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Review

The Effect of UV-C Irradiation on the Mechanical and Physiological Properties of Potato Tuber and Different Products

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Abstract: Amongst the surface treatment technologies to emerge in the last few decades, UV-C radiation surface treatment is widely used in food process industries for the purpose of shelf life elongation, bacterial inactivation, and stimulation. However, the short wave application is highly dose-dependent and induces different properties of the product during exposure. Mechanical properties of the agricultural products and their derivatives represent the key indicator of acceptability by the end-user. This paper surveys the recent findings of the influence of UV-C on the stress response and physiological change concerning the mechanical and textural properties of miscellaneous agricultural products with a specific focus on a potato tuber. This paper also reviewed the hormetic effect of UV-C triggered at a different classification of doses studied so far on the amount of phenolic content, antioxidants, and other chemicals responsible for the stimulation process. The combined technologies with UV-C for product quality improvement are also highlighted. The review work draws the current challenges as well as future perspectives. Moreover, a way forward in the key areas of improvement of UV-C treatment technologies is suggested that can induce a favorable stress, enabling the product to achieve self-defense mechanisms against wound, impact, and mechanical damage.

Keywords: UV-C radiation; stress response; mechanical properties; stimulation; potato tuber

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1. Introduction

The non-thermal technique is relatively fruitful for elongating fresh foods' shelf life. Nevertheless, its potentiality of adversely influencing sensory attributes has been highlighted [1–7]. Several non-thermal technologies for the treatment of food crops have come to emerge over the last few decades. This technology included irradiations (pulsed ultraviolet, gamma, and X-ray) pulsed electric field, pulsed electromagnetic field, cold plasma, ultra-sonication, microwave, supercritical technology, high-pressure processing, etc. [8–11]. In the classification of surface treatment, microwave surface treatment can be considered as either a thermal or non-thermal surface treatment depending on the intensity used [12,13]. It is reported that the irradiation technology is of high energy. Therefore, alongside its desirable effects, it is expected to induce undesirable alterations by interacting with different structures as well as chemical constituents of the potato tubers [14]. Among other different crop treatment techniques, such as gamma irradiation and fumigation [15], the UV-C radiation technique is one of the non-thermal technologies that is dominantly used for the surface disinfection and decontamination of crops and fruits and is by far regarded as effective [16]. UV-C radiation, emitted at wavelengths of 200–280 nm along with UV-A (320–400 nm) and UV-B (280–320 nm), is reported to be retained by the ozone layer. The different regions of UV radiation are shown in Figure 1 [17–19]. UV-C radiation, because of its high absorption level by the ozone layer, does not penetrate the earth in any appreciable amount. The shorter the wavelength, the higher the energy of the photon as depicted from the Planck relation. This short wavelength carries a higher pocket of energy which is capable of destroying microorganisms by damaging the microbial DNA, causing cross-linking between neighboring thiamine and cytosine in the same DNA strand [20,21].

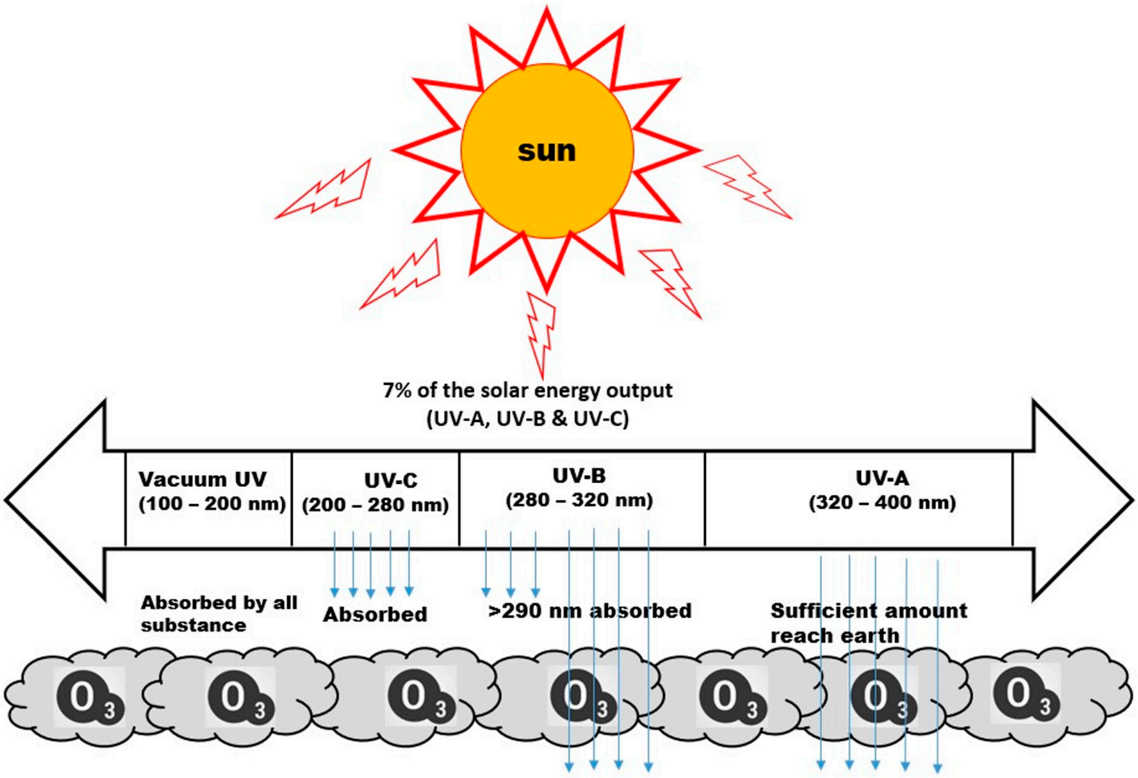

Figure 1. Different regions of UV radiation.

Even if this surface treatment has consent from Food and Drug Administration and other institutes as recognized disinfectant technology [22,23], it is important to study its impact on the characteristics of the crop. Numerous studies have already been focused on the bactericidal and fungicidal capacity of UV-C treatment in plant products, but information on product quality attributes is scanty. Limited studies have been reporting that short wave UV-C has a pronounced effect on plants' physiology and structure. It was reported that there induces a significant structural damaging effect on the plant cell, most specifically on the chloroplasts, mitochondria, and membranes [24,25]. The change in cellular structure is directly related to the overall alteration of the mechanical properties of the plant. This correlation is well described by a previous study conducted on the potato tuber cell structural parameters having a significant effect on the overall mechanical characteristics such as strength and modulus of elasticity [26]. Moreover, in the other study on UV-C exposed strawberries, cellular structural changes in relation to the physical properties of the fruit were studied stating that delayed softening and higher firmness are caused by changes in the activity of enzymes and proteins responsible for cell wall disassembly [27]. It was clearly stated that the change in mechanical characteristics of food derived from plants arises from three structural factors at the cellular level are turgor, cell wall rigidity, and cell-cell adhesion [28,29].

The mechanical characteristics of crops play a prominent role in deciding the acceptability in the chains of target users, such as food processing industries and people. Since plants are biological materials with complex structures that have high exposure to mechanical change, these changes can lead to irreversible changes in structure and other crop characteristics where these changes are reported to be invisible, having inner deformations [26]. Potatoes are the fourth-ranking food crop in the world in terms of calories and are extensively produced throughout the world [30–32]. The mechanical properties of the potato or derived products following surface treatment by irradiation during either growth or storage represent an imperative factor for meeting consumers' needs, as they are required for determining other properties when characterizing food qualities. Most importantly, one of the most important features here is the texture that potentially undergoes change, since external factors are concerned [33–37].

Studies have shown the influence of different physical treatment methods inducing a change in potato mechanical characteristics. Microwave treatment methods have found extensive applications in various processing and operations [38–41]. Studies have demonstrated their influential effects on the texture, compression test, weight loss, morphological, and microstructural changes of potatoes [42–44]. In the process of extending the shelf life of potatoes, gamma radiation is also an important facility nowadays. Several studies on the effect of gamma irradiation on physicomechanical properties of potatoes have been carried out on different potato cultivars for the evaluation of sprout weight, appearance quality, texture, specific gravity, morphology, puncture test, shear test, and compressive tests at varied dosses ranging from 0.04 to 100 kGy under different storage conditions [14,45–48]. From the result, Gamma irradiated resulted in an intact, rigid cell wall, more cavities, and bigger lamellar structure. At lower dose, mechanical properties were maintained, and sprouting was inhibited, while increased specific gravity at higher dose was also indicated. Texture was reduced with increasing dose, and the appearance of potato tuber was firm and slightly shrivelled. One of the non-destructive evaluation techniques is an ultrasound that applies a low range of intensities (0.1–20 kHz), but higher intensities (20–100 kHz) are reported to alter the physical, mechanical, and structural characteristics of starch granules derived from potato [49,50]. The results indicated that the sonicated potato tubers showed a change in molecular order in the crystalline region. A transparent appearance of the potato starch was also found. The effect of pulsed magnetic field treatment on the firmness, energy for cutting, and smoothening of the surface of potato was investigated at lower pulses ranging from 1 to 2.5 kV. It was concluded that firmness and energy for cutting were reduced while smoothening of the surface increased [8,51].

A study conducted on the impact of UV-C on mechanical characteristics of certain plant types reports that the mechanical properties are the result of the cellular change and rheology [52]. Despite the popular demand for potato tuber, there are only limited research outputs, making this area untapped for research. However, it was possible to survey some of the most up-to-date research that recognized the effect of UV-C on different characteristics, including the acrylamide content [53], color [42], density [54,55], and chemical constituents [56] of potato tuber and its derivatives. The objective of this review work is to critically review the current state of the art in the damaging effect, physiological change, and related scenarios of UV-C on the potato. Of course, this review also surveys the mechanically damaging effect of UV-C on different postharvest crops and fruits.

2. Influence of UV-C on the Physical and Mechanical Properties of Different Crops

UV-C surface treatment technology is a set of techniques by which a specific wavelength of 254 nm is delivered from a source for the purpose of microbial inactivation, disinfection, and stimulation. The short wave carries a pocket of energy necessary to inhibit microorganisms from the surface of the product by developing defense mechanisms. However, the application is highly dose dependent and results a positive and negative impact on the mechanical properties of the given product. In the quest of the current state of the art, a number of findings were reported in different types of products and varieties as well. It is apparently clear that the UV-C effect on the plant products is highly dependent on UV-C dose.

2.1. Physical Properties

With a specific focus in food characterization, textural profile analysis (TPA) offers comprehensive properties important to the acceptability of a product by the end user. A wide set of parameters traced from TPA analysis includes hardness, cohesiveness, viscosity, elasticity (springiness), adhesiveness, resilience, brittleness (fracturability), chewiness, and gumminess. This is one of the most important parameters as far as the UV-C stimulation is concerned with the cell physiology. The properties of firmness, hardness, and change in mass are critically assessed in this review as they are greatly influenced by the anatomy of the plant tissue, the strength of the cell wall, and ultimately other mechanical properties. It is one of the most important parameters when it comes to UV-C stimulation and cell physiology [57].

