OZONE: SCIENCE & ENGINEERING
https://doi.org/10.1080/01919512.2018.1490636

REVIEW

Ozone based food preservation: a promising green technology for enhanced food safety

R. Pandiselvam[a], S. Subhashini[b], E.P. Banuu Priya[c], Anjineyulu Kothakota[d], S.V. Ramesh[a], and S. Shahir[e]

[a]Physiology, Biochemistry and Post Harvest Technology Division, ICAR –Central Plantation Crops Research Institute, Kasaragod, India; [b]College of Food and Dairy Technology, Tamil Nadu Veterinary and Animal Sciences University, Chennai, India; [c]Department of Food Science and Technology, Indian Institute of Plantation Management, Bangalore, India; [d]Department of Food and Agricultural Process Engineering, Kelappaji College of Agricultural Engineering & Technology, Tavanur, India; [e]Department of Food Technology, Bannari Amman Institute of Technology, Erode, Tamil Nadu, India

ABSTRACT
Extending shelf life of food products is a major concern of the producers, and the food industry requires 'greener' alternatives to the current technologies. Ozone-based food preservation may suit this niche. Ozone is an attractive alternative preservative that food industry needs due to its properties such as quick decomposition and little residual effect during food preservation. Ozone is the strongest molecule available for the disinfection of water and is second only to elemental fluorine in oxidizing power. Ozone is being used in the food industry in various applications such as decontamination of water and equipment surfaces. Several researchers have focused on the application of ozone to inactivate microorganisms on fresh produce, like fruits, vegetables, meat, poultry, fish, and eggs, and dry produce, such as cereals, pulses, and spices. This review comprehensively analyses appropriate ozone concentrations and exposure times and discusses various factors that affect the quality and safety of food products during ozonation.

ARTICLE HISTORY
Received 21 May 2018
Accepted 15 June 2018

KEYWORDS
Food Safety; Grains; Ozone; Poultry; Seafood; Surface Decontamination; Water Treatment

Introduction

The food processing industry is increasingly taking efforts to improve the food quality and safety throughout the world. Of late, there has been a considerable increase in the number of outbreaks of food-borne disease that has been a serious concern for public health (Stephan et al. 2015). Consequently, food industries and consumers share a common concern of microbial food safety. Hence, appropriate technologies for preventing undesired microbial and fungal contamination and spoilage and for maintaining the sensory and nutritional quality of the product are required throughout the processing and distribution chain (De Souza et al. 2018). Various food preservation techniques such as chilling, water activity reduction, freezing, pasteurization, sterilization, acidification, drying, dehydration, antimicrobials, and fermentation have been evaluated to counter the food safety-related problems. However, application of some of these technologies adversely affects the appearance, color, texture, aroma, and nutrients of the food. Moreover, microbial spoilage and food contamination are major problems that are yet to be effectively controlled.

In recent years, consumers prefer the organic foods that taste better, additive-free along with extended shelf life. In this context, ozone-based food preservation technology is a boon for the consumers and producers alike. Ozone (O_3) is an allotropic form of oxygen and powerful oxidizing agent that is produced from oxygen during lightning or UV irradiation reactions (Mohammadi et al. 2017). During, ozone production, O_2 splits into highly reactive singlet oxygen, which in turn reacts with other oxygen molecules to form ozone.

Ozone is the attractive choice for the food processing and preservation industries to ensure the microbial food safety because of its very rapid action and it's strong oxidative characteristics. Also, it quickly auto-decomposes into molecular oxygen (Pandiselvam et al. 2017a), leaving no hazardous halogenated compounds in the food products. In addition, the high oxidation potential (2.07 volts) of ozone in alkaline solution makes it an effective anti-microbial agent (Fisher et al. 2000; Graham 1997). It destroys different types of microorganisms at the relatively low concentrations and meets the global demand for sustainability. Ozone will oxidize organic substances into safer elements. Ozone could be generated on-site using ozone generators with oxygen as the source gas (Nakamura et al. 2017) and hence, the necessity to store hazardous

CONTACT R. Pandiselvam ✉ anbupandi1989@yahoo.co.in Physiology, Biochemistry and Post Harvest Technology Division, ICAR –Central Plantation Crops Research Institute, Kasaragod, India

chemicals is eliminated (Pandiselvam, Thirupathi, and Anandakumar 2015). In addition, the energy input required for ozone treatment is much lower than radiation, microwave and thermal treatment (Khadre, Yousef, and Kim 2001).

Ozone is a proven technology for an antimicrobial, antiviral, antiparasitic and antifungal treatments (Naito and Takahara 2006; Varol et al. 2017). Even at very small concentrations, ozone has the powerful sanitizing capacity. On 26 June 2001, the US FDA has accorded Generally Regarded as Safe (GRAS) status for ozone and approved its use as an antimicrobial agent during the processing and storage of food products (Khadre, Yousef, and Kim 2001). This approval has opened the flood-gates to utilize the ozone for fruits and vegetable surface treatments, sanitation of food plant equipment and wastewater treatment (Loeb 2011; Qi et al. 2017; Schneider et al. 2016).

Awareness has been growing with regard to the safety of food and food products and in particular, the interference methods that are used to reduce and eliminate human pathogens not only from the fresh produce but also from the water used in food industries. The ozone-treated water can also be used in clean-in-place (CIP) systems including cleaning silos, filling machines, piping lines, homogenizers, and pasteurizers by directly injecting ozone into the network of the fluid processing system and circulating it for a stipulated time (O’Donnell et al. 2012). The other uses of ozone are disinfection of water pools and prevention of fouling of heat exchangers and cooling towers (Barry, Hristovski, and Westerhoff 2014; Jamil, Farooq, and Hashmi 2017; Ledakowicz et al. 2017; Pathapati et al. 2016; Schrank et al. 2017; Strittmatter, Yang, and Johnson 1996). At the moment, ozone technology is gradually replacing conventional sanitation and fumigation techniques including chlorine, steam or hot water, and pesticides (fumigation) like phosphine, aluminium phosphide, and methyl bromide. Moreover, a number of commercial food preservation industries in developed countries have started using ozone technology. This has been due to the rapid decomposition of ozone resulting in no residues on the treated fruits and vegetables. Hence, it could be a suitable technology for preserving products like fruits and vegetables that could be marketed under “organic” category (Karaca 2010).

