United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/petitioned-substances

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Ozone

Handling/Processing

Identification

Chemical Names:
Ozone

Other Names:
2-Trioxiden-2-ium-1-ide; Triatomic oxygen; Trioxygen; Trioxygene

Trade Names:[1]
Ozonator; Ozone Systems; Sorbal; Villa 3000

CAS Numbers:
10028-15-6

Other Codes:
EINECS: 233-069-2

Summary

This full scope technical report provides updated and new information to the National Organic Standards Board (NOSB) to support the sunset review of ozone, listed at 7 CFR 205.605(b)(21). This report focuses on the uses and applications of ozone in organic processing and handling.

The only review to include ozone on the National List was conducted in 1995 (NOP, 1995). The NOSB recommended listing the substance without annotation in 1995 (NOSB, 1995a). Ozone was included on the National List of Allowed and Prohibited Substances (hereafter referred to as the “National List”) with the first publication of the National Organic Program (NOP) Final Rule (65 FR 80548, December 21, 2000). The NOSB has since continued to recommend its renewal in 2007, 2010, 2017, and 2020 (NOSB, 2007, 2010, 2015, 2020a). Representatives from fruit producers and organic trade or business organizations expressed support for the continued listing of ozone, prior to the Fall 2020 NOSB meeting (NOSB, 2020b). They noted that ozone was very effective as a sanitizer/disinfectant and pest control agent in packing houses, helping producers meet requirements of the Food Safety Modernization Act.

Ozone is listed at § 205.605(b)(21) as a nonagricultural synthetic substance and may be used as ingredients in or on processed products labeled as “organic” or “made with organic (specified ingredients or food group(s))” without any annotation that limits its source or use.

Characterization

<u>Composition of the Substance:</u>
Ozone is a molecule composed of three oxygen atoms (O_3) (National Center for Biotechnology Information, 2024). It is often represented with the central oxygen atom connected by a double bond with one oxygen atom and connected by a single bond with another oxygen atom (see Figure 1). However, in nature, the electrons are shared equally between the two bonds.

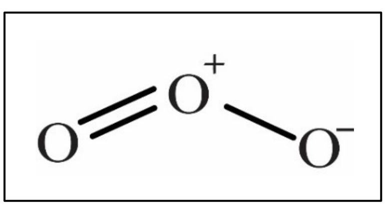

Figure 1: Chemical structure of O_3

<u>Source or Origin of the Substance:</u>
Ozone occurs naturally, mostly in the upper atmosphere. Naturally occurring ozone is often the product of ultraviolet radiation on atmospheric oxygen (O_2) (National Center for Biotechnology Information, 2024).

- Producers generate most ozone by applying a low-current electrical discharge (“corona discharge”) to atmospheric oxygen (Foley & Kirschner, 2022).
- Increasingly, producers generate ozone through the electrolysis of water (Okada & Naya, 2012).
- Producers can also generate ozone photochemically by exposing oxygen in air or water to ultraviolet light (UV) (Horvath et al., 1985; Wojtowicz, 2005).

[1] Trade names are for equipment used to generate ozone on site.

The UV method produces relatively low ozone concentrations compared to corona discharge (Wojtowicz, 2005). However, it may be suitable for producers aiming to generate small amounts of ozone in combination with disinfection effects provided by ultraviolet light (Foley & Kirschner, 2022). We found references to an older method for synthesizing ozone by feeding liquid oxygen between two electrodes separated by an inert gas (such as helium), that forms a barrier that ionizes to form plasma (Grosse & Stokes, 1967; Stokes & Streng, 1965).

Ozonation occurs in several steps (see Figure 2) (Tapp & Rice, 2012).

1. Most low-current electrical discharge systems used in food processing facilities first concentrate oxygen from atmospheric gases to about 93% pure O_2.
2. The oxygen then passes through the corona discharge ozone generator.
3. The ozone generation process is monitored and adjusted to maintain concentration.
4. Producers may either apply the ozone directly to food, or inject it into wash water, depending on the food and application. When applied directly, the generator releases ozone as a gas into the storage chamber or directly on the product. In the latter case, producers dissolve ozone into water used to wash food.
5. Producers can off-gas ozone either directly or treat it to accelerate decomposition into O_2 before releasing it into ambient air.

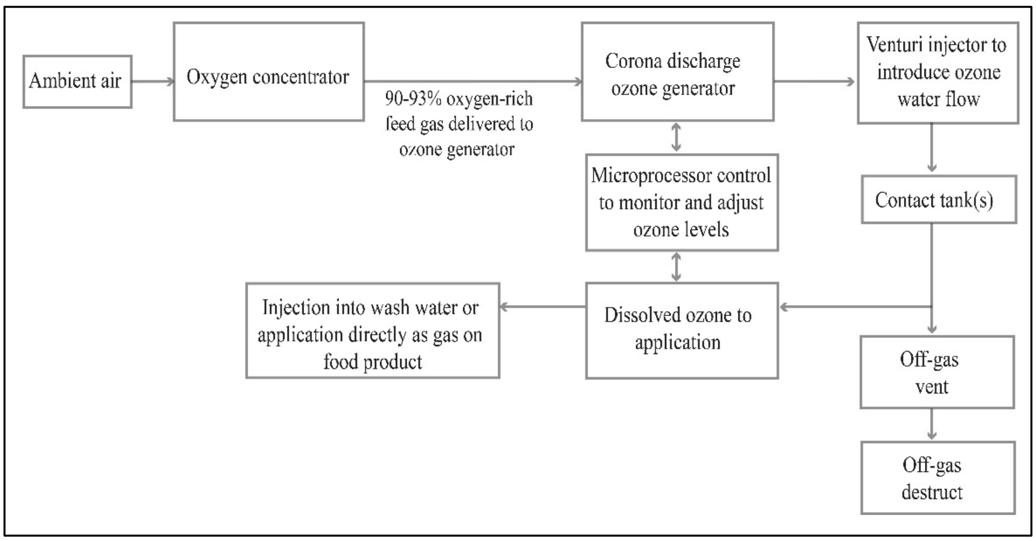

Figure 2: Flow diagram of the generation, application, and control of ozone in a food processing plant. Adapted from Tapp & Rice (2012)

Nuclear reactors also generate large quantities of concentrated ozone. Ozone is a by-product of the irradiation of ambient oxygen with combined beta, gamma, and neutron radiation in the course of operation of the reactors (Horvath et al., 1985). However, a practical way of separating ozone from radioactive material has prevented commercialization of this source (Wojtowicz, 2005). Even if the operators of nuclear reactors overcome such technical barriers, nucleo-chemical ozone sources still present additional hazards if used to handle and process food (Guzel-Seydim et al., 2004).

Properties of the Substance:

Ozone gas ranges from colorless to pale blue in appearance (see Table 1). In gaseous form, it is unstable and highly reactive. Ozone is heavier than air and rapidly decomposes into atmospheric oxygen.

Table 1: Physical and chemical properties of ozone (Foley & Kirschner, 2022; National Center for Biotechnology Information, 2024; Wojtowicz, 2005)

Property	Value
Physical state and appearance	Gas at 0 °C and 1 atm
Odor	Pungent
Color	Colorless to bluish in gas form; dark blue in liquid form; blue-black crystals in solid form
Molecular weight	47.998 g/mol
Specific gravity	1.61 at 21.1 °C and 1 atm (Compressed Gas Association, 1999)
Solubility	1.06 g L^{-1} in water at pH 3.5 at 0 °C and 1 atm
Boiling point	-112 °C
Melting point	-192 to -193 °C

Property	Value
Critical temperature	-12.1 °C
Vapor pressure	41,257 mm Hg at -12 °C
Stability	Unstable gas that rapidly decomposes to O_2 at 0 °C and 1 atm
Reactivity	Reacts with virtually every element with the exceptions of most noble metals, fluorine, and inert gases

Temperature, pressure, and ionic strength of a solution all influence the solubility of ozone (Wojtowicz, 2005). Solubility is increased by pressure and decreased by temperature (Wojtowicz, 2005). Ozone is pH neutral, but is more stable in solutions with low (acidic) pH (Galdeano et al., 2018). Specific gravities of gases are relative to air, with air having a value of 1.0 at standard temperature and pressure (Gordon, 2024). Thus, ozone is heavier than air.

Ozone is a strong oxidizing agent with an oxidation potential of 2.07 eV (Foley & Kirschner, 2022). Only a few other oxidizing agents [such as fluorine (F_2), the hydroxyl radical (OH), and nascent or monoatomic oxygen (O)] have a greater oxidation potential (Foley & Kirschner, 2022). Oxygen and the hydroxyl radical are both produced as decomposition products of ozone in aqueous solution (Dubey et al., 2022; Khadre et al., 2001). While ozone has a distinct pungent odor, it has no flavor and leaves no taste in ozonated water (Wojtowicz, 2005).

Specific Uses of the Substance:

Organic processors and handlers report that ozone is widely used as a sanitizer and to clean equipment (CCOF, 2020; Organic Trade Association, 2020). Organic fresh produce handlers use it on food contact surfaces, in direct food contact, as an ethylene scavenger, and to control insects (Organic Produce Wholesalers Coalition, 2020). Ozone is also used to sanitize barrels used to make organic wine (CCOF, 2020). One organic handler cited the Food Safety Modernization Act (Public Law 111-353, January 4, 2011) as creating the necessity for effective sanitizers in fresh fruit (Austin, 2020). While there are other options available, handlers may rotate different sanitizers as a strategy to prevent pathogen resistance (Austin, 2020). Specific examples include aqueous ozone to sanitize organic cherries prior to packing and gaseous ozone to prevent post-harvest diseases in bananas (Organic Produce Wholesalers Coalition, 2020).

The primary use of ozone globally is as a water treatment (Wojtowicz, 2005). In this capacity, ozone oxidizes organic and inorganic compounds, improving water quality when used as a broad-scope disinfectant. In food production, handlers also apply ozone directly to food as an antimicrobial treatment (O'Donnell et al., 2012). Consequentially, ozone is also a preservative (see *Evaluation Question #3*, below).

Ozone can reduce decay and extend the storage life of a variety of foods (see Table 2, below). Processors can apply ozone both as a wash water disinfectant that reduces the populations of spoilage organisms and as a gas discharged in controlled- or modified-atmosphere refrigeration chambers (Sarron et al., 2021; B. Tiwari & Muthukumarappan, 2012). Sarron et al. (2021) found that most studies of lettuce and carrots involved treatment with ozonated wash water, while most studies of tomatoes involved treatment with gaseous ozone. Ozone gas is desirable as a non-thermal, dry antimicrobial for food products that need to avoid heat and moisture to preserve quality (Afsah-Hejri et al., 2020; Gyawali et al., 2024). Researchers identified that the most studied fresh vegetables treated with ozone are lettuce, carrots, and tomatoes (Sarron et al., 2021; B. Tiwari & Muthukumarappan, 2012).

Ozone is also used as an alternative to sulfiting agents to make no-sulfite-added wines (Mostashari et al., 2022). A common use is to sanitize oak barrels between vintages (Stadler & Fischer, 2020). It can also be used for post-harvest treatment of the grapes to inactivate undesirable yeasts and microorganisms that are antagonistic to yeast fermentation and to sanitize clean-in-place systems (Mostashari et al., 2022).

Table 2: Food and beverages commonly treated with ozone

Food	Effect of ozone on pathogens and food products	References
Carrots	Ozonated wash water effectively extends carrot storage life.	(Sarron et al., 2021; N. Singh et al., 2002)
Dried fruit	Fumigation with ozone inhibits mold, controls insects, and extends the storage life of dates, figs, and other dried fruits.	(Boopathy et al., 2022; Prabha et al., 2015)
Fresh fruits and vegetables	The storage life of apples and oranges is prolonged by the degradation of ethylene by ozone in a controlled or modified atmosphere.	(Prabha et al., 2015; B. Tiwari & Muthukumarappan, 2012)
Fruit juices	Ozone can achieve a 5-log reduction of *E. coli, S.* spp, and *L. monocytogens* in apple, tomato, peach, orange, and other juices.	(Pandiselvam et al., 2019)
Grains	Ozone controls insects and mycotoxin-producing molds in stored corn, wheat, soybeans, flaxseed, and other grains and oilseeds.	(Jian et al., 2013; B. K. Tiwari et al., 2010)
Lettuce	Ozonated water extends the shelf life of fresh-cut lettuce.	(Beltrán et al., 2005)

Food	Effect of ozone on pathogens and food products	References
Milk and dairy products	Ozone gas is used to sterilize clean-in-place dairy equipment and as an atmospheric treatment in cheese storage/aging rooms to prevent unwanted molds.	(Pandiselvam et al., 2019)
Peanuts and tree nuts	Ozone inhibits *A. niger* and reduces aflatoxin and other mycotoxins in peanuts. Ozone gas is a dry processing technique also effective in decontaminating almonds, Brazil nuts, and pistachios.	(de Alencar et al., 2012; Gyawali et al., 2024)
Poultry	Ozone is used to treat poultry processing chill water.	(Pohlman, 2012)
Beef	Ozone spray can decontaminate pathogenic bacteria on beef carcasses; ozone gas in modified atmosphere refrigeration inhibits *Clostridium perfringens*.	(Pohlman, 2012)
Dried spices	Fumigation with ozone caused 100% mortality of insects in coriander and turmeric.	(Boopathy et al., 2022)
Tomatoes	Storage life is extended in modified atmosphere chambers with elevated levels of ozone gas.	(Sarron et al., 2021)
Wine	Ozone can be used as an alternative to sulfites as a sanitizer and antimicrobial in oak barrels, as a post-harvest treatment to inactivate undesirable yeasts and other microorganisms, and to sanitize equipment.	(Mostashari et al., 2022; Stadler & Fischer, 2020)

Approved Legal Uses of the Substance:

Food manufacturers use ozone as an antimicrobial and pest control agent. Therefore, the relevant legal uses of this substance are regulated by the FDA and EPA (US EPA, 2021; US FDA, 2023).

EPA

Pesticidal devices such as ozone generators do not have to be registered with the EPA, but they are still subject to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (US EPA, 2021). Manufacturers of ozone generating equipment are required to register with EPA and report to the agency the names and addresses of the establishments that install such devices (40 CFR 152.500; 41 FR 51065, November 19, 1976).

Ozone located in the lowest boundary of the stratosphere, or ground-level ozone, is classified as a pollutant by the U.S. Environmental Protection Agency (US EPA) under the Clean Air Act.

FDA

Ozone is Generally Recognized as Safe (GRAS) by the FDA without limitations other than current Good Manufacturing Practices. The FDA notes its use as an additive in contact with food, including:

- meat and poultry [21 CFR 173.368(d)]
- raw agricultural commodities [21 CFR 173.368(e)]
- bottled water (21 CFR 184.1563)

The FDA lists ozone as an antimicrobial agent that processors may use in contact with food, including meat and poultry [21 CFR 173.368(d)], unless such use is precluded by standards of identity established by the USDA's Food Safety Inspection Services (FSIS) (9 CFR 319 or 9 CFR 321, subpart P).

When producers use ozone on raw agricultural commodities such as fruit, its use is limited as an antimicrobial agent provided for under the Federal Food, Drug, and Cosmetic Act [21 U.S.C. 321(q)(1)(B)(i)]. However, producers cannot use ozone [21 CFR 173.368(d)]:

- in the field [21 USC 321(q)(1)(B)(i)(I)],
- in a treatment facility that changes the status of the produce from a raw agricultural commodity to a processed one [21 U.S.C 321(q)(1)(B)(i)(II)], or
- during transportation from the field to the treatment or processing facility [21 U.S.C 321(q)(1)(B)(i)(III)].

Bottled water treated with ozone must meet the microbiological, physical, chemical, and radiological standards established by the FDA prior to its treatment (21 CFR 184.1563; 165.110).

The FDA states the following regarding the maximum acceptable level:

> *Ozone is a toxic gas with no known useful medical application in specific, adjunctive, or preventive therapy. In order for ozone to be effective as a germicide, it must be present in a concentration far greater than that which can be safely tolerated by man and animals* [21 CFR 801.415(a)].

Food safety regulations related to meat, milk, eggs, dairy products, juices, and other foods that pose a risk of food-borne pathogens require pathogens of human health concern to be reduced by 99.999% or 10^5, commonly referred to as a 5-log reduction (US FDA, 2007; US FSIS, 2021). After a review of numerous scientific studies, researchers determined that ozone use consistently resulted in the industry standard of a 5-log reduction in pathogens (Prabha et al., 2015). The FDA states that the Hazard Analysis and Critical Control Point (HACCP) Plan requires juice manufacturers to monitor and validate that ozone and other non-thermal methods meet the 5-log standard (21 CFR 120.25).

Standard of identity for ozone under FDA:
The FDA describes the standard of identity for ozone as follows (21 CFR 173.368):

> Ozone (CAS Reg. No. 10028-15-6) may be safely used in the treatment, storage, and processing of foods, including meat and poultry (unless such use is precluded by standards of identity in 9 CFR part 319), in accordance with the following prescribed conditions:
>
> > (a) The additive is an unstable, colorless gas with a pungent, characteristic odor, which occurs freely in nature. It is produced commercially by passing electrical discharges or ionizing radiation through air or oxygen.
> >
> > (b) The additive is used as an antimicrobial agent as defined in §170.3(o)(2) of this chapter.
> >
> > (c) The additive meets the specifications for ozone in the Food Chemicals Codex, 7th ed. (2010), pp. 754-755, which is incorporated by reference. …
> >
> > (d) The additive is used in contact with food, including meat and poultry (unless such use is precluded by standards of identity in 9 CFR part 319 or 9 CFR part 381, subpart P), in the gaseous or aqueous phase in accordance with current industry standards of good manufacturing practice.
> >
> > (e) When used on raw agricultural commodities, the use is consistent with section 201(q)(1)(B)(i) of the Federal Food, Drug, and Cosmetic Act (the act) and not applied for use under section 201(q)(1)(B)(i)(I), (q)(1)(B)(i)(II), or (q)(1)(B)(i)(III) of the act.

GRAS affirmation for ozone under FDA:
The FDA states that ozone is GRAS as an antimicrobial agent (21 CFR 173.368 and 21 CFR 184.1563) when used in accordance with good manufacturing or feeding practices.

Specifications for ozone in the Food Chemicals Codex:
The 14th edition of the *Food Chemicals Codex* (U.S. Pharmacopeia, 2024) specifies the following for ozone:

> **Description:** Ozone occurs as an unstable, colorless gas. It is produced *in situ* from oxygen either by ultraviolet irradiation of air or by passing a high-voltage discharge through air. It is a potent oxidizing agent that decomposes at ambient temperature to molecular oxygen.
>
> **Identification:** Laboratory procedure uses sodium hexametaphosphate, ammonium chloride, and ammonium hydroxide as reagents. A sample of ozonated water is compared to a blank water sample that has not been ozonated. The assay uses an indigo stock solution, phosphoric acid, monobasic sodium phosphate, and malonic acid as reagents.
>
> **Assay:** Concentrations in ozonated water of between 0.01 and 0.5 mg/L of O_3.
> **Arsenic (as As):** Not established.
> **Chloride:** Not established.

Heavy Metals (as Pb): Not established.
Nonvolatile Residue: Not established.
Sulfur Compounds: Not established.

However, the FDA incorporates the standard of identity for ozone used by *Food Chemicals Code* 7th Edition [21 CFR 173.368(c)].

Action of the Substance:

Ozone as an oxidizing agent

Ozone is a strong oxidizing agent. Its potential oxidizing capacity makes ozone a powerful antimicrobial substance (Guzel-Seydim et al., 2004). Oxidizing agents typically contain electronegative atoms (such as oxygen) that strongly attract electrons from other molecules. Oxidation damage is caused by oxidizing agents that chemically react with biological components, disrupting their normal function.

More specifically, microorganisms are rapidly inactivated by a combination of reactions with intracellular enzymes, nucleic materials, and components of their enveloping protein layer (*e.g.* spore coats, viral capsids, or cell envelopes) (Khadre et al., 2001). Microbial inactivation by ozone is a complex process (Greene et al., 2012). Ozone disintegrates the cell wall and causes it to rupture (lysis) under the high oxidation potential of ozone (Aslam et al., 2020; Greene et al., 2012). Once exposed, the cell-content constituents (such as enzymes and nucleic acids) are deactivated (Greene et al., 2012; Khadre et al., 2001).

Ozone may also interfere with respiratory function in some microorganisms (Khadre et al., 2001). Researchers think that spores exposed to ozone are disrupted and degraded, exposing the core and cortex to further action by the ozone (Aslam et al., 2020; Khadre et al., 2001). Ozone inactivates viruses by what appears to be a similar mode of action of removing the viral outer coat (Khadre et al., 2001). Another hypothesis is that ozone damages viral RNA (Khadre et al., 2001). Protozoan eggs (oocytes) are also susceptible to the effects of ozone (Guzel-Seydim et al., 2004).

Synergism with essential oils

Essential oils can work synergistically with ozone, achieving greater pathogen reduction for products that are not appropriate for thermal processing methods such as carrots, lettuce, and other leafy greens (Dev Kumar & Ravishankar, 2019; Floare et al., 2023; N. Singh et al., 2002).

Interaction with ethylene

Ozone's interaction with the ripening agent ethylene is controversial and inconsistent (Prabha et al., 2015; Tokala et al., 2018). In some studies, researchers demonstrated that ethylene production increases when ozone is introduced, a phenomenon believed to be related to increased oxidative stress (Forney et al., 2003). In another study, researchers discovered that ethylene levels decreased in separate storage chambers containing table grapes and peaches, delaying degradation caused by continued ripening (Palou et al., 2002).

Combinations of the Substance:

Processors do not typically combine ozone generated on-site for antimicrobial treatment with any substance other than water, but research indicates that it may be used in conjunction with ultraviolet light, ultrasound, or cold plasma as physical methods to increase efficacy (Fan & Song, 2020; O'Donnell et al., 2012). Ozone may also be used in combination with essential oils that have antioxidant properties and antimicrobial activity (Floare et al., 2023; N. Singh et al., 2002).