The firmness of bell pepper fruit treated at 0.25 $kJ \cdot m^{-2}$ and its control sample significantly dropped at the initial storage period, but after seven days of storage the UV-C treated sample was found to be firmer than the control. A weight loss experiment in the same fruit resulted in lower weight loss in the treated sample [58]. An experiment on the UV-C treated in green asparagus confirmed an appreciable increment in tissue toughness and a significant increase in cutting energy (sheer force) even at a lower UV-C dose of 1 $kJ \cdot m^{-2}$ and 8 min exposure time [59]. Conversely, a low UV-C dose up to 3.8 $kJ \cdot m^{-2}$ is indicated to have an insignificant change in textural properties [60]. Observations on the fresh-cut melon after UV-C exposure confirms no significant difference in the firmness as a result of UV-C application at 1.2 $kJ \cdot m^{-2}$ followed by storage at 6 °C [61]. No significant difference was observed among treated and control samples in delaying softening at a lower UV-C dose. The research work on the firmness and weight loss characteristics of UV-C exposed fresh-cut apples were analyzed by different authors and resulted in no significant change in the firmness [62,63], while a decrease in weight loss by 6% was noted at an exposure time of 1 min and intensity of 1.2 $kJ \cdot m^{-2}$ UV-C [62]. For fruit crops, weight loss is an important parameter as it is associated with dehydration, which significantly determines the commercial value of the fruit. The weight loss of amaranth vegetables treated at a moderate UV-C dose of 1.7 $kJ \cdot m^{-2}$ reduced the weight loss significantly better than the control [64]. The weight loss experiment on different UV-C exposed tomato cultivars, namely "cherry tomato" and *Elpida*, showed no effect and reduced weight loss when treated at 3.7 $kJ \cdot m^{-2}$ and 4 $kJ \cdot m^{-2}$, respectively [65,66]. It was depicted that a lower UV-C dose of up to 4 $kJ \cdot m^{-2}$ has a minor effect on the firmness of tomato [67] and blueberry fruits [68]. The firmness value of different tomato cultivars was enhanced when exposed to UV-C treated in the range of 3 $kJ \cdot m^{-2}$ to 4.2 $kJ \cdot m^{-2}$ [65,66,69–72]. An experiment conducted on the quality parameters of UV-C exposed pineapple at the dose of 4.5 $kJ \cdot m^{-2}$ over the range of 0–90 s and followed by a 10 °C storage condition was able to retain the firmness properties better than the control samples [73]. Exposure to 7.11 $kJ \cdot m^{2}$ induced higher tissue softening in lettuce and caused the development of abnormal color in cauliflower [74,75].

Research work on a comparative study of the effect of UV-A and UV-C over the temperature range of 25–100 °C on oyster mushrooms reported UV-C exposed mushroom samples had a higher increase in loss modulus and loss factor than that of UV-A exposed ones. From the outcome, it was concluded UV-C light had a greater impact on the mechanical properties of oyster mushrooms compared to UV-A light [76]. Storage modulus was lower for the samples exposed to both UV-A and UV-C, indicating the samples had a viscoelastic characteristic.

In the quest for the previous state of the art, the most decisive factor was found to be firmness, which was studied dominantly following the UV-C irradiation and storage. It was also noted from recent research that firmness is an important sensory characteristic for consumers and is the factor that is highly affected by mechanical processes that potentially induce the ejection of intracellular fluid due to tissue rupture [77].

The textural aspect of mechanical property is dominantly used in the processing, as well as with raw vegetables and fruits, which is connected with the rheological characteristics of biological materials called firmness or hardness. It expresses the maximum force required to attain a specific strain in compression, puncture, and cut tests [57,78].

2.2. Mechanical Properties

Mechanical properties of harvested vegetables and fruits are important characterization throughout processing, storage, and consumption. Mechanical properties may be defined by cell structure and are dependent on the physical state, flow properties, and porosity. In the light of measurements, force-deformation methods are commonly used in textural or mechanical properties of solid foods, fresh vegetable/fruit, and their derivatives in their solid state. The basic mechanical properties that are determined from the force-deformation includes rupture force, toughness, cutting force, shear force, and strength [79], which are effective for different purposes, such as product standardization, transportation, handling, and design purposes as well. If we take account of the dimension of a product in the mechanical testing, stress–strain characterization, for example, can be used and some important properties can be obtained from the result of this test, such as yield strength, Young's modulus, ultimate strength, and modulus of elasticity.

Recent research conducted intensive work on mechanical changes of UV-C irradiated strawberries at a varied irradiation dose of 0.8, 2, and 4 kJ·m^{-2} by changing the storage duration from 0 to eight days at 0 °C. Resistance to compression, crush resistance, and distance to tissue failure attributes dropped significantly during storage. According to the author, the resistance to compression was higher at a lower UV-C dose. At 2 kJ·m^{-2} and 4 kJ·m^{-2}, tissue deformation reported a higher value [80]. In the latest work on the effect of UV-C irradiation on some of the mechanical characteristics of blueberries *'O'Neal'* a puncture test was performed at UV-C intensities of 5.3, 8.3, and 11.4 kJ·m^{-2}, exposure time of 7, 11, and 15 min, and storage time from 0 to 15 days. According to the report, mechanical parameters were not affected by UV-C treatments until 15 days of storage time when irradiated samples showed higher values of rupture force, deformation, and weight loss [81]. In a related study, a compression test (stress –strain) was performed on UV-C exposed fresh-cut apples at an exposure time of 10, 15, and 25 min and UV-C intensity at 5.6, 8.4, and 14.1 kJ·m^{-2}. True stress and deformability modulus were noticeably reduced at lower exposure time and UV-C dose [63]. The effect of UV-C on the mechanical characterization as well as the dimensions (length, width, and height) of *Faba* bean during storage was studied by considering various UV-C exposure times (0, 30, 60, and 90 min) and during storage periods of 0, three, six, and nine months. The result indicated that main dimensions, mass and bulk volume, and true volume were decreased by increasing the storage period and decreasing ultraviolet irradiation time. UV-C irradiation time increased with reducing the storage time, although, length and thickness decreased slightly. From this research, very important mechanical tests, such as shear force and shear penetration, were also investigated on the UV exposed *Faba* bean. The authors described the decrement of both the sheer force and penetration force of seed as UV-C exposure time increased during the given storage time [82]. The mechanical properties of different UV-C irradiated plant commodities are briefly presented in Table 1.

Table 1. Mechanical and related characteristics of UV-C exposed plant products.

Commodity	Operational Condition	Key Finding	Reference
Sweet corn kernels	UV-C dose at 0. 1.94, and 4.01 kJ·m^{-2}, controlled atmosphere of with %oxygen: %carbondioxide: %nitrogen ratios of 21:0.03:78, 3:10:87, and 3:15:82 at 6 °C for 20 h.	Hardness remains unchanged	[83]
Fresh-cut green onion	UV-C exposure time at 3, 5, 10, and 15 min and storage days of 5, 10, 15 days and storage temperature of 5 °C.	Higher UV-C exposure results in higher weight loss (%).	[84]

Table 1. *Cont.*

Commodity	Operational Condition	Key Finding	Reference
Tomato (*Lycopersicon esculentum* L.)	UV-C dose 3.7 kJ·m^{-2} from 0 to 25 days of storage duration time at 16 °C and relative humidity of 95%.	Firmness (Newton) decreased with storage duration. Higher resistance penetration compared to the control sample.	[85]
Cucumber (*Cucumis sativus* L.)	UV-C dose of 4.5 kJ·m^{-2} stored for 15 days at 4 °C, a combination of UV-C with Nano-coating Nanocapsules.	The UV-C control sample brought better firmness, as the loss was delayed to day 9 of storage.	[86]
Peeled garlic (*Allium sativum* L.)	UV-C dose of 2 kJ·m^{-2} stored for 15 days at room temperature.	High firmness value with the UV-C treated sample.	[87]
Cherry tomato	UV-C dose of 3.7 kJ·m^{-2}	UV-C treated and control sample both mass loss and firmness were unaffected.	[65]
Tomato (*Lycopersicon esculentum* L.)	UV-C dose of 4.2 kJ·m^{-2} for 8 min	The firmness decreased gradually during storage in both the control and UV-C treated tomatoes.	[72]
Common dandelion and purple coneflower	UV-C dose of 3.8 J·m^{-2}, 1 m of distance from light source, 10 to 120 exposure time, and 21 days of storage period.	Fresh and dry weight loss recorded for both dandelion and purple coneflower is higher than the control sample.	[88]
Strawberry	UV-C dose of 1.70 kJ·m^{-2} for 4.8 min and Storage duration of 0, 2, and 4 days at 21 °C.	No difference in firmness between fruit from control and UV-C-treated samples.	[89]
Mango (*Kensington Pride*)	UV-C dose at 4.0, 8.3, and 11.7 kJ·m^{-2}), room temperature (20 ± 1 °C), relative humidity at 80%, and ethylene storage duration from 3 to 12 days.	At a higher UV-C dose, the firmness is significantly higher than untreated fruits after 6 days of storage. No significant difference in weight loss with the control sample.	[90]
Tahitian lime (*Citrus latifolia*)	The doses were 3.4, 7.2, and 10.5 kJ·m^{-2}. Fruits were located 20 cm from the UV-C light source.	Higher dose (10.5 kJ·m^{-2}) reduced weight loss.	[91]
Mango (*Tommy Atkins*)	UV-C dose of 8220 mW·m^{-2} and exposure time of 10 and 20 min. and storage temperature 5 and 20 °C	Lower weight loss and high firmness for Samples exposed to 10 min and 5 °C.	[92]

3. Effect of UV-C on the Mechanical Properties of Potato

Potatoes belong to the family of *Solanum tuberosum* L. (Solanaceae), which is an important crop plant produced globally. There are a number of products derived from potato and consumed in the form of processed and dehydrated products, such as chips, French fries, granules, snacks, etc. The mechanical properties of the potato tuber and its derivatives represent an important quality parameter for the food industries and customers. Hence, due to the growing demand and massive production, the applicability of surface treatment is intensive. A limited number of studies have reported on the effect of UV-C on the mechanical properties of potato tuber.

Potato tuber treated with UV-C at operational conditions of 20 cm distance away from the source, exposure time of 1 h, followed by a storage period of 0–28 days at 4 °C was studied against a weight loss experiment. The author indicated that there is no significant difference observed between the control and the UV-C treated potatoes during the entire duration of the storage [93]. However, another author [94] stated reduced weight loss in different varieties of potato tuber after exposing the samples to UV-C at a power density from 80 to 100 μW·cm^{-2} and at different stages of the storage period [66]. It was reported that reduced weight could occur at the epicuticular wax morphology of the pretreated tuber, while transpiration and respiration also contributed to the enhanced weight loss. Preliminary work on the mechanical property of pre-injured potato was conducted on different varieties of potato tuber at a wavelength of 253.7 nm, a power density of 80–100 $\mu W \cdot cm^{-1}$, and exposure time of 5, 10, and 15 min and five months of storage. The result led to a smaller weight loss of samples exposed to UV-C for 10 and 15 min compared to control samples [95]. The author suggested the use of UV-C in combination with conveyors and a multi-spaced irradiator to potentially reduce weight loss caused as a result of mechanical injury during post-harvest handling. Conversely, in other research work, the effect of UV-C irradiation in the presence of fluorescence light and darkness on the weight loss of two potato species (*Agata* and *Monalisa*) was investigated at 0, 2.3, 6.9, 11.5, or 34.5 $kJ \cdot m^{-2}$ dose, 3.83 $mW \cdot cm^{-2}$ flow density and 254 nm. the author found higher weight loss than the control sample for tubers stored under fluorescent light and UV-C in darkness and they related this result with the early-stage development of sprouting as this requires dry matter from the tuber [96]. It has been found that the UV-C dose in the range of 5–20 $kJ \cdot m^{-2}$ is able to suppress the sprout propagation [97]. Research on a comparative study between sodium acid sulfate and UV-C treatment on the storage quality of fresh-cut potato was conducted. Firmness as part of the textural analysis was tested after exposing the potato for 3 min from 0 to 25 days of storage duration at 4 °C. Firmness was found to be stable in the entire duration of storage for UV-C treatment. However, it was indicated that, in the combined treated sample with UV-C and Sodium acid sulfate, the firmness was higher than the control sample in the later storage duration [98].