Despite the rapid production of food commodities, the greatest impediment to the expansion of food industry is maintaining the shelf life of the produces for long. Hence, this article presents recent developments in the field of ozone technology with special emphasis for shelf life extension of various food products. The disadvantage of ozone technology and the prospectives are also briefly discussed.

Properties of ozone

Ozone molecule is formed of three oxygen atoms and the arrangement of its unpaired electrons with an oxygen nucleus at its centre provides it a strong reactivity (Guzel-Seydim, Greene, and Seydim 2004). The central oxygen atom present in the ozone molecule is attached to the equidistant oxygen atoms; the included angle is approximately 116°49′ and the bond length is 1.278 (Beltran 2004). Ozone has a strong characteristic odor similar to fresh air after a thunderstorm (Coke 1993). The pungent odor was described by Van Marum in 1781 (Evans 1972). Due to its repeated inter-molecular rearrangement or its natural conversion from oxygen to ozone and vice-versa, ozone does not substantially accumulate without continual ozone generation (Jodzis and Patkowski 2016; Miller et al. 1978; Peleg 1976). At room temperature, ozone is a nearly colorless gas and is readily detectable at 0.01–0.05 ppm level (Mehlman and Borek 1987; Mustafa 1990).

Ozone remains an unstable gas in the room temperature as it rapidly decomposes; however, it has relatively good half-life in the gaseous state. The destruction rate of ozone is positively correlated with temperature and negatively correlated with purity of water. About 50% of ozone is destroyed in 20 min (at 20°C) in distilled water (Hill and Rice 1982). The decomposition of ozone is even faster at higher water temperatures (Rice et al. 1981). Ozone is more soluble in cold water than in hot water and solubility rate is 13 times that of O_2 (at 0–30°C) (Rice 1986). At atmospheric pressure and 0°C the density of ozone is slightly high (2.14 g. L^{-1}) in comparison to air (1.28 g. L^{-1}).

At −112°C, ozone condenses into a dark blue liquid. Liquid ozone can be detonated if greater than 20% ozone to oxygen mixture occurs. Ozone explosion with electric sparks also occurs due to sudden change in pressure or temperature (Greene et al. 2012; Von Gunten 2003). Nevertheless, practically detonation of ozone is an extremely rare event.

Application of ozone in food industries

Ozone finds a wide range of application in disinfecting the production areas, plant equipment and surfaces, sterilization, and fumigation. Apart from sterilizing the equipment and production area, it is used for preservation of food and extension of its shelf-life.

Antimicrobial effects of ozone under different treatment conditions are shown in Table 1. Ozone strongly and directly oxidizes the cytoplasmic membranes and the cell walls of bacteria. The microbiocidal effect of ozonated water takes place within five seconds of treatment (Yamayoshi and Tatsumi 1993). Ozone radiation helps in reduction of microflora and pathogens; thereby, an extension of the shelf life of a food product can be achieved (Smith and Pillai 2004). Research has provided evidence for the bactericidal action of ozone towards microorganisms including *Z. bailii* and *P. aeruginosa* (responsible for food decay), *E. faecalis* and *E. coli* (fecal contaminants), and *S. typhimurium*, *L. monocytogenes*, and *B. cereus* (pathogens causing food poisoning) (Restaino et al. 1995).

Food grains

Ozone is a potential fumigant for managing the stored product insect pests and a powerful antimicrobial agent which has a minimal or no effect on grain quality (Pandiselvam, Chandrasekar, and Thirupathi 2017; Pandiselvam, Sunoj, and Uma 2016; Pandiselvam, Thirupathi, and Vennila 2016). Ozone treatment of grain is generally applied in the hermetic storage bin at a stipulated grain moisture content and minimum bed thickness (Pandiselvam and Thirupathi 2015; Pandiselvam, Thirupathi, and Anandakumar 2015; Ravi, Venkatachalam, and Rajamani 2015). It is necessary to characterize the kinetics of gaseous ozone movement through the various grains to optimize ozone generators for use on commercial storage bins (Pandiselvam, Chandrasekar, and Thirupathi 2017; Shunmugam, Jayas, White, Muir 2005).

An oxygreen process is an advancement of application of ozone in food grains (Dubois et al. 2008, 2006). The unit operations of this process involve pre-moistening of grains using closed batch reactor and ozonation. Yvin et al. (2001) patented a protocol for ozone treatment of grains to enhance the microbial safety of flour obtained after the size reduction. However, dearth of information regarding the beneficial effects of ozone treatment of cereals, pulses, spices, and cereal-based products hampers its acceptance as a viable alternative to commercial fumigants.

According to Mendez et al. (2003), the mass transfer process of ozone through grains depends on chemical constituents of an outer layer of grain. Diffusion of ozone into the food produce depends on the several extrinsic and intrinsic factors such as bed thickness, grain temperature, moisture content of grains, shape of the treatment bin, flow rate of ozone, microbial contamination, concentration of ozone and the presence of insects (Pandiselvam et al. 2017a; Pandiselvam and Thirupathi 2015; Pandiselvam, Thirupathi, and Anandakumar 2015; Ravi, Venkatachalam, and Rajamani 2015). Moreover, most of the research that found the effectiveness of ozonation on grains were carried out in a small scale. Hence, sufficient data (diffusion and kinetics of ozone with respect to the nature of grains, storage bin dimension, and atmospheric condition) do not exist to scale up the technology. Hence, a differential kinetic diffusion equation has been proposed to explain the ozone penetration and movement in a grain column (Raila et al. 2006).

$$\frac{\partial c_o}{\partial t} = D\left(\left(\frac{1}{r}\frac{\partial}{\partial r}\right)\left[r\frac{\partial C_o}{\partial r}\right] + \frac{\partial^2 c_o}{\partial h^2}\right) - v_f\left(\frac{\partial c_o}{\partial h}\right) - kC_o \quad (1)$$

where, C_o _ ozone concentration, kg-mol/m^3; D – diffusivity, m^2/s; r – radius of the bottom of the bin, m; h – spices mound height, m; k – factor of ozone absorption; v_f – air seepage velocity in the spice layer, m/s;t – duration of exposure to ozone, s.

