ASTA WHITE PAPER ON ALTERNATIVE MICROBIAL REDUCTION TECHNOLOGIES

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Introduction to Pathogen Controls

A number of pathogens that pose a risk to human health, including *Salmonella*, *Escherichia coli*, *Clostridium perfringens* and *Bacillus cereus* may be found in spices. Although production and processing controls in the form of Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs) may be implemented to reduce filth and possible sources of pathogenic bacteria, microorganisms may still contaminate spices during cultivation, harvest, and storage (ASTA, 2020; ASTA, 2023).

The risk of microbial contamination is also influenced by a number of factors including the nature of each spice, part of the plant, naturally occurring microbial activity, surrounding environment (e.g. soil, wind, water, flora and fauna), and local growing conditions (e.g. temperature, humidity, rain and available sunlight). The control of microorganisms on spices typically requires a multi-step hurdle approach to reduce the risk of human illness. As such, it is critical that spice companies have good agricultural, harvesting, and manufacturing practices as well as validated treatment methods to control microbial contamination. Processing technologies include thermal and non-thermal approaches to reduce microbial populations.

Although infrequent, several outbreaks have been attributed to contaminated spices over the past 30 years (ASTA, 2021). The limited number of outbreaks may in part be due to the low water activity of dried spices, which prevents the growth and viability of most non-spore formers, consequently limiting the chance of illness caused by these organisms. Furthermore, the relatively low number of outbreaks may also be in part attributed to the role of spices as ingredients, and the extensive use of microbial reduction treatment to control pathogen populations in/on spices.

Conventional Treatment Methods

The most common spice processing treatments to reduce microbial populations are 1) steam treatment, 2) gamma radiation, and 3) fumigation with ethylene oxide (EtO) and 4) propylene oxide (PPO). The U.S. Food and Drug Administration (FDA) has published a comprehensive overview of these processes and evaluated their efficacy to inactivate pathogens in its 2017 Risk Profile on Pathogens and Filth in Spices (FDA, 2017).

As outlined in FDA's Draft Risk Profile on Pathogens in spices, some imported spice shipments may have to undergo reconditioning on the basis of microbial hazards to be accepted for entry. Between 2007 and 2012, CFSAN accepted 50 out of 155 reconditioning proposals for spices. All of the accepted proposals leveraged conventional treatment methods. More recently, between 2015 and 2019, half of the reconditioning proposals for imported spices and herbs were for EtO treatment (EPA, 2023). The other half included proposals for steam, irradiation, and propylene oxide. Similarly, between 2019-2022, a total of 34 reconditioning proposals (including resubmissions) leveraged conventional treatment methods (heat/steam, irradiation, EtO) (EPA, 2023). It is FDA's policy that a scientifically valid reduction (default of 5-log)[1] for

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[1] Although FDA does not require any specific performance standards, FDA has implicitly established a 5-log reduction standard in the absence of data which demonstrates that the microbiological load level in a commodity warrants a lower or higher reduction standard. FDA has established 5-log standards as the baseline in other food commodities including fruit and vegetable juices (CFR § 120.24) and nuts (FDA, 2009a, 2009b) with the exception

Salmonella must be achieved, unless sufficient evidence can be provided that an alternative log reduction is justified.

A summary of the conventional process controls, regulatory resources, and ASTA resources are available on the ASTA website.

Steam

Thermal treatments, such as steam sterilization, are widely accepted by consumers since they are considered natural. However, thermal treatments may negatively impact the quality of treated products, such as the organoleptic and color properties.

Steam treatment achieves lethality through the application of pressurized vaporized water. This can be performed in a continuous process, on a conveyor, or in a chamber. For inline processes, the steam temperature is dictated by atmospheric pressure, approximately 100°C. For chamber process the steam is introduced at a specific, sub-atmospheric pressure to control the temperature. The subsequent microbial population reduction arises from the time and temperature of spice exposure to steam treatment, and the increase in water activity due to the condensing steam. However, microorganisms have varying levels of thermal resistance, depending on factors such as environmental influences during cell growth and environmental influences during the heating cycle (FDA, 2017). Environmental influences may include pH, ionic strength, and the presence of antimicrobial compounds in the food matrix being treated. In the presence of oils in products such as peanuts and chocolate is also known to increase lethality.

