%)	AsA (ppm)
NI	0	0.36 ± 0.00 c	40.50 ± 0.35 b
I		0.23 ± 0.01 a	59.50 ± 0.35 a
NI + UV-C		0.28 ± 0.00 b	41.00 ± 0.71 b
I + UV-C		0.29 ± 0.00 b	59.50 ± 0.35 a
		**	***
NI	3	0.23 ± 0.01 b	45.00 ± 3.54
I		0.22 ± 0.00 b	50.50 ± 0.35
NI + UV-C		0.22 ± 0.02 b	39.50 ± 0.35
I + UV-C		0.27 ± 0.01 a	39.00 ± 0.71
		***	ns
NI	7	0.22 ± 0.00 a	38.00 ± 0.71 b
I		0.21 ± 0.03 a	29.50 ± 0.35 a
NI + UV-C		0.27 ± 0.00 b	39.00 ± 0.71 b
I + UV-C		0.22 ± 0.00 a	39.50 ± 0.35 b
		***	*
NI	10	0.22 ± 0.00 b	39.50± 0.35 b
I		0.22 ± 0.01 b	29.50 ± 0.35 a
NI + UVC		0.12 ± 0.00 a	40.00 ± 0.71 b
I + UVC		0.13 ± 0.01 a	39.50 ± 0.35 b
		***	***
NI	13	0.20 ± 0.01 b	29.50± 0.35 a
I		0.17 ± 0.01 a	29.00 ± 0.71 a
NI + UVC		0.13 ± 0.00 a	40.00 ± 0.71 b
I + UVC		0.15 ± 0.01 a	39.00 ± 0.71 b
		***	**
NI	17	0.13 ± 0.00 c	29.50 ± 0.35 a
I		0.14 ± 0.01 b	29.00 ± 0.71 a
NI + UVC		0.15 ± 0.00 a	39.50 ± 0.35 b
I + UVC		0.15 ± 0.00 a	29.50 ± 0.35 a
		***	***

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; ns not significant. NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; TA: percent of citric acid titratable acidity; AsA: ascorbic acid ppm.

As reported in Table 13, two-way ANOVA data showed that UV-C radiation and inoculum reduced TA % if compared to NI samples, and a decreasing trend was registered from 0 to 17 days of storage (0.29 ± 0.01 vs. 0.14 ± 0.01).

Table 13. Two-way ANOVA output on the effect of treatment and storage time on chemical quality parameters tested during the refrigerated storage (days) of strawberry fruit.

Main Factor	TA (%)	AsA (ppm)
NI	0.23 ± 0.01 a	37.00 ± 0.53 c
I	0.20 ± 0.02 b	37.83 ± 1.08 c
NI + UV-C	0.20 ± 0.01 b	39.83 ± 0.09 b
I + UV-C	0.20 ± 0.01 b	41.67 ± 0.79 a
Treatment (T)	***	***
0	0.29 ± 0.01 a	50.13 ± 1.26 a
3	0.24 ± 0.02 b	43.50 ± 0.71 b
7	0.23 ± 0.03 b	37.13 ± 0.56 c
10	0.18 ± 0.01 c	36.50 ± 0.60 c
13	0.16 ± 0.01 c	34.38 ± 0.70 d
17	0.14 ± 0.01 d	31.88 ± 0.60 e
Storage Time (days) (ST)	***	***
Treat. × Storage Time	***	***

Average data ± standard error of the mean (SEM). The same letters following the values denote no significant differences within the same column. * = 0.01 < *p*-value < 0.05; ** = 0.001 < *p*-value < 0.01; *** = 0.0001 < *p*-value < 0.001; NI: not inoculated; I: inoculated; NI + UV-C: not inoculated and UV-C treated; I + UV-C: inoculated and UV-C treated; TA: percent of citric acid titratable acidity; AsA: ascorbic acid ppm.

The AsA content decreased in all samples at the end of storage, with the sample having the highest concentration during the shelf-life period being NI + UV-C (39.50 ± 0.35 ppm) (Table 12).

The results of the two-way ANOVA showed that the sample with the highest concentration of AsA was I + UV-C (41.67 ± 0.79 ppm). Regardless of the duration of radiation and inoculation, at the end of storage on day 17, a decrease in AsA content was recorded, reaching 31.88 ± 0.60 ppm (Table 13).

4. Discussion

Although UV-C effects have been preliminarily detected in the past, there has only recently been renewed attention on exploiting them for managing postharvest strawberry decay [32,33]. This focus is linked to the growing need to develop fungicide-free postharvest approaches that guarantee the organoleptic quality and microbiological safety of fresh commodities [34]. In this context, UV-C radiation is a promising "green technology" for pursuing sustainable agriculture [27,34].