Combinations of ozone with UV light or hydrogen peroxide (H_2O_2) result in advanced oxidation processes (AOPs)[2] that are effective against the most resistant organisms (Khadre et al., 2001). However, processors generally do not use AOP techniques for direct food contact. Processors prefer to use these methods for wastewater treatment and equipment sanitizing because of their non-selective reactions (Greene et al., 2012). Direct food application of AOPs to reduce pathogens and maintain food quality remains a challenge for researchers (Fan & Song, 2020).

Ozone generation by corona discharge may produce other incidental gases, such as nitrogen oxides (NO_x) (Foley & Kirschner, 2022; Horvath et al., 1985; Tapp & Rice, 2012). These other gases are considered air pollutants found in conjunction with ozone (US EPA, 2024a).

[2] Advanced oxidation processes (AOPs) generate highly reactive intermediates—particularly the hydroxyl radical (OH^-)—in water to treat recalcitrant organic compounds (Khadre et al., 2001).

Status

Historic Use:

The word “ozone” is derived from the ancient Greeks’ description of the odor produced by lightning flash (Foley & Kirschner, 2022). Ozone was first described by Dutch scientist Martin van Marum as a phenomenon produced by passing electricity through air in 1786, but was not identified as a chemical substance until 1840 by German-Swiss chemist Christian Friedrich Schoenbein (Horvath et al., 1985). Nikola Tesla received one of the first patents for an ozone generator (Tesla, 1896).

Outside the U.S., ozone has been used extensively for water purification and other sanitizer and fumigant functions since the early 1900s (EPRI, 2001). The first practical use of ozone as a disinfectant began in 1903 as a treatment for drinking water systems in Europe (Wojtowicz, 2005). Between 1903 and 1906, Nice, France installed an ozone treatment system sufficient to disinfect the entire city water supply (Rice et al., 1981; Rideal, 1909). The earliest report of the successful use of ozone in the food industry was to increase the storage life of meat in cold storage at a facility in Cologne, Germany, in 1909 (Horvath et al., 1985). Early attempts to sterilize milk with ozone failed (Vosmaer, 1914). The French seafood industry began using ozone to treat shellfish in 1936 (EPRI, 2001). The dairy industry started to use ozone gas to remove unwanted molds from cheese storage facilities in the 1940s (EPRI, 2001).

Compared to the early adoption and long history of use in Europe, the U.S. food industry was slow to adopt ozone as an antimicrobial treatment (EPRI, 2001; Sarron et al., 2021; B. Tiwari & Rice, 2012). The FDA declared ozone to be GRAS for use in bottled water in 1995 (50 FR 57130, November 13, 1995) and GRAS for use in food processing in 1997. In 2001, the FDA recognized ozone as GRAS as a secondary direct food additive. Organic processing and handling operations used ozone as an alternative to chlorine products and other possibly compatible applications prior to the passage of the Organic Foods Production Act (NOP, 1995). We found no record in public comments or in the Technical Advisory Panel (TAP) review prior to the original NOSB recommendation explaining the specific uses and applications from early organic operations.

Organic Foods Production Act, USDA Final Rule:

The Organic Foods Production Act of 1990 (OFPA) does not include any reference to ozone (Organic Foods Production Act of 1990, 1990).

The National List includes ozone for use in organic processing and handling at 7 CFR 605(b)(21). For crop production purposes, USDA organic regulations include ozone on the National List at 7 CFR 205.601(a)(5) with an annotation specifying that ozone is only for use as an irrigation water cleaner. Ozone for handling and processing was included on 7 CFR 605(b) in the first publication of the NOP Final Rule (65 FR 80548, December 21, 2000). Use of ozone as a disinfectant in organic crop production on 7 CFR 601(a) was added to the National List in 2003 (68 FR 61987, October 31, 2003). Synthetic ozone is not allowed for organic livestock production.

In *NOP 5023: Guidance, Substances Used in Post-Harvest Handling of Organic Products*, the NOP explains that materials on the National List at 7 CFR 205.605 (such as ozone) may be used for both post-harvest handling and pest control (NOP, 2016c).

International:

International Organic Food Standards: CODEX Alimentarius Commission—Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)

Ozone does not appear in Annex 2, Table 3, “Ingredients of non-agricultural origin referred to in section 3 of these guidelines” (FAO/WHO Joint Standards Programme, 2013).[3]

[3]However, Section 5 of the Codex Guidelines provides for member states “to evaluate new substances for use in organic production” based on the following criteria in §5.1 (FAO/WHO Joint Standards Programme, 2013):

i) they are consistent with principles of organic production as outlined in these Guidelines;
ii) use of the substance is necessary/essential for its intended use;
iii) manufacture, use and disposal of the substance does not result in, or contribute to, harmful effects on the environment;
iv) they have the lowest negative impact on human or animal health and quality of life; and
v) approved alternatives are not available in sufficient quantity and/or quality.

All stakeholders should have the opportunity to be involved in the evaluation process of substances to be included on the lists (FAO/WHO Joint Standards Programme, 2013). Member states should make the list available to other countries upon request (FAO/WHO Joint Standards Programme, 2013).

International Organic Agriculture Standards: IFOAM – Organics International (International Federation of Organic Agriculture Movements)

Ozone is allowed to clean equipment without limitations in Appendix 4, Table 2, "Indicative list of equipment cleansers and equipment disinfectants" of the current IFOAM guidelines (IFOAM, 2014).

Canada: Organic production systems-General principles and management standards (CAN/CGSB-32.310), Organic production systems-Permitted substances list (CAN/CGSB-32.311)

Ozone is allowed under §8.1.2(b) of the Canadian General Standards Board's Organic Production Systems: General principles and management standards for organic production (CAN/CGSB, 2021a). Ozone appears without a limiting annotation in Table 6.5 "Processing aids" and Table 7.3 "Food-grade cleaners, disinfectants and sanitizers permitted without a mandatory removal event" of the Canadian General Standards Board's Organic production systems: Permitted Substances List (CAN/CGSB, 2021b).

Europe and United Kingdom (Northern Ireland): European Economic Community (EEC) Council Regulation (EC No. 2018/848 and 2021/1165)

Ozone does not appear in the EU organic standards. Article 24(1)(g) of EC 2018/848 says that the European Commission may authorize products for cleaning and disinfection of processing and storage facilities (EU Commission, 2018). Annex IV, Part C of the EC 2021/1165 contains the lists of products that can be used for cleaning and disinfection of processing and storage facilities (EU Commission, 2021). As of November 1, 2024, that list is empty.

The EU Expert Group for Technical Advice on Organic Production (EGTOP) considered ozone, among other cleaning and disinfecting techniques, prior to the publication of the current regulations, but did not make a conclusive recommendation about ozone and other specific substances (EGTOP, 2014, 2016). EGTOP recommended that ozone be permitted to treat potable water, but that it not be permitted for direct contact with food (EGTOP, 2014).

While the previous regulation addressed disinfection of livestock facilities, it did not explicitly address disinfection of plant material, including post-harvest washing, or disinfectants used in processing and handling (EGTOP, 2016; EU Commission, 2008a). EC 2018/848 authorizes the listing of such substances for the first time, but neither EC 2018/848 nor EC 2021/1165 established criteria to evaluate such substances (EU Commission, 2018, 2021). EGTOP proposed such criteria, along with a list of unwanted substances for organic production, processing, and handling (EGTOP, 2021). Ozone is not on any of the unwanted lists (EGTOP, 2021). The European Commission has not acted on EGTOP's recommendation as of December 2024.

Japan: Japan Agricultural Standard (JAS) for Organic Production

Ozone is allowed with limitations under the JAS standard for organic food. Ozone appears on Annex A "Additives (for Organic Processed Foods excluding Alcohol Beverages)" with the annotation "Limited to the use for disinfecting the processed meat products, or cleaning of eggs" (Japanese Agricultural Standard for Organic Processed Foods, 2022).

Korea: Republic of Korea (ROK) Korean Organic Act

Ozone is allowed with limitations under the ROK standard for organic food. Article 3 §1 of the Enforcement Rule Of The Act On The Promotion Of Environment-Friendly Agriculture And Fisheries And The Management Of And Support For Organic Foods" refers to permitted substances on Annex 1 (KMAFRA, 2020). "Ozone water" appears in Annex I, Part C, Table 1, "Substances permitted for use as food additives or processing aids" with the following annotation: "cleaning or disinfecting agent used on the surface of food" (KMAFRA, 2020).

Switzerland: Federal Office for Agriculture (FOAG), Switzerland Organic Ordinances, Organic Farming Ordinance (SR 910.18), EAER Ordinance on Organic Farming (SR 910.181), FOAG Ordinance on Organic Farming (SR 910.184)

Ozone does not appear in the Swiss Ordinances on organic farming (Swiss EAER, 1997; Swiss FOAG, 1997). Switzerland participates in EGTOP. Consequently, the status of ozone appears to be similar to that in the European Union and Great Britain, where ozone is allowed to disinfect water, but prohibited for direct food contact (EGTOP, 2014).

Taiwan: Organic Agriculture Regulations

Ozone appears in Chapter 2 "Substances allowed to be used in production, processing, packaging, distribution and sale", Part 1 "Processing, packaging, distribution, and sale", Table 4, "Other substances allowed to be used" with the condition, "Only for cleaning and infection (*sic*) purpose" (Organic Agricultural Promotion Act, 2018).

United Kingdom (Great Britain): Organic Products Regulations (2009), Retained Council Regulations (EC) (834/2007, 889/2008, and 1235/2008)

The standard for Great Britain is based on the retained European Council Regulations prior to the United Kingdom's exit from the European Union (EU Commission, 2007, 2008a, 2008b). As noted above for the EU regulation, ozone is not mentioned in the implementing regulation (EU Commission, 2008a). EGTOP recommended that ozone be allowed to treat potable water, but prohibited for direct contact with food (EGTOP, 2014).

Evaluation Questions

Classification of the Substance:

Evaluation Question #1(A): Describe if this substance is extracted from naturally occurring plant, animal, or mineral sources.

Ozone is not extracted from a naturally occurring plant, animal, or mineral source. Ozone (O_3) is produced by an electrochemical or photochemical reaction using diatomic oxygen (O_2). The oxygen used as a precursor to produce ozone is sourced from naturally occurring atmospheric oxygen (O_2).

Evaluation Question #1(B): Describe the most prevalent processes used to manufacture or formulate this substance. Include any chemical changes that may occur during manufacture or formulation of this substance.

The primary process used to generate ozone is by electrical discharge of oxygen. The only feedstock is atmospheric oxygen (O_2), which is abundant in nature. The chemical reactions involved in corona discharge are outlined in Equation 1, Equation 2, and Equation 3 (Brodowska et al., 2018; Foley & Kirschner, 2022):

$$O_2 + e^-(\text{high energy}) \rightarrow 2O + e^-(\text{low energy})$$
Equation 1

$$2O + 2O_2 \rightarrow 2O_3$$
Equation 2

$$O + O_2 + Z \rightarrow O_3 + Z$$
Equation 3

High-energy electrons (6-7 eV) break the oxygen double bonds (Foley & Kirschner, 2022). The oxygen *atoms* (O) attach to oxygen *molecules* (O_2) either by direct collision or by a three-body collision with another gas (Z), such as nitrogen or nitrogen oxides. These additional gases are also produced *in situ,* mainly by corona discharge (Foley & Kirschner, 2022; Horvath et al., 1985; Tapp & Rice, 2012).

Much of the ozone generated industrially is used for water treatments. Consequentially, researchers have been interested in the efficiencies that can be gained by generating ozone directly in water through an electrochemical reaction (Okada & Naya, 2012). The anode reactions are outlined in Equation 4, Equation 5, and Equation 6 (Okada & Naya, 2012):

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- E^0 = 1.229\,V$$
Equation 4

$$3H_2O \rightarrow O_3 + 6H^+ + 6e^- E^0 = 1.511\,V$$
Equation 5

$$O_2 + H_2O \rightarrow O_3 + 2H^+ + 2e^- E^0 = 2.075\,V$$
Equation 6

The cathode balances the reaction in Equation 7 (Okada & Naya, 2012):

$$2H^+ + 2e^- \rightarrow H_2 E^0 = 0\,V$$
Equation 7

The cumulative reactions use significantly less electricity than corona discharge (Okada & Naya, 2012) and produce hydrogen (H_2) as a co-product, which can be used to generate energy.

The third method processors used in commercial food production is photochemical, through ultraviolet (UV) light radiation (Horvath et al., 1985; Tapp & Rice, 2012). Most UV generators use low-pressure mercury lamps that cause oxygen atoms to dissociate at a wavelength of 185 nm (Tapp & Rice, 2012). The oxygen radicals formed by photodecomposition readily attach to the surrounding O_2 molecules to form ozone (O_3) (Tapp & Rice, 2012).

Evaluation Question #1(C): Discuss whether this substance is agricultural or nonagricultural. If the substance is nonagricultural, is it synthetic or nonsynthetic (natural) [7 U.S.C. 6502(22); NOP 5033-1 (Decision Tree for Classification of Materials as Synthetic or Nonsynthetic); NOP 5033-2 (Decision Tree for Classification of Agricultural and Nonagricultural Materials for Organic Livestock Production of Handling)]?

Agricultural or nonagricultural classification

Evaluation of ozone against Guidance NOP 5033-2 *Decision Tree for Classification of Agricultural and Nonagricultural Materials for Organic Livestock Production or Handling* (NOP, 2016b) is discussed below.

1. *Is the substance a mineral or bacterial culture as included in the definition of nonagricultural substance at section 205.2 of the USDA organic regulations?*

No. Ozone is produced from atmospheric oxygen and electrical discharge or UV light.

2. *Is the substance a microorganism (e.g., yeast, bacteria, fungi) or enzyme?*

No. Ozone is not a microorganism.

3. *Is the substance a crop or livestock product or derived from crops or livestock?*

No. Ozone originates from atmospheric oxygen using physical and electrochemical processes. Although crops release oxygen as part of photosynthesis, it is not possible to separate "agricultural" oxygen from "non-agricultural" sources of oxygen.

4. *Has the substance been processed to the extent that its chemical structure has been changed?*

Yes. The process of ozone generation involves the breaking of the oxygen double bonds of atmospheric oxygen (O_2) by the energy produced from electrons. The chemical structure is changed from O_2 to O_3. This is a small, but significant and essential change in chemical composition.

5. *Is the chemical change a result of naturally occurring biological processes such as fermentation or use of enzymes; or a result of mechanical/physical/biological processes described under section 205.270(a)?*

No. The ozone generation process is electrochemical or photochemical, and not biological.

Therefore, ozone should be classified as a nonagricultural substance.

Synthetic or nonsynthetic classification

Evaluation of ozone against Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a) is discussed below.

1. *Is the substance manufactured, produced, or extracted from a natural source?*

Yes. Ozone is composed entirely of oxygen, which comprises about 21% of the atmosphere. The other reactants are electrons (from electricity), generated by human-created devices.

2. *Has the substance undergone a chemical change so that it is chemically or structurally different than how it naturally occurs in the source material?*

Yes. For commercial applications, generators synthetically produce ozone from atmospheric oxygen. Diatomic oxygen is changed to triatomic oxygen (ozone) by corona discharge, electrolysis, or photochemical reactions produced by ultraviolet light.

2b. At the end of the extraction process, does the substance meet all the criteria described at 4.6 of NOP 5033?

This does not apply to ozone. The various chemical reactions do not involve an extraction process.

3. *Is the chemical change created by a naturally occurring biological process, such as composting, fermentation, or enzymatic digestion; or, by heating or burning biological matter?*

No. The chemical change for all commercial food-grade ozone, as described in this report, is the result of electrochemical reactions with either corona discharge, electrolysis, or photochemical by exposure to artificial ultraviolet light.

Therefore, ozone should be classified as synthetic according to the decision tree.

Evaluation Question #1(D): Does this substance in its raw or formulated forms contain nanoparticles?

According to NOP Policy Memo 15-2 *Nanotechnology*, nanotechnology is conducted at the nanoscale, which is about 1 to 100 nanometers (nm) (NOP, 2015). The NOP uses the term "incidental nanomaterials" to refer to substances that are byproducts of other manufacturing (*e.g.,* homogenization, milling) or that occur naturally. The NOP uses the term "engineered nanomaterials" to refer to substances designed and manufactured to have unique properties or behavior attributable to particle size. However, these terms are not mutually exclusive.

Ozone is a gas at standard temperature and pressure, and it is comprised of individual, disassociated O_3 molecules. An ozone molecule is 1.26 Å or 0.126 nm (Bocci, 2011). This size falls below the NOP's defined nanoscale range, which goes down to 1 nm (NOP, 2015). Researchers are also investigating the use of ozone nanobubbles to improve disinfection effectiveness by increasing the stability of ozone and its surface area coverage (Seridou & Kalogerakis, 2021).

Ozone fits the definition of an incidental nanomaterial because its nanoparticle scale is an aspect of its natural occurrence. However, one could argue that it also fits the definition of an engineered nanomaterial because ozone's unique properties (for example, its effectiveness as a fumigant) are attributable to its particle size. In other words, while ozone's nano-scale size is naturally occurring, some of its unique and beneficial properties are a result of its size.

Evaluation Question #1(E): Does this substance in its raw or formulated forms contain ancillary substances?

No. Food-grade ozone contains no ancillary substances as defined by the NOSB's 2016 recommendation.

Evaluation Question #1(F): Is this substance created using excluded methods?

No. Ozone is a non-agricultural synthetic chemical. It is generated from a non-biological source—atmospheric oxygen, and electricity or ultraviolet light.

Evaluation Question #2: Specify whether this substance is categorized as generally recognized as safe (GRAS) when used according to FDA's good manufacturing practices [7 CFR 205.600(b)(5)]. If not categorized as GRAS, describe the regulatory status.

Ozone is GRAS as a secondary direct food additive permitted in food for human consumption (21 CFR 173.368). It is also GRAS as an antimicrobial agent used to disinfect bottled water (21 CFR 184.1563). The water itself must meet the microbiological, physical, chemical, and radiological quality standards established by the FDA [21 CFR 165.110(b)(2) – (b)(5)]. Current good manufacturing practice requires a maximum residual level of 0.4 mg / L of ozone in the water, at the time of bottling [21 CFR 184.1563(c)].

Purpose and Necessity of the Substance:

Evaluation Question #3: Describe whether the primary technical function or purpose of this substance is a preservative [7 CFR 205.600(b)(4)].

The FDA describes a chemical preservative as follows (21 CFR 101.22):

> (a)(5) The term *chemical preservative* means any chemical that, when added to food, tends to prevent or retard deterioration thereof, but does not include common salt, sugars, vinegars, spices, or oils extracted from spices, substances added to food by direct exposure thereof to wood smoke, or chemicals applied for their insecticidal or herbicidal properties.

While this definition is somewhat ambiguous, we interpret it to mean that a chemical disinfectant, such as ozone, would not be considered a chemical preservative. Ozone is not an ingredient incorporated into food, having a lasting effect to prevent oxidation or other deterioration of food. Furthermore, ozone may be applied for insecticidal purposes (such as when used as a fumigant), or microbial disinfection (a seemingly similar purpose).

The primary technical function of ozone in food handling is as an antimicrobial disinfectant (Brodowska et al., 2018; Guzel-Seydim et al., 2004; O'Donnell et al., 2012). If other steps are taken to limit the recolonization of a treated food product (such as vacuum sealing), the disinfection of decay-causing microorganisms can help to preserve some agricultural products. Ozone also deactivates various enzymes that accelerate the degradation of various fruits, vegetables, and fruit juices, effectively extending the shelf-life of those products (Mayookha et al., 2023).

Carrots are one of the most studied vegetables in association with ozone treatment. Scientists demonstrated in numerous studies that microbial activity is decreased mainly by cellular disruption, as described in Action of the Substance, and storage life is extended via preserved quality after ozone treatment (Sarron et al., 2021). Scientists also demonstrate consistently lower microbial counts, longer storage life, and better quality of lettuce and other salad greens after treatment, when compared to untreated varieties of these crops (Sarron et al., 2021). Scientists treating tomatoes with ozone gas in a modified atmosphere storage chamber prevented microbial degradation from molds and fungi by inactivation of spores and vegetative fungi as described in Action of the Substance (Sarron et al., 2021).

Scientists have demonstrated that ozone is effective at reducing pathogenic fungi that produce mycotoxins in grains if applied when the grain is first stored, particularly if moisture levels are high (Afsah-Hejri et al., 2020; Tiwari et al., 2010). Efficacy is a function of ozone concentration, moisture content, duration, and ozone dispersion (B. K. Tiwari et al., 2010). Treatment lengths range from minutes to days and concentrations range from 50 ppm to 4% with variable results (B. K. Tiwari et al., 2010). These include *Fusarium* spp., *Aspergillus* spp., and *Penicillium* spp. In addition, the strong oxidizing properties of ozone degrades the mycotoxins produced by these organisms, including aflatoxins, ochratoxin A, fumonisins, deoxynivalenol (DON), and zearalenone (Afsah-Hejri et al., 2020).

Ozone is also effective as an insecticide for various grain storage pests when used as a fumigant (Tiwari et al., 2010). Grain damaged by insects is more prone to decomposition and molds that cause mycotoxins (Neme & Mohammed, 2017). Gaseous ozone treatments at concentrations between 25 ppm and 50 ppm over a period ranging from six hours to five days were able to achieve over 50% mortality of target pests with some treatments showing 100% efficacy against certain pests (B. K. Tiwari et al., 2010).

