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LED UVB postharvest treatments modify nutraceutical quality and physical properties of 'Cargo' blueberries

Alice Varaldo [a,*], Federica Alchera [b], Nicole Roberta Giuggioli [a], Giovanna Giacalone [a]

[a] Department of Agricultural, Food and Forest Sciences, University of Turin, Italy
[b] Department of Chemistry, University of Turin, Italy

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ABSTRACT

Blueberry harvesting is challenging: the difficulties lie in monitoring full ripeness, which is only evident in the peduncle area resulting in uneven and underripe batches. Ultraviolet (UV) irradiation has garnered attention as a non-thermal and chemical-free technology to enhance the shelf-life and quality of horticultural crops. This study focused on applying UVB irradiation (280–315 nm) on fresh blueberries to augment bioactive components and improve storage quality.

Fresh blueberries were exposed to a range of UVB irradiation durations (2 – 5 – 10 – 15 – 20 – 25 – 30 min) using a prototype UV test box. After a 48-h dark storage interval at a thermally controlled environment of 20 °C, berries quality was studied post 24 h and 48 h intervals. Quality parameters, including weight loss, color development, and concentrations of total phenols and anthocyanins, were evaluated. Statistical analyses (one-way ANOVA) were performed to determine significant differences.

UVB irradiation influenced the quality characteristics of blueberries, with optimal treatments showing reduced weight loss and enhanced color development. Phenolic content, particularly at 10-min irradiation, exhibited a notable increase. However, anthocyanin accumulation varied across treatments, suggesting UVB selective effect on specific secondary metabolite pathways. Postharvest UVB irradiation, especially at shorter durations, could be promising for enhancing blueberry quality and extending shelf-life.

1. Introduction

Recently, Ultraviolet (UV) irradiation has been considered as a promising environmentally friendly method to extend the shelf-life and preserve the quality of horticultural crops [1]. UV irradiations are commonly exploited for several purposes, including the control of postharvest diseases, the modulation of ripening and senescence, the induction of cross-stress tolerance, and the synthesis of nutraceutical compounds [2].

LEDs have been proven to be beneficial in postharvest management as they have the potential to lead to ripening and improve nutraceutical accumulation. Numerous studies claim a wide range of positive effects on plant physiology through the induction of secondary antioxidant pathways and natural defenses. For instance, UVB irradiations have been found to ensure greater accumulation of bioactive components in blueberries [3], peaches [4] and tomatoes [5]. Furthermore, promising results have been achieved in reducing microbial growth in strawberries [6]; delayed loss of resistance to skin penetration and reduction of pitting have been demonstrated in sweet cherries [7].

Given the beneficial of LED irradiation on the bioactive compounds of fruits, UVB pre-treatments may hold particular relevance for blueberries prior to cold storage. Enhancing harvesting and storage procedures is economically crucial given the large market demand. Rapid weight reduction and degradation of bioactive compounds are primary issues encountered during the postharvest cold storage of blueberries. In addition, the postharvest management of blueberries present a number of logistical challenges, leading to the distribution of low-quality products to consumers. These include complications related to monitoring full ripeness, which is only evident in the stem area. Maturity is essentially expressed by the chromatic progression from the basal region towards the peduncle zone. This transition is barely visible due to the characteristic reproductive strategy typical of the *Vaccinium corymbosum*

Abbreviations: UV, ultraviolet; a.s.l., above sea level; RH, relative humidity; ET, exposure time; C, control; D0, day 0; WL, weight loss; TPC, total phenol content; TAC, total anthocyanin content.

* Corresponding author. Department of Agricultural, Food and Forest Sciences, University of Turin, Largo Paolo Braccini 2, Grugliasco, Italy.
E-mail address: alice.varaldo@unito.it (A. Varaldo).

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L. plant, resulting in berries densely clustered at the apical area of the shoot. Such aggregation happens from the flowers organization in racemose inflorescences culminating in a corymbal system. This phenomenon leads to premature picking potentially culminating in chromatic regression during postharvest storage, attributable to decreased nutraceutical content and compromised quality attributes. The overarching aim is to introduce a marketable product distinguished by uniform visual attributes and elevated organoleptic properties, mitigating potential devaluation and lack of appeal to consumers.