A study reporting on the effect of UV-C light on a sprout length depicted that those potatoes treated with 13.6 $kJ \cdot m^{-2}$ resulted in a shorter length of sprouts compared to other UV-C doses and untreated tubers [99]. The dimensional growth of potato sprouts caused because of UV-C exposure was reported to be unknown. However, it was speculated to be a result of physical change or related to its tubular biochemistry [97]. A similar study was conducted on the impact of UV-C on the deformation of potato tuber (variety *Vineta*, *Lord* and *Owacja*) at varied UV-C doses (69.4, 86.3, and 171.9 $\mu W \cdot cm^{-2}$), exposure time (1, 10, and 30 min.), and irradiator height (40, 70 and 100 cm). Consequently, it was confirmed that UV-C induced a minor percentage of deformation of tubers, as compared to the control combination [100].

4. Stimulation Process of UV-C

4.1. Effect of UV-C on Cell Physiology and Mechanical Properties

Several studies suggested that UV-C radiation is effective not only because of its disinfecting effect, but because it may also stimulate plant defenses against mechanical damages. Exposing UV-C (or hormetin) in food crops has an important effect, called the hormetic effect [101,102], that is responsible for the production of phenylalanine ammonia-lyase (PAL), which induces the formation of a phenolic compound referred to as phytoalexins. The phytochemicals released from PAL having UV absorbing characteristics are found to be chlorogenic acid, gallic acid, epicatechin, and quercetin. This phenolic compound is capable of improving the resistance of fruits and vegetables to microorganisms and defense mechanisms. Phytoalexins give rise to the accumulation of other inducible defenses, such as cell wall modifications [103]. The phenolic content of different crops is discussed as it is the secondary metabolites that are directly connected to plant defense responses. Despite the sophisticated hormetic response process, the role of the hormetic effect in the fruits and their cellular mechanisms by the respective enzymes was demonstrated by a few researchers. The enzymes and genes can be seen in three types based on their response to the UV-C irradiation [104].

Peroxidases and reductases: responsible for oxidative burst and formation of lignin polymers creating boundaries against microorganisms.

Glucanases and chitinases: responsible for lytic activities towards major fungal cell wall components.

L-Phenylalanine ammonia-lyase (PAL): responsible for the biosynthesis of phenolic that led to cell wall modification.

A multitude of studies have shown that UV-C irradiation, depending on its dose, induces the production of phenolic components and other related defense responsive chemicals. The amount of UV-C energy per unit time (dose) released from the light source is an important factor when dealing with surface treatment [105].

4.2. Low UV-C Dose Stimulation

A number of studies investigated different properties of postharvest products when exposed to UV-C irradiation by considering a range of UV-C doses. In the subsequent sections of the review, we discuss the stimulation process of UV-C by classifying low, moderate, and high doses. The classification is mostly based on the relative comparison among the treatment levels and control samples taken in the particular work of art. There is no clear demarcation set for the UV-C dose irradiation from low to high. This is due to the fact that the change induced by UV-C is varied in different products. The effect might even be different among different varieties of the same product. However, the classification takes account of the proposition and findings of previous research. A work by a researcher depicted that a fruit could resist the effect of UV-C dose up to 4.1 $kJ \cdot m^{-2}$ [106]. Furthermore, the latest research carried out an experiment on the effect of low UV-C dose in the range below 4 $kJ \cdot m^{-2}$ [107].

Recent work on the sprouting suppression and quality attributes of potato tuber exposed to low UV-C dose indicated that the role of UV-C light is not only limited to the anti-germicidal effect, but also enables resistance to damage repair and sprouting [108]. A low UV-C dose is reported to induce a hormetic effect on vegetative crops without damaging the crop, which is termed as UV-C hormesis, making use of a harmful low dose of irradiation to induce a favorable stress response on crops [109]. In addition to the hormetic effect, the plant crop is able to offer health-promoting advantages when used by the customer which is referred to as xenohormesis [110]. This is due to the phenolic compound phytoalexins having antioxidant properties further inducing a secondary resistance in the end user's body [111]. Basically, the purpose of using non-thermal technology on harvested crops is primarily to maintain the quality without undergoing damage, which in turn delays senescence. The influence of UV-C offers a pronounced effect over UV-A and UV-B in the process of delaying senescence, and over the other non-thermal processes UV-C is considered as releasing optimized oxidative stress for defense against germ and wound response [112–115]. These effects were well demonstrated by the experiment conducted on lettuce, tomatoes, peaches, and strawberries [116–119]. From a molecular perspective, the plant develops the response by producing ROS (reactive oxygen species) that signals the physiological modification in the chloroplast, mitochondria, DNA and produces secondary metabolites [120,121]. An experimental study performed on tomato fruit in response to UV-C treatment elucidated that the response of the plant involves much greater expression of a number genes responsible for cell wall disassembly, which may be linked to physiological changes, damage resistance, and most importantly delaying softening or maintaining the firmness of the final product [122]. A recent investigation of broccoli florets exposed to a hormetic dose of 1.2 $kJ \cdot m^{-2}$ of UV-C radiation was able to maintain the lowest weight loss as compared to untreated samples [123]. Higher firmness and delayed softening at a lower UV-C dose on strawberry fruit were confirmed and it was explained that a set of genes was able to overcome cell wall degradation through the encoding process. In a previous study, UV-C radiation in strawberry fruit also maintained higher firmness and delayed softening due to the presence of a set of genes encoding for proteins and enzymes involved in cell wall degradation [27,124]. UV-C exposed fresh-cut melon at 1.18×103 $mW \cdot cm^{-2}$ caused a greater firmness during storage that is related to the accumulation of peroxidase enzyme [125]. This enzyme, as discussed in the previous section, is responsible for creating a barrier between the cell wall and the pathogen, reducing softening and enhancing firmness.

4.3. Moderate and High UV-C Dose Stimulation

The application of a high dose during treatment is indicated to have a severe effect on the physiological constituent of plant crops and potentially affect the mechanical attributes during storage. Firmness is an important quality indicating parameter that indicates the degree of softness as the crops undergo a given storage duration. Studies have not yet sufficiently shown the effect of the mechanical changes as a result of high UV-C dose. Nevertheless, some research works depicted the negative impact of high UV-C doses on the physiological constituents that are discussed in this section. The correlation between the physiological change and firmness demonstrated by a previous study indicates that softening of the fruit during storage is a result of cell wall damage that is caused by the generation of two major degrading enzymes in a cell wall, namely polygalacturonase (PG) and pectin methylesterase (PME) [126]. An experiment conducted on the physiological damage of cells of certain vegetable crops at a high UV-C dose was reported to cause cell membrane damage. A research work conducted on spinach exposed to a high UV-C dose from 7.94 to 11.35 kJ·m^{-2} 13 days of storage duration and 8 °C of storage temperature depicted the reduction of antioxidant chemicals up to 75% [127]. Likewise, in other experimental work on pepper exposed to the UV-C dose of 7 kJ·m^2, 18 days of storage duration, and 10 °C storage temperature resulted in lower antioxidant chemicals but with fewer changes [128]. The latest research work on satsuma mandarin fruit resulted in a significant decrease of DPPH (antioxidant) and phenolic compounds when exposed to a high UV-C dose of 10 kJ·m^{-2} [129]. An experimental study on Mangosteen treated over the range of 6–40 kJ·m^{-2} at 25 °C for seven days resulted in a higher defense response and decreased weight loss at 13 kJ·m^{-2} than the lower and the higher UV-C dose, which showed no significant difference from the control sample [130]. However, UV-C irradiated persimmon and cucumber at 12.9 kJ·m^{-2} at varied exposure times and storage periods were found to be ineffective for the enhancement of phytochemicals [131]. Fresh-cut lotus treated with UV-C from 0.3 to 12 kJ·m^{-2} indicated the moderate UV-C intensity from 1.5 to 3 kJ·m^{-2} was significant in inducing phenolic content [132]. A comparable result was noted in a tomato treated at a UV-C dose of 4 kJ·m^{-2} and storage temperature of 13 °C, elucidating an increase in phenolic content throughout the storage period significantly higher than the control sample [133]. In other research, using a similar dose of UV-C, the total phenolic content of fresh-cut strawberries was enhanced significantly [134]. The UV-C stimulation at a mild dose is predominantly reported to induce phytochemicals and antioxidants for the role of defense response. However, the reduction in these defense-triggering chemicals when treated at a high dose is due to the depleting activity of UV-C, resulting in membrane damage that gives rise to the change in the chemical compositions, hence lowering the antioxidant activities of the crop and lowering the firmness. The physiological change in terms of weight loss and firmness in relation to the phenolic content was excellently indicated by a recent research article conducted on UV-C exposed bitter gourd sample, maintaining two-fold lower weight loss than the control sample at prolonged days of storage [135]. The softening of tissues during the prolonged storage period is attributed to the gradual alteration in cell wall composition and cell separation [85]. Besides, a moderate dose could also result in higher softening. For instance, a tomato fruit treated at a moderate UV-C dose of 3.7 kJ·m^{-2} resulted in higher weight loss compared to untreated ones [136]. This is due to the lower production of defense response compounds. The change is induced not only by the effect of UV-C operational factors, but the inherent characteristic of the fruit is also important. In general, high-dose UV-C conditions offer unfavorable stress resulting from low quality and defense mechanisms. Some investigations concluded that low dose irradiation led to hormonal effects improvement and microbial load reduction. On the other hand, high doses or continuous exposure could lead to a significant quality loss, decrease in shelf life, and lower antimicrobial activity [137,138]. The disadvantages of inducing high UV-C dose were reported by previous research stating that accelerated ripening, senescence, lower stress response for bacterial wound, lower shelf life, and economical loss were associated with high dose exposure in postharvest fresh cuts [139]. It is highly important to ensure the optimal UV-C dose in order to avoid compromising the textural quality, shelf-life elongation, and feasibility. The linked relationship between the UV-C dose with cellular level modification and the final quality attribute of the vegetable crop is depicted diagrammatically in Figure 2 [127–129,137,138].