Ozone has antibacterial and antifungal properties, as demonstrated by experiments with almonds, Brazil nuts, and pistachios (Gyawali et al., 2024). Almonds and other shelled tree nuts are required to be heat treated or have another validated method that achieves a 4-log (99.99%) reduction in *Salmonella* (USDA Specialty Crops Program, 2022). However, in the studies we reviewed and cited in a recent literature review article (Gyawali et al., 2024), ozone failed to meet the target 4-log reduction of the pathogen of concern of the different nuts (de Oliveira et al., 2020; Gyawali et al., 2024; Perry et al., 2019).

- Brazil nuts inoculated with *A. flavus* and were treated with ozone gas for four hours at concentrations between 2.42 and 13.24 mg/L (de Oliveira et al., 2020). The treatment of 8.88 mg/L achieved a 3.1 log reduction of *A. flavus* and was not significantly different from the higher treatment (de Oliveira et al., 2020). The *A. flavus* colonies displayed a distinct change in color and shape that showed oxidation of the morphological structure (de Oliveira et al., 2020).
- Almonds and pistachios in the shell were inoculated with *Salmonella enterica*, placed in a vacuum chamber, and treated with ozone at 160 mg/m^3 for 30 minutes (Perry et al., 2019). The pistachios were also soaked in brine (Perry et al., 2019). The almonds showed a 2.9 log reduction in *Salmonella,* but the pistachios had only a 0.8 log reduction (Perry et al., 2019). The relative lack of efficacy was attributed to the ability of *S. enterica* to survive in dry environments (Perry et al., 2019).

Evaluation Question #4: Will this substance primarily be used to recreate or improve flavors, colors, textures, or nutritive values lost in processing (except when required by law)? If so, describe how [7 CFR 205.600(b)(4)].
No. We found no evidence that processors apply ozone treatments to recreate or improve flavors or colors, as it is an odorless, colorless gas that leaves no aftertaste.

Regarding nutritive value, most scientists explore whether ozone degrades nutrients rather than enhances them. Scientists observed that several foods treated with ozone lost color compared to untreated foods. Ozone treatment had this particular effect on the following agricultural products (Brodowska et al., 2018):

- apple juice
- blackberries
- broccoli
- carrots
- grapes
- lettuce

- oranges
- pistachios
- tomato juice

Evaluation Question #5: Describe any effect or potential effect on the nutritional quality of the food or feed when this substance is used [7 CFR 205.600(b)(3)].
After harvest, vitamin content begins to decline in fresh fruits and vegetables (Kader, 2002). However, ozone treatment of wash water and in storage atmospheres can have a measurable impact on nutritional quality (Aslam et al., 2020; Botondi et al., 2021; Sarron et al., 2021). Fruit and vegetable nutrient content can be preserved by inhibiting the decay process, which can lead to the loss of specific vitamins and other nutrients. Scientists observed higher vitamin A and ß-carotene (beta carotene) in carrots treated with ozone compared to untreated carrots (Sarron et al., 2021). On the other hand, the strong oxidizing potential can reduce the content of certain vitamins and ancillary nutrients. Vitamin B_1 (thiamine) and vitamin C (ascorbic acid) are the most vulnerable to loss by oxidation (Aslam et al., 2020).

Researchers who have analyzed the negative impacts on nutrient content in fresh-cut fruits and vegetables assume nutrient loss or degradation to be limited only to plant surfaces and infected cut areas (Aslam et al., 2020; Botondi et al., 2021). Studies that empirically validate this hypothesis are limited. We found one simulation that used cut leafy greens that were then washed in ozonated water and exposed to ozone gas (Shynkaryk et al., 2015). The researchers found that leaf uptake of ozone through the stomata and cut surfaces was limited to only a few millimeters (Shynkaryk et al., 2015).

In a study of strawberries, Pérez et al. (1999) reported that ozonated fruit had three times the vitamin C content compared to the untreated fruit after three days. The researchers concluded that any short-term nutrient loss from ozonation was negated by the observed increase in biosynthesis of vitamin C from stored carbohydrates (Pérez et al., 1999). By day 7 post-treatment, the ozonated fruit had slightly lower (but statistically significant) vitamin C content than the untreated fruit (Pérez et al., 1999). Scientists in another study demonstrated that ozone-treated potatoes had higher vitamin C content than untreated potatoes (Rice, 2012).

Environment and Human Health Effects

Evaluation Question #6: List any reported residues of heavy metals or other contaminants in excess of FDA tolerances that are present or have been reported in this substance [7 CFR 205.600(b)(5)].
The FDA establishes "action levels" for poisonous or deleterious substances that are unavoidable in human food and animal feed (U.S. FDA, 2000). These include aflatoxin, cadmium, lead, polychlorinated biphenyls (PCBs), and many other substances. The FDA uses different action level tolerances for these substances, depending on the commodity. Commodities are largely food items; however, the FDA also includes tolerances for ceramic and metal items, such as eating vessels and utensils. FDA guidance does not identify any action levels for these contaminant substances in ozone (US FDA, 2000).

As a gas, ozone is unlikely to be contaminated with heavy metals. We found no evidence of food-grade ozone contaminated by heavy metals or any other contaminants subject to FDA tolerances or action levels. Ozone generation by nuclear power reactors may be radioactive. However, the contamination risks associated with this production method prevent commercial applications from such sources, including food and water treatment (Guzel-Seydim et al., 2004; Wojtowicz, 2005). The current *Food Chemicals Codex* also does not specify limits on impurities in ozone for arsenic, lead, or other elemental contaminants (U.S. Pharmacopeia, 2024).

Evaluation Question #7: Discuss and summarize findings on whether the manufacture and use of this substance may be harmful to the environment or biodiversity [7 U.S.C. 6517(c)(1)(A)(i) and 7 U.S.C. 6517(c)(2)(A)(i)].
While ozone in the upper stratosphere is vital to shielding the lower atmosphere from solar radiation, at ground level, it is regarded as a pollutant (US EPA, 2024a).

Ozone generator systems produce waste ozone that needs to be vented because they are not 100% efficient in mass transfer from the carrier gas stream (Foley & Kirschner, 2022). The generator systems may include sodium bisulfite or activated carbon filters to scrub the excess ozone, but such systems add to the operational costs (Foley & Kirschner, 2022). Ozone generator systems can also use transition metals and their oxides to catalyze the decomposition of ozone to oxygen prior to venting (Foley & Kirschner, 2022). Some ozone generator systems will also heat the vent to 300 °C (572 °F) using electric or natural gas heaters to accelerate decomposition (Foley & Kirschner, 2022).

Effects on plants
Ozone is toxic to plants and animals (terrestrial and aquatic) (Wojtowicz, 2005). Ozone damage to agricultural crops caused by smog was first observed in California grapes in the 1950s (Richards et al., 1958). The impacts of ozone pollution on plant growth and health have received considerable attention from scientists worldwide (Jimenez-Montenegro et al., 2021; W. H. Smith, 1992). Ozone damage causes visible yellowing of the leaves (chlorosis) and leaf death at higher levels (Grulke & Heath, 2020; Richards et al., 1958). Exposure to 0.2 ppm ozone results in a reduction of photosynthesis by a factor of 2 (Wojtowicz, 2005).

Airborne ozone causes environmental stress in forest plants irrespective of their species (Günthardt-Goerg et al., 2023). In one experiment, exposure of forest plants to elevated ozone levels caused visible tissue damage to the leaves and other organs exposed (Grulke & Heath, 2020; Günthardt-Goerg et al., 2023). Leaves exposed to ozone also showed signs of interference with gas exchange and respiration (Günthardt-Goerg et al., 2023). Forests in the U.S. with elevated levels of ozone grew more slowly compared with forests with lower levels of ozone (Grulke & Heath, 2020). Little is known about ozone's effects on ecosystem processes, such as water, carbon, and nutrient cycling (Grulke & Heath, 2020).

Effects on aquatic animals
The adverse impacts on wildlife caused by air pollution in general and ozone in particular have been studied less than the impacts on plant life (Newman et al., 1992). Studies of the toxicity of ozone-treated wastewater demonstrate mixed results of impacts on fish and other aquatic animals. Some studies show that ozone reduces the toxicity of effluent, while other studies show the opposite (Lim et al., 2022). The results varied by the species and age of the model, and the other pollutants in the effluent. Increased toxicity could not be solely attributed to ozone exposure (Lim et al., 2022). The lethal concentrations of ozone (96 hr LC_{50}) for rainbow trout, channel catfish, and striped bass are 9.3, 30, and 80 ppb, respectively (Wojtowicz, 2005).

Effects on terrestrial animals
A review of the literature on air pollution's impact on biodiversity found only one study specific to ozone's impacts on terrestrial wildlife and biodiversity (Newman et al., 1992). The researcher documented a genetic change in the sensitivity to ozone in deer mice (Newman et al., 1992; Richkind, 1979). Deer mice collected in Los Angeles that were exposed to elevated levels of ambient ozone showed greater resistance to ozone exposure in experimental conditions than laboratory mice, but still suffered adverse health effects (Richkind & Hacker, 1980). Ozone causes lung damage and impaired respiratory function in laboratory animals (Lippmann, 1989; Menzel, 1984; NTP, 1994). Ozone caused lesions in the lungs, noses, and larynxes of exposed rats and mice in both short- and long-term studies (NTP, 1994). The lethal dose for half the experimental animals (4-h LD_{50}) for albino mice is 3.8 ppm (Wojtowicz, 2005).

Effects on environment
The U.S. EPA classifies ground-level ozone as a greenhouse gas, but notes that it is different from other greenhouse gases in several ways (US EPA, 2016). Ozone's impact on global warming and climate change depends on its placement (NASA, 2015). Stratospheric ozone has a net warming effect that is balanced by preventing harmful ultraviolet radiation from reaching the earth. Ozone causes atmospheric warming by absorbing solar radiation (Wojtowicz, 2005). Ground-level ozone is a greenhouse gas that contributes to climate change by the same pathway of trapping heat (UCAR, 2024).

Ground-level ozone varies by season and location (US EPA, 2016). More ozone is produced from both natural sources and human activity during periods of high temperatures and long day lengths (Guicherit & Roemer, 2000; US EPA, 2024c). The amount of human activity (anthropogenic) causing air pollution and altitude are also factors that influence ozone levels (Guicherit & Roemer, 2000). More NO_x and VOC pollution causes higher ozone levels, making urban areas more likely to have high ozone levels than rural areas (Guicherit & Roemer, 2000; US EPA, 2024a).

Ozone generators use electricity. The environmental impact of electricity is related to how the electricity is generated (US EPA, 2024b). Electricity produced from the burning of coal, oil, or natural gas will have a larger carbon footprint than locations that rely primarily or entirely on renewable energy (Davis et al., 2016; Schivley et al., 2018).

<u>Evaluation Question #8: Describe and summarize any reported effects upon human health from use of this substance [7 U.S.C. 6517(c)(1)(A)(i), 7 U.S.C. 6517(c)(2)(A)(i), and 7 U.S.C. 6518(m)(4)].</u>
Ozone is considered a hazardous chemical substance (NIOSH, 2019). When used as an antimicrobial substance, ozone has a beneficial effect on human health through the reduction of foodborne pathogens to safe levels

(Brodowska et al., 2018; Kim et al., 2003; O'Donnell et al., 2012; Suslow, 2004). The same chemical properties that make ozone a powerful and effective antimicrobial agent used to control food-borne pathogens also make it toxic to all living organisms, including humans (Menzel, 1984; Rice, 2012). Residual exposure in food is not an issue because ozone decomposes rapidly into oxygen after it is applied either to wash water or in the controlled/modified atmosphere chambers where food is stored (Brodowska et al., 2018; Guzel-Seydim et al., 2004; Pandiselvam et al., 2019; Tapp & Rice, 2012).

Exposure to ozone is known to induce various toxic effects on both humans and experimental animals (Beckett, 1991; Klaassen, 2001; Menzel, 1984; Rice, 2012; Seagle, 1973). It has been described as "one of the most toxic and ubiquitous air pollutants" (Menzel, 1984). Ozone's toxicity is a direct result of its strong oxidizing properties that are toxic to the cells of all living organisms (Klaassen, 2001). Exposure to ozone also increases a person's susceptibility to infections (Menzel, 1984). Researchers believe that interactions between particulate matter and ozone contribute to respiratory system damage (Beckett, 1991; Jerrett et al., 2009).

The primary human health concern of ozone treatment of food and water is worker safety. Food handling and processing plant workers in close proximity to ozone generators in water treatment and food handling facilities are exposed to higher levels of ozone than the general public (Rice, 2012; Seagle, 1973). Ozone is an irritant to the eyes, nose, mouth, and upper respiratory system. In the U.S., the permissible exposure limit (PEL) for ozone set by the Occupational Health and Safety Administration (OSHA) is 0.1 ppm or 0.2 mg/m^3 over an eight-hour time-weighted average (29 CFR 1910.1000).

Air pollution from off-gassed excess ozone in the proximity of handling facilities is also a health and safety concern (Rice, 2012). Scrubbing systems that capture the excess ozone reduce the levels of ozone released and are mostly used by very large ozone systems that generate tons of the material daily. Some smaller systems also utilize this device (Rice, 2012). Many researchers have examined the adverse health effects of ozone pollution (Bell et al., 2014; Orellano et al., 2020; Zhang et al., 2021).

Jerret et al. (2009) correlated ozone pollution levels with respiratory mortality based on data collected from a large population in the U.S. between 1977 and 2000. In 96 metropolitan statistical areas, scientists observed that for every 10 ppb increase in exposure to ozone, there was a 2.9% increase in the risk of death from respiratory causes. The researchers concluded that the risk of dying from a respiratory cause is three times more likely in metropolitan areas with the highest ozone levels compared to places with the lowest ozone concentrations (Jerrett et al., 2009).

The elderly, women, and those living in poverty are particularly susceptible to the adverse impacts of ozone pollution (Bell et al., 2014). Pediatricians have linked high levels of ozone with near-fatal and fatal asthma attacks in children (Varghese et al., 2024). Scientists conducting related research have also observed a similar pattern of elevated health risks internationally from ozone pollution (Orellano et al., 2020; Zhang et al., 2021).

Ozone demonstrates the capacity to reduce pesticide residues in various foods (Diksha et al., 2023). In one experiment, bok choy (pak choi) with residues of the organophosphorus pesticide malathion and the carbamate pesticide carbosulfan was treated with ozonated water (Wang et al., 2021). The researchers found that as ozone concentration increased, pesticides degraded more rapidly (Wang et al., 2021). These resulting decomposition products were further broken down through hydrolysis, releasing H^+ and OH^- ions in the water (Wang et al., 2021). Ozone disrupts specific types of hydrocarbons (unsaturated aliphatic moieties like alkynes and alkenes) by breaking carbon chains and releasing benzene rings in the molecular structure of pesticides (Diksha et al., 2023). The released smaller molecules are largely water soluble and can be further decomposed by hydrolysis (Diksha et al., 2023).

Alternatives

The following three sections explore possible alternatives to ozone that are non-synthetic, non-agricultural substances, organic agricultural products, and other methods that are physical, mechanical, or otherwise non-chemical in their mode of action. When considering alternatives for pathogen reduction, organic handlers and processors are required to meet all relevant food safety requirements in addition to the organic standards. These include the Food, Drug, and Cosmetic Act as amended by the Food Safety Modernization Act of 2011 (FSMA) (21 CFR 301 *et seq.*), the Federal Meat Inspection Act (21 U.S.C. 601 *et seq.*), and the implementing regulations of the FSMA (80 FR 55908, September 17, 2015). While the FSMA does not require any specific performance standard for pathogen reduction, it requires all food handling facilities to have a Food Safety Plan (21 CFR 117.126), conduct a hazard analysis (21 CFR 117.130), and implement preventive controls appropriate for food safety (21 CFR 117.135).

Some food groups have specific performance standards that handlers are required to meet. FDA guidance requires non-thermal deactivation of microorganisms in juices to be equivalent to thermal pasteurization to be considered acceptable substitutes for food safety, which is a 5-$\log_{10}$ or 99.999% reduction of the most resistant microorganism of public health significance [21 CFR 120.24(b)]. The guidance for the industry to implement the juice pasteurization requirement has become an industry-wide standard (US FDA, 2004). The standard is to achieve a 5-log decrease or 99.999% inactivation of a microorganism's colony-forming units (Režek Jambrak et al., 2018). Almonds are required to meet a 4-log decrease or 99.99% inactivation for *Salmonella* spp. (USDA Specialty Crops Program, 2022).

Alternative methods are sometimes used in combination with ozone to increase efficacy and reduce ozone use (Fan & Song, 2020; Floare et al., 2023; Khadre et al., 2001; O'Donnell et al., 2012). The alternative methods presented below may not always meet the 5-log reduction by themselves, but when combined, they can verify and validate that their HACCP Plan meets the standard (Režek Jambrak et al., 2018). Combining different technologies has the potential to protect food safety and optimize quality for a wide range of specific practical applications (Chiozzi et al., 2022; Noci, 2017; Rawson et al., 2011; Režek Jambrak et al., 2018; Singla & Sit, 2021).

<u>Evaluation Question #9: Are there alternative nonsynthetic (natural) source(s) of the substance [7 CFR 205.600(b)(1)]?</u>

We found no evidence of commercial or practical sources that offer nonsynthetic ozone. Recovery of nonsynthetic ozone appears to be unattainable with existing technologies.

<u>Evaluation Question #10: Describe all nonagricultural nonsynthetic (natural) substances or products which may be used in place of this substance [7 U.S.C. 6517(c)(1)(A)(ii)]. Identify which of those are currently allowed under the NOP regulations.</u>

Acids

Various nonsynthetic acids (*e.g.,* acetic acid, lactic acid, and citric acid) have antimicrobial properties (Bermúdez-Aguirre & Barbosa-Cánovas, 2013; In et al., 2013; Mani-López et al., 2012; Ricke, 2003). Both citric acid (produced by microbial fermentation of carbohydrate substances) and lactic acid are on the National List of nonagricultural nonorganic substances allowed as ingredients in or on processed products labeled as "organic" or "made with organic (specified ingredients or food groups) [7 CFR 205.605(a)(1)].

The mechanisms by which organic acids are thought to reduce microbial activity take place by multiple modes of action, including acidification inside the cell (cytoplasm) with subsequent uncoupling of energy production and regulation, and accumulation of the undissociated acid to toxic levels (Mani-López et al., 2012). The undissociated acid molecules flow through the cell membranes of the microorganisms and are ionized inside, deforming the cell structure and interfering with enzymatic activities, disrupting proteins and DNA structures, and ultimately damaging the extracellular membrane (In et al., 2013; Mani-López et al., 2012). The acidity inhibits cell division and decreases viability by damaging the RNA and DNA (Mani-López et al., 2012). Cells are not instantly destroyed, but are instead fatally injured (In et al., 2013).

When used at 0.5% concentration in a microbial broth, citric acid, lactic acid, and acetic acid all were effective in inhibiting the growth and reducing the populations of four *Shigella* species (*S. sonnei, S. boydii, S. flexnari,* and *S. dysenteriae*), all foodborne pathogens, by between 1 and 2 logs (In et al., 2013). Lactic acid was able to achieve a 5-log reduction of *S. sonnei* after two hours and a 2-log reduction of *S. boydii* in the same amount of time. The researchers inoculated lettuce with *Shigella* cultures and submerged them in water with a no-treatment control and a 0.5% solution of each of the three acids over a 10-hour period. While cells were not destroyed in the same way that ozone works, the various acids injure the cell to reduce its viability (In et al., 2013). Acetic acid was the most effective against *S. dysenteriae* with 100% injury after 8 hours. Lactic acid was the most effective against the other three species. (In et al., 2013). Further research is needed to determine whether these acids can achieve comparable and predictable broad-spectrum pathogen reduction and validate whether they can be a viable substitute for ozone.

Citric acid treatment of nutrient broths inoculated with *E. coli, S. aureus,* and *C. albicans* reduced the populations of all three species, with *C. albicans* showing the greatest sensitivity (Eliuz, 2020). Spinach inoculated with *E. coli, S. typhimurium* and *L. monocytogenes* had its pathogen load reduced by approximately 4-log by synergistic treatment of 1% citric acid and pulsed broad-spectrum xenon light (Cho & Ha, 2021). Citric acid achieved less than a one-log reduction of all three of the pathogens, and xenon light by itself achieved a 4-5 log reduction with a 60-minute treatment time, a 60-minute treatment time using both xenon light and citric acid achieved greater than a six-log reduction in all cases (Cho & Ha, 2021). Another experiment involved romaine lettuce, grape tomatoes, and baby carrots inoculated with *E. coli* and compared the results of treatment with ozone, citric acid, UV-light, and chlorine solutions (Bermúdez-Aguirre & Barbosa-Cánovas, 2013). Citric acid was ineffective on lettuce and carrots, and resulted in less than a 1-log reduction in tomatoes, performing significantly worse than ozone as a disinfectant (Bermúdez-Aguirre & Barbosa-Cánovas, 2013).

Microorganisms

Microorganisms appear on the National List at 7 CFR 205.605(a)(19). Beneficial microorganisms are another well-established, nonsynthetic strategy that can be used to reduce risks from foodborne pathogens, maintain product quality, and extend the shelf life of food (Bogsan et al., 2015; Devlieghere et al., 2004). Researchers observed that *Lactobacillus* spp. and other lactic acid bacteria (LAB) applied to the surface of various fresh fruits and vegetables inhibits the growth of foodborne pathogens such as *Salmonella* spp., *Listeria monocytogenes*, and *E. coli* O157:H7, by the excretion of lactic acid and competitive exclusion, production of bacteriocins, and other complex modes of action that are not fully understood (Agriopoulou et al., 2020). [4] Efficacy varied by species of beneficial bacteria, process duration, temperature, target species, and food matrix (Agriopoulou et al., 2020). As noted above, lactic acid produced by LAB inhibits and ultimately renders microorganisms non-viable (Mani-López et al., 2012). The presence of the LAB also effectively extends the shelf-life of the crops and maintains product quality (Agriopoulou et al., 2020).