In light of the above considerations, the current investigation evaluates a novel chemical-free treatment. Specifically, UVB irradiation (280–315 nm) was managed to fresh blueberries with the objective of stimulating the chromatic progression and refining storage characteristics by enhancing the levels of bioactive constituents. Numerous irradiation durations were evaluated to elucidate the response of blueberries to varying ultraviolet (UV) radiation doses. Seven specific durations (from 2 min to 30 min) were investigated based on literature suggesting that UV radiation exerts a beneficial influence on the secondary metabolites of various fruits and vegetables [8,9]. Nonetheless, there exists a gap regarding the specific optimal durations that would maximize the accumulation of phytochemical compounds in blueberries without negatively affecting their shelf-life [10]. With this objective in consideration, it may be possible to introduce a marketable product distinguished by consistent aesthetics and increased organoleptic attributes, thereby mitigating potential devaluation and lack of appeal to consumers.

2. Materials and methods

2.1. Plant material and UV treatments

Highbush blueberries (*Vaccinium corymbosum* L.) cv 'Cargo', pot cultivated, were used in this study. The site of the investigation is located at an altitude of 278 m a.s.l. and at a latitude of 45.05°. The test was carried out on six even-aged plants (5 y) at DISAFA - University of Turin (Grugliasco, TO) during the summer (July–August) 2022.

Blueberries were hand harvested from July 20th to August 10th with weekly pickings. Fruit were collected partially immature (stalk point of insertion still green/pink and zone already blue) in order to simulate a premature harvest.

After each weekly collecting, defect-free fruit were randomly divided into 8 rPet baskets of 125g each, and immediately processed under UVB action. Three picking weeks have been processed to be able to have 3 repetitions for each UVB treatment. Totally then 24 baskets were analyzed for the research purposes.

UV treatments were carried out using a prototype UV test box realized by the two companies PRO.LUX (Grugliasco, TO, Italy) and MOVE2WEB (Torino, Italy); a closed cabinet containing 20 LED strips (composed by 6 led each) on the top, including 10 UVB (PU35BM2 V0 – C3, LEXTAR, Taiwan) and 10 UVC (PU35CM1 V3 B4, LEXTAR, Taiwan). The UVB cluster LEDs have a total peak emission of 8.37 mW $^{m-2}$ at 100 mA, 25 °C, and 310 nm, and the UVC of 8.15 mW m^{-2} at 100 mA, 25 °C, and 278 nm.

The treatments were carried out by placing the blueberries contained in rPet trays on a grid. The trial was conducted at a distance of 78.5 mm (first level) from the radiating source. Samples were carefully placed in one layer by exposing the insertion stem point to UV lamps, which is the last to develop pigmentation. To identify the most promising treatment, seven exposure times (ET) were performed in triplicate (Table 1). In addition, one set of non-irradiated fruit was used as a control (C). Samples were dark stored in a perforated plastic box at 20 °C with 65 % of relative humidity (RH %) for 48 h. Blueberries were processed for quality analysis after 24 h and 48 h of storage.

Table 1
UVB tests performed in triplicate for research purposes. Exposure Time (ET) and target dose.

ET (min)	Target dose (KJ m^{-2})
0	0.00
2	2.20
5	5.60
10	11.50
15	17.00
20	23.00
25	28.00
30	34.00

2.2. Quality analysis

Quality analyses were performed at the DISAFA laboratory – University of Turin (Grugliasco, TO) before the UV treatments at d 0 (D0), at mid-term (T24), and at the end of the storage period (T48). For each treatment and analyses time, the following data were collected:

2.2.1. Weight loss (WL)

Throughout the start of the storage phase and following intervals of 24 h and 48 h within the storage period, individual specimens were carefully weighed using a calibrated analytical balance with an accuracy of up to two decimal places. The quantified mass changes, or weight decrements (WL), were determined using the specific mathematical expression denoted as equation (I). Where W_{D0} is the sample weight at the start of the storage phase, W_{T24} is the sample weight after 24 h of storage and W_{T48} is the sample weight after 48 h of storage. The derived values from this calculation were subsequently presented and interpreted as percentage variations relative to the initial weight of the samples.

$$WL = (W_{D0} - W_{T24\ or\ T48}) / W_{D0} \quad \text{(I)}$$

2.2.2. Color development (Δh°)

Berries surface color was determined with a colorimeter (CR400, Minolta, Japan) under similar lighting conditions. The results were expressed in the CIE color space with C as the standard illuminant and an observation angle of 2°.