Pandiselvam, Chandrasekar, and Thirupathi (2017), Pandiselvam et al. (2017b), and Pandiselvam et al. (2018) expressed the ozone concentration profile in grain bulks by a using algebraic form of the equation (2).

$$\begin{aligned} c_{i,j+1} - c_{i,j} = A(c_{i-1,j+1} - 2c_{i,j+1} + c_{i+1,j+1} + c_{i-1,j} \\ -2c_{i,j} + c_{i+1,j}) - B(c_{i,j+1} - c_{i,j}) \end{aligned} \quad (2)$$

in which,

$$A = \frac{\partial t D_e}{2 * z^2}$$

and

$$B = \frac{\partial t}{\partial z}$$

where, c is Ozone concentration, ppm; t is time, s; D_e is diffusivity, m^2 s^{-1}; and V_z is the velocity of ozone in 'Z' direction.

Pandiselvam and Thirupathi (2015) and Pandiselvam, Thirupathi, and Anandakumar (2015) expressed the reaction kinetics of ozone gas in green gram and paddy, respectively, by fitting the data with the equation (3), (4) and (5). They found that the dynamics of ozone gas decomposition follows the first order kinetic model.

$$(O_3) = (O_3)_0 - kt \quad (3)$$

$$\text{In}(O_3) = \text{In}(O_3)_0 - kt \quad (4)$$

$$\frac{1}{O_3} = \frac{1}{(O_3)_0} + kt \quad (5)$$

Where,

(O_3) is the ozone concentration (ppm), $(O_3)_0$ is the initial ozone concentration (ppm),

Table 1. Antimicrobial effects of ozone under different treatment conditions.

Application	Treatment	Purpose	Results	Reference
Date fruit	Gaseous Ozone at 1, 3, and 5 ppm	Total bacterial count, Coliform, *Staphylococcus aureus* and yeast/mold counts were examined	*Escherichia coli* and *S. aureus* were eliminated in ozone treated samples (5 ppm for 60 min)	Najafi and Khodaparast (2009)
Fresh-cut green leaf lettuce	0.5–4.5 ppm	*Listeria monocytogenes* counts and the overall visual quality of lettuce	The quality and safety of lettuce samples treated at the optimum ozonation condition (2 ppm) were compared with the chlorinated water (100 ppm), organic acid (0.25 g/100 g citric acid plus 0.50 g/100 g ascorbic acid), and water treatments applied at 10°C for 2 min.	Ölmez and Akbas (2009)
Tomato	20, 35, and 50 ppm	Longer shelf life by reducing the surface microbial count	Ozone treatment delayed the development of red colour and rotting. Colour development and rotting followed a trend of Hill's equation. Shelf life was enhanced by 12 days when treated tomatoes were stored at 15°C.	Zambre, Venkatesh, and Shah (2010)
High-moisture Maize	Treatment I –22% moisture content 60–1120 ppm ozone in air during application for periods of 5 or 24 h Treatment II –26% moisture content 1090–8680 ppm ozone during application for 24 h	Ozone treatments decreased dry matter loss compared to the control, but not to a level that would likely justify ozone treatment at the rates and treatment times used	Single ozone treatments of 1 and 2 mg kg maize^{-}1 min^{-}1 were equally effective, reducing dry matter loss by 1.3 percentage points compared to the control after 30 d of storage. Repeat treatments at 2 mg kg maize_1 min_1 did not reduce dry matter loss compared to the single treatment.	White et al. (2010)
Storage insect pests (Red flour beetle)	Larvae and adults exposed to 40 ppm of ozone for 6 or 24 h	*Tribolium castaneum*	Ozone caused down-regulation of genes protecting against oxidative stress. Ozone induced little lipid peroxidation.	Holmstrup et al. (2011)
Fresh-cut carrots	Ozonized in water (1:2 w/v at 200 mg O_3/h) for 10 min and stored under controlled atmosphere (CA) conditions (2% O_2, 5% CO_2 and 93% N_2) at 6 ± 1° C and 85% RH for up to 30 d.		Reduced the lignification and maintained the keeping quality of fresh-cut carrots during CA storage	Chauhan et al. (2011)
Radish (*Raphanus sativa*) and Moong bean (*Phaseolus aureous*) sprouts	2 ppm ozone and 2% malic acid	*Shigella* spp	Malic acid and ozone alone reduced the pathogen populations less than 3 log in both sprouts following complete immersion and spraying. Whereas, combination of both the sanitizers reduced the pathogen populations significantly ($P < 0.05$) by 4.4 log in radish and 4.8 log in moong bean sprouts	Singla, Ganguli, and Ghosh (2011)
Dried oregano	Ozone treatment up to 120 min under continuous stream of two different constant ozone concentrations (2.8 and 5.3 mg/L).	Salmonella serotypes (*S. Typhimurium*, *S. Newport* and *S. Montevideo*)	Over 2 log reduction in the microbial population can be obtained on dried oregano by gaseous ozone treatments with an acceptable taste, flavour and appearance	Torlak and Sert (2013)
Raw Chicken	Gaseous ozone for 1 min to 9 min at a dose of 33 mg/min	*Listeria monocytogenes*	Ozone could be used as an effective method for inactivating 2×10^6 CFU/g of *L. monocytogenes* on chicken samples	Muthukumar and Muthuchamy (2013)
Whole milk powder (WMP) and skimmed-milk powder (SMP).	Continuous stream of constant ozone concentrations of 2.8 and 5.3 mg L^{-1} for up to 120 min	*Cronobacter*	Samples inoculated at 5.92 log cfu g^{-1} were exposed to ozone. Initial levels of *Cronobacter* in SMP were reduced by 2.71 and 3.28 log after 120 min of ozonation at 2.8 and 5.3 mg L^{-1}, respectively. Counts were reduced by 1 log less in WMP after the same exposure period	Torlak, Sert, and Ulca (2013)
Fresh cut lettuce (*Lactuca sativa*) and green bell pepper (*Capsicum annuum*)	Ozonated water (0.5 mg/L)	Coliform Yeasts/molds	Best sanitation results achieved when vegetables immersed in continuously ozonated water (0.5 mg/L). Dipping of vegetables in chlorinated (20 ppm) or pre – ozonated water was not so effective. Bacteria as coliforms and total aerobic mesophiles were more sensitive to ozone.	Alexopoulos et al (2013)
Corn with different moisture content (MC)	90 mg L^{-1} ozone for 20 min and 40 min	effect on degradation of aflatoxin B_1 (AFB_1)	Ozonation can quickly and effectively degrade AFB_1 in corn and diminish ACC's toxicity	Luo et al. (2014)
Beverage industry		Cleaning-in-Place (CIP)	Ozone treatment resulted in a substantial improvement in the removability of d-limonene from both EPDM and silicone gaskets; the removal efficiencies were 87% for the EPDM gasket in 60 min and 100% for the silicone gasket in 30 min.	Nishijima et al. (2014)
Strawberry	0.075 mg/L ozone, 6 mg/L chlorine dioxide and ultrasound at 30 Watt	Shelf life	Combination treatments of ultrasound, ozone and chlorine dioxide could be used for prolonging shelf life of strawberries	Aday and Caner (2014)

(*Continued*)

Table 1. (Continued).