In its review of the scientific literature, FDA found that the reductions in total aerobic plate count ranged from 1.3 log for a 16-minute continuous process at 100°C at atmospheric pressure to 7.9 log for a pressurized autoclave process in saturated steam at 121°C for 15 minutes (FDA, 2017). Several different continuous and inline steam pasteurization processes have been approved by the California Almond Board TERP Committee for the 4-log and 5-log reduction of *Salmonella*. The temperature of these processes varies between 50°C (chamber) and 100°C (in-line). Steam treatment also yielded higher reductions of spice microflora than dry heat or microwave treatment. However, few studies have been published on the reduction of *Salmonella* in spices by steam treatment (Newkirk et al., 2018).

Irradiation

Non-thermal treatments, such as irradiation, are also conventionally used to decontaminate spices. Irradiation treatment may use Cobalt-60 or Cesium-137 as a source of gamma rays for application to pre-packaged foods to achieve microbial lethality. Recommended minimum doses range from 3 to 9 kilogray (kGy) for caraway, cinnamon, paprika, red pepper, and turmeric, to 7 to 15 kGy for onion powder (ASTM International, 2010).

According to section 201(s) of the FD&C Act, sources of irradiation used on food are contained under the definition of food additives. Per 21 CFR 179.26, spices may be irradiated with a

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of almonds. The Almond Board of California conducted a risk assessment to determine the levels of *Salmonella* and likelihood of salmonellosis from almond consumption to justify a 4-log reduction standard in raw almonds. Prior to this risk assessment, the almond industry was similarly held to the default 5-log reduction standard. Risk assessments in other commodities have led to higher reduction in standards, such as in pasteurized milk (6-log) and pasteurized liquid egg (8.75-log).

maximum absorbed dose of 30 kGy, and the spices are subsequently required to be labeled with the phrase “treated with radiation” or “treated by irradiation” if used directly. If used on an ingredient, the final packaged product may not require such label declaration (21 CFR 179.26(c)(2)(ii)). Besides the United States’ regulatory limit on up to 30 kGy in dosage, other regulatory bodies have lower limits, examples are Canada, Japan and EU where a **maximum** of 10 kGy is allowed.

Studies on the efficacy of gamma radiation are summarized in FDA’s Risk Profile on Pathogens and Filth in Spices. The studies suggest that gamma radiation is the most efficient method of pathogen elimination while resulting in the fewest changes in physiochemical quality parameters of spices. ASTA has prepared a literature review on inactivation of microorganisms in spices by ionizing radiation that is available on the association’s website (ASTA, 2021).

However, there is a lack of consumer acceptance of irradiated food products. Additionally, due calls for the use of the radioisotope to be phased out (Comben, 2021; Zimmerman, 2020; Chou et al., 2018; Lieberman et al., 2020) and the aforementioned labeling requirements, there are commercial viability challenges associated with irradiation.

Ethylene Oxide (EtO) and Propylene Oxide (PPO)

Sterilization with EtO, and to a lesser extent PPO, are also prominent techniques leveraged by the spice industry. EtO is a colorless gas that reacts with components in vegetative cells and spores, resulting in cell inactivation. It is commonly used as an alternative to heat treatments as it has been shown to have minimal impact on the organoleptic and optical properties of spices.

EtO is regulated by the U.S. Environmental Protection Agency (EPA) under the U.S. Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Spices may be treated with EtO consistent with EPA’s regulation under 40 CFR 180.151 (EPA, 2012c). However, regulatory scrutiny of EtO has increased in recent years on both the state and federal levels. In April 2023, EPA’s Office of Chemical Safety and Pollution Prevention released a Proposed Interim Decision (PID) for EtO that proposes a phased cancellation of EtO on spices for which there are viable alternative treatment methods (EPA, 2023). The PID also includes proposed mitigation measures to decrease worker exposure, including lower caps on the amount of EtO used, engineering controls, and monitoring requirements. Additionally, the application of EtO treatment to spices is prohibited in many countries.

Given that spice products can be treated with EtO while in their primary bulk packaging, EtO treatment offers the unique benefit of reducing the likelihood of post-process contamination. The efficacy of EtO treatment to inactivate pathogens has been extensively reviewed by the FDA and summarized in its 2017 Risk Profile on Pathogens and Filth in Spices.

PPO is also used as a fumigant to inactivate pathogens in spices. Although PPO is considered as the nearest alternative to EtO treatment, the current PPO label limits the application only to Crop Group 19 materials, which excludes several key spices for which EtO currently serves as an important treatment method including turmeric, ginger, and capsicums.