In the present study, the hue angle (h°) was considered, which is calculated from the parameters a* and b* using the equations and $h^\circ = \tan^{-1}\left(b^*/a^*\right)$ [11]. C* expresses a measure of color intensity and h° is an angular measure that identifies the hue according to its similarity to red, yellow, green, or blue, or a combination of two of these attributes in turn. Samples color was measured in the pedicle insertion area of 30 fruits, which is the last to develop color. In the present work, the hue angle was studied from D0 to 24 h and 48 h of shelf-life, then the Δh° was calculated using equation (II).

$$\Delta h^\circ = \left(h^\circ_{T24\ or\ T48} - h^\circ_{D0}\right) / h^\circ_{D0} \quad \text{(II)}$$

2.2.3. Total phenol content variance (ΔTPC)

For the tests, extracts were prepared according to the protocol of Šavikin et al. [12].

The extraction was performed by adding 10 mL of solvent extraction (MeOH 500 mL + HCL 1.4 mL + H_2O 14 mL) to 4 g of fruit and homogenizing for 1 min with an Ultra-Turrax T18 basic (Janke and Kunkel, IKA®-Labortechnik, G). The samples were then placed in an ultrasonic bath (VWR Ultrasonic cleaner, G) containing water at 50 °C, for 20 min. The solutions were then centrifuged at 2.5 g for 10 min using the AVANTIM J-25 centrifuge (Beckamn Instruments Inc.). The clear juice (supernatant) was collected and stored at −26 °C until analysis.

TPC was determined using the Folin–Ciocalteu reagent [13], and the concentration was estimated from a standard curve of gallic acid. Absorbance was measured at 760 nm. TPC was stated as mg gallic acid

equivalents (GAE) expressed on a fresh weight basis. Three replicates were carried out for each treatment. The results were expressed as a percentage of TPC accumulation compared to D0 using equation (III).

$$\Delta TPC = (TPC_{T24\ or\ T48} - TPC_{D0}) / TPC_{T24\ or\ T48} \quad \text{(III)}$$

2.2.4. Total anthocyanin content variance (ΔTAC)

TAC analysis followed the pH differential protocol [14]. Clear juice was obtained from blueberry samples as in previous analysis according to Šavikin et al. [12].

The juice (20 μL) was diluted separately with 2 mL each of pH 1 (potassium chloride 0.025 mol L^{-1}) and pH 4.5 (sodium acetate 0.4 mol L^{-1}) buffer solution. The absorbance values of the solution were determined spectrophotometrically at both λ 520 nm and λ 700 nm (U-5100, Hitachi, J). The total anthocyanin content was determined using equation (IV):

$$TAC = A \times MW \times DF \times \frac{10^3}{\varepsilon} \times L \quad \text{(IV)}$$

TAC: total anthocyanin content as mg pelargonidin-3-glucoside L^{-1}.

A: difference of absorbance $((A520_{nm} - A700_{nm})_{pH1} - (A520_{nm} - A700_{nm})_{pH4.5})$
MW: molecular weight of pelargonidin (433.2 g mol^{-1}).
DF: dilution coefficient (10).
L: optical path in cm.
E: extinction coefficient (48,340 L mol^{-1} cm^{-1}).

Three replicates of each treatment were performed, and the concentrations were expressed as mg pelargonidin-3-glucoside L^{-1} expressed on a fresh weight basis. Results were expressed as a percentage of TAC accumulation compared to D0 using equation (V).

$$\Delta TAC = (TAC_{T24/T48} - TAC_{D0}) / TAC_{T24/T48} \quad \text{(V)}$$

2.2.5. Statistical analysis

The statistical processing was performed using R Studio software version 4.1.2 (Integrated Development for R. RStudio, PBC, Boston, MA, USA).

The quality data were first tested for normality and the percentage values were logarithmically transformed before ANOVA was performed. Factor-designed analysis of variance (one-way ANOVA) was applied to study the quality data, with ET as factor. Multifactorial analysis (two-way ANOVA) was applied to the weight loss data, with ET and storage time (24 h–48 h) as factors. Least Significant Differences (LSD) at the significance level of 0.05 ($p \leq 0.05$) were used to compare means with Tukey's test.