Application	Treatment	Purpose	Results	Reference
Wheat starch	Ozone gas for 15, 30, and 60 min at 5° C at a concentration of 0.00042 g dissolved ozone/100 g	Starch gelatinization	Ozonation resulted in decreased retrogradation, increased thermal stability and increased gelatinization in wheat starch. Ozonation decreased the pasting temperature of wheat starch. Ozonation can be used as an alternative to chemical and thermal treatments to modify wheat starch.	Çatal and İbanoğlu (2014)
Wine grapes	Grapes were ozone-treated (1.5 g/h) for 18 h (A = shock treatment), then dehydrated or ozone-treated (1.5 g/h) for 18 h and at 0.5 g/h for 4 h each day (B = long-term treatment) during dehydration.	Fungi and yeast	Ozone reduced the fungi and yeasts contamination of about 50%. Ozone shock treatment preserved polyphenols, anthocyanins and carotenoids. Ozone long term treatment reduced the activity of PME and PG	Botondi et al. (2015)
Prebiotic orange juice	The juice was directly and indirectly exposed to a plasma field at 70 kV for different treatment times: 15, 30, 45 and 60 s. For ozone processing, different loads (0.057, 0.128 and 0.230 mg/O3 mL of juice) were evaluated	Phenolic and Antioxidant activity	Prebiotic orange juice was treated by atmospheric cold plasma (ACP). Prebiotic orange juice was ozone treated with crescent ozone loads. Treatments did not affect the phenolic content and antioxidant capacity and oligosaccharides content of the juice	Almeida et al. (2015)
Fish meat from bighead carp (*Hypophthalmichthys nobilis*)	Ozone washing treatment (with ozonized water and ozone-flotation) for 5–20 min	Elimination of geosmin in fish muscle	Ozone for the removal of geosmin in freshwater fish was effective. The physicochemical properties of myofibrillar protein could be enhanced by ozone. The mechanism of ozone-induced oxidation in the gel structure was shown	Zhang et al. (2016)
Starch characterization of wheat grains	Ozone gas was fed at the bottom of the reactor through a micro-porous plate with a flow rate of 33.34 L/min TPN.	Oxidation of starch	Ozone treatment does not lead to physicochemical modifications and molecular structure of starch	Gozé et al. (2016)
Fresh produce	The efficacy of application of high ozone concentration (1.5 g/m^3) short term during the vacuum cooling step in combination with low ozone concentration (0.032–0.528 g/m^3) long term sanitization treatments (days)	*E. coli* O157:H7 ATCC 43,889	*E. coli* O157:H7 count reduction during vacuum cooling drops under high ozone demand. Application of ozone during vacuum cooling reduces internalized bacterial counts.	Shynkaryk et al. (2016)
Potato starch		Starch modification; Starch oxidation	The ozone can modify the potato starch structure and properties. Part of the hydroxyl groups were oxidized to carbonyl and carboxyl groups. The glycosidic bonds were hydrolysed, especially from the amylose molecules. The reactions occurred mainly in the amorphous region of the granule.	Castanha, Da Matta Junior, and Augusto (2017)
Sugarcane juice		Use of ozonation as an alternative to sulphitation	The reaction mechanism was proposed for gallic acid degradation by ozone based on Criegee mechanism. Ozonation was an efficient method to reduce the potential low molecular weight pigment present in the sugarcane.	De Souza Sartori et al. (2017)
Apples	Ozone concentration of 1 ppm every 12 hours for 1 min	To inhibit fungal disease	Ozone at 1 ppm was unsuccessful in terms of inhibition of fungal disease. However, utilization of ozone slowed down the ripening of apples.	Antos et al. (2018)
Extruded dog food	Ozone concentration of 40 and 60 μmol/mol at 30, 60, and 120 min of exposure	Decontamination of *Aspergillus flavus* spores inoculated extruded food through ozone gas	The highest reduction of 98.3% was observed for *Aspergillus flavus* spores, when gas was applied for 120 min, regardless of the O_3 concentration.	Silva, Pereira, and Scussel (2018)

t is the time (min) and k is the rate constant (min^{-1}).

Kells et al. (2001) evaluated the efficiency of ozone fumigation in corn grains against the insects such as red flour beetle (*Tribolium castaneum*), maize weevil (*Sitophilus zeamais*) and larvae of Indian meal moth. Significant insect mortality, even up to 100%, was observed compared to the maximum of 10% in the control. Also, *Sitophilus zeamais* was found to be most sensitive to the ozone treatment. Kinetics of ozone-based control over insect respiration revealed that the process entails two-phase inhibition of respiration in *T. castaneum, S. oryzae*, and *Rhyzopertha dominica*. The first phase is characterized with low respiration rate that coincides with the need for insects to reduce the ozone toxicity followed by an increase in respiration rate characterized with degradation of ozone to oxygen (Lu et al. 2009).

