Current Challenges of Physical Treatments to Control Quality and Postharvest Diseases of Fresh Fruits and Vegetables

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Abstract. Physical treatments have gained interest in recent years to improve quality and safety of fresh fruits and vegetables, due to the emergence of non-chemical techniques. Indeed, the use of fungicides is becoming restricted because of the concerns of the consumers for human health and for the release of fungicides in the environment. Physical treatment appears to promote sustainable technology. This review attempts to highlight the use of the light treatments in postharvest, with visible and UV-C. These treatments already showed interesting perspectives of applications due to, their direct impact onto pathogens, and the induction of resistance onto the host. The mode of action is not well known, but some new tools such as ohmic methods will help to highlight physiological and biochemical pathways on which the phenomena are based. Despite a wide range of positive impact of light treatments in several research works, their commercial use remains limited in relation to their potential market.

1. Introduction

Fruits and vegetables remain alive after harvest and are susceptible to many postharvest defects inducing losses. These losses are caused by sensorial and nutritional quality defects and by many postharvest diseases related to fungal pathogens. Postharvest losses are significant and might represent up to 40% for some harvested commodities. One of the leading strategies consists in developing processing techniques for reducing losses, while insuring food safety, in the context of constantly growing population [1]. Different postharvest strategies are commercially used to reduce the respiratory rate, the ripening, the senescence, and the decay while preserving quality. A current strategy consists in using synthetic fungicides which are relatively inexpensive, easy to apply and inducing curative and preventive action. However, the use of chemicals is becoming more and more restricted because of their toxicity for human health, and the global concern for the release of fungicides in the environment. Thus, the development of alternative non-chemical techniques are gaining interest in many research programs worldwide.

Physical treatments are emerging to increase shelf-life of fresh fruits and vegetables. The most well-known physical treatment is the modification of the atmosphere. In controlled atmosphere (CA) and modified atmosphere (MA), the O₂ level is decreased and the CO₂ level is increased to reduce the vegetable metabolism. CA and MA can also reduce physiological disorders such as the superficial scald in apples and postharvest decay. However, CA and MA are not always sufficient to reduce browning or others postharvest changes. Heat treatments are also largely used. Traditionally, it could be applied in the form of hot water dip, vapor, or hot air. More recently, the interest in radio frequency or microwave energy treatments to heat fruits have raised. The mode of action of all heat treatments involve effects on both plant pathogen and host. Heat treatment usually causes a direct inhibition of spore germination and
of fungi mycelial growth. Heat treatment also induces different defense lines in host such as the
reinforcement of plant cell walls and the occlusion of stomata, micro-cracks which are the main entry
points for wound pathogens, accumulation of stress and defense proteins (heat shock proteins,
pathogenesis-related proteins), and antioxidant enzymes. Others promising technologies consist in using
light treatment such as ultraviolet-C and visible light.

The objective of this paper is to review the current state of knowledge on the effects and the use
of UV-C and visible light. This paper will also present some previous investigations on this topic and
the main issues to be addressed in the coming years to favor the use of these technologies.

2. UV-C treatments

2.1. Definition

The UV portion of the electromagnetic spectrum include long-wave UV-A radiation (320 – 400 nm),
medium-wave UV-B radiation (280- 320 nm), and short-wave UV-C radiation (200 – 280 nm).
Following the Plank relation, the shorter the wavelength is, the higher is the photonic energy provided.
Thus, UV-C is usually more effective for destroying microorganisms at a lower doses than that of UV-
B and UV-A. In the mid 1980’s, the development of an innovative UV-C light application technology
for controlling postharvest decay has emerged[2] A low UV-C light dose (7.3 kJ.m⁻²) has been effective
to control black mold (Aspergillus niger), blue mold (Penicillum expansium) and bacteria soft rot
(Erwinia spp.) in onions. Collaborative research on the technique increased and the first international
conference entitled “The use of UV-C as a Postharvest Treatment : Status and Prospectives” was
organised by a European COST working group (Action 924) in Antalya (Turkey) on November 9th to
11th, 2005 for its promotion.