3. Results and discussion

The fruits analyses at D0 showed, low TPC and TAC concentration (Table 2). This result is a consequence of unripe samples that in fact, are characterized by a hue angle which displays pink coloring.

3.1. Effect of UVB action on blueberries quality characteristics

The weight loss (WL %) after 24 h and 48 h of storage at 20 °C is reported in Table 3. The analysis, showed a modified behavior for UVB-treated blueberries, compared to the control (C). The statistically lowest WL were found with 2 min and 5 min irradiation after 24 h of storage, where the fruit lost the 2.92 % and the 2.88 % of weight respectively, compared to D0. Conversely, the statistically highest losses are found with 15 min treatments after 48 h of storage. For all other combinations of ET and storage time, it is difficult to identify a trend, but long UV treatments combined with long storage times showed the highest weight losses. This may be due to the increased transpiration associated with the temperatures developed during the long treatment followed by a long period at room temperature, as well as the low air RH % during the storage. The high temperature is the result of heat dissipation from the LED lamps, which, combined with the low relative humidity during storage, has accelerated the senescence of the berries. The combination of high temperature and low humidity can effectively cause high respiration and transpiration in fruit [15], leading to higher water losses and consequently greater weight loss.

Nevertheless, the results showed that WL % could be inhibited when the blueberries are treated with low doses of UVB. Short heat treatments have been observed to reduce postharvest fruit transpiration [16], and to inhibit pathogens. It has been reported [17] that UVB and UVC irradiation, alters the cuticular wax profile of grapes to favor greater production of total waxes and triterpenoids, and the increase in this ratio (waxes/triterpenoids) is strongly correlated with reduced cuticular transpiration. The blueberries samples, in this case, may have been exposed to the same phenomenon. As a result of an increase in cuticular waxes, the fruit suffered a slight weight loss due to a lower transpiration, despite the low relative humidity during storage.

The benefits of low-dose irradiation on fresh blueberries, especially with UVB lamps, have been confirmed as promising in other studies. It has been reported that UV treatments delays weight loss during postharvest storage of sweet cherries [18] and blueberries [19–21], thereby extending the fruit's shelf-life.

This finding may be of particular interest as weight loss is a key problem in postharvest storage, both as a deterioration of the fruit and as a reduction in economic value. According to the literature, the maximum weight loss before blueberries become unsaleable is approximately 5 %–8 % [22]. Thus low doses of UVB could prolong the salability of the product.

The changes in skin color of blueberries treated with different energy doses, after 24 h and 48 h at room temperature storage (20 °C), are shown in Fig. 1. The hue angle (h°) indicates the actual color, i.e. the blueness. Negative percentage differences from D0 indicate a shift towards more blue tones.The values related at mid-storage (Fig. 1A) showed a marked color change from red to blue, with the highest

Table 2
Blueberries characteristics at D0 (day zero): Total anthocyanin content (TAC), Total phenol content (TPC) and hue angle (h°). Data are the mean of fifteen replicates ± SD.

Day	TAC	TPC	Color (h°)
	mgCYAN/100g fw	mgGAE/100g fw	
D0	9.67 ± 4.31	174.55 ± 21.82	326.38 ± 9.54

Table 3
Effect of pre-storage UVB treatment and storage life at 20 °C on 'Cargo' blueberries Weight Loss (WL %). Data are the mean ± SE of nine replicates. Same letters indicate no statistical differences among data; $p \leq 0.05$.

Storage at 20 °C	ET (min)	Weight Loss (%)			
24 h	0 (C)	3.33	±	0.0016	cde
	2	2.92	±	0.0040	e
	5	2.88	±	0.0040	e
	10	4.30	±	0.0040	abcde
	15	3.33	±	0.0049	cde
	20	3.38	±	0.0049	bcde
	25	3.47	±	0.0040	bcde
	30	3.29	±	0.0040	de
48 h	0 (C)	5.24	±	0.0016	abcd
	2	5.14	±	0.0040	abcd
	5	4.92	±	0.0040	abcde
	10	5.73	±	0.0040	ab
	15	6.03	±	0.0049	a
	20	5.31	±	0.0049	abcd
	25	5.65	±	0.0040	abc
	30	5.64	±	0.0040	abc