Another area of potential use of ozone treatment is its anti-fungal activity in stored grains. As fungal infection of grains depends on many factors such as cultural practices, weather parameters, storage conditions and innate resistance of the plants, ozone could be potentially used in treating fungi of stored grains. Ibanoglu (2002) observed little changes in the flour yield, proximate composition including water, ash and protein content of wheat grains that were treated with ozonated water. Also, significant differences were not observed with falling number, rheological characteristics of dough obtained from wheat grain that underwent ozone treatment. Interestingly, the levels of microorganisms were found to be low in flour of treated grains suggesting the efficacy of ozone treatment (Ibanoglu 2002). Dubois et al. (2006) showed that phytate and vitamin contents in wheat kernels were not affected by ozone treatment. Ozone pre-treatment (10 $g.kg^{-1}$) reduced the reduction energy of milling of wheat kernels (Desvignes et al. 2008). Trombete et al. (2016) reported that ozone treatment (10 to 60 $mg.L^{-1}$ for 2–5 h) of wheat kernels (2 to 5 kg) had no effect on flour extraction rate. Recent studies showed that ozone treatment (aqueous ozonation 0.00042 g/100 g water on 10 g starch for 15 min) tends to increase the swelling power of wheat starch (Castanha, Da Matta Junior, and Augusto 2017). Gozé et al. (2016) observed that ozone treatment (33.34 $L.min^{-1}$) had no effect on gelatinization, pasting, and molecular weight distribution of amylopectin of the wheat starches. Ozone treatment (0.02 and 0.06 $L.min^{-1}$ up to 30 min) for sorghum flour rich in tannins caused degradation and polymerization of starch (Yan et al. 2012). Isolated proteins treated with ozone gas (5 $g.h^{-1}$) for 1 h decreased the content of sulfhydryl group in the wheat proteins (Obadi et al. 2016). Gozé et al. (2017) found that ozone treatment (2.0 m^3 $NTP.h^{-1}$) on wheat kernels protein (10 kg) reduced the SDS solubility of wheat prolamins. Savi et al. (2014) systematically studied the effect of ozone (60 µmol/mol, 3 h) on the lipid peroxidation profile in wheat kernels (350 g). According to the authors, lipid peroxidation profile was not affected by ozone gas treatment. In contrast, Obadi et al. (2018) found that ozone gas treatment (5 $g.h^{-1}$ for 45 min) oxidized linoleic acid in wheat flour. Mei et al. (2016) showed that increasing ozone exposure time for 2 h decreased the setback and breakdown viscosity of flour.

Generally, the germination capacity of grain decreases upon fungal contamination, but with ozone treatment, the grains show improved germination and at least no deleterious effects were observed following the ozone treatment (Mendez et al. 2003; Yvin and Coste 1997). Intriguingly, short-term ozone treatment caused improved germination rate of corn seeds than those exposed to the longer periods (Violleau et al. 2008). This positive effect of ozone exposure on the germination of seeds and bulbs has been recognized and patented by Yvin and Coste (1997). Savi et al. (2014) found that ozone treatment for 3 h reduced the germination capacity by 12%. Nevertheless, no effect of germination was reported after ozone treatment on corn grains by Mendez et al. (2003) who used 50 ppm of ozone. Also, the treatment did not affect the moisture, ash or protein content of the soft or hard wheat grains.

Fruits and vegetables

Fruits and vegetables are highly susceptible to spoilage causing micro-organisms. Ozone exposure is a viable alternative in preserving various food products such as juice, ice cream, jam, jellies, sorbet, pickles and nutraceutical applications. Ozone treatment is used in fruit and vegetable processing in order to inactivate the pathogenic and spoilage-causing microorganisms, mycotoxins and to destroy pesticide and chemical residues (De Souza et al. 2018; Kim, Yousef, and Dave 1999). It is preferred because of the absence of residual effect of chlorine, even at low concentrations, associated with the most popular disinfectants.

Ozone finds broad application in the food processing industry, including wastewater treatment, drinking water disinfection and surface decontamination of fruits and vegetables (Guzel-Seydim, Greene, and Seydim 2004; Karaca and Velioglu 2007). It is regularly used for washing of vegetables and fruits (Karaca and Velioglu 2007; Liangji 1999). Ozone treatments of blackberries and grapes greatly reduce the deterioration caused by fungal infection and thereby increase its shelf life (Beuchat 1992). Apples in a stainless steel chamber could be stored (at 0 to 1°C and 90 to 95% RH) without considerable weight loss and inactivation of spoilage-causing microbes due to treatment with ozone at the rate of 5 to 6 mg/liter daily for 4 h (Bazarova 1982). Later the beneficial effect of ozone in increasing the shelf life of fruits was attributed to oxidation of ripening hormone ethylene and effective removal of toxic metabolic products (Horvath, Bilitzky, Huttner 1985).

Ozone treatment in vegetables has similar advantages experienced in storage and processing of fruits. Ozone treatment (0.2 µg. L^{-1} for 8 h day^{-1}) of onions and potatoes stored in wooden chambers decreased surface microbial infection and reduced the activity of antioxidant enzymes such as *catalase, peroxidase*, decreased oxygen intake and chemiluminescence (Faitel'berg-Blank et al. 1979). The spoilage induced losses during storage of onions and potatoes post-treatment were 1 and 0.8%, respectively as against the 9.7 and 6.7% losses for the untreated controls.

Aqueous ozone solution has been regularly applied to fresh-cut vegetables to reduce the microbial count and to increase the shelf-life (Beltrán et al. 2005a, 2005b). The bacterial count has been greatly reduced in the number of fruits and vegetables such as blackberries, black pepper, broccoli, carrots, grapes, shredded lettuce, and tomatoes when treated with ozone (Barth et al. 1995; Kim, Yousef, and Dave 1999; Sarig et al. 1996; Zhao and Cranston 1995). Further, potentially pathogenic organisms and spoilage causing microbes were reduced in fruits and vegetable products following ozone treatment. A potentially harmful ingredient in any fresh vegetable or fruit is residual pesticide; hence rinsing with ozonated water (1.4 mg.L^{-1}) for a short period of 15 minutes could remove more than one-quarter (27–34%) of residual pesticides in vegetables (Wu et al. 2007). However, it was proposed that higher concentration of ozone could further remove even greater amounts of pesticide residues (Ong et al. 1996; Ou-Yang, Liu, and Ying 2004).

Industrial scale use of ozone in storage of onions, potatoes, and sugar beets at an ozone concentration of 3 mg.L^{-1} remarkably inhibited bacterial and mold count without compromising the biochemical composition of the vegetables and its sensory quality (Baranovskaya et al. 1979). Kim, Yousef, and Dave (1999) treated the lettuce with ozone under different mechanical actions (sonication, stirring, and stomaching). They have concluded that bubbling gaseous ozone at 4.9%, vol/vol (flow rate of 0.5 liter/min) was the most effective ozonation method for reducing microbial load. For efficient ozone delivery to eradicate microorganisms which is present in lettuce, ozone bubbling should be combined with high-speed stir. Gaseous ozone application showed various levels of success depending upon the process and product. Postharvest decay and spoilage of fruits and vegetables due to microbes have been reduced by continuous exposure to the ozone (Aguayo, Escalona, and Artes 2006; Barth et al. 1995; Liew and Prange 1994; Palou et al. 2002; Perez et al. 1999; Sarig et al. 1996; Tzortzakis et al. 2007; Tzortzakis, Singleton, and Barnes 2007). De Souza et al. (2018) evaluated the effect of ozone as the gaseous state (0 – 5 mg L^{-1}) and aqueous ozone (0 – 10 mg L^{-1}) on the quality of carrots. Carrots exposed to gaseous ozone and aqueous ozone did not alter the firmness, weight loss percentage, and the color of the vegetable. However, in treatments with aqueous ozone temporarily affected the pH of carrots. They concluded that O_3 as gas reduced the sharp increase of soluble solids during storage, thereby increasing the shelf-life of carrots.