In this regard, this paper provides a new framework for managing postharvest gray mold decay of strawberry fruit, highlighting for the first time a good performance of UVC irradiation, even when applied for just 1 min. This aspect becomes even more noteworthy since this experimental procedure does not result in adverse effects associated with UV-C treatments being observed on fruit. These findings are in partial accordance with those reported in the literature, although in the past, studies of UV-C efficacy on quantification of decay and the phytotoxicity evaluation were lacking or partial, and in others the assessment of UV-C efficacy was carried out in combination with other control means (e.g., innovative packaging film) [32,33,35]. On the other hand, Forges et al. [36] performed a study also including the phytotoxicity assessment, but the UV-C evaluation was carried out only on strawberry plants and not on fruit. Further studies also showed good performance of UV-C radiation against other targeted fungal decays, including gray mold, in field or experimental semi-field conditions, and assessed the UV-C effects on the canopy [37,38], thus corroborating the data shown herein. In this regard, this paper plays an important role since strawberries, especially the recognized "Maletto brand", are among the most perishable fruits [39]. This is due to their high metabolic and softening rates, as well as

their high decay susceptibility, which normally lead to a very brief postharvest life, even under proper refrigeration [40,41].

In the past, several studies highlighted that UV-C treatments, when applied at similar rates, are able to reduce significantly the deterioration of strawberries during storage. Daiuto et al. [42] reported that higher intensity of UV-C radiation could be effective in delaying the respiration rate, which retards fruit weight losses. In particular, weight loss was lower in fruit subjected to treatments with high light intensity, suggesting a positive effect on maintaining tissue integrity [35,43]. On the contrary, our results showed greater weight loss in samples exposed to UV-C. This is probably due to the fact that the application of UV-C could stress the fruit, increasing the respiration rates of the samples. Photo-oxidation reactions in plants trigger the production of free radicals and superoxide, and can accelerate senescence [44,45].

Visual appearance and the absence of microbial symptoms are crucial factors for strawberry consumers, as any signs of fruit surface decay are often perceived negatively [33]. The literature reports contrasting results about the effect of UV-C rays on the color characteristics of strawberries, but in this paper no significant difference was detected. Some authors have observed a reduction in color values in treated fruit compared to control samples, while others have not detected significant variations in color attributes [33,46,47]. According to Souza et al. [48], different intensities of UV-C treatment can induce postharvest abiotic stress which, in turn, can influence color changes on the fruit surface.

During the postharvest period, TA is consumed in the respiration process, resulting in a reduction in its amount [49]. Our findings are consistent with several studies [33,50] that showed a reduction in citric acid in strawberry fruit during storage. Unlike Pan et al. [51], the treatments do not significantly affect the content and titratable acidity; herein, the treatment reduces the TA content.

Vitamin C content tends to decrease during storage as well. The composition of the storage atmosphere affects changes in vitamin C content. In particular, low oxygen concentrations can help preserve levels, as they reduce respiration and ascorbate oxidase activity [52]. Mditshwa et al. [53] observed that ascorbate oxidase activity decreases under the influence of UV-C rays, thus promoting the preservation of vitamin C during storage. However, the effectiveness of UV-C treatment depends on the intensity and duration of irradiation [54].

5. Conclusions

Our data provide a valuable perspective about postharvest application of UV-C irradiation to manage gray mold of strawberry, demonstrating that the exposure time of treatment can be reduced to just 1 min.

The rising consumer demand for chemical residue-free food has triggered a strategic shift toward sustainable Green Technologies. Responding to this premise, this study shows that a very brief postharvest UV-C exposure is able to manage fungal decay without detrimental effects. Although UV-C radiation can induce light stress, i.e., insignificant weight losses, during room-temperature storage, this drawback was successfully overcome when treatment was coupled with low-temperature storage. The choice of the cultivar Portola emphasizes the feasibility of this procedure for protecting high-quality niche productions, such as the recognized commodity of the Maletto district on Mount Etna. Our findings provide a theoretical and practical basis to develop an eco-friendly alternative to fungicide reliance. Future studies should focus on the biochemical and tissue-level changes to elucidate the effects of UV-C on cellular respiration and senescence.

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gation, methodology, validation, software, visualization, writing—original draft. C.A.C.R.: data curation, investigation, methodology, validation, software, visualization, writing—original draft. G.I.: data curation, investigation, methodology, validation, visualization, writing—original draft. E.L.B.: methodology, validation, software, visualization, writing—original draft. C.D.P.: data curation, investigation, methodology, validation, software, visualization. G.L.Q.: data curation, investigation, methodology, validation, software, visualization. M.R.: validation, software, visualization. G.T.: investigation, methodology, validation, visualization. S.S.: methodology, validation, software, visualization. Y.R.D.: validation, software, visualization. G.M.: conceptualization, supervision, validation, visualization, funding acquisition, project administration, resources, investigation, writing—review and editing. A.V.: conceptualization, data curation, formal analysis, methodology, supervision, validation, software, visualization, funding acquisition, project administration, resources, investigation, writing—original draft, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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