Bacteriocins

Toxins produced by bacteria, known as bacteriocins, are another possible alternative for ozone (Devlieghere et al., 2004; Schneider et al., 2018; Yang et al., 2014). As noted above, LAB produces bacteriocins, and other microbial species commonly used in food handling and processing also produce bacteriocins (Devlieghere et al., 2004; Yang et al., 2014). Bacteriocins can be classified as colicins or microcins, based on their specific activity against target pathogens and by their mode of action (Yang et al., 2014). Colicins are high molecular weight antibacterial proteins produced by bacteria that kill closely related species to reduce competition for space and nutrients (Yang et al., 2014). The colicin-producing species also produces immunity proteins that inactivate the colicins to avoid committing suicide (Kleanthous, 2010). Microcins are low molecular weight peptides that have more diverse modes of action and a broader range of activity than colicins (Yang et al., 2014). Some microcins have an antibiotic mode of action or are used as precursors to synthetic antibiotics (Yang et al., 2014). One such bacteriocin petitioned for inclusion on the National List of nonagricultural ingredients allowed for use in organic processing and handling was nisin (NOSB, 1995b). The NOSB did not recommend that it be added to the National List (NOSB, 1995a).

Bacteriophages

Another newer strategy is to use viruses that infect bacteria, or bacteriophages (O'Sullivan et al., 2019; Wei et al., 2019). Bacteriophages are the most abundant organisms on earth (O'Sullivan et al., 2019; Yusuf, 2018). These viruses attach and inject themselves into their specific bacterial host and replicate as a parasite, ultimately causing cellular death (O'Sullivan et al., 2019; Yusuf, 2018). This is referred to as the lytic cycle (O'Sullivan et al., 2019). Phages are host-specific and are unable to propagate without a bacterial cell (O'Sullivan et al., 2019). Scientists have studied phages and their derivatives for *Listeria monocytogenes* (Misiou et al., 2018), *Salmonella spp.* (Wei et al., 2019), and *E. coli* O157:H7 (Rozema et al., 2009) for their efficacy in reducing those foodborne pathogens. Pathogen reductions are generally within the 90-95% range, far short of the target 5-log reduction (Mahony et al., 2011; O'Sullivan et al., 2019). Phages generally do not achieve sufficient target pathogen reduction to qualify as alternatives to pasteurization, but show promise as a preharvest intervention when used as part of an integrated pathogen program combined with various physical techniques, such as high-pressure processing (Mahony et al., 2011; Misiou et al., 2018; O'Sullivan et al., 2019). The FDA has approved *Listeria* specific phages for use in meat and poultry products (21 CFR 172.785).

Essential Oils

Essential oils are potential antimicrobial alternatives to ozone. We discuss essential oils as organic agricultural substances in further detail later in this report (see *Evaluation Question #11*, below). However, many of these biological active components also serve as flavors (Burt, 2004; FEMA Expert Panel, 2022). Nonagricultural nonsynthetic flavors appear on the National List at 7 CFR 605(a)(12).

Evaluation Question #11: Provide a list of organic agricultural products that could be alternatives for this substance [7 CFR 205.600(b)(1)].

Various essential oils are effective antibacterials for various food applications (Burt, 2004; Laranjo et al., 2017; Yusuf, 2018). Producers use approximately 300 essential oils commercially as flavors and fragrances (Burt, 2004; Ríos, 2016). Farmers and ranchers use essential oils as biopesticides in organic crop and livestock production (Baker & Grant, 2018; Chang et al., 2022; Rawat, 2021). However, essential oils are not yet a widely accepted material in

[4] Bacteriocins are toxins produced by bacteria that inhibit or kill other bacteria.

post-harvest handling (Chang et al., 2022; Laranjo et al., 2017). Essential oils are not explicitly included on the list of allowed non-organic agricultural ingredients (7 CFR 205.606). As such, they would be required to be from organic sources if used as ingredients or processing aids for products labeled as "organic" [7 CFR 205.301(b)] or "100% organic" [7 CFR 205.301(a)].

The European Pharmacopoeia identifies 29 different essential oils that have antimicrobial effects on bacteria (both gram positive and gram negative), fungi, and yeast (Pauli & Schilcher, 2009). Scientists consider most of these materials weak-to-moderate antimicrobials, and they are not consistently active across all targeted species of foodborne pathogens (Pauli & Schilcher, 2009). As such, most would not achieve disinfection results comparable to ozone. However, concentrating the active components of essential oils can increase their efficacy as antimicrobials. The main foodborne pathogens studied for the antimicrobial efficacy of various essential oils are (Burt, 2004):

- *Listeria monocytogenes*
- *Salmonella typhimurium*
- *Escherichia coli* O157:H7
- *Shigella dysenteria*
- *Bacillus cereus*
- *Staphylococcus aureus*

Among the fungi studied are *Aspergillus* spp., *Fusarium* spp., *Penicillium* spp., and other mycotoxin-producing species (Dwivedy et al., 2016; Pauli & Schilcher, 2009). In one study, scientists directly compared the antimicrobial activity of ozone with various essential oils in preserving ancient Egyptian archeological objects from *Aspergillus* spp. and other microorganisms responsible for decay. They concluded that the essential oils provided "aesthetically acceptable" results with "negligible toxicity to human health and the environment" (Geweely, 2022).

While essential oils clearly demonstrate antimicrobial activity, their effects on microorganisms are usually weaker than those of synthetic compounds (Wińska et al., 2019). However, essential oils often work synergistically with each other and with other preservation methods (Burt, 2004; Hyldgaard et al., 2012). Essential oil components also have antioxidant activity (Lis-Balchin et al., 1998). [5] Essential oils do vary in quality and potency based on the concentration of their biologically active components (Burdock, 2016; Burt, 2004). Isolating or concentrating the biologically active components of essential oils can improve the efficacy and reduce the variability of the results (Lis-Balchin et al., 1998). However, consumer acceptance of the flavors of essential oils at concentrations sufficient to reduce pathogens is a limitation to their practical application as an antimicrobial (Targino de Souza Pedrosa et al., 2021).

While a comparison of all the essential oils reported to have antimicrobial activity comparable to ozone is beyond the scope of this report, we selected cinnamon oil, peppermint oil, and thyme oil as model essential oils to examine based on the following criteria (NOP, 2024; US FDA, 2020):

(1) Commercial availability of organic sources identified through the Organic Integrity Database (OID).
(2) Available data and studies on essential oils' human health and environmental effects.
(3) Available scientific literature reviews that include an extensive range of uses and applications of essential oils.
(4) In the cases of peppermint oil and thyme oil, the availability of peer-reviewed journal articles that directly compare the efficacy of those essential oils with ozone.
(5) The essential oils selected are FDA GRAS.

We found that the available data and research rarely specified that the essential oils under review were organic. Similarly, we found few studies of essential oil antimicrobial efficacy related directly to organic food processing.

Commercial availability

Many certified organic essential oils are currently available on the market. A keyword search of "essential oils" on the OID identified approximately 219 certified organic handlers (NOP, 2024). Additional keyword searches on the OID for "cinnamon oil" yielded 54 certified organic handlers, "peppermint oil" yielded 141 certified organic handlers, and "thyme oil" yielded 65 certified organic handlers (NOP, 2024). In total, we identified 239 handlers that have at least one of the three specific essential oils used as models or that handle generic essential oils. Handling operations may be distributors and not primary manufacturers. Furthermore, some handlers are certified by multiple agents, with agents certifying different specific essential oils sold by a given operation.

[5] An antioxidant is a substance that counteracts deterioration of food by inhibiting its oxidation.

Cinnamon oil

Cinnamon oil is extracted from the bark of trees from the genus *Cinnamonium* (Ravindran et al., 2004). Most cinnamon in the world is from *Cinnamonium cassia*, also known as cassia (Madan & Kannan, 2004). Sri Lankan or true cinnamon (*C. zeylanicum* also known as *C. verum*) accounts for most of the rest of the oil, which can also be extracted from the leaves and twigs of this species (Ravindran et al., 2004). Another minor source is korintji or Indonesian cinnamon (*Cinnamonium burmanii*) (Khan & Abourashed, 2010). Cinnamaldehyde—also known as cinnamic aldehyde—is a flavonoid and secondary plant metabolite that makes up between 60-90% of cinnamon oil and is the principal biologically active component (Dayananda et al., 2004).

Cinnamon oil from *C. cassia* is effective against a large number of yeasts, fungi, and bacteria (both gram-positive and gram-negative) including (Pauli & Schilcher, 2009):

- *Campylobacter jejeuni*
- *Candida albicans*
- *E. coli* O157:H7
- *Staphylococcus aureus*
- *Shigella* spp.

Researchers studying different *Cinnamomum* species found that cassia oil was the most effective in inhibiting *Salmonella* spp., and cinnamon oil had the highest efficacy against *B. cereus* (Ezzaky et al., 2023). However, both oils were relatively ineffective against *E. coli* and *S. aureus*.

Scientists concluded that cinnamon oil was the most effective of 51 different essential oils against *Pseudomonas aeruginosa*, with an 85.8% reduction in growth, and *Torulopsis utilis,* with a 100% reduction in growth . Fasake et al. (2022) compared fresh-cut cauliflower (*Brassica oleracea* var. *botrytis*) treated with either ozonated water, cinnamon oil, oregano (*Origanum* spp,) oil, or left untreated, wrapped in modified atmosphere packaging, and refrigerated. The researchers reported that ozone and cinnamon oil each inhibited the total bacterial count (TBC) on the cauliflower stored for 21 days. The cauliflower with the ozonated water treatment had a slightly lower TBC than the one treated with cinnamon oil, but the difference was not statistically significant (Fasake et al., 2022). The TBC for cauliflower treated with oregano oil was higher than ozonated water or cinnamon oil, but still lower than the untreated control (Fasake et al., 2022).

Cinnamon oil combined with salt (sodium chloride) effectively inhibited the infection, growth, and aflatoxin production by *Aspergillus flavus* and *A. glaucus* grown on corn (*Zea mays*), but cinnamon oil alone was less effective (Chatterjee, 1989). Montes-Belmont and Carvajal (1998) concluded that cinnamon oil was the most effective of the 11 essential oils tested for control of *A. flavus* on corn without phytotoxicity.[6] Other foodborne pathogens inhibited by cinnamon oil include (Gupta et al., 2008; G. Singh et al., 2007):

- *Aspergillus flavus*
- *Aspergillus ochraceus*
- *Aspergillus terreus*
- *Penicillium citrinum*
- *Panicillium viridicatum*
- *Bacillus* sp.
- *Listeria monocytogenes*
- *E. coli* sp.
- *Klebsiella* sp.
- *Rhizomucor* sp.

Cinnamon and its derivatives, including the essential oil, are FDA GRAS (21 CFR 180.20). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) concluded that cinnamon derivatives do not pose food safety concerns at the current estimated levels of intake (JECFA, 2001). While cases of acute toxicity are rare, pediatricians reported this occurring in young children either accidentally or intentionally ingesting relatively large amounts (Schwartz, 1990).

Cinnamon oil is used to control Varroa mites (*Varroa jacobsoni*) (Kraus et al., 1994), and American foulbrood (*Paenibacillus larvae*) (Gende et al., 2009) in bees (*Apis mellifera*). At the doses effective to control foulbrood (50 µg/ml), cinnamon oil was reported to be virtually non-toxic (Gende et al., 2009). However, a much higher

[6] Phytotoxic: Toxic to plants.

10% solution was fatal to almost 99% of the bees treated (Kraus et al., 1994). We found no evidence that cinnamon oil has adverse effects on aquatic organisms.

Peppermint oil

Processors extract mint oil from plants of the genus *Mentha* by steam distillation (Burdock, 2016; Denny & Lawrence, 2007; Khan & Abourashed, 2010). The most common species used for the production of mint essential oils are corn mint (*Mentha arvense*), peppermint (*Mentha piperata*), and spearmint (*Mentha spicata*) (Denny & Lawrence, 2007). Menthol is a simple monoterpenoid that is the primary active substance in peppermint oil and corn mint oil. Spearmint oils are often over 50% carvone (Lawrence, 2007).

Peppermint oil inhibits the growth of many different bacteria, fungi, and yeasts (Khan & Abourashed, 2010; Pauli & Schilcher, 2009; Shah & D'Mello, 2004). It is also an antiviral agent (Alankar, 2009). Ezzaky et al. (2023) concluded that mint oil was the most effective against *E. coli* and *S. aureus* in a study comparing the efficacy of essential oils in *Cinnamonium* spp, *Mentha* spp., and *Salvia* (sage) *spp.* Argawal et al. (2008) reported that of 30 plant oils tested, peppermint oil showed the greatest inhibition of *C. albicans* after eucalyptus oil.

Peppermint oil showed a synergistic effect with ozone treatment on the following microorganisms (Floare et al., 2023):

- *Candida albicans*
- *E. coli*
- *P. aeruginosa*
- *S. aureus*
- *S. mutans*

The addition of peppermint oil increased the efficiency of ozone and decreased the effective exposure time of ozone from 120 seconds to 55 seconds (Floare et al., 2023). The inhibitory rates obtained by the mixture increased when compared with the inhibitory rates of ozone or essential oils when applied as single compounds (Floare et al., 2023). The essential oils increased the potency of the ozone (Floare et al., 2023).

Peppermint oil and spearmint oil are FDA GRAS (21 CFR 182.200). Cornmint oil is also GRAS, based on a declaration from the Flavors Extract Manufacturers Association Expert Panel (R. Smith et al., 2005). Some individuals are allergic to mint (Tran et al., 2010; Woolf, 1999). Symptoms reported by allergic individuals include the following (Malekmohammad et al., 2021; Tran et al., 2010; Woolf, 1999):

- contact dermatitis (itchy rash including from exposure to peppermint oil in lip balm)
- ataxia
- hot flashes
- drowsiness
- shortness of breath
- abdominal pain
- metabolic acidosis
- hyperextension of the extremities
- tremors
- unconsciousness

Large doses of peppermint oil can be nearly fatal and can cause organ damage when ingested or injected (Behrends et al., 2005; Nath et al., 2012). Peppermint oil is frequently used in herbal medicines. Some patients receiving these therapeutics have reported drug interactions and side effects, including apnea or bronchial and/or laryngeal spasms (Malekmohammad et al., 2021). Peppermint oil is also contraindicated as herbal medicine in patients with bile duct obstruction, gall bladder inflammation, and liver disorders (Malekmohammad et al., 2021). We found no reports of adverse environmental impacts of peppermint oil.

The primary active substance in peppermint oil, menthol, has been widely studied for its effects on human health and non-target species (Hayes et al., 2007; Malekmohammad et al., 2021). Much of the research on the human health effects of menthol is related to its use as an additive to cigarettes. However, some research involves candies and personal care products such as toothpaste (Hayes et al., 2007; Malekmohammad et al., 2021). Menthol has a low potential for toxicity to humans (Hayes et al., 2007). While it is safely used in food, some sensitive people reported heartburn, irritation, contact dermatitis, slowed heartbeat (bradycardia), and abdominal pain (Malekmohammad et al., 2021). Menthol is commonly used to treat tracheal mites (*Acarapis woodie*) in honeybees (*Apis mellifera*).

Scientists concluded that menthol had the greatest margin of safety for bees of all the essential oil isolates tested (Ellis & Baxendale, 1997).

Thyme oil

Processors extract thyme oil by water and steam distillation of the flowering tops of common thyme (*Thymus vulgaris*), creeping thyme *(T. serpyllum*), and red or Spanish thyme (*Thymus zygis*) (Burdock, 2016; Khan & Abourashed, 2010; Lawrence et al., 2002). The primary active constituent is thymol, a monoterpenoid phenol (Coimbra et al., 2022; Lawrence et al., 2002; Zarzuelo & Crespo, 2003). Other biologically active components include linalool and p-cymene (Coimbra et al., 2022).

Scientists reported that thyme oil in aqueous suspension reduced the population of *E. coli* O157:H7 bacteria on lettuce to a level not significantly different from the population reduction achieved by ozonated water (Singh et al., 2002). In contrast, thyme oil was slightly, but significantly, less effective than ozonated water in treating baby carrots inoculated with *E. coli* O157:H7 bacteria (Singh et al., 2002). Researchers concluded that the most effective treatment was sequential washing with thyme oil, ozonated water, and aqueous chlorine dioxide (ClO_2) (Singh et al., 2002).

While most studies of essential oils do not specify whether organic sources were used, we found data from one study of organic thyme. Organic thyme oil from four species in a chitosan film inhibited the growth of the foodborne pathogens *Serratia marcescens, Listeria innocua,* and *Alcaligenes faecalis*. However, it was ineffective in inhibiting *Enterobacter amnigenus* (Ballester-Costa et al., 2016). Scientists also demonstrated that thyme oil inhibits the growth of methicillin-resistant *S. aureus* at a relatively low dose (Shukr & Metwally, 2014).

In another study, scientists treated minced pork inoculated with four subspecies of *Salmonella* with thyme oil and refrigerated it for 15 days (Boskovic et al., 2017). The thyme oil treatment reduced the pathogens at all levels; however, the most effective dose of 0.9% had a flavor that was unacceptable to the professional food science sensory panel (Boskovic et al., 2017).

Thyme oil extracted from *Thymus vulgaris, T. serpyllum,* and *T. zygis* var. gracilis is FDA GRAS (21 CFR 182.20). We found no evidence of thyme oil reported as a food allergen or indicated with other adverse human health effects.

Honeybees tolerate thyme oil with few fatalities when treated for Varroa mites (*Varroa destructor*) at doses between 6 and 30 grams (g) in powdered form over a period of 8 to 49 days (Imdorf et al., 1999). Efficacy increased with both dose and duration (Imdorf et al., 1999). Honey bees had a 50% mortality (LC_{50}) when exposed in a Petri dish to a concentration of 8.05 µL thymol in an alcohol solution for 72 hr (Damiani et al., 2009). Honeybees treated with 12.5 and 25 g of thymol powder for 28 days suffered no significant mortality losses, although losses were not quantified (Calderone et al., 1997). Queen bees appear to be more susceptible to thymol toxicity than worker bees (Whittington et al., 2000). Thyme oil is not toxic to the beneficial predator *Atheta coriaria*, known as the rove beetle (Echegaray & Cloyd, 2012).

<u>Evaluation Question #12: Describe if there are any alternative practices that would make the use of this substance unnecessary [7 U.S.C. 6518(m)(6)].</u>

Heat is one of the oldest practices used to reduce microbial activity in food (Potter & Hotchkiss, 1998). Thermal technologies are defined as those that use temperatures in excess of 80 °C (176 °F) to reduce foodborne pathogens to safe levels (Chiozzi et al., 2022). However, heat degrades most fresh fruits and vegetables (Kader, 2002). Therefore, thermal technologies are not a practical alternative to antimicrobial treatment by ozone for these applications. Non-thermal processing refers to techniques that operate at temperatures less than 30 °C (86 °F) (Chiozzi et al., 2022). Ozonation is a non-thermal process, along with ultraviolet (UV) light, ultrasound, pulsed electric fields, and high hydrostatic pressure processing (Chiozzi et al., 2022; Rawson et al., 2011). Pulsed electric fields and cold plasma are proposed as other non-thermal options (Chiozzi et al., 2022; Režek Jambrak et al., 2018), but they are omitted because, at present, they do not appear to be in widespread commercial use and their status in the organic standards is not clear. These alternative methods are all in commercial use at present and may be used to disinfect foods that are not appropriate for thermal processing (Chiozzi et al., 2022).

Ultraviolet light

UV light has germicidal properties between 200-280 nm in the electromagnetic spectrum, known as UV-C (Choudhary & Bandla, 2012). The FDA does not classify UV as "ionizing radiation" at 21 CFR 179.26, which is prohibited for use in organic production and handling [7 CFR 205.105(f)]. The FDA allows UV to be used on food and food products for surface microorganism control, to sterilize water used in food production, and to reduce human pathogens and other microorganisms in juice products [21 CFR 179.39(b)]. The FDA specifies that the UV light is from low-pressure mercury lamps emitting 90% of the emission at a wavelength of 253.7 nm [21 CFR 179.39(a)]. However, the FDA regulations specify UV used to treat food, food products, and water used as a food ingredient to be generated without ozone production [21 CFR 179.39(b)]. Ozone is produced by UV light from oxygen under standard temperature and pressure exposed to wavelengths below 240 nm on the electromagnetic spectrum (Horvath et al., 1985; SCHEER, 2017).

Microbial inactivation and protein damage are caused by UV-C light being absorbed by the organism's DNA (Chiozzi et al., 2022). The waves cause the formation of DNA photoproducts that result in mutation and cell death (Chiozzi et al., 2022). Applications of UV light for food disinfection include:

- juices (Basak et al., 2023; Koutchma et al., 2016; Rawson et al., 2011)
- fresh fruits and vegetables (Bermúdez-Aguirre & Barbosa-Cánovas, 2013; Chiozzi et al., 2022)
- milk and dairy products (Chawla et al., 2021; Chiozzi et al., 2022)
- meat and poultry products (Chiozzi et al., 2022)
- nuts (Gyawali et al., 2024)

The efficacy of UV-C is a function of radiant energy and exposure time, with greater intensity and longer exposure times causing more cell death (Bermúdez-Aguirre & Barbosa-Cánovas, 2013; Chiozzi et al., 2022; Koutchma et al., 2016). Microorganisms of concern also vary in their susceptibility, with gram negative bacteria being more sensitive (Bermúdez-Aguirre & Barbosa-Cánovas, 2013). Results vary widely by food type, target organism, radiant energy, and exposure time (Bermúdez-Aguirre & Barbosa-Cánovas, 2013; Chiozzi et al., 2022; Noci, 2017). Most studies reported a greater than 1- but less than 5-log reduction in the organism of public health concern with UV-C as the only treatment, with some studies reporting less than a 1-log reduction (Chiozzi et al., 2022; Koutchma et al., 2016; Noci, 2017).