Quality attributes of ozone treated fruits and vegetables

The effect of ozonation on weight loss percentage of fruits and vegetables has been studied by several researchers who reported most diverse results. Weight loss was reduced in strawberries (Nadas, Olmo, and Garcia 2003) exposed to ozone at 3 µg.L^{-1} for 3 days and in papaya (Ali, Ong, Forney 2014) exposed to ozone at 2.8 – 9.3 µg.L^{-1} for 4 days. Several other studies including carrots treated with ozone at 0.6 – 2 µg.L^{-1} for up to 4 days (Forney et al. 2007); in tomatoes treated with ozone at 20 µg L^{-1} for 10 min (Rodoni et al. 2009), and in peppers treated with ozone at 2 µg L^{-1} for 1 – 5 min (Horvitz and Cantalejo 2012) reported that the weight remained unaffected. These results suggest that for each commodity, there is a threshold limit of ozone concentration and exposure time above which damage may be caused to the product.

The color of the fruit and vegetable is important because any alteration in color might be considered as a symptom of senescence (Nunes et al. 2009). Ozonation had no significant effect on the change in color of apples (Sharpe et al. 2009), tomatoes (Bermudez-Aguirre and Barbosa-Canovas 2013), and papaya (Kying and Ali 2016) during storage. Conversely, ozone treatment at 38 to 95 µg L^{-1} for 10 min delayed the development of red color during the storage of tomatoes (Zambre, Venkatesh, and Shah 2010). Bermudez-Aguirre and Barbosa-Canovas (2013) noticed the bleaching effect of ozone at 10 to 115 µg L^{-1} on the orange-red color of carrots. Ali, Ong, Forney

(2014) observed that changes in papaya peel color when treated with gaseous ozone at 4.5 μg.L-1 for 96 h. The possibility of ozone reacting with the carotenoids in the food products, thereby causing discoloration, could not be ignored (Sandhu, Manthey, and Simsek 2011).

Firmness is an important textural property for fruits and vegetables. Many research papers have reported that ozone treatment retained the firmness in tomatoes, strawberries, kiwi, and papaya (Ali, Ong, and Forney 2014; Kying and Ali 2016; Minas et al. 2012; Tzortzakis et al. 2011). However, several studies showed that ozone did not alter the firmness of grapes, pears, and apples (Horvitz and Cantalejo 2012; Martinez-Sanchez et al. 2008; Sharpe et al. 2009). Nevertheless, changes in the surface color of peaches and carrots after application of ozone have been documented (Badiani et al. 1995; Liew and Prange 1994). Carrot sticks tissue toughening has been delayed after the ozone treatment (Chauhan et al. 2011). These changes may be due to changes in an internal structure of the cell wall including cellulose and lignin content and reduced lignification (An, Zhang, and Lu 2007).

Fruit juice

Fruit juices are rich source of vitamins, anthocyanins, phenolic compounds, and carotenoids (Abeysinghe et al. 2007). Thus, fruit juice consumption has increased worldwide and considered to be mainstay for a healthy lifestyle (Jaramillo-Sánchez et al. 2017). Pasteurized juices typically had undergone negative modifications in functional compounds, flavor, and color (Rivas et al. 2006). Huge demands for healthy, safe and preservatives free juices with "fresh-like" characteristics (Jaramillo-Sánchez et al. 2017; Pandiselvam et al. 2017a). Food technologists and processing industries are looking for alternative interventions to thermal pasteurization techniques. Ozone is an attractive option for the food processing industry.

A great boost to the use of ozonation in various fruit juices came when the US FDA approved it as a direct food additive (FDA 2001). This has been possible because ozonation effects five log reductions in the population of pathogens such as *E. coli, Listeria monocytogens and Salmonella*. Ozone has been tried for processing of apple cider (Steenstrup and Floros 2004), orange juice (Tiwari et al. 2008a), tomato juice (Tiwari et al. 2009a), blackberry juice (Tiwari et al. 2009b), apple juice (Choi et al. 2012), peach juice (Jaramillo-Sánchez et al. 2017), cantaloupe melon juice (Fundo et al. 2018) and sugarcane juice (Garud et al. 2018). The approved level of ozone in bottled juices is 0.4 mg.L^{-1} even though ozone itself does not leave any residual effects (Williams, Sumner, and Golden 2005). Efficacy of ozonation for the inactivation of microorganisms in fruit juice depends on pH of juice, additives (surfactants and sugars), temperature, concentration, ozone flow rate, organic matter content, and solids content (Choi et al. 2012).

The effect of ozone on the quality of fruit juice depends not only on ozone concentration and exposure time but also on the chemical composition of fruit juice. Ozone treatment resulted in modifications of color in apple cider (Choi and Nielsen 2005), orange juice (Tiwari et al. 2008b), and strawberry juice (Tiwari et al. 2009c). Aqueous ozonation generates the hydroxyl radicals in the medium that may unlock the aromatic rings and lead to oxidation of aldehydes, organic acids, and ketones (Patil and Bourke 2012). Jaramillo-Sánchez et al. (2017) observed that slight increase in the browning of ozonized peach juices. Browning development in ozonated peach juice could be associated with enzymatic action and non-enzymatic reaction, which could be stimulated by the oxidation of phenolic compounds by ozone (McEvily, Iyengar, and Otwell 1992). Also, ozone treatment has no effect on pH, °Brix, cloud value, and titratable acidity of apple cider (Choi and Nielsen 2005) and tomato and orange juice (Tiwari et al. 2008b, 2009a).