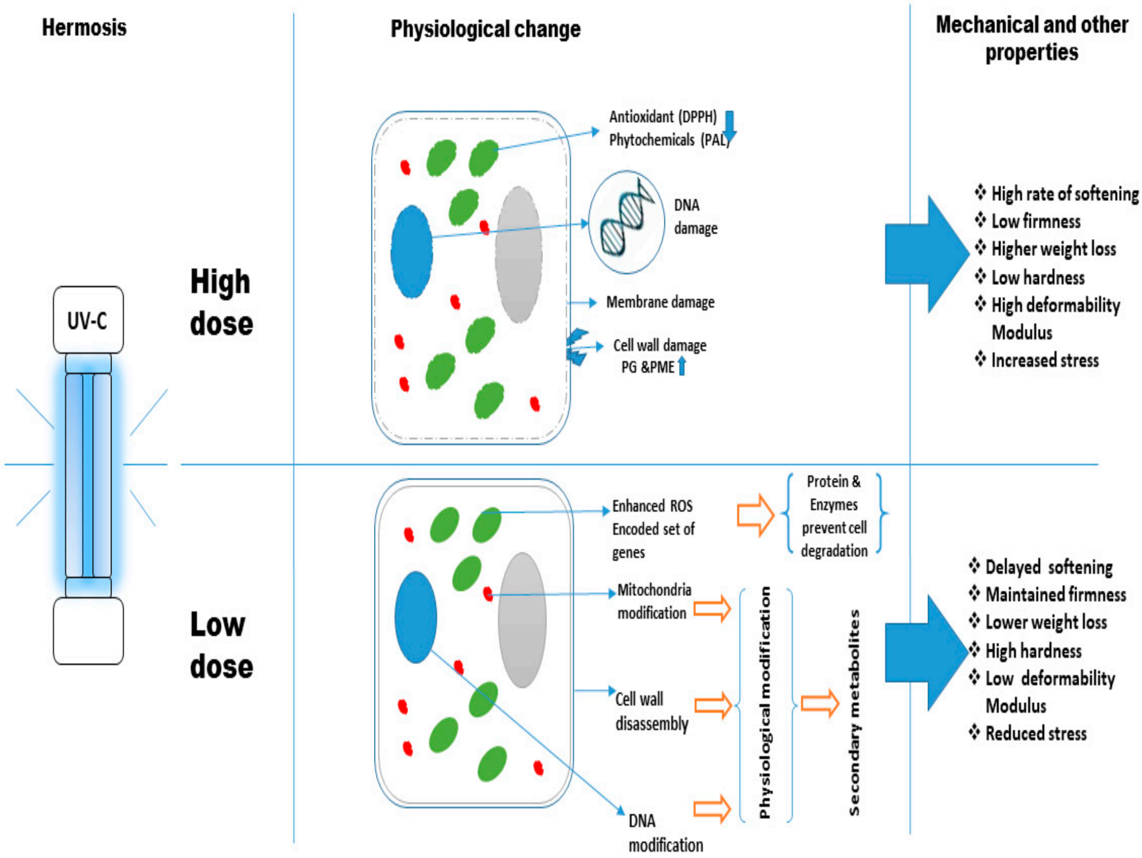

Figure 2. Diagrammatic representation for stress response as a result of low and high UV-C hermosis effect. The physiological modification encountered gives rise to changes in mechanical and other attributes of the vegetable.

Table 2 shows miscellaneous horticulture products exposed at different UV-C doses and their resulting changes in quality texture, antioxidant, enzymes, and phenolic compounds.

Table 2. Different horticultural product's metabolic activities when subjected to a varied UV-C dose and other operational conditions.

Commodity	Operating Condition	Key Finding	Reference
Tomato (*Solanum lycopersicum*)	UV-C dose of 4 kJ·m^{-2}, exposure time of 6 min.	Increase in phenolic compounds content.	[133]
Blueberries	UV-C dose of 0.43, 2.15, 4.30 and 6.45 kJ·m^{-2}.	Higher antioxidant capacity in fruit treated with 2.15, 4.30, and 6.45 kJ·m^{-2} compared to the control fruit. Increased phenolic components in a lesser amount at 0.43 kJ·m^{-2}.	[140]
Fragrant pear (*Korla*)	UV-C irradiation of 0.12, 0.24, 0.36, 0.48, 0.72 and 1.08 kJ·m^{-2}.	low-dose UV-C irradiation (0.36 kJ·m^{-2}) enhanced the phenolic compound.	[141]

Table 2. *Cont.*

Commodity	Operating Condition	Key Finding	Reference
Mandarin (*Satsuma*)	UV-C dose of 0.75, 1.5 and 3.0 kJ·m^{-2}.	Phenolic acids and antioxidant capacity were not significantly affected by UV-C treatments, while 1.5 and 3.0 kJ·m^{-2} significantly increased flavonoids and total phenolics. 0.75 kJ·m^{-2} was infective to induce any change.	[142]
Garlic (*Danyang*)	UV-C of 25 kJ·m^{-2}, exposure time of 380 s.	The UV-C treatment reduces microorganisms present and no significant differences in quality attributes, phenolic compounds, and antioxidants.	[143]
Fresh-cut Rocket Leaves	UV-C dose at 1, 3 and 5 kJ·m^{-2}.	The optimum dose of UV-C for enhancing total anthocyanin content was 3.0 kJ·m^{-2}.	[144]
Mango (*Haden*)	UV-C dose of 2.46 and 4.93 kJ·m^{-2}.	the highest accumulation of phytochemicals in mangoes exposed to 4.93 kJ·m^{-2}.	[145]

5. Factors Affecting UV-C Process in Stimulation

The efficiency of UV stimulation on crops is affected by factors, such as light source, product composition, flow profile, and geometric configuration. UV light has a great impact on the quality attribute of food in relation to wavelength, intensity, and exposure. Total dosage (energy per unit area) is the main factor determining fruit and vegetable responses to UV-C, but the intensity of the radiation (dose per unit time) may also determine treatment outcome. The degree to which the stimulation occurs by UV radiation is directly related to the UV dose. The UV-C dose (J·cm^{-2}) is expressed in terms of the UVC intensity flux (W·cm^{-2}) and exposure time (s), as calculated from the correlation presented in Equation (1).

$$\text{Dose} = \text{UVC Intensity}\cdot\text{Exposure time} \tag{1}$$

The UV-C intensity rate is the total amount of radiant flux passing from all angles through a unit area that is determined based on the location of the sample under exposure. However, the UV-C intensity is not equal to the amount of energy absorbed by the exposed sample. The effect of UV-C exposure time (20–40 min at 15 cm distance) on the defense response chemical content is well experimented with in recent research on bitter gourd resulting in a significant change in the quality attributes [135]. Distance from the source to the sample is an important factor that affects intensity flux and stimulation. The shorter the distance, the higher the radiant flux to effectively stimulate or disinfect the sample of the crop. This correlation is well described by the Equation (2) shown below [146,147].

$$\text{UVC intensity } (r) = \left(\frac{P}{2\pi r}\right)\cdot e^{-\alpha.r} \tag{2}$$

The UVC fluence rate at radial distance r from the lamp is proportional to P, which is UV-C power emitted per unit arc length of the lamp, and α is the absorption coefficient (cm^{-1}). During UV-C irradiation into the sample, the performance of absorption to induce a change is also dependent on the composition of the food product. The surface of the food item determines the penetration ability of UV-C light. A higher value of α leads to a decrease in the penetration ability of UV-C, resulting in the minimal effectiveness of the stimulation of UV-C dose [148]. Complete information and characterization of the absorptive characteristics of a sample are very important when estimating the required UVC dose. For example, in fruits, there is a presence of epicuticular waxes, which contain a microcrystalline structure. Exposure of fruit to UV-C changes the wax morphology, composition, and structure, eventually resulting in a change in surface permeability. This phenomenon can lead to weight loss (water vapor, volatile compounds, etc.), which is a decisive parameter in the quality attribute of fruit [149]. In some vegetable plants, such as Brussels sprout, exposure to a hormetic dose of UV-C resulted in reduced weight loss due to the modification from shorter crystalline structures leading to a dense wax structure, lowering permeability because of a better protective layer [150]. The purity of the sample also affects the stimulation process. The existence of suspended solids and soluble components in the food matrix weakens the application of UVC radiation by inducing light scattering, absorption, and reflection [151]. Due to these factors influencing the efficiency of the UV-C irradiation, the UV-C station needs a proper and operational dose followed by validation using a computer program to confirm the distribution of the irradiation and its stress.

6. Innovative Technologies Used in Combination with UV-C

The investigation of the combined effects of different methods and UV-C on the textural attributes of fruits and vegetables is recently come to emerge showing a glimpse of light in the improvement of the surface treatment. However, it is very limited and difficult to examine the advantageous facets as compared to the conventional single UV-C irradiation. Few studies have reported on the combined effects on the textural attributes.

The quality of strawberries subjected to different patterns of cyclic and repetitive low dose resulted in an improvement in some of the quality parameters. In their study, they exposed the sample at 4 $kJ \cdot m^{-2}$ prior to storage for single time, two step at 2 $kJ \cdot m^{-2}$ consecutively at harvest and after four days of storage, and multistep 0.8 $kJ \cdot m^{-2}$ after zero, two, four, six, and eight days of storage, respectively. From their result, a single step UV-C exposure resulted in a tendency of sustaining higher firmness and delayed softening than the control sample. Two- and multi-step treatments resulted in a higher textural property [107]. The quality of sweet cherry was studied by exposing the fruit to a single and combined operation of UV-B (21.6 $kJ \cdot m^{-2}$), UV-C (21.6 $kJ \cdot m^{-2}$), and combination with a coating of the sample with 1% chitosan for 24 days and 8 °C. Their result indicated that the combination of UV-C, UV-B, and chitosan coating was able to slow the weight loss and maintain firmness better than the control sample in comparison to the singular effects [152]. In a similar study, grapes treated at 6 kJ/m^2 UV-C and 0.5% chitosan reduced weightlessness. A combined treatment of UV-C and Chlorine dioxide (ClO_2) on spinach leaves and tomato surface resulted in no significant effect on the texture of the sample after seven days of storage [153]. The combined effect of UV-C irradiation at 2 $kJ \cdot m^{-2}$ and modified atmosphere packaging in cold storage was studied on the quality of cherry tomato, resulting in lower weight loss and maintained firmness [154]. Asparagus exposed to a combined treatment technique of UV-C at 1 $kJ \cdot m^{-2}$ and ozonized water at 3 ppm for 3 s resulted in improved cutting energy compared to the control over a four-day storage period [70]. The quality of date palm was studied by exposing it to alkaline electrolyte water, neutral electrolyzed water, ozonated water, and UV-C [155]. They found that the combination of neutral electrolyzed water and UV-C treated at 6.22 $kJ \cdot m^{-2}$ resulted in a lower weight loss while a triple combination between neutral, alkaline, and UV-C at 6.22 $kJ \cdot m^{-2}$ brought a higher firmness value as compared to the control and other combinations.

7. Conclusions

The research works on the UV-C surface treatment of fruits and vegetables is slowly increasing due to the growing industrialization, the concern for quality, health, and safety, and customer demand for fresh harvested fruit and vegetable crops. This multidimensional factor makes the area untapped for research.