Emerging and/or Not Widely Adopted Treatment Methods

Other treatment options have been studied for many years and reviewed in the scientific literature; however, these technologies are currently not widely used due to commercial limitations, and/or lack of widespread applicability and/or evidence on efficacy. These include ultrasonication, pulsed energies, ohmic heating, microwave radiation, radiofrequency heating, infrared radiation, and non-thermal technologies. These technologies are explained in more detail below.

Thermal Technologies

Ohmic Heating

Ohmic heating is the process through which an electric current is passed through a food matrix. The electrical energy is dissipated into heat, which results in rapid and uniform heating of the food matrix, inactivating microbes (Mudgal, 2019). Ohmic heating results in predominantly thermal effects (Wang & Sastry, 2002), as well as non-thermal effects on microbial populations due to the presence of the electrical current during the heating process. However, the current can only inactivate enzymes that contain prosthetic metallic groups (Makroo et al., 2020). Furthermore, the process requires that the food matrix being treated contains sufficient water and electrolytes to properly conduct the electric current (Imai et al., 1995).

Studies have been conducted on the application of ohmic heating in food processing for a variety of purposes, including the enhancement of the drying process (Zhong and Lima, 2003), enhancement of oil recovery (Nema, 2006; Pare et al., 2012), and microbial inactivation in various fruits and vegetables. Although research on spices is limited, studies have reported that the application of ohmic heating for fruits and vegetables for the purpose of microbial reduction have resulted in minimal impact on nutrition and organoleptic properties (Lima & Sastry, 1999; Lima, et al., 1999; Icier & Ilicali, 2005; Icier et al., 2008).

Ohmic heating may serve as a strategy to treat leafy spices (Mudgal, 2019). However, additional information on the heating patterns is required to understand the efficacy of ohmic heating for seed spices and spices with low water activity (Mudgal, 2019).

Microwave Heating

Microwaves are a portion of the electromagnetic spectrum with wavelengths ranging from 1m – 1mm with frequencies between 300 MHz and 300 GHz, respectively. Application of microwaves to a food matrix results in the movement of dipoles and ions, resulting in the creation of heat. The efficacy of microwave heating is dependent on several food-related properties, such as moisture content, density, dielectric properties and temperature, as well as the design of the heating device (Eliasson, 2015). Due to the ability of microwaves to penetrate into the food matrix, this technique generally allows for more homogenous heating than some other heating methods.

However, in a comparison of the decimal reductions of microbial populations in spices from different heat treatments, FDA has indicated that microwave treatment may not provide an adequate reduction of pathogens (FDA, 2017). The decimal reduction of microwave treatment ranged from 0.2 to 3.8 logs in commodities such as oregano, black pepper, red chili, rosemary, and sage.

In one study, the application of microwave decontamination to paprika powder at 98°C for 1.5 minutes (followed by a subsequent holding time of 20 minutes in a conventional oven) resulted in a 4.8 log reduction in the total number of mesophilic bacteria (Eliasson et al., 2015). Another study examining the efficacy of microwave heating in black pepper noted reduced microbial load levels with minimal impact on volatile oil, piperine, and resin content (Jeevitha et al., 2016).

Infrared Heating

Infrared radiation (IR) is the band of electromagnetic spectrum with wavelengths of 0.78µm to 1mm. Application of infrared radiation to a food matrix results in a change in the rotation and vibration of molecules, leading to energy absorption that is transferred to heat when the molecules return to their normal state (Eliasson et al., 2015). Infrared radiation is divided into three categories: near (0.76 to 2µm), medium (2 to4µm), and far (4 to1000µm) IR. The various types of IR result in differing amounts of transmitted energy, and thus rate of temperature change and penetration depth. Generally, IR heating is considered a surface treatment method, as the average penetration depth ranges from 0.31 to 4.76 mm (Skjöldebrand, 2001).

A variety of studies have investigated the efficacy of IR decontamination of herbs and spices, including paprika powder, black pepper, cumin seeds, and oregano (Staack et al., 2008a; Erdoğdu and Ekiz, 2011, 2013; Eliasson et al., 2014). The studies indicate that IR is effective as a surface treatment and did not yield significant changes in volatile oil content or color of black pepper or cumin seeds. While Eliasson et al. observed slight color and compositional changes in treated oregano, the laboratory conditions may not be consistent with commercial parameters.