Cheese

Ozone has been utilized as an alternative preservation method for cheese where the growth of moulds adversely affects its sensory properties. Storage of cheese could be carried out by ozonating the atmosphere for at least 4 h for 3-day interval at the rate of 5 to 7 μg.L^{-1} for 4 months in an otherwise non-ozonized atmosphere mould growth appears in a month. Ozone concentrations as low as 0.1 to 10 μg.L^{-1} in the cheese-ripening process controlled the emergence of mould spores without compromising the sensory qualities of cheeses (Shiler, Eliseeva, and Chebotarev 1978). Variety of cheese types such as Kostroma, Poshekhonskii, Rossiiskii, and Swiss-type were stored in an ozonated atmosphere at 2–4°C and 85 to 90% relative humidity (Gabriel'yants' et al. 1980). Shiler et al. (1983) have advocated an ozonation process for both ripening and storing the Swiss-type cheese to inactivate microorganisms. Horvath, Bilitzky, Huttner (1985) documented the effective utility of ozone, even at low concentrations (0.02 mg.L^{-1}), in enhancing the storage life of cheese to 11 weeks. Further, experiments on cheddar cheese have reinforced the utility of ozone's oxidizing power in eliminating the odor associated with cheese storage rooms.

Meat

A major issue associated with the consumption of meat is illness that ensues due to contamination of meat with *Campylobacter, E.coli, Listeria* and *Salmonella*. Hence, the meat industry explores new strategies to fight against these hazardous pathogens. Kaess and Weidemann (1968) demonstrated the utility of ozone treatment, at > 2 $\mu g.L^{-1}$, in decreasing the *Pseudomonas* spp. count of contaminated beef. The color of the muscle surface treated with < 0.6 $\mu g.L^{-1}$ ozone did not differ from that of the control. Kaess and Weidemann (1973) showed the synergistic effect of ozone (at the flow rate of 0.5 $\mu g.L^{-1}$), and UV of 0.2 $\mu W.cm^{-2}$ in inhibiting the growth of *Thamnidium* spp. and *Penicillium* spp Ozone treatment (100 ppm for 30 min) had little effect on counts of *Lactobacillus, Microbacterium thermosphactum*, and *P. fluorescens* on a beef surface (Fournaud and Lauret 1972). Spraying beef brisket fat with ozonated water (5 $g.L^{-1}$) and hydrogen peroxide (50 $g.L^{-1}$) solution was effective in reducing bacterial contamination, when compared to treatments with acetic acid (20 $g.L^{-1}$), trisodium phosphate (120 $g.L^{-1}$), and a commercial sanitizer (3 $g.L^{-1}$) (Gorman et al. 1995).

Carcasses of beef are generally contaminated with faecal matter when normal dressing procedures are followed. Hence, in order to explore the potential of ozonated water in decontaminating the beef carcasses, Castillo et al. (2003) investigated the effect of an ozone treatment spray (95 $mg.L^{-1}$ ozone concentration at 80 $lb.in^{-2}$) to beef carcasses and compared it with plain water washing (increase of pressure up to 400 $lb.in^{-2}$). Though significant differences were not observed between the treatments, ozone treatment caused a reduction in pathogen count.

In addition, Reagan et al. (1996) assessed the efficacy of ozone against microorganism in beef carcasses. They reported that ozone treatment reduced the microbial load of the carcass by 1.30 $CFU.cm^{-2}$, in comparison to hydrogen peroxide treatment (1.14 $CFU.cm^{-2}$). Novak and Yuan (2004a) reported the effect of ozone treatment before cooking to control the microorganisms. Ozonated beef was cooked at 45–75°C to study the population of *Clostridium perfringens* (enterotoxin-producing strains). The pre-treatment of aqueous ozone reduced *C. perfringens* population by 1–2 log $CFU.g^{-1}$. Additionally, the spores were more resistant to ozone than thermal treatments. Novak and Yuan (2004b) investigated the effect of heat and ozone treatment on reduction of *C. perfringens* spores on beef surfaces which were aseptically packed under modified atmosphere. They have found that *C. perfringens* spores remained dormant in beef through a 10-day storage at 25°C and inhibited spore germination count with increasing CO_2 concentrations in the atmosphere. Horvath, Bilitzky, and Huttner (1985) observed that the growth of microflora on meat surfaces decreased in the presence of ozone; however, no inhibitory effect was observed in the meat that was heavily contaminated. Jhala et al. (2002) studied the impact of ozone and bacteriocin from *Propionibacteriums hermanii* on *L. monocytogenes* in cooked and cured a ham. They observed a synergistic activity between bacteriocin and ozone (0.2–1.0 ppm), causing an inactivation of 3 log reductions of *L. monocytogenes*.

Poultry

Ozone has been tested for disinfecting hatching eggs, poultry carcass, poultry chiller water, and contaminated eggs. Cultures of *Streptococcus, Staphylococcus*, and *Bacillus* species, *E. coli, Salmonella typhimurium, P. fluorescens*, and *A. fumigates* (isolated from poultry hatcheries) were exposed to gaseous ozone and the efficacy of ozone gas was investigated (Whistler and Sheldon 1989). Yang and Chen (1979) evaluated the efficacy of ozone on microflora of poultry meat. The broiler carcasses were divided into breast and thigh pieces and natural microflora were inoculated. The inoculated culture was washed with 3.88 $mg.L^{-1}$ ozone with a flow rate of 2050 mL min^{-1} for 20 min. This study revealed that ozone-based washing reduced the microbial counts in the carcass. The ozone treatment increased poultry shelf life by 2.4 days. Furthermore, ozone treatment was most effective for reducing the Gram-negative rods. Sheldon and Brown (1986) tested the effects of ozone on the poultry chiller water and broiler carcasses. Carcasses, chilled with water containing ozone (3.0 to 4.5 ppm) for 45 min, showed low microbial count during storage. Rudavskaya and Tishchenko (1978) observed the keeping quality of eggs after ozonation. Eggs were treated with gaseous ozone (10 to 12 µg/liter air) for 6 h and stored at 21°C with 86% RH and 29°C with 75% RH for 6 months. All sensory quality parameters showed desirable values in the ozone-treated samples than in the controls. Krivopishin, Emel'yanov, and Tregubov (1977) suggested an ozonation method for preservation of eggs. Eggs were dipped in paraffin wax at 40 to 45°C and treated for 10 to 30 min in air containing 1 to 3 $mg.L^{-1}$ ozone showed potential. In a hyper pasteurization process patented by Cox, Cox, and Cox (1995), washed eggshell are treated with a combination of heat (59.4°C) and ozone in a vacuum chamber increased its shelf-life and reduced the microbes. On the other hand, effect of ozone in the refrigerated storage of poultry in alleviating the ill-effects of microorganisms was documented by Nieto, Jiménez-Colmenero, and Peláez (1984). This study also showed that chicken meat could be stored for up to 13 days at a temperature of 2 ± 1°C and a relative humidity of 93 ± 2% when the atmosphere is enriched with ozone.