The determination of the appropriate dose to encounter a favorable stress response and to achieve required mechanical properties is highly varied with different plants exhibiting their own physicochemical properties. Furthermore, the standard textural quality requirements in processing industries for different products are various. The combined technologies are sophisticated and less feasible in terms of energy and mass requirement. The need to focus on the optimization of the process parameter of the UV-C chamber is by far promising. In addition to this, the physicochemical characteristics in the capacity of perceiving light require careful investigation prior to determining the irradiation dose. From the review, low and moderate doses are reported to induce a better favorable physiological stress response, while the high dose reduces the enzymatic role (PAL) to produce phenolic and antioxidants responsible for cell wall modification. From the review, it was possible to understand the strong link between the cellular physiological changes that give rise to the changes in mechanical characteristics of the product. Little is known about the study of UV-C exposed potato tuber mechanical properties, as it is the largest food crop in the world and the key economic driving agricultural product in the frozen market. More studies are needed to address this hurdle process with the priority for stable crops that are produced extensively throughout the globe, such as potato tuber, from which a number of derivative products are produced. Optimization and intensification of the process will offer opportunities to improve the quality and ultimately scale-up towards effective commercialization.

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References

1. Soares, I.G.; Silva, E.B.; Amaral, A.J.; Machado, E.C.; Silva, J.M. Physico-chemical and sensory evaluation of potato (*Solanum tuberosum* L.) after irradiation. *An. Acad. Bras. Ciências* **2016**, *88*, 941–950. [CrossRef] [PubMed]
2. Nawara, P.; Gliniak, M.; Popardowski, E.; Szczuka, M.; Trzyniec, K. Control system of a prototype measurement system for the identification of ultra-low photonic emission of organic materials. In Proceedings of the 2018 Progress in Applied Electrical Engineering, Koscielisko, Poland, 18–22 June 2018. [CrossRef]
3. Jakubowski, T. Transfer of microwave irradiation effects of seed potatoes (*Solanum tuberosum* L.) to the plants of next generations. *Bulg. J. Agric. Sci.* **2015**, *21*, 1185–1193.
4. Kielbasa, P.; Drozdz, T.; Nawara, P.; Drozdz, M.; Trzyniec, K. Assessment of the potential of using photon emission to identify selected qualitative features of organic matter. In Proceedings of the 2018 Applications of Electromagnetics in Modern Techniques and Medicine, Racławice, Poland, 9–12 September 2018; pp. 117–120. [CrossRef]
5. Nawara, P.; Trzyniec, K.; Dróżdż, T.; Popardowski, E.; Juliszewski, T.; Zagórda, M.; Miernik, A. Analysis of the possibility of identifying the quality parameters of the oil using ultra-weak secondary luminescence. *Prz. Elektrotech.* **2020**, *96*, 117–120. (In Polish) [CrossRef]
6. Jakubowski, T. The influence of selected physical methods on the content of starch and simple sugars in stored potato tubers. In Proceedings of the 2019 Applications of Electromagnetics in Modern Engineering and Medicine, Janow Podlaski, Poland, 9–12 June 2019; pp. 63–66. [CrossRef]
7. Jakubowski, T. The reaction of garden cress (*Lepidium sativum* L. to microwave radiation. In Proceedings of the 2018 Applications of Electromagnetics in Modern Techniques and Medicine, Racławice, Poland, 9–12 September 2018; pp. 81–84. [CrossRef]
8. Fauster, T.; Schlossnikl, D.; Rath, F.; Ostermeier, R.; Teufel, F.; Toepfl, S.; Jaeger, H. Impact of pulsed electric field (PEF) pretreatment on process performance of industrial French fries production. *J. Food Eng.* **2018**, *235*, 16–22. [CrossRef]
9. Jadhav, H.B.; Annapure, U.S.; Deshmukh, R.R. Non-thermal technologies for food processing. *Front. Nutr.* **2021**, *8*, 657090. [CrossRef]
10. Huang, H.W.; Wu, S.J.; Lu, J.K.; Shyu, Y.T.; Wang, C.Y. Current status and future trends of high-pressure processing in food industry. *Food Control* **2017**, *72*, 1–8. [CrossRef]

11. Jakubowski, T. The effect of stimulation of seed potatoes (*Solanum tuberosum* L.) in the magnetic field on selected vegetation parameters of potato plants. *Prz. Elektrotech.* **2020**, *96*, 166–169.
12. Jakubowski, T. The influence of microwave radiation at the frequency 2.45 GHz on the germination. *Prz. Elektrotech.* **2018**, *94*, 254–325. [CrossRef]
13. Jakubowski, T. Effect of microwave radiation on the germination of *Solanum tuberosum* L. tubers. *Bangladesh J. Bot.* **2016**, *45*, 1255–1257.
14. Mahto, R.; Das, M. Effect of gamma irradiation on the physico-mechanical and chemical properties of potato (*Solanum tuberosum* L.), cv. 'Kufri Sindhuri', in non-refrigerated storage conditions. *Postharvest Biol. Technol.* **2014**, *92*, 37–45. [CrossRef]
15. Jamieson, L.E.; Meier, X.; Page, B.; Zulhendri, F.; Page-Weir, N.; Brash, D.; McDonald, R.M.; Stanley, J.; Woolf, A.B. A review of postharvest disinfestation technologies for selected fruits and vegetables. *Plant Food Res. Client Rep.* **2009**, *19*, 36072.
16. Lu, C.; Ding, J.; Park, H.K.; Feng, H. High intensity ultrasound as a physical elicitor affects secondary metabolites and antioxidant capacity of tomato fruits. *Food Control* **2020**, *113*, 107176. [CrossRef]
17. Hockberger, P.E. A History of Ultraviolet Photobiology for Humans, Animals and Microorganisms. *Photochem. Photobiol.* **2002**, *76*, 561–579. [CrossRef]
18. Bintsis, T.; Litopoulou-Tzanetaki, E.; Robinson, R.K. Existing and potential applications of ultraviolet light in the food industry–a critical review. *J. Sci. Food Agric.* **2000**, *80*, 637–645. [CrossRef]
19. Darras, A.I.; Tsikaloudakis, G.; Lycoskoufis, I.; Dimitriadis, C.; Karamousantas, D. Low doses of UV-C irradiation affects growth, fruit yield and photosynthetic activity of tomato plants. *Sci. Hortic.* **2020**, *267*, 109357. [CrossRef]
20. Vanhaelewyn, L.; Van Der Straeten, D.; De Coninck, B.; Vandenbussche, F. Ultraviolet radiation from a plant perspective: The plant-microorganism context. *Front. Plant Sci.* **2020**, *11*, 597642. [CrossRef]
21. Rameš, J.; Chaloupecký, V.; Sojková, N.; Bencko, V. An attempt to demonstrate the increased resistance of selected bacterial strains during repeated exposure to UV radiation at 254 nm. *Cent. Eur. J. Public Health* **1997**, *5*, 30–31.
22. United States Food and Drug Administration—FDA. Ultraviolet radiation for the processing and treatment of food. In *Code of Federal Regulations*; 21 Part, Section 179.39; FDA: Silver Spring, MD, USA, 2002.
23. National Archives and Records Administration, Code of Federal Regulations. 21 CFR 179.39—Ultraviolet Radiation for the Processing and Treatment of Food. Available online: https://www.govinfo.gov/app/details/CFR-2011-title21-vol3/CFR-2011-title21-vol3-sec179-39/context (accessed on 4 May 2022).
24. Frohnmeyer, H.; Staiger, D. Ultraviolet-B radiation-mediated responses in plants. Balancing damage and protection. *Plant Physiol.* **2003**, *133*, 1420–1428. [CrossRef]
25. Bassham, J.A.; Calvin, M. The path of carbon in photosynthesis. In *Die CO_2-Assimilation. The Assimilation of Carbon Dioxide. Handbuch der Pflanzenphysiologie*; Pirson, A., Ed.; Encyclopedia of Plant Physiology; Springer: Berlin/Heidelberg, Germany, 1960; p. 5. [CrossRef]
26. Konstankiewicz, K.; Pawlak, K.; Zdunek, A. Influence_of_structural_parameters. *Int. Agrophys.* **2000**, *15*, 243–246.
27. Pombo, M.A.; Dotto, M.C.; Martínez, G.A.; Civello, P.M. UV-C irradiation delays strawberry fruit softening and modifies the expression of genes involved in cell wall degradation. *Postharvest Biol. Technol.* **2009**, *51*, 141–148. [CrossRef]
28. Jackman, R.L.; Stanley, D.W. Perspectives in the textural evaluation of plant foods. *Trends Food Sci. Technol.* **1995**, *6*, 187–194. [CrossRef]
29. Waldron, K.W.; Smith, A.C.; Parr, A.J.; Ng, A.; Parker, M.L. New approaches to understanding and controlling cell separation in relation to fruit and vegetable texture. *Trends Food Sci. Technol.* **1997**, *8*, 213–221. [CrossRef]
30. Ichiki, H.; Van, N.N.; Yoshinaga, K. Stone-clod Separation and Its Application to Potato Cultivation in Hokkaido. *Eng. Agric. Environ. Food* **2013**, *6*, 77–85. [CrossRef]
31. Zhang, D.Q.; Mu, T.H.; Sun, H.N.; Chen, J.W.; Zhang, M. Comparative study of potato protein concentrates extracted using ammonium sulfate and isoelectric precipitation. *Int. J. Food Prop.* **2017**, *20*, 2113–2127. [CrossRef]
32. Ezekiel, R.; Singh, N.; Sharma, S.; Kaur, A. Beneficial phytochemicals in potato—A review. *Food Res. Int.* **2013**, *50*, 487–496. [CrossRef]
33. Flegg, P.B.; Spencer, D.M.; Wood, D.A. *The Biology and Technology of the Cultivated Mushroom*; John Wiley & Sons Ltd.: Chichester, UK, 1985; pp. i–xii+347.
34. Miernik, A.; Jakubowski, T. Selected methods for starch content determination in plant materials. *J. Phys. Conf. Ser.* **2021**, *1782*, 012019. [CrossRef]
35. Nawara, P.; Jakubowski, T.; Sobol, Z. Application of the CIE L∗a∗b∗ method for the evaluation of the colour of fried products from potato tubers exposed to C band ultraviolet light. *E3S Web Conf.* **2019**, *132*, 02004. [CrossRef]
36. Błaszczak, W.; Sadowska, J.; Fornal, J.; Vacek, J.; Flis, B.; Zagórski-Ostoja, W. Influence of cooking and microwave heating on microstructure and mechanical properties of transgenic potatoes. *Food/Nahrung* **2004**, *48*, 169–176. [CrossRef]
37. Jakubowski, T. A system for the control and recording of physical parameters inside a chamber for UV-C irradiating of biological material. *E3S Web Conf.* **2019**, *132*, 01006. [CrossRef]
38. Gliniak, M.; Tomasik, M.; Popardowski, E.; Knaga, J.; Lis, A.; Gliniak, M. Application of natural luminescence for analysis of the radionuclide migration path during hard coal combustion. In Proceedings of the 2018 Applications of Electromagnetics in Modern Techniques and Medicine, Racławice, Poland, 9–12 September 2018; pp. 61–64. [CrossRef]

