UV-C LEDs for Food Safety

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Abstract

As a response to continued public health concerns about food safety, the disinfection of food, its packaging and food preparation surfaces are just a few examples of the diverse applications being contemplated for the wider installation of germicidal ultraviolet solutions among different points along the safe food delivery chain. UV-C disinfection is a proven technology that can offer an economically-sound, effective and versatile dry-processing technology, which could improve plant and consumer safety, extend shelf life and avoid spoilage and waste. With the continued improvement in UV-C LED performance, significant opportunities exist to design flexible and configurable solutions effectively, innovatively providing new processes, while advancing appropriate validation and verification methods and approaches.

Introduction

According to the Centers for Disease Control (CDC), when two or more people get the same illness from the same contaminated food or beverage source, the event is called a foodborne disease outbreak. In 2013, the CDC reported that 46% of such events were directly attributable to contaminated fresh-cut produce (Painter et al. 2013). What had been touted as the cornerstone of a healthy American diet, three servings of fruits and vegetables daily, was instead, when improperly sanitized, understood to be a potential public health hazard. Although it was acknowledged that healthy foods must be safeguarded, not much has changed since. Recently, Food Safety News (2017) noted that pathogen laden fresh produce still remains among the top public health concerns after yet another leafy green recall. On April 19, 2018, the New York Times (2018) reported contaminated cut romaine lettuce, harvested in Yuma, Arizona, continues to cause serious illness, and one reported death, across many states unabated.

Particularly problematic is the contamination of apples, cucumbers, and the aforementioned leafy greens by pathogenic bacteria, such as *salmonella*, *listeria* and *E. coli* O157:H7. Contamination can be introduced at various points along the food handling spectrum from production, through harvesting and processing, and then transport, storage or during display or preparation, ultimately infecting unprotected consumers (Nüesch-Inderbinen and Stephan 2016). The encouraging news is that because of such concerns, efforts into improving methods to effectively reduce and eliminate disease causing pathogens and food spoilage organisms have increased substantially at intervention points along the supply chain.

Investigations have particularly focused on microbial reductions closer to the production, since when contamination happens early in the production or processing cycle, the ripple effect of outbreaks becomes wider spread.

Unfortunately, arising from increased imports, lax controls as new food delivery mechanisms emerge and the high volume of food processed, contaminated food continues

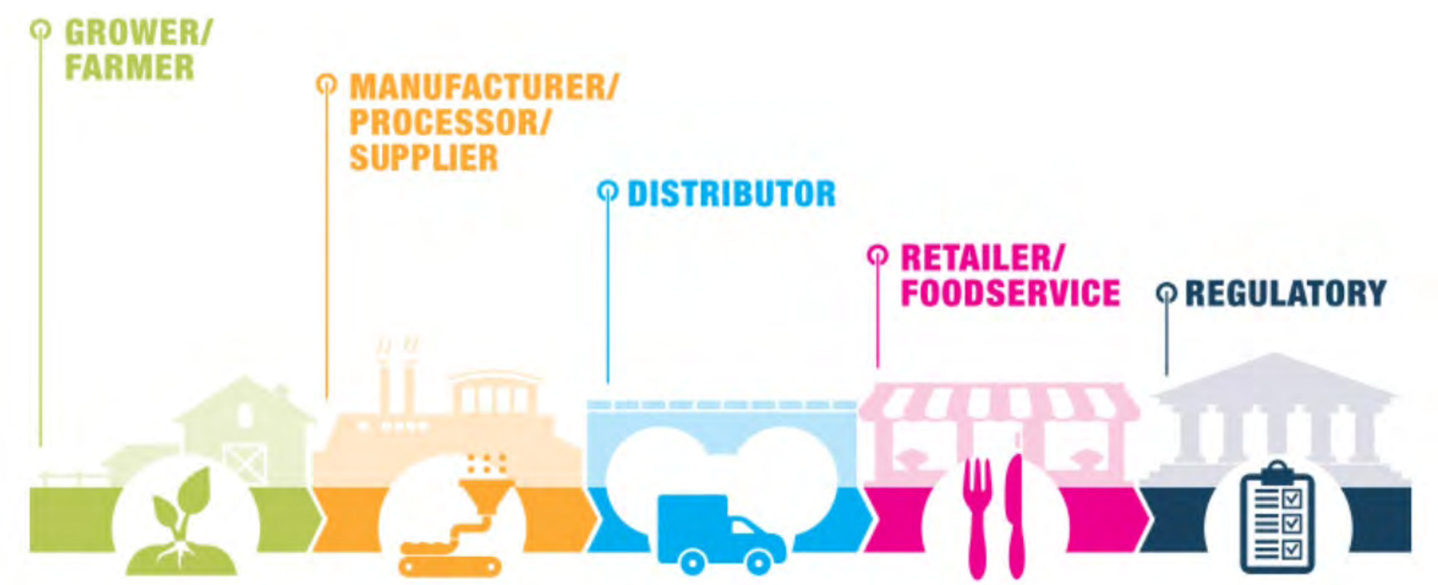

Figure 1. Color-coded intervention points. Image courtesy of the Food Safety Summit 2018.