One disadvantage is that UV-C can disinfect only transparent foods and the food surface of opaque foods; it is ineffective where target organisms are shielded from the light (Bermúdez-Aguirre & Barbosa-Cánovas, 2013; Noci, 2017). Another disadvantage is that UV can reduce vitamin C (ascorbic acid) content in juices (Basak et al., 2023; Chiozzi et al., 2022; Koutchma et al., 2016).

Ultrasound

Ultrasound is another physical process used with modest success in controlling various spoilage organisms (Chiozzi et al., 2022; Režek Jambrak et al., 2018; Singla & Sit, 2021; Welti-Chanes et al., 2017). The term "ultrasound" refers to acoustic waves that are above the maximum frequency audible to human, which is approximately 20 kHz (Lacefield, 2014). Food treated with ultrasound is divided into two categories: low intensity with low energy and frequency higher than 100 kHz and high intensity with high energy and low frequency between 20 and 100 kHz (Welti-Chanes et al., 2017). Ultrasound's mode of action is known as "cavitation" or the formation of gas bubbles caused by the sound frequencies (Lacefield, 2014). Cavitation acts on microbes by removing the cells from the food surface, rendering them less resistant to sanitizers (Arvanitoyannis et al., 2017).

Ultrasound is the most commonly used medical diagnostic tool in the 21st century, and is considered one of the safest for humans (Lacefield, 2014). Most food industry applications are low-intensity and used in inspections for quality and detection of foreign matter (Welti-Chanes et al., 2017). High-intensity ultrasound was first used commercially for emulsification in 1960, with food applications among the first group of industrial applications (Mason, 2003). Manufacturers of food-grade ultrasound transducers for cleaning and sanitation include Parsonics (Parsonics, 2024), Kemet (Kemet, 2024), Christeyns (Christeyns, 2024), and Hielscher (Hielscher, 2024).

High-pressure processing

Processors use high-pressure processing (HPP), also known as high hydrostatic pressure (HHP) processing to inactivate microorganisms in juices, milk and dairy products, fruit and vegetable preparations, and meat and poultry products (Aganovic et al., 2021; Cano-Lamadrid & Artés-Hernández, 2022; Chiozzi et al., 2022). For this method, processors put food products in packaging that can withstand high pressure and subject them to hydrostatic pressure between 100 and 1,000 MPa and temperatures between 0 °C and 120 °C (32 °F-248 °F) (Aganovic et al., 2021). Efficacy varies depending on characteristics of the food including (Aganovic et al., 2021):

- pH
- moisture content
- physical composition
- entrapment of microorganisms in the food matrix

The most common application of HPP is decontamination of meat and meat products (Huang et al., 2017). The US Food Safety Inspection Service (US FSIS) recognizes that HPP can achieve a 5-log reduction in *E. coli* O157:H7 and *Salmonella* in ready-to-eat meat and poultry products, but notes that some strains are pressure-resistant (US FSIS, 2012). For that reason, inspection personnel are required to verify that the Hazard Analysis and Critical Control Point (HACCP) plan is effective in achieving the 5-log reduction (US FSIS, 2012). Other pathogenic strains of *E. coli* in beef may be controlled, as well (Sheen et al., 2015).

Fruit and vegetable juice matrices are particularly amenable to HPP and account for a large number of commercial applications of this technology (Huang et al., 2017; Roobab et al., 2021). HPP treated carrot juice had sensory characteristics of color, appearance, aroma, taste, and overall acceptability that were more similar to fresh juice when compared to thermally-treated juice, with approximately the same level of microbial inactivation (Zhang et al., 2016). Compared with UV light and thermal processing, HPP shows excellent retention of vitamin content in various fruit and vegetable juices, particularly vitamin C (Koutchma et al., 2016; Rawson et al., 2011). Thermal processing is sufficient, as long as the processing controls are documented (US FDA, 2004). HPP is not likely to require prior FDA approval because it is a physical process and not a chemical additive or exposure to radioactive substances, unlike ionizing radiation or chemical treatment, but it still needs to be verified and validated by a process authority with expertise in food safety (US FDA, 2004).

Processors can also use HPP in wine production (Bañuelos et al., 2020). While ozone is a substitute for sulfur dioxide and other sulfiting agents, HPP also shows promise as a substitute for no-sulfite-added wines (Bañuelos et al., 2020).

Dairy processors first used HPP to preserve unrefrigerated fluid milk in 1899 (Hite, 1899). Sensory and quality panelists have rated HPP treated milk and plant-based milk substitutes as having superior sensory quality and nutritional content compared to thermally processed versions. Researchers also reported that the HPP treated milk and plant-based milk substitutes achieved comparable levels of pathogen reduction and shelf stability compared to thermally processed versions (Andrés et al., 2016; Goyal et al., 2013; Huppertz, 2010; Rendueles et al., 2011). However, dairy processors have been reluctant to replace thermal pasteurization with HPP pasteurization for various reasons (*e.g.,* cost, regulatory uncertainty, and lack of familiarity with the technology) despite documented benefits in quality and functionality (Huppertz, 2010).

The most frequently mentioned barrier to adoption is the cost. HPP equipment is relatively expensive to purchase when compared with alternative antimicrobial technologies (Aganovic et al., 2021; Chiozzi et al., 2022; Huppertz, 2010). HPP is also more scale-limited than thermal processing because it requires batch processing, and the largest vessels reported to withstand the high pressure have a 600 L (~160 gal) capacity (Huppertz, 2010). The regulations of HPP are also not as clearly defined as with thermal technology, leading to some resistance to its adoption (Huang et al., 2017). Processors in the U.S. that use HPP are responsible for the verification and validation of its efficacy (21 CFR 120.25). High-pressure processing is not likely to require FDA prior approval, but any such assumption should be verified by the process authority specified in the HACCP Plan (US FDA, 2004).

Authors

The following individuals participated in research, data collection, writing, editing, and/or final approval of this report:

- Brian Baker, Principal, Belcairn Concerns LLC
- Peter O. Bungum, Research and Education Manager, OMRI
- Colleen E. Al-Samarrie, Technical Research Analyst, OMRI
- Ashley Shaw, Technical Research and Administrative Specialist, OMRI

All individuals comply with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

Appendix A

Sources of Organic Essential Oils

Table 3 contains a list of USDA NOP certified organic essential oil handlers downloaded from the USDA Organic Integrity Database (OID) on November 4, 2024. The database is a union of the search for "Essential oils", "Cinnamon oil", "Peppermint oil", and "Thyme oil" certified as organic under the handler scope. Handling operations may be distributors and not primary manufacturers. Some operations are certified by more than one agent, with certification agents certifying different essential oils handled by the same handler.

Table 3: Sources of Organic Essential Oils

Operation name[a]	Certified essential oil(s)	Certifier[b]	Country[c]
A G Organica Private Limited	Cinnamon oil, Peppermint oil, Thyme oil	ECO	India
A To Z Beauty, Llc Dba Cliganic	Peppermint oil, Essential oils (other)	QAI	USA
AAC Natural Products Private Limited	Cinnamon oil, Peppermint oil, Thyme oil	MAYA	India
Aadroit Indulgence Pvt. Ltd.	Cinnamon oil, Peppermint oil, Thyme oil	MAYA	India
Aaron Thomas Company, Inc.	Cinnamon oil	QAI	USA
Abdullah Inan-inan Tarim Ürünleri Ticaret	Thyme oil	ECO	Turkey
Actionpak Inc.	Peppermint oil, Essential oils (other)	PCO	USA
Agrinsa Agroindustrial S.a.	Essential oils (other)	OIA	Argentina
Agropecuária Gavião Ltda	Essential oils (other)	IBD	Brazil
Al Dahlia For Import & Export	Peppermint oil, Thyme oil, Essential oils (other)	BIOI	Egypt
All-One-God-Faith, Inc. Dba Dr. Bronner's Magic Soaps, Dba Dr. Bronner's	Cinnamon oil, Peppermint oil	OTCO	USA
Alpha Research & Development Ltd	Peppermint oil, Thyme oil	ECO	USA
Amrita Aromatherapy, Inc.	Essential oils (other)	OTCO	USA
Apple Food Industries	Peppermint oil	ECO	India
Arasa Gida Perakende Yatirim Ve Isletme San. Tic. A.s	Essential oils (other)	OIA	Turkey
Aroma Source Sarl Sarl	Essential oils (other)	ECO	Madagascar
Aromatics Llc	Essential oils (other)	MTDA	USA
Aryan Food Ingredients Ltd	Cinnamon oil, Peppermint oil, Thyme oil	MAYA	India
Aryan International Fzc	Cinnamon oil, Peppermint oil, Thyme oil	BIOI	UAE
ATS Trade Llc	Essential oils (other)	OIA	Argentina
Auburndale Plant Holdings, Llc	Peppermint oil	OTCO	USA
Australian Botanical Products	Peppermint oil, Essential oils (other)	ACO	Australia
Ayanda African Oils	Essential oils (other)	ECO	South Africa
Azafran Innovacion Ltd.	Cinnamon oil, Peppermint oil	ECO	India
Azure Farm	Peppermint oil	OTCO	USA
B D Aromatics Pvt. Ltd.	Peppermint oil	ECO	India
B&B Family Farm	Essential oils (other)	WSDA	USA
B&P Via Pack Brasil Produtos Alimentícios Ltda	Essential oils (other)	IBD	Brazil
Bigaflor Sa	Essential oils (other)	ECO	Tunisia
Bio Extracts (pvt) Ltd.	Essential oils (other)	CUC	Sri Lanka
Bio- Logic Sarl	Essential oils (other)	ECO	Madagascar
Biolandes Maroc Sarl	Essential oils (other)	ECO	Morocco
Bleroch S.a.	Essential oils (other)	OIA	Uruguay
Bonnie House Co., Ltd	Peppermint oil, Essential oils (other)	ACO	Taiwan
Bonnie House Pty Ltd	Peppermint oil, Essential oils (other)	ACO	Australia
Botanic Healthcare Llc	Cinnamon oil, Peppermint oil	ONE	USA
Botanika Tarim Ürünleri Kozmetik Gida Yag San. Tic. Ltd. Sti.	Thyme oil	ECO	Turkey
Bothota Organic Growers	Cinnamon oil	CUC	Sri Lanka
Brasil Citrus Indústria E Comércio Ltda	Essential oils (other)	IBD	Brazil
Bulk Cart (the)	Peppermint oil, Thyme oil	ONE	USA
C & A Service, Inc. - Abington, Md	Peppermint oil, Thyme oil	WFCFO	USA
Callisons, Inc.	Peppermint oil	OTCO	USA
Calosur Industrial S.a.	Essential oils (other)	OIA	Uruguay
Celebration Holdings Private Limited	Peppermint oil, Essential oils (other)	CUC	Sri Lanka
Charasmatic Trading & Consulting	Cinnamon oil, Peppermint oil, Thyme oil	OTCO	USA
Citrus & Allied Essences Ltd - Belcamp	Peppermint oil, Thyme oil	WFCFO	USA

Operation name[a]	Certified essential oil(s)	Certifier[b]	Country[c]
Clear Petroleum S.a.	Essential oils (other)	OIA	Argentina
Colombo Export & Import Agencies (pvt) Ltd	Essential oils (other)	CUC	Sri Lanka
Cosmetik Lab	Essential oils (other)	ECO	Morocco
Cupi Essential	Essential oils (other)	BIOI	Albania
Cvista, Llc	Essential oils (other)	OC	USA
Daily Harvest, Inc.	Peppermint oil	QAI	USA
Delbia Do Company	Essential oils (other)	NFC	USA
Ditco Dis Ticaret Gida San. Ltd. Sti.	Thyme oil	ECO	Turkey
Earthstar Farms, Llc	Essential oils (other)	CDA	USA
Ecocitrus - Cooperativa Dos Citricultores Ecologicos Do Vale Do Cai Ltda.	Essential oils (other)	IBD	Brazil
Ecodab Gida Tarim Kozmetik Yag Yem San.ve Tic.ltd.sti.	Thyme oil	ECO	Turkey
Elaga Sa	Essential oils (other)	ECO	Burundi
Elmar Limité	Essential oils (other)	ECO	Bosnia and Herzegovina
Eoas Organics (pvt) Ltd	Essential oils (other)	CUC	Sri Lanka
Espar S.r.l.	Essential oils (other)	OIA	Argentina
Essenceworks Pty Ltd	Thyme oil, Essential oils (other)	ACO	Australia
Ethereal Ingredients Private Limited	Cinnamon oil, Peppermint oil, Thyme oil	IBD	India
Excellentia Flavours Llc Dba Excellentia International	Peppermint oil, Thyme oil	OTCO	USA
Expo Ceylon	Essential oils (other)	CUC	Sri Lanka
Extracts-unlimited, Llc	Peppermint oil, Thyme oil	OTCO	USA
Fairoils Madagascar Sarl	Essential oils (other)	ECO	Madagascar
Fdb Agroexport S.a.	Essential oils (other)	OIA	Argentina
Filaroma Ltd	Cinnamon oil, Peppermint oil	ECO	Mauritius
Firmenich Inc	Peppermint oil	ECO	USA
Fitzgerald's Organic Farm	Essential oils (other)	WSDA	USA
Flatiron Fields Llc	Essential oils (other)	WSDA	USA
Flavor Producers Llc	Peppermint oil	OTCO	USA
Flavorchem Corporation	Peppermint oil	QAI	USA
Flavorfocus, Llc Dba Brookside Flavors & Ingredients	Peppermint oil	OTCO	USA
Floribis Sarl	Essential oils (other)	ECO	Madagascar
Forest Farmstead	Essential oils (other)	WSDA	USA
Fragrant Garden Sa	Essential oils (other)	ECO	Madagascar
Fuerte Del Bañado S.a.	Essential oils (other)	OIA	Argentina
G R Davis Pty Ltd	Essential oils (other)	ACO	Australia
Galowin S.a.	Essential oils (other)	OIA	Uruguay
Gie Targanine	Essential oils (other)	ECO	Morocco
Global Essence, Inc.	Peppermint oil, Thyme oil	QAI	USA
Going Natural S.r.l.	Essential oils (other)	OIA	Argentina
Gold Coast Ingredients, Inc.	Cinnamon oil, Peppermint oil, Thyme oil	QAI	USA
Golden Grove Naturals Pty Ltd	Peppermint oil, Essential oils (other)	ACO	Australia
Grain Millers, Inc.	Peppermint oil	OTCO	USA
Green Mountain Flavors, Inc.	Cinnamon oil, Peppermint oil	OTCO	USA
Greenleaf Extractions Pvt Ltd	Peppermint oil	BIOI	India
H2ea Sarl	Essential oils (other)	ECO	Morocco
Halilovic D.o.o.	Essential oils (other)	ECO	Bosnia and Herzegovina
Hangzhou Natur Foods Co., Ltd.	Essential oils (other)	IBD	China
Hashem Brothers For Essential Oils And Aromatic Products	Peppermint oil	CUC	Egypt
Hddes Extracts (pvt) Ltd	Cinnamon oil, Peppermint oil, Thyme oil, Essential oils (other)	CUC	Sri Lanka
Ideal Providence Farm Sole Propritorship	Essential oils (other)	ECO	Ghana
Il Health & Beauty Natural Oils Co., Inc.	Peppermint oil, Thyme oil, Essential oils (other)	ONE	USA
Imcd Us Llc	Peppermint oil	QAI	USA
Inducitrica S.a.	Essential oils (other)	OIA	Argentina
Indus Cosmeceuticals Pvt. Ltd.	Cinnamon oil, Peppermint oil, Thyme oil, Essential oils (other)	ECO	India

Operation name[a]	Certified essential oil(s)	Certifier[b]	Country[c]
Intercit Inc Dba Firmenich	Peppermint oil	ECO	USA
Intraflavors	Essential oils (other)	ECO	Madagascar
Jall - Extração E Comercialização De Óleos Essenciais Ltda (aka Oleos Essenciais)	Essential oils (other)	IBD	Brazil
Jardin Du Soleil	Essential oils (other)	WSDA	USA
Jedwards International, Inc.	Peppermint oil	QAI	USA
Joh. Vögele Kg	Peppermint oil, Thyme oil	ECO	Germany
Jsh Farms, Inc. Dba Sunwest Ingredients	Essential oils (other)	ODA	USA
Kerry Ingredients & Flavours	Peppermint oil, Thyme oil	OTCO	USA
La Moraleja S.a.	Essential oils (other)	OIA	Argentina
Labbeemint, Inc.	Essential oils (other)	WSDA	USA
Laboratorio Elea Phoenix S.a.	Essential oils (other)	OIA	Argentina
Lake Alfred Holdings, Llc Dba Florida Caribbean Distillers Lake Alfred, Llc	Peppermint oil	OTCO	USA
Las Frutas Global Gida San. Ve Tic. Ltd. Sti.	Peppermint oil, Thyme oil	ECO	Turkey
Latin Lemon S.a.	Essential oils (other)	OIA	Argentina
Lavender Hill Farm	Essential oils (other)	WSDA	USA
Lebermuth Company (the), Inc.	Peppermint oil, Thyme oil	OTCO	USA
Lemur International, Inc	Essential oils (other)	WFCFO	USA
Lermond Company (the), Llc	Peppermint oil	OTCO	USA
Lihini Nature Products (pvt) Ltd	Essential oils (other)	CUC	Sri Lanka
Litoral Citrus S.a.	Essential oils (other)	ECO	Argentina
Lotus Brands, Inc	Essential oils (other)	WFCFO	USA
M3r International Llc	Essential oils (other)	OIA	Argentina
Mada Perfect Choice (mapec)	Essential oils (other)	ECO	Madagascar
Madamanag Sarl	Essential oils (other)	ECO	Madagascar
Makingcosmetics Inc.	Peppermint oil, Essential oils (other)	WSDA	USA
Mane Kancor Ingredients Private Ltd	Peppermint oil	ECO	India
Maple Holistics Llc	Essential oils (other)	NFC	USA
Marshall's Flavor House, Inc. Dba Avron Resources	Peppermint oil, Thyme oil	OTCO	USA
Matha Exports International Llp	Peppermint oil, Thyme oil	ECO	India
Mava Sa Société Anonyme	Essential oils (other)	ECO	Madagascar
Meabeauty	Peppermint oil	ECO	Tunisia
Mel-co	Essential oils (other)	OC	USA
Metarom Usa, Llc	Peppermint oil	OTCO	USA
Milky Way Trading Dba Get Natural Essential Oils	Peppermint oil, Thyme oil, Essential oils (other)	PCO	USA
Millot Aromatiques Bio	Essential oils (other)	ECO	Madagascar
Moksha Lifestyle Products	Cinnamon oil, Peppermint oil, Thyme oil	MAYA	India
Moksha Organics	Cinnamon oil, Peppermint oil, Thyme oil	ECO	India
Morechem Co., Ltd.	Peppermint oil	CUC	Korea (the Republic of)
Morning Myst Botanics	Essential oils (other)	WSDA	USA
Most Wise International Limited	Peppermint oil	CUC	Hong Kong
Mountain Valley Organics, Llc Dba Mountain Valley Botanics Dba Mountain Valley Garlic	Essential oils (other)	WSDA	USA
Mudar India Exports	Peppermint oil	CUC	India
Nap Naturally Australian Products Pty Ltd	Essential oils (other)	ACO	Australia
Nathan's Naturals Llc	Essential oils (other)	WSDA	USA
Natural Farms Llc	Essential oils (other)	OIA	Argentina
Naturally Australian Products (nap), Inc. Dba Nap Global Essentials	Cinnamon oil, Peppermint oil	OTCO	USA
Navada Imports, Llc	Thyme oil	OTCO	USA
Neikim S.a.	Essential oils (other)	OIA	Uruguay
New Directions Australia	Essential oils (other)	ACO	Australia
Niche Naturals Llc	Essential oils (other)	OIA	USA
Nisarga Biotech Pvt. Ltd.	Peppermint oil	ECO	India
Nishant Aromas Private Limited	Peppermint oil	CUC	India
Norwest Ingredients, Llc	Peppermint oil	OTCO	USA
Noushig, Inc. Dba Amoretti	Peppermint oil	OC	USA
Now Canada (division Of Puresource Corporation)	Peppermint oil	ECO	Canada