39. Kharchenko, S.; Borshch, Y.; Kovalyshyn, S.; Piven, M.; Abduev, M.; Miernik, A.; Popardowski, E.; Kiełbasa, P. Modeling of aerodynamic separation of preliminarily stratified grain mixture in vertical pneumatic separation duct. *Appl. Sci.* **2021**, *11*, 4383. [CrossRef]
40. Jakubowski, T.; Syrotyuk, S.; Yankovska, K. The use of microwave radiation with a frequency of 2.45 GHz as a factor reducing the storage losses of potato tubers. *J. Phys. Conf. Ser.* **2021**, *1782*, 012011. [CrossRef]
41. Gliniak, M.; Tomasik, M.; Popardowski, E.; Knaga, J.; Lis, A.; Gliniak, M. Application of natural luminescence for assessment of hard coal quality. In Proceedings of the 2018 Applications of Electromagnetics in Modern Techniques and Medicine, Racławice, Poland, 9–12 September 2018; pp. 73–76. [CrossRef]
42. Sobol, Z.; Jakubowski, T.; Nawara, P. The effect of UV-C stimulation of potato tubers and soaking of potato strips in water on color and analyzed color by CIE l*a*b*. *Sustainability* **2020**, *12*, 3487, Correction in *Sustainability* **2020**, *12*, 7473. [CrossRef]
43. Shen, H.; Fan, D.; Huang, L.; Gao, Y.; Lian, H.; Zhao, J.; Zhang, H. Effects of microwaves on molecular arrangements in potato starch. *RSC Adv.* **2017**, *7*, 14348–14353. [CrossRef]
44. Xie, Y.; Yan, M.; Yuan, S.; Sun, S.; Huo, Q. Effect of microwave treatment on the physicochemical properties of potato starch granules. *Chem. Cent. J.* **2013**, *7*, 113. [CrossRef]
45. Teixeira, B.S.; Inamura, P.Y.; Mastro, N.L. The influence of gamma irradiation on texture, color and viscosity properties of potato starch. In Proceedings of the 2015 International Nuclear Atlantic Conference—INAC 2015, São Paulo, Brazil, 4–9 October 2015.
46. Wang, J.; Chao, Y. Effect of gamma irradiation on quality of dried potato. *Radiat. Phys. Chem.* **2003**, *66*, 293–297. [CrossRef]
47. Chung, H.J.; Liu, Q. Molecular structure and physicochemical properties of potato and bean starches as affected by gamma-irradiation. *Int. J. Biol. Macromol.* **2010**, *47*, 214–222. [CrossRef]
48. Rezaee, M.; Almassi, M.; Minaei, S.; Paknejad, F. Impact of post-harvest radiation treatment timing on shelf life and quality characteristics of potatoes. *J. Food Sci. Technol.* **2013**, *50*, 339–345. [CrossRef]
49. Zhu, J.; Li, L.; Chen, L.; Li, X. Study on supramolecular structural changes of ultrasonic treated potato starch granules. *Food Hydrocoll.* **2012**, *29*, 116–122. [CrossRef]
50. Chung, K.M.; Moon, T.W.; Kim, H.; Chun, J.K. Physicochemical properties of sonicated mung bean, potato, and rice starches. *Cereal Chem.* **2002**, *79*, 631–633. [CrossRef]
51. Liu, C.; Grimi, N.; Lebovka, N.; Vorobiev, E. Effects of preliminary treatment by pulsed electric fields and convective air-drying on characteristics of fried potato. *Innov. Food Sci. Emerg. Technol.* **2018**, *47*, 454–460. [CrossRef]
52. Gormley, T.R. Texture studies on mushrooms. *Int. J. Food Sci. Technol.* **1969**, *4*, 161–169. [CrossRef]
53. Sobol, Z.; Jakubowski, T.; Surma, M. Effect of Potato Tuber Exposure to UV-C Radiation and Semi-Product Soaking in Water on Acrylamide Content in French Fries Dry Matter. *Sustainability* **2020**, *12*, 3426. [CrossRef]
54. Sobol, Z.; Jakubowski, T. The effect of storage duration and UV-C stimulation of potato tubers, and soaking of potato strips in water on the density of intermediates of French fries production. *Prz. Elektrotech.* **2020**, *96*, 242–245. [CrossRef]
55. Sobol, Z.; Jakubowski, T.; Wrona, P. The effect of UV-C stimulation of potato tubers and soaking of potato strips in water on density differences of intermediates for French-fry production. In Proceedings of the Contemporary Research Trends in Agricultural Engineering, Proceedings of the BIO Web Conferences, Kraków, Poland, 25–27 September 2017; EDP Sciences: Les Ulis, France, 2018; p. 02031. [CrossRef]
56. Pelai, Z.; Pedisi, S.; Repaji, M.; Zori, Z.; Levaj, B. Effect of UV-C Irradiation, Storage and Subsequent Cooking on Chemical Constituents of Fresh-Cut Potatoes. *Foods* **2021**, *10*, 1698. [CrossRef] [PubMed]
57. Peleg, M. On fundamental issues in texture evaluation and texturization—A view. *Food Hydrocoll.* **2006**, *20*, 405–414. [CrossRef]
58. Ma, L.; Wang, Q.; Li, L.; Grierson, D.; Yuan, S.; Zheng, S.; Wang, Y.; Wang, B.; Bai, C.; Fu, A.; et al. UV-C irradiation delays the physiological changes of bell pepper fruit during storage. *Postharvest Biol. Technol.* **2021**, *180*, 111506. [CrossRef]
59. Huyskens-Keil, S.; Hassenberg, K.; Herppich, W.B. Impact of postharvest UV-C and ozone treatment on textural properties of white asparagus (*Asparagus officinalis* L.). *J. Appl. Bot. Food Qual.* **2012**, *84*, 229–234.
60. Poubol, J.; Lichanporn, I.; Puthmee, T.; Kanlayanarat, S. Effect of ultraviolet-C irradiation on quality and natural microflora of asparagus spears. *Acta Hortic.* **2010**, *875*, 257–262. [CrossRef]
61. Manzocco, L.; da Pieve, S.; Maifreni, M. Impact of UV-C light on safety and quality of fresh-cut melon. *Innov. Food Sci. Emerg. Technol.* **2011**, *12*, 13–17. [CrossRef]
62. Manzocco, L.; Da Pieve, S.; Bertolini, A.; Bartolomeoli, I.; Maifreni, M.; Vianello, A.; Nicoli, M.C. Surface decontamination of fresh-cut apple by UV-C light exposure: Effects on structure, colour and sensory properties. *Postharvest Biol. Technol.* **2011**, *61*, 165–171. [CrossRef]
63. Gómez, P.L.; Alzamora, S.A.; Castro, M.A.; Salvatori, D.M. Effect of ultraviolet-C light dose on quality of cut-apple: Microorganism, color and compression behavior. *J. Food Eng.* **2010**, *98*, 60–70. [CrossRef]
64. Gogo, E.O.; Opiyo, A.M.; Hassenberg, K.; Ulrichs, C.; Huyskens-Keil, S. Postharvest UV-C treatment for extending shelf life and improving nutritional quality of African indigenous leafy vegetables. *Postharvest Biol. Technol.* **2017**, *129*, 107–117. [CrossRef]
65. Vunnam, R.; Hussain, A.; Nair, G.; Bandla, R.; Gariepy, Y.; Donnelly, D.J.; Kubow, S.; Raghavan, G.S. Physico-chemical changes in tomato with modified atmosphere storage and UV treatment. *J. Food Sci. Technol.* **2014**, *51*, 2106–2112. [CrossRef] [PubMed]
66. Cote, S.; Rodoni, L.; Miceli, E.; Concellón, A.; Civello, P.M.; Vicente, A.R. Effect of radiation intensity on the outcome of postharvest UV-C treatments. *Postharvest Biol. Technol.* **2013**, *83*, 83–89. [CrossRef]