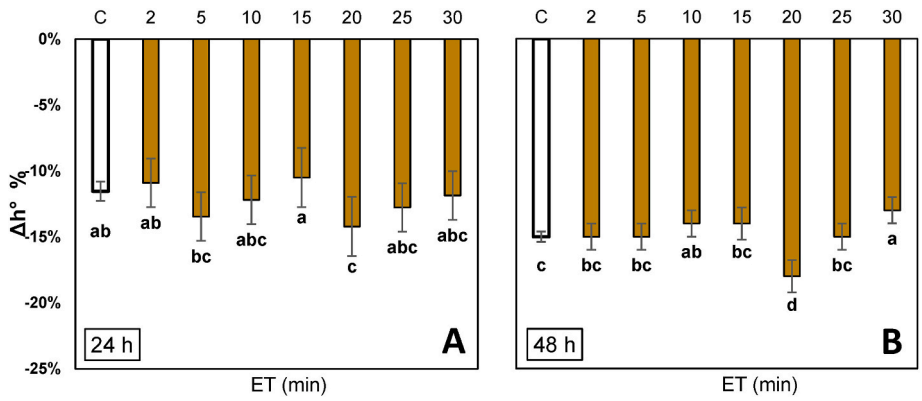

Fig. 1. Effect of pre-storage UVB treatment on 'Cargo' blueberries color development (Δh° %). Data are the mean ± SE of ninety replicates. A: Δh° % after 24 h of storage, B: Δh° % after 48 h of storage. Same letters indicate no statistical differences among data; $p \leq 0.05$. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

development recorded in 20 min-treated blueberries. On the contrary, the lowest levels of pigmentation were found in the 15-min UVB treatments, similar to the control and the 2-min sample. At the end of the shelf-life (Fig. 1B), the Δh° % suggests that coloring is affected by storage time. In fact, the pigmentation is higher after 48 h of storage than after 24 h. Furthermore, the differences in color development between the control and the light-treated samples are less pronounced. However, the significantly higher pigmentation is still found in correlation with 20-min UVB treated berries. Otherwise, the 30-min irradiated fruits show the statistically lowest color changes. The observed trend may be owing to the accumulation of anthocyanins, which, as the main pigments in blueberry (Vaccinium spp.) fruit, determine the typical purple-blue color [23]. Given that surface color parameters (lightness, chroma, and hue angle) have been demonstrated to show weak correlations ($r < 0.4$) with natural anthocyanin accumulation measured at harvest and during postharvest storage of blueberries [24], our findings suggest that the observed color development may be attributable to the effects of UVB irradiation. In this context, UV irradiation may have elicited oxidative stress within the fruit cells. Such stress could have subsequently activated the biosynthesis of polyphenols, including anthocyanins, as a defense mechanism, given their antioxidant properties, thereby potentially conferring protection against oxidative damage and improving the surface pigmentation of the berry.

3.2. Effect of UVB action on nutraceutical properties

The evolution of the bioactive compounds in the berries after 24 h and 48 h of shelf-life is reported in Figs. 2–3. UVB irradiation induced more pronounced alterations in TPC levels than in TAC levels when compared to the control group. Specifically, the 10-min exposure appeared to provide a beneficial effect on TPC, with blueberries showing a statistically significant phenolic increase (+15%) after a 24-h shelf-life period (Fig. 2A). On the other hand, 2 min of irradiation did not show any positive effect, but rather caused a decrease in TPC (−3 %). Finally, the remaining treatment intervals, despite demonstrating an increase in TPC, did not exhibit statistically significant differences compared to the control. In general, following a 24-h period at 20 °C, there was an ascending trend in TPC accumulation observed up to the 10-min mark, at which point the peak was attained, followed by a subsequent decline up to the 30-min irradiation.

Fruit exposed to a 48 h storage period exhibited a different TPC dynamics (Fig. 2B). Specifically, the 5-min treatment manifested the least TPC accumulation, whereas the most pronounced increments in polyphenols were observed in fruits irradiated for 15, 25, and 30 min. Such differential responses may be attributed to prolonged storage of fruit at room temperature. Under these conditions there has be verified an evident increase in TPC, however predominantly from berries dehydration themselves, as evidenced by the statistically elevated WL%. In this latter case, the phenolic components become more concentrated, rendering the fruits richer in TPC, and potentially undermining the effect of UV treatment. In fact, prolonged storage at a high temperature can lead to significant weight losses as a consequence of excessive moisture loss [25]. Furthermore, while the TPC levels in non-irradiated berries remained consistent throughout the shelf-life, it is noteworthy that a greater accumulation of phenolics was detected for 15-min treatment.