to be introduced into the supply chain. This is alarmingly problematic because contamination is not detected until closer to consumption, so developing and validating newer disinfection techniques and technologies at later intervention points, as well as increased regulatory vigilance, as shown in Figure 1, has taken on increased significance. As a result, the application of germicidal ultraviolet light (UV-C) has emerged as a key technology to protect consumers from exposure to foodborne pathogens (Ribeiro et al. 2012) at each colored coded intervention interface.

Utilization of germicidal UV-C

The acceptance by the US Food and Drug Administration (FDA) of UV-C as a safe alternative to thermal pasteurization of juice products to further the preservation of different foods and extend their shelf life has also been an innovation driver to position UV-C as an effective disinfectant against spoilage organisms (Koutchma 2014). The key drivers of UV-C treatment have been its relatively low cost compared to other treatments, non-thermal and non-chemical character and dry, residue-free, non-toxic processing nature. However, the UV-C efficacy depends greatly on the species of pathogen, the variety of produce, whether the food is whole, partially intact or fully cut, the initial degree of microbial contamination, the topography of the plant surface and where in production cycle the intervention takes place (Tarak et al. 2016). All these factors pose hard to overcome challenges to the wider deployment of germicidal light.

The conventional way of generating UV-C light is to use high-voltage, arc-discharge mercury or amalgam lamps that can generate photons solely at 253.7 nm. Engineering the efficient delivery of UV-C light and validating its efficacy is practiced worldwide for a variety of applications. They have been historically proven to be effective for municipal drinking water disinfection and, more recently, hospital surface sanitation. They are perceived as a viable solution by their intended user base. Acceptance of UV-C as a germicidal agent has become even more critical as bacteria acquire increasing antibiotic resistance and mounting global pressures on the environment stress safe food and sufficient clean water supplies.

Unfortunately, the use of these UV-C light sources is generally not viewed as food plant or food preparation area friendly. The equipment that houses them is bulky and requires significant setup expenses and ongoing operational safety controls to optimize germicidal light delivery, as well as to provide requisite worker protection. Although they require less electrical power than other non-thermal processing technologies (Koutchma et al. 2016), they are a challenge to clean and maintain. In addition, they do not operate efficiently in cold temperatures and, because of limited lamp lifetime, scheduled lamp replacement is necessary. For the sake of completeness, one also could envision using broad spectrum xenon lamps or cold cathode lamps as an alternative. These lamps may partially overcome cold temperature output degradation, in refrigerated environments, but do not overcome other food safety deployment limitations, such as placing breakable quartz lamps, most of which contain mercury, although encased in Teflon® sheaths to contain the shards and toxicity, in close proximity to leafy greens and edibles. Mercury exposure is recognized as dangerous to human health, and there are treaties limiting its use (Bloomberg News 2017).

> If UV light holds such potential, what other germicidal light sources, especially mercury-free ones, are available to utilize? The answer has been found in exploring the application of germicidal light emitting diodes (LEDs) to food safety.

All these issues beckon the question, if UV light holds such potential, what other germicidal light sources, especially mercury-free ones, are available to utilize? The answer has been found in exploring the application of germicidal light emitting diodes (LEDs) to food safety. If UV-C LEDs' performance has been extensively studied and proven-in for low flow, point of use, drinking water treatment (Pagan and Lawal 2015), their effectiveness continues to be optimized by synergistic blending of wavelengths (Beck et al. 2017), and as their manufacture and application knowledge matures and becomes widespread (Chen et al. 2017, Lawal et al. 2018), why not also apply them to sanitizing and extending shelf life of fresh produce?

A role for UV-C LEDs

UV-C LEDs are small, robust, low-cost, energy-efficient, require no warm-up time, contain no toxic elements and emit light at multiple individual wavelengths within the UV-C range. The devices also operate efficiently at low temperatures, which is a critical component of fruit and vegetable processing. Additionally, UV-C LEDs enable flexible mechanical design over rigid lamps and their required bulky ballasts, overcoming some deployment obstacles by allowing configurable light delivery.

Ongoing research at Agriculture and Agri-Food Canada (AAFC), and other institutions, has indeed shown the

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effectiveness of select wavelengths of UV-C LEDs against the aforementioned list of *salmonella*, *listeria* and *E. coli* O157:H7 (Green et al. 2017).