Operation name[a]	Certified essential oil(s)	Certifier[b]	Country[c]
Now Foods, Inc.	Peppermint oil, Essential oils (other)	QAI	USA
Nutpro S.r.l.	Essential oils (other)	OIA	Argentina
Nutrin S.a.	Essential oils (other)	OIA	Argentina
Oc Flavors, Llc Dba Mosaic Flavors	Peppermint oil	QAI	USA
Oh, Oh Organic, Inc.	Peppermint oil	OTCO	USA
Onsibon S.a.	Peppermint oil, Essential oils (other)	OIA	Argentina
Organic Botanicals, Llc	Essential oils (other)	WSDA	USA
Organic India Private Limited	Peppermint oil	CUC	India
Organic Infusions Inc	Cinnamon oil, Thyme oil	OC	USA
Organic Suppliers S.r.l	Essential oils (other)	OIA	Argentina
Origines Sarl	Essential oils (other)	ECO	Madagascar
Paclantic Naturals Llc.	Peppermint oil	ECO	USA
Panisal S.a.	Essential oils (other)	OIA	Uruguay
Pearl Banyan Capitol Llc Dba Banyan Botanicals Formerly Known As Banyan Trading Co	Cinnamon oil	QAI	USA
Pehuajo Prome S.a.	Essential oils (other)	OIA	Argentina
Phalada Agro Research Foundations Pvt. Ltd.	Peppermint oil	CUC	India
Phoenix Flavors, Llc	Cinnamon oil, Thyme oil	OTCO	USA
Pikes Peak Organic Manufacturing	Essential oils (other)	WFCFO	USA
Plant Lipids Private Limited	Cinnamon oil	BIOI	India
Plantus Industria E Comércio De Óleos Extratos E Saneantes Ltda	Essential oils (other)	IBD	Brazil
Plenty Foods Pty Ltd	Essential oils (other)	ACO	Australia
Pompeii Street Soap Co.	Essential oils (other)	PCO	USA
Positively Aromatic, Llc	Essential oils (other)	WSDA	USA
Proagri Solutions Llc	Cinnamon oil, Peppermint oil	OTCO	USA
Pt. Tripper Nature	Essential oils (other)	CUC	Indonesia
Pure Essential Oils & Herbs	Peppermint oil, Thyme oil, Essential oils (other)	BIOI	Egypt
Purple Path Farm	Essential oils (other)	WSDA	USA
Quantum Fulfillment And Support Llc	Essential oils (other)	NFC	USA
Quintis Sandalwood Pty Ltd	Essential oils (other)	ACO	Australia
Rakesh Products	Cinnamon oil, Peppermint oil, Thyme oil	CUC	India
Rakesh Sandal Industries	Cinnamon oil, Peppermint oil, Thyme oil	ECO	India
Randriampenomaro Harimanana	Essential oils (other)	ECO	Madagascar
Reliable Products Inc. Dba Reliable Products Inc. / Pure Farms Organic	Thyme oil	OTCO	USA
Reroot Organic Pvt.ltd	Peppermint oil	ECO	India
Robertet, Inc.	Peppermint oil	OTCO	USA
Rocky Mountain Oils	Essential oils (other)	UDAF	USA
Romonti, Inc.	Essential oils (other)	WFCFO	USA
S.a. San Miguel A.g.i.c.i. Y F	Essential oils (other)	OIA	Argentina
S.a. Treated Poles & Timber T/a Windy Ridge Oils Cc	Essential oils (other)	ECO	South Africa
S.a. Veracruz	Essential oils (other)	OIA	Argentina
Santis Sarl	Essential oils (other)	ECO	Morocco
Shemen Tov Corp. Dba Chandeau Oils	Peppermint oil, Thyme oil	OTCO	USA
Sigma Services Corporation - Zion	Essential oils (other)	QAI	USA
South American Grain S.a.	Essential oils (other)	OIA	Argentina
Soyatech Pty Ltd	Essential oils (other)	ACO	Australia
Stabril S.a.	Essential oils (other)	OIA	Uruguay
Sterling Speciality Ingredients Llc	Essential oils (other)	OIA	USA
Sugrain S.a.	Essential oils (other)	OIA	Uruguay
Sunatura Exports Private Limited	Cinnamon oil, Peppermint oil, Thyme oil	CUC	India
Sundale S.a.	Essential oils (other)	OIA	Uruguay
Sunflag Agrotech 2	Peppermint oil	MAYA	India
Sustainable Botanicals International	Peppermint oil, Thyme oil	NFC	USA
Switch Supply Pty Ltd	Cinnamon oil, Peppermint oil, Essential oils (other)	ACO	Australia
Tech-vina Joint Stock Company	Essential oils (other)	CUC	Viet Nam
Tecnodesierto S.a.	Essential oils (other)	OIA	Argentina

Operation name[a]	Certified essential oil(s)	Certifier[b]	Country[c]
Ten Days Manufacturing Dba Daily Manufacturing	Essential oils (other)	OC	USA
Tks Co-pack Manufacturing, Llc	Essential oils (other)	UDAF	USA
Topical Pharmaceuticals Inc	Peppermint oil	ECO	USA
Tribal Medicinals	Peppermint oil	ECO	India
Trustee For Hornshaw Family Trust (the)	Essential oils (other)	ACO	Australia
Tsp Agro S.a.	Essential oils (other)	OIA	Argentina
Türer Tarim Ve Orman Ürünleri Ith. Ihr. San. Ve Tic. Ltd. Sti.	Thyme oil	ECO	Turkey
Uncle Harry's Natural Products	Essential oils (other)	WSDA	USA
Ungerer And Company	Peppermint oil	OTCO	USA
Ute Bv S.a.	Essential oils (other)	OIA	Argentina
Uyar Tarim Ürünleri Gida San. Ve Tic. A.s.	Thyme oil	BIOI	Turkey
Vicente Trapani S.a.	Essential oils (other)	OIA	Argentina
Vietnam Staraniseed Cassia Manufacturing And Exporting Joint Stock Company (vina Samex ., Jsc)	Cinnamon oil, Essential oils (other)	CUC	Viet Nam
Vital Mark Pty Ltd	Essential oils (other)	ACO	Australia
Vlakbult Farming T/a Highland Essential Oils Vlakbult Plaas Boerdery Pty Ltd	Thyme oil	ECO	South Africa
Wee Hoe Cheng Chemicals Pte Ltd	Essential oils (other)	CUC	Singapore
Wholesale Botanics, Inc.	Essential oils (other)	ONE	USA
Wishbone Organics Inc	Essential oils (other)	OIA	USA
Wishbone S.r.l.	Essential oils (other)	OIA	Argentina
Zara Voyages Sarl	Essential oils (other)	ECO	Madagascar

[a] Operation names may be truncated. Note that some essential oils represented as certified organic under the USDA NOP standard may be produced by standards other than the USDA NOP and recognized as equivalent under an international arrangement before it is repackaged under the supervision of a USDA Accredited Certifying Agent.

[b] USDA Accredited Certifying Agents:

- [ACO] ACO Certification Ltd.
- [AI] Americert International
- [BAC] BioAgriCert
- [BCS] Kiwa BCS Öko-Garantie GmbH
- [BIOI] Bio.Inspecta
- [CAAE] Servicio de Certificación CAAE S.L.U.
- [CCOF] CCOF
- [CDA] Colorado Department of Agriculture
- [CERES] CERES
- [CMEX] Certificadora Mexicana de Productos y Procesos Ecologicos SC
- [CUC] Control Union Certifications
- [ECO] Ecocert SAS (formerly Ecocert SA)
- [IBD] IBD Certifications
- [IDA] Idaho Department of Agriculture
- [IDALS] Iowa Department of Agriculture and Land Stewardship
- [IMOC] IMOcert Latinoamerica LTDA
- [LETIS] LETIS S.A.
- [MAYA] Mayacert S.A.
- [MTDA] Montana Department of Agriculture
- [MOSA] Midwest Organic Services Association, Inc.
- [NFC] Natural Food Certifiers
- [OEFFA] Ohio Ecological Food and Farm Association
- [OCI] OneCert, International Private Limited
- [ONE] OneCert, Inc.
- [ODA] Oregon Department of Agriculture
- [OTCO] Oregon Tilth Certified Organic
- [OC] Organic Certifiers, Inc.
- [OCIA] Organic Crop Improvement Association

- [OIA] Organización Internacional Agropecuaria
- [PCO] Pennsylvania Certified Organic
- [QAI] Quality Assurance International
- [QCS] Quality Certification Services
- [SCS] SCS Global Services, Inc.
- [SRS] SRS Certification GmbH
- [TDA] Texas Department of Agriculture
- [TNC] Transitioning to a New Certifier
- [UDAF] Utah Department of Agriculture and Food
- [WSDA] Washington State Department of Agriculture
- [WFCFO] Where Food Comes From Organic (formerly A Bee Organic)

[c] Physical location of the operation where given:

- China = The People's Republic of China
- Laos = Lao People's Democratic Republic
- Netherlands = The Netherlands
- Russia = The Russian Federation
- UAE = United Arab Emirates
- UK = The United Kingdom of Great Britain and Northern Ireland
- USA = The United States of America.

References

Afsah-Hejri, L., Hajeb, P., & Ehsani, R. J. (2020). Application of ozone for degradation of mycotoxins in food: A review. *Comprehensive Reviews in Food Science and Food Safety*, *19*(4), 1777–1808. https://doi.org/10.1111/1541-4337.12594

Aganovic, K., Hertel, C., Vogel, Rudi. F., Johne, R., Schlüter, O., Schwarzenbolz, U., Jäger, H., Holzhauser, T., Bergmair, J., Roth, A., Sevenich, R., Bandick, N., Kulling, S. E., Knorr, D., Engel, K.-H., & Heinz, V. (2021). Aspects of high hydrostatic pressure food processing: Perspectives on technology and food safety. *Comprehensive Reviews in Food Science and Food Safety*, *20*(4), 3225–3266. https://doi.org/10.1111/1541-4337.12763

Agarwal, V., Lal, P., & Pruthi, V. (2008). Prevention of *Candida albicans* biofilm by plant oils. *Mycopathologia*, *165*(1), 13–19.

Agriopoulou, S., Stamatelopoulou, E., Sachadyn-Król, M., & Varzakas, T. (2020). Lactic acid bacteria as antibacterial agents to extend the shelf life of fresh and minimally processed fruits and vegetables: Quality and safety aspects. *Microorganisms*, *8*(6). https://doi.org/10.3390/microorganisms8060952

Alankar, S. (2009). A review on peppermint oil. *Asian Journal of Pharmaceutical and Clinical Research*, *2*(2), 27–33.

Andrés, V., Villanueva, M.-J., & Tenorio, M.-D. (2016). Influence of high pressure processing on microbial shelf life, sensory profile, soluble sugars, organic acids, and mineral content of milk- and soy-smoothies. *LWT*, *65*, 98–105. https://doi.org/10.1016/j.lwt.2015.07.066

Arvanitoyannis, I. S., Kotsanopoulos, K. V., & Savva, A. G. (2017). Use of ultrasounds in the food industry–Methods and effects on quality, safety, and organoleptic characteristics of foods: A review. *Critical Reviews in Food Science and Nutrition*, *57*(1), 109–128.

Aslam, R., Alam, M. S., & Saeed, P. A. (2020). Sanitization potential of ozone and its role in postharvest quality management of fruits and vegetables. *Food Engineering Reviews*, *12*(1), 48–67. https://doi.org/10.1007/s12393-019-09204-0

Austin, H. (2020, September 29). *NOSB Comments~Virtual Fall Meeting~2020. Handling Subcommittee Materials~Written Comments, Comment ID: AMS-NOP-20-0041-0487*. Regulations.gov. https://www.regulations.gov/comment/AMS-NOP-20-0041-0487

Baker, B. P., & Grant, J. A. (2018). *Active ingredients eligible for minimum risk pesticide use: Overview of the profiles*. New York State IPM Program. https://ecommons.cornell.edu/server/api/core/bitstreams/3b1a195d-b17b-43ad-aad0-5d1a04d82cff/content

Ballester-Costa, C., Sendra, E., Fernández-López, J., & Viuda-Martos, M. (2016). Evaluation of the antibacterial and antioxidant activities of chitosan edible films incorporated with organic essential oils obtained from four Thymus species. *Journal of Food Science and Technology*, *53*, 3374–3379.

Bañuelos, M. A., Loira, I., Guamis, B., Escott, C., Del Fresno, J. M., Codina-Torrella, I., Quevedo, J. M., Gervilla, R., Chavarría, J. M. R., de Lamo, S., Ferrer-Gallego, R., Álvarez, R., González, C., Suárez-Lepe, J. A., & Morata, A. (2020). White wine processing by UHPH without SO2. Elimination of microbial populations and effect in oxidative enzymes, colloidal stability and sensory quality. *Food Chemistry*, *332*, 127417. https://doi.org/10.1016/j.foodchem.2020.127417

Basak, S., Shaik, L., & Chakraborty, S. (2023). Effect of ultraviolet and pulsed light treatments on ascorbic acid content in fruit juices-A review of the degradation mechanism. *Food Chemistry Advances*, *2*, 100333. https://doi.org/10.1016/j.focha.2023.100333

Beckett, W. S. (1991). Ozone, air pollution, and respiratory health. *The Yale Journal of Biology and Medicine*, *64*(2), 167.
Behrends, M., Beiderlinden, M., & Peters, J. (2005). Acute lung injury after peppermint oil injection. *Anesthesia & Analgesia*, *101*(4), 1160–1162.

Bell, M. L., Zanobetti, A., & Dominici, F. (2014). Who is more affected by ozone pollution? A systematic review and meta-analysis. *American Journal of Epidemiology*, *180*(1), 15–28.

Beltrán, D., Selma, M. V., Marín, A., & Gil, M. I. (2005). Ozonated water extends the shelf life of fresh-cut lettuce. *Journal of Agricultural and Food Chemistry*, *53*(14), 5654–5663.

Bermúdez-Aguirre, D., & Barbosa-Cánovas, G. V. (2013). Disinfection of selected vegetables under nonthermal treatments: Chlorine, acid citric, ultraviolet light and ozone. *Food Control*, *29*(1), 82–90. https://doi.org/10.1016/j.foodcont.2012.05.073

Bocci, V. (2011). *Ozone*. Springer.

Bogsan, C. S., Nero, L. A., & Todorov, S. D. (2015). From traditional knowledge to an innovative approach for bio-preservation in food by using lactic acid bacteria. In M.-T. Lion (Ed.), *Beneficial Microorganisms in Food and Nutraceuticals* (pp. 1–36). Springer. https://www.academia.edu/download/52828962/Beneficial_Microorganisms_in_Food_and_Nu.pdf#page=10

Boopathy, B., Rajan, A., & Radhakrishnan, M. (2022). Ozone: An alternative fumigant in controlling the stored product insects and pests: A status report. *Ozone: Science & Engineering*, *44*(1), 79–95. https://doi.org/10.1080/01919512.2021.1933899

Boskovic, M., Djordjevic, J., Ivanovic, J., Janjic, J., Zdravkovic, N., Glisic, M., Glamoclija, N., Baltic, B., Djordjevic, V., & Baltic, M. (2017). Inhibition of *Salmonella* by thyme essential oil and its effect on microbiological and sensory properties of minced pork meat packaged under vacuum and modified atmosphere. *International Journal of Food Microbiology*, *258*, 58–67. https://doi.org/10.1016/j.ijfoodmicro.2017.07.011

Botondi, R., Barone, M., & Grasso, C. (2021). A review into the effectiveness of ozone technology for improving the safety and preserving the quality of fresh-cut fruits and vegetables. *Foods*, *10*(4), 748.

Brodowska, A. J., Nowak, A., & Śmigielski, K. (2018). Ozone in the food industry: Principles of ozone treatment, mechanisms of action, and applications: An overview. *Critical Reviews in Food Science and Nutrition*, *58*(13), 2176–2201. https://doi.org/10.1080/10408398.2017.1308313

Burdock, G. (2016). *Fenaroli's handbook of flavor ingredients*. CRC press.

Burt, S. (2004). Essential oils: Their antibacterial properties and potential applications in foods—A review. *International Journal of Food Microbiology*, *94*(3), 223–253.

Calderone, N. W., Wilson, W. T., & Spivak, M. (1997). Plant extracts used for control of the parasitic mites Varroa jacobsoni (Acari: Varroidae) and Acarapis woodi (Acari: Tarsonemidae) in colonies of Apis mellifera (Hymenoptera: Apidae). *Journal of Economic Entomology*, *90*(5), 1080–1086.

CAN/CGSB. (2021a). *Organic Production Systems: General Principles and Management Standards* (32.310-2020). Canadian General Standards Board.

CAN/CGSB. (2021b). *Organic Production Systems: Permitted Substances List* (32.311-2020). Canadian General Standards Board.

Cano-Lamadrid, M., & Artés-Hernández, F. (2022). By-products revalorization with non-thermal treatments to enhance phytochemical compounds of fruit and vegetables derived products: A review. *Foods*, *11*(1). https://doi.org/10.3390/foods11010059

CCOF. (2020, September 30). *RE: Handling Subcommittee: 2022 Sunset Reviews, Comment ID AMS-NOP-20-0041-0640*. Regulations.gov. https://www.regulations.gov/comment/AMS-NOP-20-0041-0640

Chang, Y., Harmon, P. F., Treadwell, D. D., Carrillo, D., Sarkhosh, A., & Brecht, J. K. (2022). Biocontrol potential of essential oils in organic horticulture systems: From farm to fork. *Frontiers in Nutrition*, *8*, 805138.

Chatterjee, D. (1989). An effective formulation for mould- and aflatoxin-free storage of corn. *Letters in Applied Microbiology*, *9*(1), 25–28. https://doi.org/10.1111/j.1472-765X.1989.tb00283.x

Chawla, A., Lobacz, A., Tarapata, J., & Zulewska, J. (2021). UV light application as a mean for disinfection applied in the dairy industry. *Applied Sciences*, *11*(16). https://doi.org/10.3390/app11167285

Chiozzi, V., Agriopoulou, S., & Varzakas, T. (2022). Advances, Applications, and Comparison of Thermal (Pasteurization, Sterilization, and Aseptic Packaging) against Non-Thermal (Ultrasounds, UV Radiation, Ozonation, High Hydrostatic Pressure) Technologies in Food Processing. *Applied Sciences*, *12*(4). https://doi.org/10.3390/app12042202

Cho, G.-L., & Ha, J.-W. (2021). Synergistic effect of citric acid and xenon light for inactivating foodborne pathogens on spinach leaves. *Food Research International*, *142*, 110210.

Choudhary, R., & Bandla, S. (2012). Ultraviolet pasteurization for food industry. *International Journal of Food Science and Nutrition Engineering*, *2*(1), 12–15.

Christeyns. (2024). *Hygeine through cavitation: Ultrasonic cleaning in the food industry*. https://www.christeyns.com/article/hygiene-through-cavitation-ultrasonic-cleaning-in-the-food-industry/

Coimbra, A., Ferreira, S., & Duarte, A. P. (2022). Biological properties of Thymus zygis essential oil with emphasis on antimicrobial activity and food application. *Food Chemistry*, *393*, 133370. https://doi.org/10.1016/j.foodchem.2022.133370

Compressed Gas Association. (1999). Ozone. In *Handbook of Compressed Gases* (pp. 563–567). Springer.

Damiani, N., Gende, L. B., Bailac, P., Marcangeli, J. A., & Eguaras, M. J. (2009). Acaricidal and insecticidal activity of essential oils on *Varroa destructor* (Acari: Varroidae) and *Apis mellifera* (Hymenoptera: Apidae). *Parasitology Research*, *106*(1), 145–152.

Davis, C., Bollinger, L. A., & Dijkema, G. P. J. (2016). The state of the states: Data-driven analysis of the US Clean Power Plan. *Renewable and Sustainable Energy Reviews*, *60*, 631–652. https://doi.org/10.1016/j.rser.2016.01.097

Dayananda, K., Senanayake, U., & Wijesekera, R. (2004). Harvesting, Processing, and Quality Assessment of Cinnamon Products. In P. Ravindran, K. Nirmal Babu, & M. Shylaja (Eds.), *Cinnamon and Cassia: The Genus Cinnamomum* (pp. 130–155). CRC Press.

de Alencar, E. R., Faroni, L. R. D., Soares, N. de F. F., da Silva, W. A., & da Silva Carvalho, M. C. (2012). Efficacy of ozone as a fungicidal and detoxifying agent of aflatoxins in peanuts. *Journal of the Science of Food and Agriculture*, *92*(4), 899–905.

de Oliveira, J. M., de Alencar, E. R., Blum, L. E. B., de Souza Ferreira, W. F., Botelho, S. de C. C., Racanicci, A. M. C., Santos Leandro, E. dos, Mendonça, M. A., Moscon, E. S., Bizerra, L. V. A. dos S., & da Silva, C. R. (2020). Ozonation of Brazil nuts: Decomposition kinetics, control of Aspergillus flavus and the effect on color and on raw oil quality. *LWT*, *123*, 109106. https://doi.org/10.1016/j.lwt.2020.109106

Denny, E. F. K., & Lawrence, B. M. (2007). The distillation of mint oils: History, current theory and practice. In B. M. Lawrence (Ed.), *Mint: The genus Mentha* (pp. 185–216). CRC Press.

Dev Kumar, G., & Ravishankar, S. (2019). Ozonized water with plant antimicrobials: An effective method to inactivate Salmonella enterica on iceberg lettuce in the produce wash water. *Environmental Research*, *171*, 213–217. https://doi.org/10.1016/j.envres.2018.11.023

Devlieghere, F., Vermeiren, L., & Debevere, J. (2004). *New preservation technologies: Possibilities and limitations*. *14*(4), 273–285. Scopus. https://doi.org/10.1016/j.idairyj.2003.07.002

Diksha, Samandeep, Rehal, J., & Kaur, J. (2023). Removal of pesticide residues in food using ozone. *Food Chemistry Advances*, *3*, 100512. https://doi.org/10.1016/j.focha.2023.100512

Dubey, P., Singh, A., & Yousuf, O. (2022). Ozonation: An evolving disinfectant technology for the food industry. *Food and Bioprocess Technology*, *15*(9), 2102–2113. https://doi.org/10.1007/s11947-022-02876-3

Dwivedy, A. K., Kumar, M., Upadhyay, N., Prakash, B., & Dubey, N. K. (2016). Plant essential oils against food borne fungi and mycotoxins. *Food Mycology*, *11*, 16–21. https://doi.org/10.1016/j.cofs.2016.08.010

Echegaray, E. R., & Cloyd, R. A. (2012). Effects of reduced-risk pesticides and plant growth regulators on rove beetle (Coleoptera: Staphylinidae) adults. *Journal of Economic Entomology*, *105*(Copyright (C) 2015 American Chemical Society (ACS). All Rights Reserved.), 2097–2106. https://doi.org/10.1603/EC12244

EGTOP. (2014). *Final report on food (III)*. Expert Group for Technical Advice on Organic Production. https://agriculture.ec.europa.eu/document/download/75909936-89df-4141-980b-ffb71f23f763_en?filename=egtop-final-report-food-iii_en.pdf

EGTOP. (2016). *Final report on cleaning and disinfection*. Expert Group for Technical Advice on Organic Production. https://agriculture.ec.europa.eu/document/download/4ff119b1-b95a-48af-bbff-0830027e337c_en?filename=final_report_egtop_on_cleaning_disinfectant_en.pdf

EGTOP. (2021). *Criteria for evaluation of products for cleaning and disinfection* [Final Report]. Expert Group for Technical Advice on Organic Production. https://agriculture.ec.europa.eu/document/download/4ff119b1-b95a-48af-bbff-0830027e337c_en?filename=final_report_egtop_on_cleaning_disinfectant_en.pdf

Eliuz, E. (2020). Antimicrobial activity of citric acid against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans* as a sanitizer agent. *Eurasian Journal of Forest Science*, *8*(3), 295–301.