67. Tzortzakis, N.; Borland, A.; Singleton, I.; Barnes, J. Impact of atmospheric ozone-enrichment on quality-related attributes of tomato fruit. *Postharvest Biol. Technol.* **2007**, *45*, 317–325. [CrossRef]
68. Perkins-Veazie, P.; Collins, J.K.; Howard, L. Blueberry fruit response to postharvest application of ultraviolet radiation. *Postharvest Biol. Technol.* **2008**, *47*, 280–285. [CrossRef]
69. Stevens, C.; Liu, J.; Khan, V.A.; Lu, J.Y.; Kabwe, M.K.; Wilson, C.L.; Igwegbe, E.C.; Chalutz, E.; Droby, S. The effects of low-dose ultraviolet light-C treatment on polygalacturonase activity, delay ripening and Rhizopus soft rot development of tomatoes. *Crop Prot.* **2004**, *23*, 551–554. [CrossRef]
70. Tiecher, A.; de Paula, L.A.; Chaves, F.C.; Rombaldi, C.V. UV-C effect on ethylene, polyamines and the regulation of tomato fruit ripening. *Postharvest Biol. Technol.* **2013**, *86*, 230–239. [CrossRef]
71. Obande, M.A.; Tucker, G.A.; Shama, G. Effect of preharvest UV-C treatment of tomatoes (*Solanum lycopersicon* Mill.) on ripening and pathogen resistance. *Postharvest Biol. Technol.* **2011**, *62*, 188–192. [CrossRef]
72. Bu, J.; Yu, Y.; Aisikaer, G.; Ying, T. Postharvest UV-C irradiation inhibits the production of ethylene and the activity of cell wall-degrading enzymes during softening of tomato (*Lycopersicon esculentum* L.) fruit. *Postharvest Biol. Technol.* **2013**, *86*, 337–345. [CrossRef]
73. Pan, Y.G.; Zu, H. Effect of UV-C radiation on the quality of fresh-cut pineapples. *Procedia Eng.* **2012**, *37*, 113–119. [CrossRef]
74. Allende, A.; McEvoy, J.L.; Luo, Y.; Artes, F.; Wang, C.Y. Effectiveness of two-sided UV-C treatments in inhibiting natural microflora and extending the shelf-life of minimally processed 'Red Oak Leaf' lettuce. *Food Microbiol.* **2006**, *23*, 241–249. [CrossRef] [PubMed]
75. Artés, F.; Gómez, P.; Aguayo, E.; Escalona, V.; Artés-Hernández, F. Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. *Postharvest Biol. Technol.* **2009**, *51*, 287–296. [CrossRef]
76. Edward, T.L.; Kirui, M.S.K.; Omolo, J.O.; Ngumbu, R.G.; Odhiambo, P.M. Effect of Ultraviolet-A (UV-A) and Ultraviolet-C (UV-C) Light on Mechanical Properties of Oyster Mushrooms during Growth. *J. Biophys.* **2014**, *2014*, 687028. [CrossRef] [PubMed]
77. Meng, X.; Zhang, M.; Zhan, Z.; Adhikari, B. Changes in Quality Characteristics of Fresh-cut Cucumbers as Affected by Pressurized Argon Treatment. *Food Bioprocess Technol.* **2014**, *7*, 693–701. [CrossRef]
78. Tabilo-Munizaga, G.; Barbosa-Cánovas, G.V. Rheology for the food industry. *J. Food Eng.* **2005**, *67*, 147–156. [CrossRef]
79. Ohwovoriole, E.N.; Oboli, S.; Mgbeke, A.C. Studies and preliminary design for a cassava tuber peeling machine. *Trans. ASAE* **1988**, *31*, 380–0385. [CrossRef]
80. Araque, L.C.O.; Ortiz, C.M.; Darré, M.; Rodoni, L.M.; Civello, P.M.; Vicente, A.R. Role of UV-C irradiation scheme on cell wall disassembly and surface mechanical properties in strawberry fruit. *Postharvest Biol. Technol.* **2019**, *150*, 122–128. [CrossRef]
81. Jaramillo Sánchez, G.; Contigiani, E.V.; Coronel, M.B.; Alzamora, S.M.; García-Loredo, A.; Nieto, A.B. Study of UV-C treatments on postharvest life of blueberries 'O'Neal' and correlation between structure and quality parameters. *Heliyon* **2021**, *7*, e07190. [CrossRef]
82. Mohammed, H.E.S.H.; Suliman, A.E.R.E.; Ahmed, A.E.R.; Ebrahim, M.A. Ultraviolet effect on faba bean seed quality during storage. *Asian J. Plant Sci.* **2020**, *19*, 26–34. [CrossRef]
83. Chudhangkura, A.; Teangpook, C.; Sikkhamondhol, C.; Jariyavattanavijit, C. Effects of ultraviolet C, controlled atmosphere, and ultrasound pretreatment on free ferulic acid in canned sweet corn kernels. *J. Food Sci. Technol.* **2018**, *55*, 4167–4173. [CrossRef] [PubMed]
84. Kasim, M.U.; Kasim, R.; Erkal, S. UV-C treatments on fresh-cut green onions enhanced antioxidant activity, maintained green color and controlled 'telescoping'. *J. Food Agric. Environ.* **2008**, *6*, 63–67.
85. Ait Barka, E.; Kalantari, S.; Makhlouf, J.; Arul, J. Impact of UV-C irradiation on the cell wall-degrading enzymes during ripening of tomato (*Lycopersicon esculentum* L.) fruit. *J. Agric. Food Chem.* **2000**, *48*, 667–671. [CrossRef]
86. Zambrano-Zaragoza, M.L.; Quintanar-Guerrero, D.; González-Reza, R.M.; Cornejo-Villegas, M.A.; Leyva-Gómez, G.; Urbán-Morlán, Z. Effects of uv-c and edible nano-coating as a combined strategy to preserve fresh-cut cucumber. *Polymer* **2021**, *13*, 3705. [CrossRef] [PubMed]
87. Park, M.H.; Kim, J.G. Low-dose UV-C irradiation reduces the microbial population and preserves antioxidant levels in peeled garlic (*Allium sativum* L.) during storage. *Postharvest Biol. Technol.* **2015**, *100*, 109–112. [CrossRef]
88. Castronuovo, D.; Sofo, A.; Lovelli, S.; Candido, V.; Scopa, A. Effects of UV-C radiation on common dandelion and purple coneflower: First results. *Int. J. Plant Biol.* **2017**, *8*, 61–64. [CrossRef]
89. Forges, M.; Bardin, M.; Urban, L.; Aarrouf, J.; Charles, F. Impact of UV-C radiation applied during plant growth on pre-and postharvest disease sensitivity and fruit quality of strawberry. *Plant Dis.* **2020**, *104*, 3239–3247. [CrossRef]
90. Pristijono, P.; Golding, J.B.; Bowyer, M.C. Postharvest UV-C treatment, followed by storage in a continuous low-level ethylene atmosphere, maintains the quality of 'Kensington pride' mango fruit stored at 20 °C. *Horticulturae* **2019**, *5*, 1. [CrossRef]
91. Pristijono, P.; Bowyer, M.C.; Papoutsis, K.; Scarlett, C.J.; Vuong, Q.V.; Stathopoulos, C.E.; Golding, J.B. Improving the storage quality of Tahitian limes (Citrus latifolia) by pre-storage UV-C irradiation. *J. Food Sci. Technol.* **2019**, *56*, 1438–1444. [CrossRef]
92. González-Aguilar, G.A.; Wang, C.Y.; Buta, J.G.; Krizek, D.T. Use of UV-C irradiation to prevent decay and maintain postharvest quality of ripe 'Tommy Atkins' mangoes. *Int. J. Food Sci. Technol.* **2008**, *36*, 767–773. [CrossRef]
93. Lin, Q.; Xie, Y.; Liu, W.; Zhang, J.; Cheng, S.; Xie, X.; Guan, W.; Wang, Z. UV-C treatment on physiological response of potato (*Solanum tuberosum* L.) during low temperature storage. *J. Food Sci. Technol.* **2017**, *54*, 55–61. [CrossRef] [PubMed]
94. Jakubowski, T.; Królczyk, J.B. Method for the reduction of natural losses of potato tubers during their long-term storage. *Sustainability* **2020**, *12*, 1048. [CrossRef]

95. Jakubowski, T. Use of UV-C radiation for reducing storage losses of potato tubers. *Bangladesh J. Bot.* **2018**, *47*, 533–537. [CrossRef]
96. Rocha, A.B.O.; Honório, S.L.; Messias, C.L.; Otón, M.; Gómez, P.A. Effect of UV-C radiation and fluorescent light to control postharvest soft rot in potato seed tubers. *Sci. Hortic.* **2015**, *181*, 174–181. [CrossRef]
97. Cools, K.; del Carmen Alamar, M.; Terry, L.A. Controlling sprouting in potato tubers using ultraviolet-C irradiance. *Postharvest Biol. Technol.* **2014**, *98*, 106–114. [CrossRef]
98. Xie, Y.; Lin, Q.; Guan, W.; Cheng, S.; Wang, Z.; Sun, C. Comparison of Sodium Acid Sulfate and UV-C Treatment on Browning and Storage Quality of Fresh-Cut Potatoes. *J. Food Qual.* **2017**, *2017*, 5980964. [CrossRef]
99. Pristijono, P.; Bowyer, M.C.; Scarlett, C.J.; Vuong, Q.V.; Stathopoulos, C.E.; Golding, J.B. Effect of UV-C irradiation on sprouting of potatoes in storage. In Proceedings of the VIII International Postharvest Symposium: Enhancing Supply Chain and Consumer Benefits-Ethical and Technological Issues 1194, Cartagena, Spain, 21–24 June 2016; pp. 475–478. [CrossRef]
100. Jakubowski, T. Impact of UV-C Irradiation of Potato Seed Tubers on the Defects in Potato Plant Crops. *Agric. Eng.* **2019**, *23*, 71–77. [CrossRef]
101. Stevens, C.; Khan, V.A.; Lu, J.Y.; Wilson, C.L.; Chalutz, E.; Droby, S.; Kabwe, M.K.; Haung, Z.; Adeyeye, O.; Pusey, L.P.; et al. Induced resistance of sweetpotato to Fusarium root rot by UV-C hormesis. *Crop Prot.* **1999**, *18*, 463–470. [CrossRef]
102. Stevens, C.; Khan, V.A.; Lu, J.Y.; Wilson, C.L.; Pusey, P.L.; Igwegbe, E.C.; Kabwe, K.; Mafolo, Y.; Liu, J.; Chalutz, E.; et al. Integration of ultraviolet (UV-C) light with yeast treatment for control of postharvest storage rots of fruits and vegetables. *Biol. Control* **1997**, *10*, 98–103. [CrossRef]
103. Mercier, J. Role of phytoalexins and other antimicrobial compounds from fruits and vegetables in postharvest disease resistance. In *Proceedings-Phytochemical Society of Europe*; Oxford University Press Inc.: Oxford, UK, 1996; Volume 41, pp. 221–242.
104. Gonzalez-Aguilar, G.A.; Villa-Rodriguez, J.A.; Ayala-Zavala, J.F.; Yahia, E.M. Improvement of the antioxidant status of tropical fruits as a secondary response to some postharvest treatments. *Trends Food Sci. Technol.* **2010**, *219100*, 475–482. [CrossRef]
105. Shama, G. Process challenges in applying low doses of ultraviolet light to fresh produce for eliciting beneficial hormetic responses. *Postharvest Biol. Technol.* **2007**, *44*, 1–8. [CrossRef]
106. Pan, J.; Vicente, A.R.; Martínez, G.A.; Chaves, A.R.; Civello, P.M. Combined use of UV-C irradiation and heat treatment to improve postharvest life of strawberry fruit. *J. Sci. Food Agric.* **2004**, *84*, 1831–1838. [CrossRef]
107. Ortiz Araque, L.C.; Rodoni, L.M.; Darré, M.; Ortiz, C.M.; Civello, P.M.; Vicente, A.R. Cyclic low dose UV-C treatments retain strawberry fruit quality more effectively than conventional pre-storage single high fluence applications. *LWT-Food Sci. Technol.* **2018**, *92*, 304–311. [CrossRef]
108. Hassan, H.; Abd El-Rahman, A.; Liela, A. Sprouting suppression and quality attributes of potato tubers as affected by post-harvest UV-C treatment under cold storage. *Int. J. Adv. Res* **2016**, *4*, 241–253. [CrossRef]
109. Shama, G.; Alderson, P. UV hormesis in fruits: A concept ripe for commercialization. *Trends Food Sci. Technol.* **2005**, *16*, 128–136. [CrossRef]
110. Terry, L.A.; Joyce, D.C. Elicitors of induced disease resistance in postharvest horticultural crops: A brief review. *Postharvest Biol. Technol.* **2004**, *32*, 1–13. [CrossRef]
111. Xu, Y.; Charles, M.T.; Luo, Z.; Mimee, B.; Tong, Z.; Véronneau, P.Y.; Rolland, D.; Roussel, D. Preharvest ultraviolet C treatment affected senescence of stored strawberry fruit with a potential role of microRNAs in the activation of the antioxidant system. *J. Agric. Food Chem.* **2018**, *66*, 12188–12197. [CrossRef]
112. Zhang, W.; Jiang, W. UV treatment improved the quality of postharvest fruits and vegetables by inducing resistance. *Trends Food Sci. Technol.* **2019**, *92*, 71–80. [CrossRef]
113. Xu, Y.; Charles, M.T.; Luo, Z.; Mimee, B.; Tong, Z.; Roussel, D.; Rolland, D.; Véronneau, P.Y. Preharvest UV-C treatment affected postharvest senescence and phytochemicals alternation of strawberry fruit with the possible involvement of abscisic acid regulation. *Food Chem.* **2019**, *299*, 125138. [CrossRef]
114. Vàsquez, H.; Ouhibi, C.; Lizzi, Y.; Azzouz, N.; Forges, M.; Bardin, M.; Nicot, P.; Urban, L.; Aarrouf, J. Pre-harvest hormetic doses of UV-C radiation can decrease susceptibility of lettuce leaves (*Lactuca sativa* L.) to *Botrytis cinerea* L. *Sci. Hortic.* **2017**, *222*, 32–39. [CrossRef]
115. Ouhibi, C.; Attia, H.; Nicot, P.; Lecompte, F.; Vidal, V.; Lachaâl, M.; Urban, L.; Aarrouf, J. Effects of nitrogen supply and of UV-C irradiation on the susceptibility of *Lactuca sativa* L. to *Botrytis cinerea* and *Sclerotinia minor*. *Plant Soil* **2015**, *393*, 35–46. [CrossRef]
116. Yang, Z.; Cao, S.; Su, X.; Jiang, Y. Respiratory activity and mitochondrial membrane associated with fruit senescence in postharvest peaches in response to UV-C treatment. *Food Chem.* **2014**, *161*, 16–21. [CrossRef]
117. Pombo, M.A.; Rosli, H.G.; Martínez, G.A.; Civello, P.M. UV-C treatment affects the expression and activity of defense genes in strawberry fruit (*Fragaria* × *ananassa*, Duch.). *Postharvest Biol. Technol.* **2011**, *59*, 94–102. [CrossRef]
118. Ouhibi, C.; Attia, H.; Rebah, F.; Msilini, N.; Chebbi, M.; Aarrouf, J.; Urban, L.; Lachaal, M. Salt stress mitigation by seed priming with UV-C in lettuce plants: Growth, antioxidant activity and phenolic compounds. *Plant Physiol. Biochem.* **2014**, *83*, 126–133. [CrossRef]
119. Charles, M.T.; Tano, K.; Asselin, A.; Arul, J. Physiological basis of UV-C induced resistance to *Botrytis cinerea* in tomato fruit. V. Constitutive defence enzymes and inducible pathogenesis-related proteins. *Postharvest Biol. Technol.* **2009**, *51*, 414–424. [CrossRef]
120. Urban, L.; Charles, F.; de Miranda, M.R.A.; Aarrouf, J. Understanding the physiological effects of UV-C light and exploiting its agronomic potential before and after harvest. *Plant Physiol. Biochem.* **2016**, *105*, 1–11. [CrossRef]

