Post-Harvest Produce Preservation using Deep UV LED Technology

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ABSTRACT

With the ever-increasing human population within developing countries, limited availability and access to clean water, ever present climate change call for the coming of a second green revolution. An important component of this second green revolution is extending the shelf life of post-harvest fruits and vegetables. Deep Ultraviolet Light Emitting Diodes (DUV LEDs) provide an energy efficient and hazardous material free solution. Through the implementation of Deep UV LED technology, we at Rensselaer Polytechnic Institute (RPI) have extended the shelf life of several fruits and vegetables using DUV LEDs ranged within 250nm-365nm. Results revealed that the increase in post-harvest shelf life of berries and fruits was due to total UV dosage rather than power density distribution. The effects for different berries varied significantly. Dosages greater than 2.6×10^3 J/m^{2}were shown to significantly maintain the visual appearance of the berries and prevent mold growth for a minimum of 7 days.

Keywords: Post harvest, UV LEDS, Preservation,

INTRODUCTION

According to a United States Department of Agriculture (USDA) in 2010, approximately 133 billion pounds of food was wasted with an estimated consumer value loss of 161 billion dollars [1]. In the United States, Canada, Australia, and New Zealand combined, 52% of vegetalbles and fruits, 50% of grain products and seafood, 22% of meat, and 20% of milk are wasted. [2]. In order to reduce food spoilage and loss of valuable resources, novel and sustainable methods of produce preservation must be implemented.

Using UV light to kill pathogenic microorganisms is not itself a novel technology and has been applied to water, air, and surface disinfection. [3-9] It has been well studied that the UV light damages the DNA of microorganism thereby inhibiting replication. Furthermore, such technology has also been applied to the post-harvest treatment of produce in order to increase its shelf life 10]. For produce, it was shown that UV light could induce the plant to resist the infection of microbes by activating various anti-fungal and anti-senescence complexes [11-13]. Furthermore, plants treated under the UV-B spectrum (280nm-315nm) wavelengths resulted in increased flavonoid and antioxidant levels in produce [14-17].

However, most of these disinfections has been performed through the use of low and medium pressure lamps. These lamps are bulky, brittle, require high input voltage, and contain hazardous material. Hence, they are not optimal UV sources for Point Of Use (POU) function.

Through the use of DUV LED technology, a new green revolution can occur in minimizing the food loss of produce due to spoilage. DUV LED technology possesses none of the limitations of conventional UV sources. The diodes are compact, require minimal input power, and have narrow bandwidth for optimization of desired produce preservation. Most importantly, the flexibility of design is important. Due to small dimensions and low power consumption DUV LEDs can be implemented into existing/future produce preservation designs.

With these key points in mind, we at RPI designed experiments in order to test the feasibility of illuminating post-harvest produce with LEDs. Furthermore, we determined minimal dosage at several wavelengths in order to extend the shelf life and visual quality of the aforementioned produce.

METHODS

A UV LED illumination system was created within a mini-refrigerator in order to mimic a real world scenario.

The produce was placed in plastic containers lined inside with aluminum foil. This was done in order to maximize the UV illumination as the aluminum foil reflects the UV light. The various produce was then placed on a thin metal mesh to allow the UV light to illuminate said produce as uniformly as possible and to minimize any shadowing. In order to mitigate the effects of desiccation for this experiment, the produce containers were sealed with a thin plastic film. Measurements of the film transparency showed that the absorption within the tested UV range was negligible. The containers were then placed for testing under the UV LED illumination system.

The experiments were conducted at standard refrigerator temperatures of 4-6 ^oC. Containers were removed from the refrigerator and opened several times a day with the plastic film being removed in order to properly examine the produce. Furthermore, multiple images were taken during these stages in order to monitor the progress of the experiments visually. To insure proper optical output power, the power of each LED used was monitored through the use of a UV enhanced silicon photodiode. The LED testing regime was chosen in order to minimize the power degradation which did not exceed a few percent during the entirety of the experiments on the various LEDs.

RESULTS

Tests were performed under a wide spectrum covering all of the UV spectrum. Table 1 provides a valuable insight into the effects of said spectra on strawberry longevity by preventing the proliferation of mold.

Table 1. UV Post harvest treatment of strawberries.

	Control sample	**Under UV illumination**
λ=254nm, 17mW/m^2 14 days		
λ =276nm, 30mW/m^2, 11 days		
λ =292nm, 50mW/m^2 15 days		
λ =316nm, 30mW/m^2 21 days		

The data from Table 1 reveals that the use of DUV LEDs at various wavelengths increased the shelf life of the strawberries for a minimum of 11 days. In order to better understand if optical output power or total dosage determined whether there was mold proliferation, a UV pulse and constant exposure experiment was performed.

In this experiment, strawberries were illuminated with a constant and pulsed 272nm light of different dose. The average power densities for the constant and pulsed illuminations were identical, approximately 18mW/m^2. Under the pulsed illumination regime, the peak optical output power within the pulse was 100 time higher at approximately 1.8W/m^2. As a result, the illumination dose was the same for both batches.