Ellis, M. D., & Baxendale, F. P. (1997). Toxicity of seven monoterpenoids to tracheal mites (Acari: Tarsonemidae) and their honey bee (Hymenoptera: Apidae) hosts when applied as fumigants. *Journal of Economic Entomology*, *90*(5), 1087–1091.

EPRI. (2001). *The use of ozone as an antimicrobial agent: Agricultural and food processing technical assessment*. Electric Power Research Institute.

EU Commission. (2007). *On organic production and labelling of organic products and repealing Council Regulation (EEC) No 2092/91* (EC 834/2007). https://eur-lex.europa.eu/eli/reg/2007/834/oj

EU Commission. (2008a). *Organic production and labelling of organic products with regard to organic production, labelling and control* (EC 889/2008). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:250:0001:0084:EN:PDF

EU Commission. (2008b). *Laying down detailed rules for implementation of Council Regulation (EC) No 834/2007 as regards the arrangements for imports of organic products from third countries* (EC 1235/2008). https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008R1235

EU Commission. (2018). *On organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007* (EC 2018/848). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:250:0001:0084:EN:PDF

EU Commission. (2021). *Authorising certain products and substances for use in organic production and establishing their lists* (EC 2021/1165). https://eur-lex.europa.eu/eli/reg_impl/2021/1165/oj

Ezzaky, Y., Elmoslih, A., Silva, B. N., Bonilla-Luque, O. M., Possas, A., Valero, A., Cadavez, V., Gonzales-Barron, U., & Achemchem, F. (2023). In vitro antimicrobial activity of extracts and essential oils of Cinnamomum, Salvia, and Mentha spp. Against foodborne pathogens: A meta-analysis study. *Comprehensive Reviews in Food Science and Food Safety*, *22*(6), 4516–4536.

Fan, X., & Song, Y. (2020). Advanced oxidation process as a postharvest decontamination technology to improve microbial safety of fresh produce. *Journal of Agricultural and Food Chemistry*, *68*(46), 12916–12926.

FAO/WHO Joint Standards Programme. (2013). *Codex Alimentarius Guidelines for the Production, Processing, Labelling and Marketing of Organic Processed Foods* (3rd ed.). FAO/WHO. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXG%2B32-1999%252Fcxg_032e.pdf

Fasake, V., Dash, S. K., Dhalsamant, K., Sahoo, N. R., & Pal, U. S. (2022). Effect of ozone and antimicrobial treatments on the shelf life of cauliflower under modified atmosphere packaging. *Journal of Food Science and Technology*, *59*(8), 2951–2961. https://doi.org/10.1007/s13197-021-05326-8

FEMA Expert Panel. (2022). GRAS Flavoring Substances. *Food Technology*, *76*(3), 58–70.

Floare, A.-D., Dumitrescu, R., Alexa, V. T., Balean, O., Szuhanek, C., Obistioiu, D., Cocan, I., Neacsu, A.-G., Popescu, I., Fratila, A. D., & Galuscan, A. (2023). Enhancing the Antimicrobial Effect of Ozone with Mentha piperita Essential Oil. *Molecules*, *28*(5). https://doi.org/10.3390/molecules28052032

Foley, P., & Kirschner, M. J. (2022). Ozone. In *Ullmann's Encyclopedia of Industrial Chemistry* (6th ed., pp. 1–10). Wiley-VCH. https://doi.org/10.1002/14356007.a18_349.pub2

Forney, C. F., Song, J., Fan, L., Hildebrand, P. D., & Jordan, M. A. (2003). Ozone and 1-methylcyclopropene alter the postharvest quality of broccoli. *Journal of the American Society for Horticultural Science*, *128*(3), 403–408.

Galdeano, M. C., Wilhelm, A. E., Goulart, I. B., Tonon, R. V., Freitas-Silva, O., Germani, R., & Chávez, D. W. H. (2018). Effect of water temperature and pH on the concentration and time of ozone saturation. *Brazilian Journal of Food Technology*, *21*(0). https://doi.org/10.1590/1981-6723.15617

Gende, L. B., Maggi, M. D., Damiani, N., Fritz, R., Eguaras, M. J., & Floris, I. (2009). Advances in the apiary control of the honeybee American Foulbrood with Cinnamon (*Cinnamomum zeylanicum*) essential oil. *Bulletin of Insectology*, *62*(1), 93–97.

Geweely, N. S. (2022). A novel comparative review between chemical, natural essential oils and physical (ozone) conservation of archaeological objects against microbial deterioration. *Geomicrobiology Journal*, *39*(6), 531–540.

Gordon, E. R. (2024). Density and Specific Gravity. In *Fundamentals of general organic and biological chemistry*. LibreTexts. https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Fundamentals_of_General_Organic_and_Biological_Chemistry_(LibreTexts)/01%3A_Matter_and_Measurements/1.12%3A_Density_and_Specific_Gravity

Goyal, A., Sharma, V., Upadhyay, N., Sihag, M., & Kaushik, R. (2013). High pressure processing and its impact on milk proteins: A review. *J. Dairy Sci. Technol*, *2*(1), 2319–3409.

Greene, A. K., Güzel-Seydim, Z. B., & Seydim, A. C. (2012). Chemical and physical properties of ozone. In *Ozone in food processing* (pp. 19–31). Wiley Online Library.

Grosse, A. V., & Stokes, C. S. (1967). *Method for the production of ozone using a plasma jet* (US Patent Office Patent 3,309,300).

Grulke, N. E., & Heath, R. L. (2020). Ozone effects on plants in natural ecosystems. *Plant Biology*, *22*(S1), 12–37. https://doi.org/10.1111/plb.12971

Guicherit, R., & Roemer, M. (2000). Tropospheric ozone trends. *Chemosphere - Global Change Science*, *2*(2), 167–183. https://doi.org/10.1016/S1465-9972(00)00008-8

Günthardt-Goerg, M. S., Schläpfer, R., & Vollenweider, P. (2023). Responses to airborne ozone and soilborne metal pollution in afforestation plants with different life forms. *Plants*, *12*(16), 3011.

Gupta, C., Garg, A. P., Uniyal, R. C., & Kumari, A. (2008). Antimicrobial activity of some herbal oils against common food-borne pathogens. *African Journal of Microbiology Research*, *2*(10), 258–261.

Guzel-Seydim, Z. B., Greene, A. K., & Seydim, A. (2004). Use of ozone in the food industry. *LWT-Food Science and Technology*, *37*(4), 453–460.

Gyawali, R., Mahapatra, A. K., Bardsley, C. A., & Niemira, B. A. (2024). Nonthermal techniques, antimicrobial agents, and packaging methods to improve the microbial safety of nuts. *Trends in Food Science & Technology*, *146*, 104363. https://doi.org/10.1016/j.tifs.2024.104363

Hayes, J. R., Stavanja, M. S., & Lawrence, B. M. (2007). Biological and toxicological properties of mint oils and their major isolates: Safety assessment. In B. M. Lawrence (Ed.), *Mint: The genus Mentha.* (pp. 422–491). CRC Press.

Hielscher. (2024). *Ultrasound in the food industry*. https://www.hielscher.com/food_01.htm

Hili, P., Evans, C., & Veness, R. (1997). Antimicrobial action of essential oils: The effect of dimethylsulphoxide on the activity of cinnamon oil. *Letters in Applied Microbiology*, *24*(4), 269–275.

Hite, B. H. (1899). *The effect of pressure in the preservation of milk: A preliminary report* (Bulletin 58). West Virginia Agricultural Experiment Station.

Horvath, M., Bilitzky, L., & Huttner, J. (1985). *Ozone*. Elsevier.

Huang, H.-W., Wu, S.-J., Lu, J.-K., Shyu, Y.-T., & Wang, C.-Y. (2017). Current status and future trends of high-pressure processing in food industry. *Food Control*, *72*, 1–8. https://doi.org/10.1016/j.foodcont.2016.07.019

Huppertz, T. (2010). High pressure processing of milk. In M. W. Griffiths (Ed.), *Improving the Safety and Quality of Milk* (pp. 373–399). Woodhead Publishing. https://doi.org/10.1533/9781845699420.4.373

Hyldgaard, M., Mygind, T., & Meyer, R. L. (2012). Essential oils in food preservation: Mode of action, synergies, and interactions with food matrix components. *Frontiers in Microbiology*, *3*. https://doi.org/10.3389/fmicb.2012.00012

IFOAM. (2014). *IFOAM Norms*. IFOAM. https://www.ifoam.bio/en/ifoam-norms

Imdorf, A., Bogdonoff, S., Ochoa, R. I., & Calderone, N. W. (1999). Use of essential oils for the control of Varroa jacobsoni Oud. In honey bee colonies. *Apidologie*, *30*(2–3), 209–228.

In, Y.-W., Kim, J.-J., Kim, H.-J., & Oh, S.-W. (2013). Antimicrobial activities of acetic acid, citric acid and lactic acid against *Shigella* species. *Journal of Food Safety*, *33*(1), 79–85. https://doi.org/10.1111/jfs.12025

Japanese Agricultural Standard for Organic Processed Foods, 18 Japanese Agricultural Standard (2022). https://www.japaneselawtranslation.go.jp/notices/view/134

JECFA. (2001). *Evaluation of certain food additives and contaminants*. World Health Organization. http://whqlibdoc.who.int/trs/WHO_TRS_901.pdf

Jerrett, M., Burnett, R. T., Pope, C. A., Ito, K., Thurston, G., Krewski, D., Shi, Y., Calle, E., & Thun, M. (2009). Long-term ozone exposure and mortality. *New England Journal of Medicine*, *360*(11), 1085–1095. https://doi.org/10.1056/NEJMoa0803894

Jian, F., Jayas, D. S., & White, N. D. (2013). Can ozone be a new control strategy for pests of stored grain? *Agricultural Research*, *2*, 1–8.

Jimenez-Montenegro, L., Lopez-Fernandez, M., & Gimenez, E. (2021). Worldwide Research on the Ozone Influence in Plants. *Agronomy*, *11*(8). https://doi.org/10.3390/agronomy11081504

Kader, A. A. (2002). *Postharvest Technology of Horticultural Crops*. University of California, Agriculture and Natural Resources. https://books.google.com/books?id=O1zhx2OWftQC

Kemet. (2024). *Ultrasonic cleaning for the food industry*. https://www.kemet.co.uk/blog/cleaning/ultrasonic-cleaning-for-the-food-industry#:~:text=Ultrasonic%20cleaning%20ensures%20thorough%20sanitation,and%20complying%20with%20safety%20regulations.

Khadre, M. A., Yousef, A. E., & Kim, J.-G. (2001). Microbiological Aspects of Ozone Applications in Food: A Review. *Journal of Food Science*, *66*(9), 1242–1252. https://doi.org/10.1111/j.1365-2621.2001.tb15196.x

Khan, I. A., & Abourashed, E. A. (2010). *Leung's encyclopedia of common natural ingredients used in food, drugs, and cosmetics /* (3rd ed.). John Wiley & Sons. http://encompass.library.cornell.edu/cgi-bin/checkIP.cgi?access=gateway_standard%26url=http://app.knovel.com/web/toc.v/cid:kpLECNIUF1

Kim, J.-G., Yousef, A. E., & Khadre, M. A. (2003). Ozone and its current and future application in the food industry. In *Advances in Food and Nutrition Research* (Vol. 45, pp. 167–218). Academic Press. https://doi.org/10.1016/S1043-4526(03)45005-5

Klaassen, C. D. (Ed.). (2001). *Casarett and Doull's Toxicology: The basic science of poisons* (6th ed.). McGraw-Hill.

Kleanthous, C. (2010). Swimming against the tide: Progress and challenges in our understanding of colicin translocation. *Nature Reviews Microbiology*, *8*(12), 843–848. https://doi.org/10.1038/nrmicro2454

KMAFRA. (2020). *Enforcement Rule Of The Act On The Promotion Of Environment-Friendly Agriculture And Fisheries And The Management Of And Support For Organic Foods*. Korean (Republic of) Ministry of Agriculture, Food, and Rural Affairs.

Koutchma, T., Popović, V., Ros-Polski, V., & Popielarz, A. (2016). Effects of Ultraviolet Light and High-Pressure Processing on Quality and Health-Related Constituents of Fresh Juice Products. *Comprehensive Reviews in Food Science and Food Safety*, *15*(5), 844–867. https://doi.org/10.1111/1541-4337.12214

Kraus, B., Koeninger, N., & Fuchs, S. (1994). Screening of Substances for their effect on *Varroa jacobsoni* – Attractiveness, repellency, toxicity and masking effects of ethereal oils. *Journal of Apicultural Research*, *33*(1), 34–43.

Lacefield, J. (2014). Physics of ultrasound. In D. Dance, S. Christofides, A. Maidment, I. McLean, & K. Ng (Eds.), *Diagnostic radiology physics: A handbook for teachers and students* (pp. 291–309). International Atomic Energy Agency.

Laranjo, M., Fernandez-Leon, A. M., Potes, M., Agulhero-Santos, A., & Elias, M. (2017). Use of essential oils in food preservation. In A. Mendez-Vilas (Ed.), *Antimicrobial Research: Novel Bioknowledge and Educational Programs* (pp. 177–188). Formatex Research Center.

Lawrence, B. M. (2007). Oil composition of other *Mentha* species and hybrids. In B. M. Lawrence (Ed.), *Mint: The genus Mentha* (pp. 325–346). CRC Press.

Lawrence, B. M., Tucker, A. O., Stahl-Biskup, E., & Sáez, F. (2002). The genus Thymus as a source of commercial products. In *Thyme. The genus Thymus* (pp. 252–262). CRC Press.

Lim, S., Shi, J. L., von Gunten, U., & McCurry, D. L. (2022). Ozonation of organic compounds in water and wastewater: A critical review. *Water Research*, *213*, 118053. https://doi.org/10.1016/j.watres.2022.118053

Lippmann, M. (1989). Health effects of ozone a critical review. *JAPCA*, *39*(5), 672–695.

Lis-Balchin, M., Deans, S. G., & Eaglesham, E. (1998). Relationship between bioactivity and chemical composition of commercial essential oils. *Flavour and Fragrance Journal*, *13*(2), 98–104. https://doi.org/10.1002/(SICI)1099-1026(199803/04)13:2<98::AID-FFJ705>3.0.CO;2-B

Madan, M., & Kannan, S. (2004). Economics and Marketing of Cinnamon and Cassia–A Global View. In P. Ravindran, K. Nirmal Babu, & M. Shylaja (Eds.), *Cinnamon and cassia: The genus Cinnamomum* (pp. 285–310). CRC.

Mahony, J., McAuliffe, O., Ross, R. P., & Van Sinderen, D. (2011). Bacteriophages as biocontrol agents of food pathogens. *Current Opinion in Biotechnology*, *22*(2), 157–163.

Malekmohammad, K., Rafieian-Kopaei, M., Sardari, S., & Sewell, R. D. E. (2021). Toxicological effects of Mentha x piperita (peppermint): A review. *Toxin Reviews*, *40*(4), 445–459. https://doi.org/10.1080/15569543.2019.1647545

Mani-López, E., García, H., & López-Malo, A. (2012). Organic acids as antimicrobials to control Salmonella in meat and poultry products. *Food Research International*, *45*(2), 713–721.

Mason, T. J. (2003). Sonochemistry and sonoprocessing: The link, the trends and (probably) the future. *Selected Papers from the Eighth Conference of the European Society of Sonochemistry*, *10*(4), 175–179. https://doi.org/10.1016/S1350-4177(03)00086-5

Mayookha, V. P., Pandiselvam, R., Kothakota, A., Padma Ishwarya, S., Chandra Khanashyam, A., Kutlu, N., Rifna, E. J., Kumar, M., Panesar, P. S., & Abd El-Maksoud, A. A. (2023). Ozone and cold plasma: Emerging oxidation technologies for inactivation of enzymes in fruits, vegetables, and fruit juices. *Food Control*, *144*, 109399. https://doi.org/10.1016/j.foodcont.2022.109399

Menzel, D. B. (1984). Ozone: An overview of its toxicity in man and animals. *Journal of Toxicology and Environmental Health*, *13*(2–3), 181–204. https://doi.org/10.1080/15287398409530493

Misiou, O., van Nassau, T. J., Lenz, C. A., & Vogel, R. F. (2018). The preservation of Listeria-critical foods by a combination of endolysin and high hydrostatic pressure. *International Journal of Food Microbiology*, *266*, 355–362. https://doi.org/10.1016/j.ijfoodmicro.2017.10.004

Montes-Belmont, R., & Carvajal, M. (1998). Control of *Aspergillus flavus* in maize with plant essential oils and their components. *Journal of Food Protection*, *61*(5), 616–619.

Mostashari, P., Gavahian, M., Jafarzadeh, S., Guo, J.-H., Hadidi, M., Pandiselvam, R., Huseyn, E., & Mousavi Khaneghah, A. (2022). Ozone in wineries and wine processing: A review of the benefits, application, and perspectives. *Comprehensive Reviews in Food Science and Food Safety*, *21*(4), 3129–3152. https://doi.org/10.1111/1541-4337.12971

NASA. (2015). *Ozone Facts*. Goddard Space Flight Center, National Aeronautics and Space Administration. https://ozonewatch.gsfc.nasa.gov/facts/SH.html

Nath, S. S., Pandey, C., & Roy, D. (2012). A near fatal case of high dose peppermint oil ingestion-Lessons learnt. *Indian Journal of Anaesthesia*, *56*(6), 582.

National Center for Biotechnology Information. (2024). *Pubchem compound summary for cid 24823, ozone*. https://pubchem.ncbi.nlm.nih.gov/compound/24823

Neme, K., & Mohammed, A. (2017). Mycotoxin occurrence in grains and the role of postharvest management as a mitigation strategies. A review. *Food Control*, *78*, 412–425. https://doi.org/10.1016/j.foodcont.2017.03.012

Newman, J. R., Schreiber, R. K., & Novakova, E. (1992). Air Pollution Effects on Terrestrial and Aquatic Animals. In J. R. Barker & D. T. Tingey (Eds.), *Air Pollution Effects on Biodiversity* (pp. 177–233). Springer US. https://doi.org/10.1007/978-1-4615-3538-6_10

NIOSH. (2019, October 30). *Ozone*. NIOSH Pocket Guide to Chemical Hazards. https://www.cdc.gov/niosh/npg/npgd0476.html

Noci, F. (2017). Dairy products processed with ultrasound. In D. Bermudez-Aguirre (Ed.), *Ultrasound: Advances for Food Processing and Preservation* (pp. 145–180). Academic Press. https://doi.org/10.1016/B978-0-12-804581-7.00006-3

NOP. (1995). *Technical advisory panel report, processing: Ozone*. https://www.ams.usda.gov/sites/default/files/media/Oz18%20Technical%20Advisory%20Panel%20Report%20%281995%29.pdf

NOP. (2015). *Policy memorandum 15-2 (nanotechnology)*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP-PM-15-2-Nanotechnology.pdf

NOP. (2016a). *Guidance 5033-1, decision tree for classification of materials as synthetic or nonsynthetic*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP-Synthetic-NonSynthetic-DecisionTree.pdf

NOP. (2016b). *NOP 5033-2, guidance, decision tree for classification of agricultural and nonagricultural materials for organic livestock production or handling.* National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP-Ag-NonAg-DecisionTree.pdf

NOP. (2016c, January 15). *NOP 5023: Guidance, substances used in post-harvest handling of organic products.* National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP%205023%20Post%20Harvest%20Hdlg%20Rev01.pdf

NOP. (2024). *USDA Organic Integrity Database*. https://organic.ams.usda.gov/integrity/

NOSB. (1995a). *Final minutes of the National Organic Standards Board full board meeting, Austin, TX, October 31-November 4, 1995*. USDA Agricultural Marketing Service. http://www.ams.usda.gov/sites/default/files/media/Thiram%20minutes%201995.pdf

NOSB. (1995b). *Technical Advisory Panel report, processing: Nisin*. https://www.ams.usda.gov/sites/default/files/media/Nis%20Technical%20Advisory%20Panel%20Report.pdf

NOSB. (2007). *Sunset: Ozone gas* [Formal recommendation of the National Organic Standards Board (NOSB) to the National Organic Program (NOP):]. USDA Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/NOP%20Final%20Sunset%20Rec%20Ozone%20Gas%20in%20Crops.pdf

NOSB. (2010). *Reaffirmation of Sunset recommendations for 205.605 (a) & (b) and 205.606 materials from the April 2010 NOSB meeting* [Formal recommendation of the National Organic Standards Board (NOSB) to the National Organic Program (NOP):]. USDA Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/NOP%20Final%20Sunset%20Rec%20Ozone%20Gas%20in%20Crops.pdf

NOSB. (2015). *Sunset 2017 NOSB final review handling substances §205.605(b)* [Formal recommendation of the National Organic Standards Board (NOSB) to the National Organic Program (NOP):]. USDA Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/HS%202017%20Sunset%20Final%20Rvw%20605%28a%29_%28b%29_606_final%20rec.pdf

NOSB. (2020a). *2022 Sunset reviews—Handling (§§ 205.605, 205.606)* [Formal recommendation of the National Organic Standards Board (NOSB) to the National Organic Program (NOP):]. USDA Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/HS2022SunsetRecs_webpost.pdf

NOSB. (2020b, October 1). *Meetings: National Organic Standards Board, Docket# AMS-NOP-20-0041*. Regulations.Gov. https://www.regulations.gov/document/AMS-NOP-20-0041-0001

NTP. (1994). *NTP toxicology and carcinogenesis studies of ozone (CAS No. 10028-15-6) and Ozone/NNK (CAS No. 10028-15-6/64091-91-4) in F344/N rats and B6C3F1 mice (inhalation studies)* (National Toxicology Program Technical Report Series 440; pp. 1–314). US National Institute for Environmental Health Services National Toxiclogy Porgram. https://pubmed.ncbi.nlm.nih.gov/12595923/

O'Donnell, C., Tiwari, B. K., Cullen, P., & Rice, R. G. (2012). *Ozone in food processing*. John Wiley & Sons.