In one study comparing the treatment of paprika powder (adjusted water activity of 0.88) with infrared and microwave heating, researchers found that treatment with IR resulted in a 3.8 log reduction of aerobic mesophilic bacteria after heating the sample for 3.7 minutes to a temperature of 98°C (Eliasson et al., 2015). However, Eliasson et al. (2015) noted that the IR technique required a longer heating time than the microwave treatment. This is because for commodities such as paprika powder, which had an infrared penetration depth of 3.7mm (Erdoğdu et al., 2015), the infrared heat flux must be administered in a stepwise manner to avoid overheating the surface of the sample and to allow the interior to be heated by conduction. Heating times for paprika powder treated with IR range from 3.7 minutes (Eliasson et al., 2015) to 4.5 minutes (Staack et al., 2008b) to reach 98 to 100°C with a water activity of 0.88.

Radio Frequency Heating

Radio frequency treatment is a heating method that operates in the frequency range of 3 kHz to 300 mHz. However, only certain frequencies (13.56, 27.12, and 40.68 MHz) are permissible for industrial, scientific, and medical applications (Chen & Subbiah, 2019). Heat is generated in the food product through molecular friction caused by ionic conduction and dipole rotation of water molecules (Wei et al., 2018). Efficacy of radio frequency heating has been evaluated in whole black peppercorns (Wei et al., 2018), black and red pepper (Kim et al., 2012), and paprika, white pepper, and cumin powder (Ozturk et al., 2020). In a recent study on the efficacy of radio frequency heating to reduce *Salmonella* in dried basil leaves, a 4.8 log CFR/g reduction in the *Salmonella* population was recorded after 55 seconds (80°C) of treatment (Verma et al., 2021). After 65 seconds of treatment (100°C), the population reached below the limit of detection (>6.5 log CFU/g). The study indicated that radio frequency heating had no significant effect on the quality parameters of the dried basil, including color, total volatiles, total phenolics, and antioxidant activity.

Radio frequency heating has been recorded to have a greater penetration depth than those of microwaves because of its longer wavelengths, resulting in more uniform heating. Additionally, radio frequency heating is considered suitable for low-moisture foods, such as spices. However, the heating rate and efficacy of radio frequency heating are dependent on a variety of factors, including the dielectric properties of the food matrix being treated, temperature, density, and chemical composition. For example, in a study evaluating the efficacy of radio frequency heating on cumin seeds, variations in heating rate and microbial inactivation were observed between two samples, even after the samples were equilibrated to the same water activity (Chen et al., 2017). Thermal imaging of the two samples showed differences in heating rates due to variations in sample characteristics. The study revealed that cold-spot temperature and moisture content are critical process control parameters in radio frequency heating processing when used as a microbial intervention technique.

Non-Thermal Technologies

UVC-LED Treatment

Ultraviolet (UV) radiation is a well-established method for the reduction of pathogens from foods and has been tested in a variety of spices, including black pepper and powdered red pepper (Cheon et al., 2015; Ha & Kang, 2013). UV mercury lamps have traditionally been used to decontaminate foods; however, these lamps have been reported to have several disadvantages, including a required warm-up period before use and pose a potential health risk to treatment employees and consumers should the lamp break and release mercury particles into the food matrix undergoing treatment.

Ultraviolet light emitting diodes (UV-LEDs) are an emerging technology that have been suggested as alternatives to conventional mercury UV lamps for microbial reduction in a variety of foods. The LEDs are comprised of layers of semiconductor material which emit light upon the application of an electrical current. Notably, UV-LEDs do not require mercury which reduces their environmental and human health hazard. They have been considered cost-effective by the food industry (D’Souza et al., 2015). However, this method is most effective as a surface treatment as penetration into the food matrix is limited.

Emerging research on the efficacy of this technology for the inactivation of bacteria in powdered ingredients, such as spices, has been undertaken. One study found that reductions of *Listeria monocytogenes, Escherichia coli, Bacillus subtilis,* and *Salmonella typhimurium* following treatment with UVC-LEDS were comparable to, or exceeded, those using a traditional UV mercury lamp in seasoning powders. However, the study noted that gram-positive pathogens were more resistant to treatment (Nyhan et al., 2021).

Electron Beam (e-beam) Irradiation

Electron beam (e-beam) irradiation is a nonthermal, chemical-free decontamination technology that leverages low-dose ionizing radiation to treat food matrices. E-beam applications are divided into three categories: high-energy (5 to10 MeV) applications, medium-energy (1 to 5 MeV) applications, and low-energy (0.1 to 1 MeV) applications. Low-energy applications include surface sterilization, while high-energy applications may include food pasteurization.