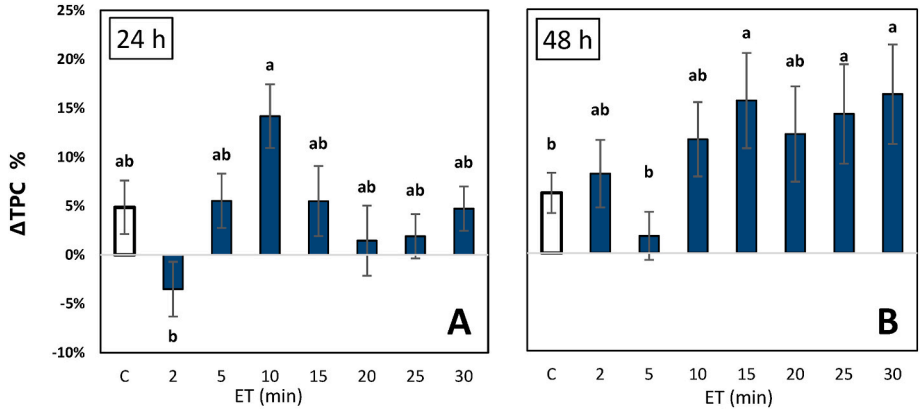

Fig. 2. Effect of pre-storage UVB treatment on 'Cargo' blueberries phenols enrichment (ΔTPC %). Data are the mean ± SE of nine replicates. A: ΔTPC % after 24 h of storage, B: ΔTPC % after 48 h of storage. Same letters indicate no statistical differences among data; $p \leq 0.05$.

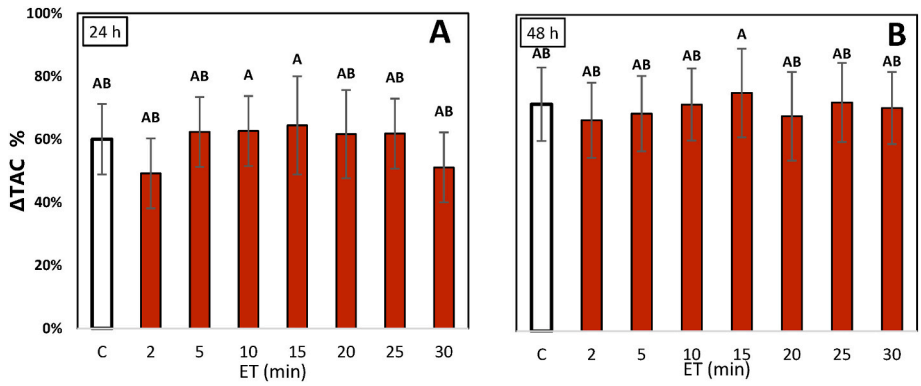

Fig. 3. Effect of pre-storage UVB treatment on 'Cargo' blueberries anthocyanin enrichment (ΔTAC %). Data are the mean ± SE of nine replicates. A: ΔTAC % after 24 h of storage, B: ΔTAC % after 48 h of storage. Same letters indicate no statistical differences among data; $p \leq 0.05$.

Although numerous significant differences are evident in ΔTPC %, the enrichment in anthocyanin compounds appears less clear across the ETs (Fig. 3). Nonetheless, specific significant responses emerged: following a 24-h storage, blueberries exposed to 10 min and 15 min irradiations exhibited the statistically highest ΔTAC %, and after 48 h the most important enhancement was observed in fruits irradiated for 15 min.

It is noteworthy that, accounting total phenols, the effect of UVB on phenols metabolic pathways does not seem to affect the accumulation of anthocyanins, which increase at an unsatisfactory rate. However, the effect of UV irradiation, on phenolic compounds in blueberries, is evident, with trends indicating a modulation of other secondary metabolites beyond anthocyanins. In blueberries, anthocyanins consist of aglycones, which are mainly cyanidin, delphinidin, malvidin, and petunidin. Instead, the non-anthocyanin phenols are mostly flavanols, consisting of myricetin and quercetin, with small amounts of other phenolic compounds such as chlorogenic acid (hydroxycinnamate) and stilbenes [20]. Thus, the discrepancy between anthocyanin and phenolic development may be due to UVB action affecting non-anthocyanin phenolic compounds. Moreover this evolution could appear in a cultivar-dependent way, typical of cv 'Cargo', as other studies confirm the consistency between anthocyanin and phenolic compounds progress in other cultivars i.e. 'Northland' [26], 'Duke' [19] and 'Bluecrop' [3].