2.2 Mode of action

The mode of action of UV-C treatment involves effects on both plant pathogen and host. Absorption of
UV-C radiation by conjugated carbon to carbon double bonds in proteins and nucleic acids may result
in DNA structural changes which are incriminated in the well-documented antimicrobial effects of UV
light onto microorganisms. In the last decades, UV-C have been used as a germicidal treatment to delay
fungal growth, bacterial and virus development (Table1). UV-C was effective in reducing the rate of
fruit infection and the size of lesions by B. cinerea in grapes and bell pepper [3,4]. UV-C can reduce the
incidence of various fungi such as Rhizopus and, Monilia, but also decreases their total viable counts
[5–7]. Moreover, UC is effective in reducing Listeria monocytogenes or Salmonella enterica bacteria
which are the main pathogens found in fruits and vegetables [8].

| Species and cultivar   | Tested UV-C dose and optimum (kJ.m⁻²) | Targeted pathogrn          | Authors                  |
|-----------------------|---------------------------------------|-----------------------------|--------------------------|
| Tomatoes              | 3.6                                   | Rhizopus                    | Steven et al. 2004       |
| Tables grapes         | 0.125 to 4 (0.1)                      | Botrytis cinerea            | Nigro et al. 1998        |
| Mangoes               | 5 to 10                               | Natural decay               | Gonzalez et al. 2001     |
| Strawberry            | 0.25 to 4 (0.5 and 1)                 | B. cinerea and natural decay| Nigro et al. 2000        |
| Peaches               | 7.5                                   | Monilia                     | Stevens et al. 1998      |
| Fresh-cut apples      | 1 to 24 (1 and 2)                     | Total viable counts         | Manzoceco et al. 20011   |
| Lettuces              | 1.18;2.37 and 7.11                    | Natural microflora          | Allende et al. 2006      |
| Baby spinach          | 2.4 – 24                              | Listeria monocytogenes and Salmonella enterica | Escalona et al.2010 |
| Bell pepper           | 2.2 to 4.4                            | Botrytis cinerea            | Mercier et al. 2001      |
| Lettuce               | 0.85                                  | Botrytis cinerea and Sclerotinia | Ouhibi et al. 2014      |
In addition to the direct activity against pathogens, UV-C can also interact with plants cells. Some responses have been observed on mitochondria, chloroplasts, and membranes. Damaging effects of UV-C on plants components emphasize the main importance of the step involving dose selection and application [9].

UV-C can also modulate defense in plants [10,11]. Induced resistance by the application of low or sub-lethal doses of UV-C could be the result of the phenomenon termed “hormesis”. Hormesis is defined as the stimulation of a beneficial effect by low doses of a potentially harmful agent [12]. UV-C may stimulate the secondary metabolism which is known to play a beneficial role on health and plant defense (Table 2). UV-C stimulates all phyto-alexins, phenolic compounds [13–15], and antioxidant capacity [16,17]. UV-C could modulate at proteomic level. First data seemed to suggest that the proteins affected by UV-C, could regulate biological processes which contribute to changes in fruits and crops, leading to postharvest deterioration of commodities [18]. Finally, UV-C stimulates the expression and enzymatic activity of a set of genes that are related to plant defense against pathogens such as glucanase, chitinase, and PAL[19–21].