Okada, F., & Naya, K. (2012). Electrolysis for ozone water production. In V. Linkov & J. Kleperis (Eds.), *Electrolysis* (p. Ch. 12). IntechOpen. https://doi.org/10.5772/51945

Orellano, P., Reynoso, J., Quaranta, N., Bardach, A., & Ciapponi, A. (2020). Short-term exposure to particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), and ozone (O3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. *Environment International*, *142*, 105876. https://doi.org/10.1016/j.envint.2020.105876

Organic Agricultural Promotion Act (2018). https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=M0030093

Organic Foods Production Act of 1990, 7 U.S.C. §6501 § 6501 (1990). https://uscode.house.gov/view.xhtml?path=/prelim@title7/chapter94&edition=prelim

Organic Produce Wholesalers Coalition. (2020, September 29). *Comments to NOSB from Organic Produce Wholesalers Coalition, Comment ID AMS-NOP-20-0041-0614*. Regulations.gov. https://www.regulations.gov/comment/AMS-NOP-20-0041-0614

Organic Trade Association. (2020, October 2). *RE: Handling subcommittee—2022 sunset reviews for §205.605, Comment ID AMS-NOP-20-0041-0729*. Regulations.gov. https://www.regulations.gov/comment/AMS-NOP-20-0041-0729

O'Sullivan, L., Bolton, D., McAuliffe, O., & Coffey, A. (2019). Bacteriophages in food applications: From foe to friend. *Annual Review of Food Science and Technology*, *10*, 151–172.

Palou, L., Crisosto, C. H., Smilanick, J. L., Adaskaveg, J. E., & Zoffoli, J. P. (2002). Effects of continuous 0.3 ppm ozone exposure on decay development and physiological responses of peaches and table grapes in cold storage. *Postharvest Biology and Technology*, *24*(1), 39–48.

Pandiselvam, R., Subhashini, S., Banuu Priya, E., Kothakota, A., Ramesh, S., & Shahir, S. (2019). Ozone based food preservation: A promising green technology for enhanced food safety. *Ozone: Science & Engineering*, *41*(1), 17–34.

Parsonics. (2024). *Ultrasound technology in food manufacturing*. https://parsonicscorp.com/about-us/

Pauli, A., & Schilcher, H. (2009). *In Vitro* antimicrobial activities of essential oils monographed in the European Pharmacopoeia 6th edition. In K. H. C. Baser & G. Buchbauer, *Handbook of essential oils: Science, technology, and applications* (pp. 353–547). CRC Press.

Pérez, A. G., Sanz, C., Ríos, J. J., Olias, R., & Olías, J. M. (1999). Effects of ozone treatment on postharvest strawberry quality. *Journal of Agricultural and Food Chemistry*, *47*(4), 1652–1656.

Perry, J. J., Peña-Melendez, M., & Yousef, A. E. (2019). Ozone-based treatments for inactivation of Salmonella enterica in tree nuts: Inoculation protocol and surrogate suitability considerations. *International Journal of Food Microbiology*, *297*, 21–26. https://doi.org/10.1016/j.ijfoodmicro.2019.02.025

Pohlman, F. W. (2012). Ozone in meat processing. In C. O' Donnell, B. K. Tiwari, P. Cullen, & R. G. Rice (Eds.), *Ozone in food processing* (pp. 123–136). Wiley Online Library.

Potter, N. N., & Hotchkiss, J. H. (1998). *Food science* (5th ed.). Aspen.

Prabha, V., Barma, R. D., Singh, R., & Madan, A. (2015). Ozone technology in food processing: A review. *Trends in Biosciences*, *8*(16), 4031–4047.

Ravindran, P., Shylaja, M., Nirmal Babu, K., & Krishnamoorthy, B. (2004). Botany and crop improvement of cinnamon and cassia. In P. Ravindran, K. Babu, & M. Shylaja (Eds.), *Cinnamon and cassia: The genus Cinnamomum* (pp. 14–79). CRC.

Rawat, D. (2021). Essential oils in organic agriculture: A review of practices and potential. *Natural Volatiles and Essential Oils*, *8*(2), 182–189.

Rawson, A., Patras, A., Tiwari, B. K., Noci, F., Koutchma, T., & Brunton, N. (2011). Effect of thermal and non thermal processing technologies on the bioactive content of exotic fruits and their products: Review of recent advances. *Exotic Fruits: Their Composition, Nutraceutical and Agroindustrial Potential*, *44*(7), 1875–1887. https://doi.org/10.1016/j.foodres.2011.02.053

Rendueles, E., Omer, M. K., Alvseike, O., Alonso-Calleja, C., Capita, R., & Prieto, M. (2011). Microbiological food safety assessment of high hydrostatic pressure processing: A review. *LWT - Food Science and Technology*, *44*(5), 1251–1260. https://doi.org/10.1016/j.lwt.2010.11.001

Režek Jambrak, A., Vukušić, T., Donsi, F., Paniwnyk, L., & Djekic, I. (2018). Three pillars of novel nonthermal food technologies: Food safety, quality, and environment. *Journal of Food Quality*, *2018*(1), 8619707. https://doi.org/10.1155/2018/8619707

Rice, R. G. (2012). Health and safety aspects of ozone processing. In C. O' Donnell, B. K. Tiwari, P. Cullen, & R. G. Rice (Eds.), *Ozone in food processing* (pp. 265–288). Wiley Online Library.

Rice, R. G., Robson, C. M., Miller, G. W., & Hill, A. G. (1981). Uses of ozone in drinking water treatment. *Journal (American Water Works Association)*, *73*(1), 44–57. JSTOR.

Richards, B. L., Middleton, J. T., & Hewitt, W. B. (1958). Air pollution with relation to agronomic crops: V. Oxidant stipple of grape. *Agronomy Journal*, *50*(9), 559–561. https://doi.org/10.2134/agronj1958.00021962005000090019x

Richkind, K. E. (1979). *Genetic responses to air pollution in mammalian populations.* [University of California, Los Angeles]. https://www.cabidigitallibrary.org/doi/full/10.5555/19790147444

Richkind, K. E., & Hacker, A. D. (1980). Responses of natural wildlife populations to air pollution. *Journal of Toxicology and Environmental Health*, *6*(1), 1–10. https://doi.org/10.1080/15287398009529826

Ricke, S. (2003). Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. *Poultry Science*, *82*(4), 632–639.

Rideal, S. (1909). The purification of water by ozone. *Journal of the Royal Sanitary Institute*, *30*(1), 32–57. https://doi.org/10.1177/146642400903000104

Ríos, J.-L. (2016). Essential oils: What they are and how the terms are used and defined. In V. R. Preedy (Ed.), *Essential Oils in Food Preservation, Flavor and Safety* (pp. 3–10). Academic Press. https://doi.org/10.1016/B978-0-12-416641-7.00001-8

Roobab, U., Shabbir, M. A., Khan, A. W., Arshad, R. N., Bekhit, A. E.-D., Zeng, X.-A., Inam-Ur-Raheem, M., & Aadil, R. M. (2021). High-pressure treatments for better quality clean-label juices and beverages: Overview and advances. *LWT*, *149*, 111828. https://doi.org/10.1016/j.lwt.2021.111828

Rozema, E. A., Stephens, T. P., Bach, S. J., Okine, E. K., Johnson, R. P., Stanford, K., & Mcallister, T. A. (2009). Oral and rectal administration of bacteriophages for control of Escherichia coli O157:H7 in feedlot cattle. *Journal of Food Protection*, *72*(2), 241–250. https://doi.org/10.4315/0362-028X-72.2.241

Sarron, E., Gadonna-Widehem, P., & Aussenac, T. (2021). Ozone treatments for preserving fresh vegetables quality: A critical review. *Foods*, *10*(3), 605.

SCHEER. (2017). *Opinion on biological effects of UV-C radiation relevant to health with particular reference to UV-C lamps*. European Commission's Scientific Committee on Health, Environmental and Emerging Risks. https://health.ec.europa.eu/system/files/2018-03/scheer_o_002_0.pdf

Schivley, G., Azevedo, I., & Samaras, C. (2018). Assessing the evolution of power sector carbon intensity in the United States. *Environmental Research Letters*, *13*(6), 064018. https://doi.org/10.1088/1748-9326/aabe9d

Schneider, T., Hahn-Löbmann, S., Stephan, A., Schulz, S., Giritch, A., Naumann, M., Kleinschmidt, M., Tusé, D., & Gleba, Y. (2018). Plant-made Salmonella bacteriocins salmocins for control of Salmonella pathovars. *Scientific Reports*, *8*(1), 1–10. https://doi.org/10.1038/s41598-018-22465-9

Schwartz, R. H. (1990). Cinnamon oil: Kids use it to get high. *Clinical Pediatrics*, *29*(3), 196.

Seagle, E. F. (1973). Ozone as an Occupational Health Hazard. *Occupational Health Nursing*, *21*(8), 14–17.

Seridou, P., & Kalogerakis, N. (2021). Disinfection applications of ozone micro-and nanobubbles. *Environmental Science: Nano*, *8*(12), 3493–3510.

Shah, P., & D'Mello, P. (2004). A review of medicinal uses and pharmacological effects of *Mentha piperita*. *Natural Product Radiance*, *3*(4), 214–221.

Sheen, S., Cassidy, J., Scullen, B., & Sommers, C. (2015). Inactivation of a diverse set of shiga toxin-producing Escherichia coli in ground beef by high pressure processing. *Food Microbiology*, *52*, 84–87. https://doi.org/10.1016/j.fm.2015.07.001

Shukr, M., & Metwally, G. F. (2014). Evaluation of topical gel bases formulated with various essential oils for antibacterial activity against methicillin-resistant Staphylococcus aureus. *Tropical Journal of Pharmaceutical Research*, *12*(6), 877–884.

Shynkaryk, M. V., Pyatkovskyy, T., Mohamed, H. M., Yousef, A. E., & Sastry, S. K. (2015). Physics of fresh produce safety: Role of diffusion and tissue reaction in sanitization of leafy green vegetables with liquid and gaseous ozone-based sanitizers. *Journal of Food Protection*, *78*(12), 2108–2116. https://doi.org/10.4315/0362-028X.JFP-15-290

Singh, G., Maurya, S., DeLampasona, M., & Catalan, C. A. (2007). A comparison of chemical, antioxidant and antimicrobial studies of cinnamon leaf and bark volatile oils, oleoresins and their constituents. *Food and Chemical Toxicology*, *45*(9), 1650–1661.

Singh, N., Singh, R. K., Bhunia, A. K., & Stroshine, R. L. (2002). Efficacy of chlorine dioxide, ozone, and thyme essential oil or a sequential washing in killing Escherichia coli O157:H7 on lettuce and baby carrots. *LWT*, *35*(8), 720–729. https://doi.org/10.1006/fstl.2002.0933

Singla, M., & Sit, N. (2021). Application of ultrasound in combination with other technologies in food processing: A review. *Ultrasonics Sonochemistry*, *73*, 105506. https://doi.org/10.1016/j.ultsonch.2021.105506

Smith, R., Cohen, S., Doull, J., Feron, V., Goodman, J., Marnett, L., Portoghese, P., Waddell, W., Wagner, B., & Adams, T. (2005). GRAS substances 22. *Food Technology*, *59*(8), 24–62.

Smith, W. H. (1992). Air pollution effects on ecosystem processes. In *Air pollution effects on biodiversity* (pp. 234–260). Springer.

Stadler, E., & Fischer, U. (2020). Sanitization of Oak Barrels for Wine—A Review. *Journal of Agricultural and Food Chemistry*, *68*(19), 5283–5295. https://doi.org/10.1021/acs.jafc.0c00816

Stokes, C. S., & Streng, L. A. (1965). Production of ozone by use of plasma jet. *Industrial & Engineering Chemistry Product Research and Development*, *4*(1), 36–39.

Suslow, T. (2004). *Ozone applications for postharvest disinfection of edible horticultural crops* (8133). UCANR Publications. https://escholarship.org/content/qt3d08r5ns/qt3d08r5ns.pdf

Swiss EAER. (1997). *EAER Ordinance on organic farming* (Ordinance 910.181). https://www.fedlex.admin.ch/eli/cc/1997/2519_2519_2519/en

Swiss FOAG. (1997). *Ordinance on organic farming and the labelling of organically produced products and foodstuffs* (Ordinance 910.18). https://www.fedlex.admin.ch/eli/cc/1997/2519_2519_2519/en

Tapp, C., & Rice, R. G. (2012). Generation and control of ozone. In *Ozone in food processing* (pp. 33–54). Wiley Online Library.

Targino de Souza Pedrosa, G., Pimentel, T. C., Gavahian, M., Lucena de Medeiros, L., Pagán, R., & Magnani, M. (2021). The combined effect of essential oils and emerging technologies on food safety and quality. *LWT*, *147*, 111593. https://doi.org/10.1016/j.lwt.2021.111593

Tesla, N. (1896). *Apparatus for producing ozone* (US Patent Office Patent 568,177).

Tiwari, B. K., Brennan, C. S., Curran, T., Gallagher, E., Cullen, P. J., & O' Donnell, C. P. (2010). Application of ozone in grain processing. *Journal of Cereal Science*, *51*(3), 248–255. https://doi.org/10.1016/j.jcs.2010.01.007

Tiwari, B., & Muthukumarappan, K. (2012). Ozone in fruit and vegetable processing. In C. O' Donnell, B. K. Tiwari, P. Cullen, & R. G. Rice (Eds.), *Ozone in food processing* (pp. 55–80). Wiley Online Library.

Tiwari, B., & Rice, R. G. (2012). Regulatory and legislative issues. In C. O'Donnell, B. Tiwari, P. Cullen, & R. Rice (Eds.), *Ozone in food processing* (pp. 7–17). Wiley Online Library.

Tokala, V. Y., Singh, Z., & Payne, A. D. (2018). Postharvest Uses of Ozone Application in Fresh Horticultural Produce. In *Postharvest Biology and Nanotechnology* (pp. 129–170). https://doi.org/10.1002/9781119289470.ch6

Tran, A., Pratt, M., & DeKoven, J. (2010). Acute allergic contact dermatitis of the lips from peppermint oil in a lip balm. *Dermatitis*, *21*(2), 111–115.

UCAR. (2024). *Ozone in the troposphere*. University Corporation for Atmospheric Research. https://scied.ucar.edu/learning-zone/air-quality/ozone-troposphere

US EPA. (2016). *Atmospheric concentrations of greenhouse gases*. US Environmental Protection Agency. https://www.epa.gov/sites/default/files/2016-08/documents/print_ghg-concentrations-2016.pdf

US EPA. (2021). Devices. In *Pesticide Registration Manual*. US Environmental Protection Agency. https://19january2017snapshot.epa.gov/pesticide-registration/pesticide-registration-manual-chapter-13-devices_.html#devices2

US EPA. (2024a). *Ground-level ozone pollution*. US Environmental Protection Agency. https://www.epa.gov/ground-level-ozone-pollution

US EPA. (2024b). *Human health & environmental impacts of the electric power sector*. US Environmental Protection Agency. https://www.epa.gov/power-sector/human-health-environmental-impacts-electric-power-sector

US EPA. (2024c). *Trends in ozone adjusted for weather conditions*. US Environmental Protection Agency. https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions

US FDA. (2000). *Action levels for poisonous or deleterious substances in human food and animal feed* (Guidance for Industry) [Guidance Document for Industry]. US Food and Drug Administration. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-poisonous-or-deleterious-substances-human-food-and-animal-feed

U.S. FDA. (2000, August). *Guidance for industry: Action levels for poisonous or deleterious substances in human food and animal feed*. U.S. Food & Drug Administration; FDA. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-poisonous-or-deleterious-substances-human-food-and-animal-feed

US FDA. (2004). *Guidance for industry: Juice hazard analysis critical control point hazards and control guidance* (Guidance for Industry) [Guidance Document for Industry]. US Food and Drug Administration. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-juice-hazard-analysis-critical-control-point-hazards-and-controls-guidance-first

US FDA. (2007). *Hazards & control guide for dairy foods HACCP* (Guidance for Processors) [Guidance Document for Industry]. US Food and Drug Administration. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-juice-hazard-analysis-critical-control-point-hazards-and-controls-guidance-first

US FDA. (2020, July 31). *GRAS substances (SCOGS) database*. https://www.fda.gov/food/generally-recognized-safe-gras/gras-substances-scogs-database

US FDA. (2023, July 6). *Understanding how the FDA regulates food additives and GRAS ingredients*. FDA; FDA. https://www.fda.gov/food/food-additives-and-gras-ingredients-information-consumers/understanding-how-fda-regulates-food-additives-and-gras-ingredients

US FSIS. (2012). *High pressure processing (HPP) and inspection program personnel (IPP) verification responsibilities* (6120.2; FSIS Directive). USDA Food Safety Inspection Service. https://www.fsis.usda.gov/sites/default/files/media_file/2020-07/6120.2.pdf

US FSIS. (2021). *FSIS cooking guideline for meat and poultry products* (FSIS-GD-2021-14; FSIS Guideline). USDA Food Safety Inspection Service. https://www.fsis.usda.gov/sites/default/files/media_file/2020-07/6120.2.pdf

U.S. Pharmacopeia. (2024). *Food chemicals codex* (14th ed.). US Pharmacoepial Convention.

USDA Specialty Crops Program. (2022). *Specifications for whole shelled almonds* (Commodity Specifications). USDA Agricultural Marketing Service Specialty Crops Program. https://www.ams.usda.gov/sites/default/files/media/Section32SpecificationforWholeShelledAlmondsAugust2022.pdf

Varghese, D., Ferris, K., Lee, B., Grigg, J., Pinnock, H., & Cunningham, S. (2024). Outdoor air pollution and near-fatal/fatal asthma attacks in children: A systematic review. *Pediatric Pulmonology*, *59*(5), 1196–1206. https://doi.org/10.1002/ppul.26932

Vosmaer, A. (1914). Applications of ozone. *Industrial & Engineering Chemistry*, *6*(3), 229–232.

Wang, S., Wang, J., Li, C., Xu, Y., & Wu, Z. (2021). Ozone treatment pak choi for the removal of malathion and carbosulfan pesticide residues. *Food Chemistry*, *337*, 127755. https://doi.org/10.1016/j.foodchem.2020.127755

Wei, S., Chelliah, R., Rubab, M., Oh, D.-H., Uddin, M. J., & Ahn, J. (2019). Bacteriophages as potential tools for detection and control of Salmonella spp. In food systems. *Microorganisms*, *7*(11), 1–570.

Welti-Chanes, J., Morales-de la Peña, M., Jacobo-Velázquez, D. A., & Martín-Belloso, O. (2017). Opportunities and challenges of ultrasound for food processing: An industry point of view. In D. Bermudez-Aguirre (Ed.), *Ultrasound: Advances for Food Processing and Preservation* (pp. 457–497). Academic Press. https://doi.org/10.1016/B978-0-12-804581-7.00019-1

Whittington, R., Winston, M. L., Melathopoulos, A. P., & Higo, H. A. (2000). Evaluation of the botanical oils neem, thymol, and canola sprayed to control *Varroa jacobsoni* Oud.(Acari: Varroidae) and *Acarapis woodi* (Acari: Tarsonemidae) in colonies of honey bees (*Apis mellifera* L., Hymenoptera: Apidae). *American Bee Journal*, *140*(7), 567–572.

Wińska, K., Mączka, W., Łyczko, J., Grabarczyk, M., Czubaszek, A., & Szumny, A. (2019). Essential Oils as Antimicrobial Agents—Myth or Real Alternative? *Molecules*, *24*(11). https://doi.org/10.3390/molecules24112130

Wojtowicz, J. A. (2005). Ozone. In *Kirk-Othmer Encyclopedia of Chemical Technology*. https://doi.org/10.1002/0471238961.1526151423151020.a01.pub2

Woolf, A. (1999). Essential oil poisoning. *Journal of Toxicology: Clinical Toxicology*, *37*(6), 721–727.

Yang, S.-C., Lin, C.-H., Sung, C. T., & Fang, J.-Y. (2014). Antibacterial activities of bacteriocins: Application in foods and pharmaceuticals. *Frontiers in Microbiology*, *5*, 241.

Yusuf, M. (2018). Natural antimicrobial agents for food biopreservation. In A. M. Grumezescu & A. M. Holban (Eds.), *Food Packaging and Preservation* (pp. 409–438). Academic Press. https://doi.org/10.1016/B978-0-12-811516-9.00012-9

Zarzuelo, A., & Crespo, E. (2003). The medicinal and non-medicinal uses of thyme. In E. Stahl-Biskup & F. Sáez (Eds.), *Thyme: The genus Thymus* (Vol. 24, pp. 1–43). CRC Press.

Zhang, Y., Liu, X., Wang, Y., Zhao, F., Sun, Z., & Liao, X. (2016). Quality comparison of carrot juices processed by high-pressure processing and high-temperature short-time processing. *Innovative Food Science & Emerging Technologies*, *33*, 135–144. https://doi.org/10.1016/j.ifset.2015.10.012

Zhang, Y., Ma, Y., Feng, F., Cheng, B., Shen, J., Wang, H., Jiao, H., & Li, M. (2021). Respiratory mortality associated with ozone in China: A systematic review and meta-analysis. *Environmental Pollution*, *280*, 116957. https://doi.org/10.1016/j.envpol.2021.116957