In general, postharvest UVB irradiation changed the contents and composition of blueberries, which are undoubtedly UV dose-dependent, mostly in the early stages of room temperature storage. Therefore, it can be considered that treatments ranging from 5 min to 10 min can be considered as a satisfactory compromise between enrichment of polyphenols and limitation of decays to improve the blueberries qualitative characteristics.

These result were similar to those obtained by Ref. [3] who explained how UVB exposure can increase the phenolic compounds, with a maximum at the low dosage and short storage at room temperature. Furthermore, consistent to our findings [27], observed higher anthocyanin concentrations in UVB-treated blueberries compared to control and high-dose irradiation. The positive effect of UVB on phenolic accumulation is also confirmed by the finding that these radiation promotes anthocyanin biosynthesis through the transcripts of genes involved in the activities of the anthocyanin pathway [26]. Taking into account our findings and the referenced literature, postharvest UV exposure can regulate the expression of genes encoding enzymes involved in the biosynthesis of anthocyanins, such as phenylalanine ammonia-lyase (PAL), chalcone synthase (CHS), and dihydroflavonol reductase (DFR), whose enzymes catalyze key reactions in anthocyanin production [28].

In summary, post-harvest UV irradiation may enhance phenolics biosynthesis in blueberries through a combination of mechanisms, including the induction of oxidative stress and activation of specific genes, thereby contributing to their coloration and potentially conferring benefits in terms of nutritional quality and shelf-life.

4. Conclusions

The present study meant to identify a chemical-free strategy to improve postharvest quality of blueberries in response to incorrect pickings. Specifically, the effects of UVB irradiation on blueberries have been explored, aiming to understand its potential in altering the fruit secondary metabolism and storage characteristics.

Our findings indicate that UVB treatments, at a specific wavelength, led to reduced weight loss, which is crucial for preserving the fruit's economic value and marketability. Additionally, UVB irradiation influenced the color development of the berries, shifting them towards a more blue hue, which is indicative of enhanced anthocyanin content. Biochemically, UVB treatments promoted the accumulation of phenolic compounds in blueberries. While some variations in anthocyanin content were observed across different treatments, the overall trend suggested that moderate UVB doses could be optimal for enhancing both phenolic and anthocyanin concentrations. The main results, in fact, showed that low doses of UVB (5–10 min) can induce a significant enrichment in anthocyanins (+60 %) and phenols (+15 %) mostly in the early stage of storage at 20 °C, with promising results in terms of weight loss which 5 min-treated samples are statistically lower than the control.

Although the research has allowed the introduction of a new technique to improve the blueberries postharvest quality, future studies should focus on how the UV irradiation affects the nutraceutical composition by deepening the research on the development of the whole berry phenolic profiles. In addition, cold storage periods should be tested to verify if UVB radiation improves blueberry shelf-life, as well as improving the phenolic composition and reducing short-term weight loss. In this way, it would be possible to fill the research gaps that exist in long cold storage studies and in evaluation of bioactive compounds. Furthermore, given the promising outcomes of the treatments, further studies will focus on the treatment timings that revealed the most potential, delving deeper into their impacts also on mechanical properties and microbiological attributes as well as molds by studying the incidence of disease.

In conclusion, UVB pre-treatment seems to be a promising approach in the supply chain strategy to improve the storage and shipping quality of harvested blueberries. This could open up new opportunities for fruit that would otherwise become food waste due to its low-quality characteristics. Currently, postharvest irradiation treatment for this purpose is likely to be too expensive for commercial use, but given the high value-added of soft fruit added, it could become a viable strategy to enhance the postharvest quality of blueberries, offering both economic and nutritional benefits.

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CRediT authorship contribution statement

Alice Varaldo: Conceptualization, Formal analysis, Investigation, Writing – original draft. **Federica Alchera:** Conceptualization, Formal analysis, Investigation. **Nicole Roberta Giuggioli:** Resources. **Giovanna Giacalone:** Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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