121. Urban, L.; Chabane Sari, D.; Orsal, B.; Lopes, M.; Miranda, R.; Aarrouf, J. UV-C light and pulsed light as alternatives to chemical and biological elicitors for stimulating plant natural defenses against fungal diseases. *Sci. Hortic.* **2018**, *235*, 452–459. [CrossRef]
122. Liu, C.; Cai, L.; Han, X.; Ying Tiejin, T. Temporary effect of postharvest UV-C irradiation on gene expression profile in tomato fruit. *Gene* **2011**, *486*, 56–64. [CrossRef]
123. Duarte-Sierra, A.; Nadeau, F.; Angers, P.; Michaud, D.; Arul, J. UV-C hormesis in broccoli florets: Preservation, phyto-compounds and gene expression. *Postharvest Biol. Technol.* **2019**, *157*, 110965. [CrossRef]
124. Li, D.; Luo, Z.; Mou, W.; Wang, Y.; Ying, T.; Mao, L. ABA and UV-C effects on quality, antioxidant capacity and anthocyanin contents of strawberry fruit (*Fragaria ananassa* Duch.). *Postharvest Biol. Technol.* **2014**, *90*, 56–62. [CrossRef]
125. Lamikanra, O.; Kueneman, D.; Ukuku, D.; Bett-Garber, K.L. Effect of Processing Under Ultraviolet Light on the Shelf Life of Fresh-Cut Cantaloupe Melon. *J. Food Sci.* **2005**, *70*, C534–C539. [CrossRef]
126. Prasanna, V.; Prabha, T.N.; Tharanathan, R.N. Fruit ripening phenomena—An overview. *Crit. Rev. Food Sci. Nutr.* **2007**, *47*, 1–19. [CrossRef]
127. Artés-Hernández, F.; Escalona, V.H.; Robles, P.A.; Martínez-Hernández, G.B.; Artés, F. Effect of UV-C radiation on quality of minimally processed spinach leaves. *J. Sci. Food Agric.* **2009**, *89*, 414–421. [CrossRef]
128. Vicente, A.R.; Pineda, C.; Lemoine, L.; Civello, P.M.; Martinez, G.A.; Chaves, A.R. UV-C treatments reduce decay, retain quality and alleviate chilling injury in pepper. *Postharvest Biol. Technol.* **2005**, *35*, 69–78. [CrossRef]
129. Phonyiam, O.; Ohara, H.; Kondo, S.; Naradisorn, M.; Setha, S. Postharvest UV-C Irradiation Influenced Cellular Structure, Jasmonic Acid Accumulation, and Resistance against Green Mold Decay in Satsuma Mandarin Fruit (*Citrus unshiu*). *Front. Sustain. Food Syst.* **2021**, *5*, 336. [CrossRef]
130. Sripong, K.; Jitareerat, P.; Uthairatanakij, A. UV irradiation induces resistance against fruit rot disease and improves the quality of harvested mangosteen. *Postharvest Biol. Technol.* **2019**, *149*, 187–194. [CrossRef]
131. Imaizumi, T.; Yamauchi, M.; Sekiya, M.; Shimonishi, Y.; Tanaka, F. Responses of phytonutrients and tissue condition in persimmon and cucumber to postharvest UV-C irradiation. *Postharvest Biol. Technol.* **2018**, *145*, 33–40. [CrossRef]
132. Wang, D.; Chen, L.; Ma, Y.; Zhang, M.; Zhao, Y.; Zhao, X. Effect of UV-C treatment on the quality of fresh-cut lotus (*Nelumbo nucifera* Gaertn.) root. *Food Chem.* **2019**, *278*, 659–664. [CrossRef]
133. Liu, C.; Zheng, H.; Sheng, K.; Liu, W.; Zheng, L. Effects of postharvest UV-C irradiation on phenolic acids, flavonoids, and key phenylpropanoid pathway genes in tomato fruit. *Sci. Hortic.* **2018**, *241*, 107–114. [CrossRef]
134. Li, M.; Li, X.; Han, C.; Ji, N.; Jin, P.; Zheng, Y. UV-C treatment maintains quality and enhances antioxidant capacity of fresh-cut strawberries. *Postharvest Biol. Technol.* **2019**, *156*, 110945. [CrossRef]
135. Prajapati, U.; Asrey, R.; Varghese, E.; Singh, A.K.; Pal Singh, M. Effects of postharvest ultraviolet-C treatment on shelf-life and quality of bitter gourd fruit during storage. *Food Packag. Shelf Life* **2021**, *28*, 100665. [CrossRef]
136. Charles, M.T.; Benhamou, N.; Arul, J. Physiological basis of UV-C induced resistance to *Botrytis cinerea* in tomato fruit: III. Ultrastructural modifications and their impact on fungal colonization. *Postharvest Biol. Technol.* **2008**, *47*, 27–40. [CrossRef]
137. Quintero-Cerón, J.P.; Bohorquez-Pérez, Y.; Valenzuela-Rea, C.; Solanilla-Duque, J.F. Advancements in the application of short-wave ultraviolet light (UVC) in whole and fresh-cut fruit and vegetables: A review. *Rev. Tumbaga* **2013**, *8*, 29–60.
138. Rivera-Pastrana, D.M.; Gardea Béjar, A.A.; Martínez-Téllez, M.A.; Rivera-Domínguez, M.; González-Aguilar, G.A. Postharvest biochemical effects of UV-C irradiation on fruit and vegetables. *Artículo Revisión Rev. Fitotec. Mex* **2007**, *30*, 361–372.
139. Nigro, F.; Ippolito, A.; Lima, G. Use of UV-C light to reduce Botrytis storage rot of table grapes. *Postharvest Biol. Technol.* **1998**, *13*, 171–181. [CrossRef]
140. Wang, C.Y.; Chen, C.T.; Wang, S.Y. Changes of flavonoid content and antioxidant capacity in blueberries after illumination with UV-C. *Food Chem.* **2009**, *117*, 426–431. [CrossRef]
141. Sun, T.; Ouyang, H.; Sun, P.; Zhang, W.; Wang, Y.; Cheng, S.; Chen, G. Postharvest UV-C irradiation inhibits blackhead disease by inducing disease resistance and reducing mycotoxin production in 'Korla'fragrant pear (*Pyrus sinkiangensis*). *Int. J. Food Microbiol.* **2022**, *362*, 109485. [CrossRef]
142. Shen, Y.; Sun, S.; Qiao, L.; Chen, J.; Liu, D.; Ye, X. Effect of UV-C treatments on phenolic compounds and antioxidant capacity of minimally processed Satsuma mandarin during refrigerated storage. *Postharvest Biol. Technol.* **2013**, *76*, 50–57. [CrossRef]
143. Gutiérrez, D.R.; Rodríguez, S.D.C. Combined Effect of UV-C and Ozone on Bioactive Compounds and Microbiological Quality of Fresh-Cut Rocket Leaves. *Am. J. Food Sci. Technol.* **2019**, *7*, 71–78. [CrossRef]
144. Wu, J.; Liu, W.; Yuan, L.; Guan, W.Q.; Brennan, C.S.; Zhang, Y.Y.; Zhang, J.; Wang, Z.D. The influence of postharvest UV-C treatment on anthocyanin biosynthesis in fresh-cut red cabbage. *Sci. Rep.* **2017**, *7*, 5232. [CrossRef]
145. González-Aguilar, G.A.; Zavaleta-Gatica, R.; Tiznado-Hernández, M.E. Improving postharvest quality of mango 'Haden' by UV-C treatment. *Postharvest Biol. Technol.* **2007**, *45*, 108–116. [CrossRef]
146. Watada, A.E.; Ko, N.P.; Minott, D.A. Factors affecting quality of fresh-cut horticultural products. *Postharvest Biol. Technol.* **1996**, *9*, 115–125. [CrossRef]
147. Brecht, J.K. Physiology of lightly processed fruits and vegetables. *HortScience* **1995**, *30*, 18–22. [CrossRef]
148. Abe, F.; Saito, K.; Miura, K.; Toriyama, K. A single nucleotide polymorphism in the alternative oxidase gene among rice varieties differing in low temperature tolerance. *FEBS Lett.* **2002**, *527*, 181–185. [CrossRef]
149. Ribeiro, C.; Canada, J.; Alvarenga, B. Prospects of UV radiation for application in postharvest technology. *Emir. J. Food Agric.* **2012**, *24*, 586–597. [CrossRef]

150. Reed, D.W.; Tukey, H.B.J. Light intensity and temperature effects on epicuticular wax morphology and internal cuticle ultrastructure of carnation and Brussels sprouts leaf cuticles. *J. Am. Soc. Hortic. Sci.* **1982**, *107*, 417–420.
151. Delorme, M.M.; Guimarães, J.T.; Coutinho, N.M.; Balthazar, C.F.; Rocha, R.S.; Silva, R.; Margalho, L.P.; Pimentel, T.C.; Silva, M.C.; Freitas, M.Q.; et al. Ultraviolet radiation: An interesting technology to preserve quality and safety of milk and dairy foods. *Trends Food Sci. Technol.* **2020**, *102*, 146–154. [CrossRef]
152. Abdipour, M.; Sadat Malekhossini, P.; Hosseinifarahi, M.; Radi, M. Integration of UV irradiation and chitosan coating: A powerful treatment for maintaining the postharvest quality of sweet cherry fruit. *Sci. Hortic.* **2020**, *264*, 109197. [CrossRef]
153. Park, S.H.; Kang, J.W.; Kang, D.H. Inactivation of foodborne pathogens on fresh produce by combined treatment with UV-C radiation and chlorine dioxide gas, and mechanisms of synergistic inactivation. *Food Control* **2018**, *92*, 331–340. [CrossRef]
154. Choi, D.S.; Park, S.H.; Choi, S.R.; Kim, J.S.; Chun, H.H. The combined effects of ultraviolet-C irradiation and modified atmosphere packaging for inactivating Salmonella enterica serovar Typhimurium and extending the shelf life of cherry tomatoes during cold storage. *Food Packag. Shelf Life* **2015**, *3*, 19–30. [CrossRef]
155. Jemni, M.; Gómez, P.A.; Souza, M.; Chaira, N.; Ferchichi, A.; Otón, M.; Artés, F. Combined effect of UV-C, ozone and electrolyzed water for keeping overall quality of date palm. *LWT-Food Sci. Technol.* **2014**, *59*, 649–655. [CrossRef]