Perhaps even more enlightening, parallel work has reported that UV-A LEDs at 365 nm and near UV LEDs emitting at wavelengths at 405 nm and blue LEDs emitting at 460 nm have also been shown to reduce infectious pathogens on food (McKenzie et al. 2014, Guffey et al. 2016). Although these wavelengths have a different inactivation mechanism, which produces a weaker antibacterial effect for the same delivered UV dose than those of UV-C LEDs, their attributes may overcome other UV treatment limitations because of improved emitted light interactions with rough irregular surfaces and their established user safety during exposure. There may be lessons gleaned from their deployment in healthcare settings (Maclean et al. 2013) that may be applicable to their use for fruit and vegetable safety. In addition, building on the work in point of use water treatment, synergistic inactivation wavelengths could be identified that could overcome identified challenges and drive optimized germicidal light treatment.

Multi-wavelength approaches – combining UV-C LEDs with 405 nm LEDs

A 1978 microbiology experiment was prescient. Among several findings, Tyrrell and Peak (1978) reported a lethal interaction between various monochromatic wavelengths in the repair-proficient *E. coli* K-12 strain AB 1157, except in the case of pre-exposure to 405-nm, which resulted in a protection against the inactivation resulting from subsequent exposure to 365 nm or 254 nm radiations. Put another way, in the context of applying LED technology to food safety, the germicidal efficacy can be improved by combining different LED wavelengths to produce a synergistic inactivation effect and solutions can be fine-tuned to produce the most effective inactivation wavelengths for a particular food in a specific food handling environment in a way that also protects workers and food handlers. Selectivity and combinatory outputs of LED opens the door to creative end-product designs for deployable along the food supply chain.

To test out this assertion, the first in a planned set of experiments was conducted that utilized the test fixture shown in Figure 2. This fixture contains arrays of 275 nm and 405 nm LEDs and enables micro adjustments of exposure times and intensities of each wavelength. Challenged by *E. coli*, the dual wavelength approach successfully demonstrated the expected synergistic pathogen reduction effects. Hence, utilization of this dual wavelength approaches could address problematic contamination of fruits and vegetables aiming to ameliorate public health concerns. The method is adaptive and scalable and can be fine-tuned to multiple food safety applications as well. Such insights undergird defensible claims found in an associated pending patent (Gordon 2017).

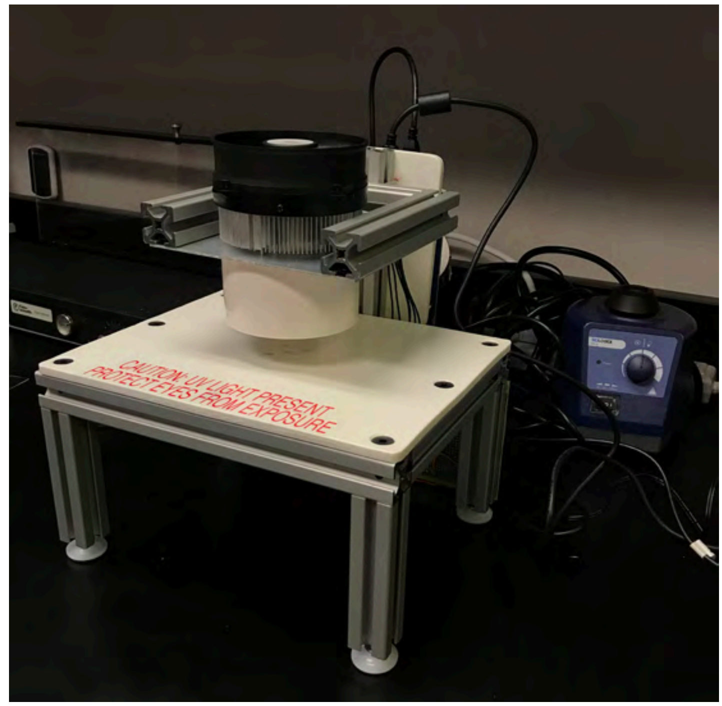

Figure 2. Dual wavelength 275 nm/405 nm LED test fixture

Conclusion

Germicidal light holds great promise for advancing food safety. As more experimentation and validation work is conducted, scalable, tunable, nimble, configurable and tailored multi-wavelength LED-based light fixtures could emerge as environmentally friendly solutions to save energy, save water, reduce costs, lower reliance on toxic chemicals, improve worker and consumer safety and extend fruit and vegetable shelf life. They present a new technological solution with enormous potential for control of dangerous pathogens and forestalling spoilage throughout the supply chain from farm to fork. ■

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