E-beam technology can inhibit microbial growth and inactivate microbes through both direct or indirect damage to the physiological metabolism and chemical reactions performed by microbes (Lung et al., 2015). E-beam irradiation has been approved by the FDA and is considered equivalent to cobalt-60 gamma-irradiation technology. As such, it is subject to the same labeling requirements. FDA has specified a maximum allowable dose of e-beam irradiation for the purpose of microbial decontamination in dry or dehydrated spices and food seasonings at 30 kGy (21 CFR 179). However, unlike conventional gamma-irradiation, e-beam irradiation does not require the use of cobalt-60, making the technology easier to adapt.

Applications of low energy e-beam and high energy e-beam to spices have been studied. In one study, low energy e-beam irradiation (300 keV, 5 min) and high energy e-beam irradiation (10 MeV, 6 kGy) were applied to samples of black pepper, white pepper, and allspice to assess the efficacy of the treatment to inactivate bacteria (Gryczka et al., 2020). A 6-log reduction in total number of aerobic bacteria was observed in white pepper and allspice following treatment with low energy 3-beam irradiation for 5 minutes when paired with and without additional heat treatment. Samples of black pepper were not decontaminated under the same conditions; however, a 6-log reduction was observed following treatment for 15 minutes or longer. A 6-log reduction was also noted in black pepper following treatment with high energy 3-beam irradiation for 30 minutes at 80°C. In another study, it was determined that 100 keV of low-energy e-beam were required to reduce microbial loads to levels lower than 10 CFU/g in white pepper, coriander, and basil, and 210 keV for black pepper (Hayashi et al., 1998). A third study evaluated the efficacy of low-energy e-beam treatment to reduce *Salmonella* Rissen populations in black peppercorns using the surrogate *Enterococcus faecium* (Murdoch et al., 2022). It concluded that that the treatment of black peppercorns with low-energy e-beam consistently resulted in a 5-log reduction of *Salmonella* Rissen.

Even at the high energy levels, the penetration of e-beam into dense products is limited. With spices in bulk packaging, such as drums and poly-woven bags, it is difficult to achieve uniform penetration and lethality. Electron beam pasteurization has been performed on a conveyorized system that is designed to transport very specific spices or herbs. The conveyors are typically not suited for a wide range of spices which makes this option less cost effective.

Cold plasma

Cold plasma (or non-equilibrium plasma) is a non-thermal technology wherein energy is applied to a reactive gas mixture around a food ingredient to inactivate microbes on the surface. Several different cold plasma processes have been developed but in general they rely on oxidation as the chemistry of inactivation.

Various studies have demonstrated that cold plasma for microbial reduction in spices is effective, with varying impact on the spices' organoleptic properties, color, and functional ingredients (Kim et al., 2013; Bagheri & Abbaszadeh, 2021; Wiktor et al., 2020; Herwig et al., 2015). One study reported greater than a 3 log reduction in the native microflora on pepper seeds and paprika power after treatment with cold plasma for 60 minutes (Hertwig et al., 2015). A 1.6-log reduction of native microflora was observed in crushed oregano; however, the researchers related the differences in reduction to the oregano's lower initial microbial load. By comparison, Wiktor et al. (2020) evaluated the efficacy of cold plasma to reduce mold (*Aspergillus niger*) and bacteria (*Bacillus subtilis*) in whole black pepper, allspice berries, and juniper berries following treatment for 15 to 60 seconds. After 45 seconds of treatment, no molds were found in any of the spice samples. However, bacteria were present even after 60 seconds of treatment. Thus, cold plasma treatment duration and strength vary by ingredient, initial microbial load, and the physiochemical properties of the ingredient.

Ozone

In addition to pathogenic bacteria, spices and herbs may also be contaminated with toxigenic fungi. Ozone can be used as an antifungal, anti-mycotoxigenic, and antimicrobial agent in foods. Ozone promptly decays upon application, without leaving residues on treated food products. Furthermore, it is Generally Recognized As Safe (GRAS) for the treatment of foods (21 CFR 173.386). As another example of pasteurization by oxidation, ozone has shown varying impacts on color, organoleptics, and functionality of the target spices.

Ouf and Ali (2021) analyzed the fungal contamination of nine dried herbs and spices before and after treatment with ozone for up to 280 minutes. Percent reduction of fungal contamination ranged from 96 to 98%. Reductions in the production of total mycotoxins were also observed. However, significant reductions in the volume of essential oils in chamomile and peppermint (26 to 57%) were observed, indicating that ozone treatment may negatively impact herb quality and major active constituents.