### Table 2. Some hormetic responses of UV-C.

| Species and cultivar | Optimum UV-C dose (kJ.m⁻²) | Included defense | Authors |
|----------------------|-----------------------------|------------------|---------|
| Tomatoes             | 3,7                         | Accumulation of the phytolalexin-rishitin | Charles et al, 2008 |
| Tomatoes             | 3,7                         | Increase the expression of pathogenesis-related proteins (PR-proteins) (glucanase, chitinase) | Charles et al, 2009 |
| Grafes               | 6                           | Increase in Resveratrol | Freitas et al., 2015 |
| Grafes               | -                           | Increase in Stillbene | Guerrero et al., 2010 |
| Mangos               | 0 - 4,9                     | Improve the total antioxidant capacity (ORAC,DPPH) | Gonzalez et al., 2007 |
| Mangos               | 6                           | Increase PAL, chitinase, Glucanase, POD et phenols | Spekong et al., 2012 |
| Mangos               | 0,001; 0,003 and 0,007      | Proteome changes | George et al., 2015 |
| Strawberry           | 4,1                         | Increase defense responses (genes, enzymes) and delays fruit softening | Pombo et al., 2011, 2009 |
| Strawberry           | 0,43; 2,15 and 4,30         | Increase phenols, antioxidant capacity and enzymes | Erkan et al., 2008 |
| Blueberry            | 1 to 4                      | Increase in anthocyanin, total phenolics, antioxidant capacity | Perkins-Veazie et al., 2008 |

Additional research is needed to better understand the UV-C mechanisms and favor their application at commercial scale. The systemic effect need to be clarified. It seems also important to elucidate whether UV-C can induce any response on a non-visible part of a commodity. We have to demonstrate whether a treated resource could be adversely affected. We also have to investigate the impact UV-C treatment may have from an agronomical point of view. The application of pre-harvest UV-C treatment is almost unexploited to control postharvest diseases, and effective relationships between pre and post-harvest.

### 3. Visible light treatments

Visible light exposure represents a novel approach, environmental-friendly, that can be used to preserve the overall quality of fresh-commodities. It is well known that in plants, darkness induces the expression of genes implicated in chlorophyll, proteins, chloroplast degradation, and an increase of the reactive species to oxygen [22]. However, in many cases, light is not controlled during post-harvest storage and products are commercially stored under darkness, which induces accelerated senescence. Light exposure can delay tissue browning of fresh-cut romaine lettuces [23], fresh-cut celery [24] and the yellowing of
broccoli [25]. Light has also a positive effect on nutritional quality. Continuous light (around 35 $\mu$mol.m$^{-2}$.s$^{-1}$) seems to maintain soluble sugars and ascorbic acid in freshly-cut romaine lettuce [26]. Leaves of spinach being stored under visible light are exhibiting higher rates of ascorbic and folic acids among the endogenous pool of vitamins, than those stored under dark conditions [27]. Some recent investigations showed that the daily light or brief pulses exposure, could delay postharvest decay. Light pulses of 30 $\mu$mol.m$^{-2}$.s$^{-1}$ can be used to extend postharvest life of spinach leaves [28]. Exposure to 2 h of light with 30–37 $\mu$mol.m$^{-2}$.s$^{-1}$ seems sufficient to delay postharvest senescence of basil leaves, and suppress chlorophyll and protein losses [29]. In Lamb’s lettuces, intermittent low intensity light cycles partially increases photosynthesis. The metabolism of the green tissues remains effective to provide carbon moieties for the synthesis of bioactive molecules involved in delaying senescence [30].

Thus, light exposure during post-harvest significantly decreases the cut-edge browning of fresh-cut lettuces, which is one of the main attributes for consumer acceptability [31]. However, the way to apply light can modify the product physiology, attractiveness, and rate of dehydration. This study underlined the potential of using intermittent moderate level of light (50 $\mu$mol.m$^{-2}$.s$^{-1}$) as a short post-harvest treatment to maintain the quality of fresh-cut products. Moreover, a memory effect has been highlighted since the positive effect of light can be maintained, even when commodities are stored later under darkness. Although there is a strong need to make further research on this topic, the present study brings various perspectives of investigation according to the modality of the application of light.

4. Conclusion
Treatments such as UV-C and visible light might positively impact product quality and seem attractive. However, their commercial uses have been rather limited so far, in relation their potential market. The complexity of the mode of action which involves direct effect onto pathogens and indirect effect onto the host, need to be further investigated and clarified. The new ohmic tools could help to highlight underlying physiological and biochemical pathways.

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