In this experiment two batches of strawberries were illuminated with constant and pulsed light for one hour and were then placed into the refrigerator. Exposure during one hour at 18mw/m^2 resulted in the total dose of ~65 J/m^2.

Table 2 shows the initial condition of strawberries and after 14 days of storage. It is seen that, illumination in this regime is not enough to prevent mold growth, although the peak power during illumination in the pulse regime was rather high (1.8W/m^2**).** Therefore we concluded and that it is indeed the total dosage that prevents mold proliferation.

Table 2. Constant and Pulse Testing illuminaiton

Day	**Constant illumination**	**Pulse illumination**
Initial condition		
Day 14		

The minimum dose requirements are presented in Table 3. Results revealed that a minimum optical dosage of 2.6x10^3 J/m^2 was required in order to prevent mold proliferation. Therefore, it was shown that it was not the optical output power which was important, but the overall dosage that determined for how long the produce would stay unspoiled by the mold.

Table 3. UV Dosages of Strawberries

Power density	**Duration**	**Dose**	**Storage time extended**
18 mw/m^2	40 hours	2.6×10^3 j/m^2	Yes
50 mw/m^2	7 days	30×10^3 j/m^2	Yes
18 mw/m^2	1 hour	65 j/m^2	No
18 mw/m^2	7days	11×10^3 j/m^2	Yes

Overall, UV illumination decreased mold proliferation in strawberries by a minimum of 50% as shown in Figure 1.

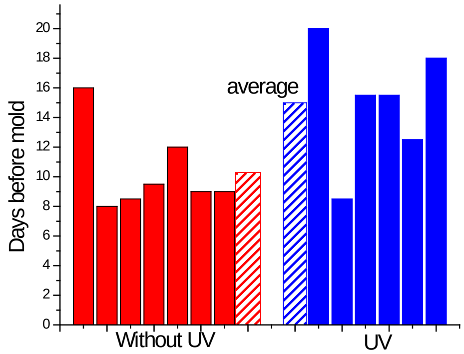

Figure 1. Quantified UV Effects on Strawberry Mold Proliferation

Testing on blueberries and raspberries did not present such a significant effect on mold proliferation as strawberries.

We found that blueberries are in good condition after 3 weeks of storage with 254nm and 292nm UV illumination as well as blueberries kept without illumination. Some minor dry out was observed for all sets of berries. An important conclusion is that UV illumination does not accelerate the decay process. Therefore the design of the refrigerator or storage box with illumination for different produce including blueberries is possible.

Experiments with rasberries showed that indeed UV low power 290nm illumination prevents the mold growth on raspberries. Mold started to grow on unilluminated batch of strawberries on 14th day of storage. Illuminated berries did not develop mold. However another kind of deterioration was found on both batches (see Table 4).

One significant aspect to note regarding the raspberries was that there was some mold growth in the hollow section of the berry. This would present a problem in UV illumination as the light would need to be directed inside the berry. The raspberry illumination results are presented in Figure 4.

An interesting result occurred when bananas were illuminated with 276nm wavelength light. Exposure to said wavelength accelerated the ripening of the banana instead of keeping it fresh longer at an optical output power of $20mW/m^2$. This evidence is shown in Table 5.

Table 4. UV LED illumination of raspberries.

14 days of storage without UV	UV, □=2 density ~ $30mW/m^2$
	
	

Table 5. UV LED illumination of bananas.

Day of the experim ent	Without UV illumination	UV, 276 nm
Initial conditio n		
Day 6		

Currently, testing at RPI is being performed by directly inoculating produce with necrotrophic mold and then illuminating said produce with UV light. This testing is being performed under a New York State Pollution Prevention Institute Student Award. The produce chosen for these experiments were strawberries. Furthermore, the experiments are geared towards real life scenarios requiring UV illumination such as supermarkets.

DISCUSSION

The proof of concept regarding using DUV LEDs for post -- harvest produce preservation is readily apparent. Future research will be geared towards collaboration with various industry partners to implement the technology into various areas such as, but not limited to, post harvest produce transportation, supermarkets, and end user refrigeration systems. By extending the shelf life of various produce we as a society can drastically reduce waste of said produce and our limited natural resources. Fewer produce in landfills will result in less methane. Reduction of fertilizer usage will lower the concentrations of phosphorus and various nitrates from entering our freshwater systems and leading to eutrophication and harmful algal blooms. Produce staying on the shelves longer could reduce their price and lead to significantly greater access to nutritious food to everyone. The ripple effects of implementing this technology are extensive.

DUV LED technology is also environmentally friendly and creates no wasteful by-products that must be then disposed of. Their low input power requirements allow for simple circuitry which could be more easily integrated into existing Original Equipment Manufacturer (OEM) products for consumer use.

The next significant green revolution will be fueled by environmentally friendly and sustainable technology such as DUV LED's. As their efficiency increases and their cost decreases, the acessibility and feasibility of this technology will be tremendous. Our growing population and limited arable land for agriculture will require us as a society to rethink how we handle our food supply. Waste will have to be curtailed in order to feed a growing population not just within the United States, but throughout the result of the developing world. This novel approach will ensure that future generations will thrive knowing that their food supply will be safe and securely ensured.

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