Organic Chemicals

A variety of organic mixtures can be leveraged as processing aids to combat microbial populations in dried spices. Some companies have created unique blends containing active ingredients as well as other constituents that can impact the efficacy and utilization of the mixture on certain commodities, including spices (Hylton et al., 2019). Similar blends have been used for many years in the produce industry as a wash or spray before final processing to reduce microbial populations (Singh et al., 2018). The mixtures can inactivate pathogens on contact by permeating cell walls and membranes, resulting in the denaturing of cellular components, such as enzymes, proteins, and DNA. Organic acids have also been shown to be cost-efficient and environmentally friendly (Zoellner et al., 2018).

As a specific example, one certified-organic, GRAS blend of compounds to inactive pathogens and indicator microorganisms in spices and dried vegetables has been patented as Neo-Pure. The solution is misted onto the spice product, but subsequently biodegrades, leaving no residues. The efficacy of this specific technology to reduce populations of *Salmonella* and its surrogate, *Enterococcus faecium NRRL B-2354*, has been evaluated on a variety of spices, dehydrated vegetables, nuts, seeds, and grains, including achieving TERP-approval by the Almond Board of California.

Ultrasonics

Ultrasonic treatment is an airborne acoustic technology. Acoustic waves, typically at frequencies from 20 kHz to 500 MHz, can be used to decontaminate the surface of food ingredients (Chemat et al., 2011). Ultrasonication causes the rapid compression and expansion of liquid particles, the intensity of which depends on the ultrasonic power and frequency, leading to microbial cell lysis and microbial displacement (Chaturvedi et al., 2021). Several microorganisms have been studied to evaluate the efficacy of ultrasonication for microbial inactivation, including mesophilic bacteria in coriander leaves (Michelino et al., 2018), and *L. monocytogenes* and *Salmonella* in fresh bell pepper (Luo and Oh, 2016). Reductions in microbial counts by ultrasonication in the scientific literature range from 0.79 log CFU/g to greater than a 5-log reduction in various food commodities (Michelino et al., 2018; Pokhrel et al., 2017; Zhu et al., 2017). The efficacy of ultrasonication in the reduction of microbial populations has been demonstrated to depend on the characteristics of the ultrasonic waves, exposure time, the food matrix, and the pathogen itself.

In spices, ultrasonic treatment has been shown to yield a 2.19 log CFU/g reduction of *B. subtilis* vegetative cells in black pepper after 30 minutes of treatment with acoustic waves at 170W, with no significant effects on the phenolic content or rheological properties of the ingredient (Charoux et al., 2019). However, no significant reductions were observed in samples contaminated with *B. subtilis* spores.

Pulsed Light

Pulsed light decontamination utilizes short, high-power pulses of broad-spectrum light to destroy bacteria, yeasts, and molds on the surface of foods (Woodling & Moraru, 2006). The combination of broad-spectrum UV content and elevated temperatures results in bacteria disruption. However, the overall bacteria reduction obtained from treatment is dependent on a variety of factors, including the energy delivered through each flash, the physiochemical characteristics of the ingredient being treated, the target microorganism, and the distance between the lamp and ingredient.

Limited research is available on the efficacy of pulsed light treatment of powered/granulated food ingredients. In one study, a 1 log reduction of *B. subtilis* was recorded when dried spices, including ground caraway, red pepper, and black pepper, were treated with 10 flashes of pulsed light (Nicorescu et al., 2013). In another study, reduction of 0.45 and 0.66 log CFU/mL in ground black pepper and red pepper, respectively, when treated with 12.31 J/cm^2 of pulsed light (Hwang et al., 2021). A greater than 3 log reduction was achieved for sesame seeds under a total energy fluence of 11.26 J/cm^2. Additionally, no significant changes in color, water activity, or moisture content were observed.

Conclusions

This paper summarizes the publicly available scientific literature for a variety of new and emerging alternative treatments methods for spices and herbs. ASTA does not endorse or recommend any one technology, but instead urges users of any of the information presented in this document to conduct its own research to determine which applications may be most appropriate for a company’s needs.

A variety of factors influence the selection of a treatment method, including the effects of the method on product attributes, product labeling requirements, customer performance criteria, consumer preferences, scalability of the method, and cost. Critically, the method must be able to achieve a scientifically valid reduction for *Salmonella* and control other pathogens identified as hazards, and companies must have validation studies demonstrating this reduction is being achieved. Furthermore, spice quality, including flavor and color, must be maintained to a commercially viable standard. While there are scientific studies on a number of potential alternative technologies that might have applicability in the spice industry, the exploration of the commercial viability of these methods will require time and resources by each company to research the potential applicability to their product portfolio.

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