Seafood

Seafood products are one of the principal sources of protein content and hence preservation of seafood is a research priority in food industry. Freezing is one of the major technologies, which have provided means to overcome the perishable nature of seafood products. Ozone treatment also contributes to the maintenance of the quality of seafood products. Powell et al. (1979) reported that the largest numbers of microorganisms are found in the intestine, slime, and gills. The preservation effect of ozone on the jack mackerel (*Trachurus trachurus*) and shimaaji (*Caranx mertensi*) was investigated by Haraguchi, Shimizu, and Aiso (1969). Results reveal that incorporation of 0.6 ppm ozone in 3% NaCl solution decreased the count of viable bacterial cells in the skin of the gutted fish. Further, the treatment increased the storage life of fish from 20% to 60% when the treatment was provided periodically (every 2 days). Chen, Chang, and Ing (1987) developed an ozone-based in-plant sterilization methodology for frozen fishery products. It paved way for inactivation of harmful pathogenic organisms such as *E. coli, Salmonella aureus. Salmonella typhimurium*, and *V. parahaemolyticus* using ozone in distilled water. Ozone (6 ppm) treatment of live fish prolonged their quality characteristics for one month which were stored at 0 and 5°C (Gelman et al. 2005; Nash 2002). The combination of ozone treatment with cold storage (0 °C) is an attractive option for prolonging the storage life of fish.

The use of aqueous ozonation for washing of fish reduced the microflora. The treatment had no negative effect on the quality of the product (Gelman et al. 2005; Ravesi, Licciardello, and Racicot 1988). Paranjpye et al. (2008) studied the effect of washing and direct exposure of frozen shrimp contaminated by *L. monocytogenes* with ozone-containing water (5 ppm) and ozone gas. They found that shrimp was soaked or washed with ozone-containing water (20 or 60 min), or exposed to ozone gas for similar durations, the treatment was ineffective against *L. monocytogenes.*

To improve the efficacy of ozone treatments, fresh fish should be treated with ozonated water because bacterial attack occurs through skin of the fish over time. Treatment with aqueous ozonation minimizes the washing time and improves color (Naito and Takahara 2006). Ozone treatment was used to improve the washing process for dark-fleshed fish surimi (Chen and Lao 1997). Thus, the researchers found that aqueous ozonation minimized the washing time and improved color of surmi minces. Naito and Sannomiya (1985) have investigated the effect of ozone treatment (0.2–0.5 ppm (v/v)) of dried cuttlefish. The results showed dramatic reductions of *M. caseolticus, Micrococcus varians*, and *M. colpogenes*, which resulted in an increased storage period. They found that dried cuttlefish exposed to gaseous ozone (low concentrations) rapidly reduce the *Micrococcus* and causes no discolorations.

Water treatment in food industry

Water is a principal ingredient of food processing industry as it is indispensable for many unit operations such as blanching, chilling, cooling, heating, pasteurizing, rinsing, soaking, steam production, and washing etc (Casani, Rouhany, and Knochel 2005; Poretti 1990). The main considerations for water efficiency in food processing industry are economical, environmental and technological. Since exhaustive water recycling is a necessity in the food industry, economic considerations are given much importance. However, it is important to consider the quality and safety of the finished products following water treatment (Kirby, Bartram, and Carr 2003). Several water treatment procedures based on membrane bioreactors, nanofiltration (NF) and reverse osmosis (RO) have been developed to reduce BOD and COD and microbial load to attain acceptable drinking standards (Fahnrich, Mavrov, and Chmiel 1998; Noronha et al. 2002) however with low efficiency and involves at least double-staged process. Ozone treatment evinces much interest since the anti-microbial activity of ozone is about 3,000 times higher than what was observed with chlorine, and also it efficiently dissolves in water (Miguel et al. 2016). Ozone directly reacts with water at low pH whereas non-selective, indirect reaction of ozone with water at high pH produces reactive oxygen species (ROS) (Hoigné and Bader 1977). Of late these properties of ozone makes it a convenient choice for degradation of contaminants in wastewater (Huber et al. 2003; Kianmehr and Kfoury 2016; Mella et al. 2017; Quero-Pastor et al. 2016; Ternes et al. 2003) and drinking water (Dietrich et al. 2017; Miguel et al. 2016; Ternes et al. 2003; Vieno et al. 2007). Water in combination with a sanitizing agent is traditionally used for washing caracasses with the high microbial population. Ozonized water is a great water-sanitizer combination that has been effectively utilized in removing or killing *Enterococcus faecalis* and *Escherichia coli*, and various other food-borne pathogens such as *Bacillus cereus, Listeria monocytogenes, Salmonella typhimurium, Staphylococcus aureus*, and *Yersinia enterocolitica* (Khadre, Yousef, and Kim 2001; Kim, Yousef, and Dave 1999; Restaino et al. 1995). Disinfectant processes such as advanced oxidation technologies (AOT), UV based microbial treatment are regularly used in combination with ozone to achieve effective disinfection because the drawbacks associated with chlorine treatment are avoided (Fawell 2000; Suslow 2001). In addition, ozone dissolution in water has been successfully utilized in the removal of 1,4-dioxane found in the drinking water (Dietrich et al. 2017). Prior filtration of water is essential for efficient ozone treatment as it improves ozone dissolution, eliminates suspended solids, compounds, and optimal reduction of microbial load (EPRI 1999; Gil et al. 2009; Hampson and Fiori 1997; Sheldon and Brown 1986).

Prospectives

The effectiveness of ozone treatment strongly depends on the selection of a sufficiently effective ozone dose. The high moisture foods including vegetables and fruits are most affected by the negative effects of ozone due to their high moisture content, enzymes and phenolic compounds (Sandhu, Manthey, and Simsek 2011). However, the ozone treatment conditions should be particularly determined for all types of food products for the safe and effective use of ozone. In case of microbes, varied sensitivity to ozone treatment was observed which depends on the product being treated, initial inoculum level or level of contamination, type of microorganisms, physiological state of the bacterial cells and type of an organic material (Miller et al. 1978). But, care must be taken if higher ozone concentrations are required for antimicrobial treatments, because it can negatively affect the food quality by the reduction of polyphenols, vitamins, and volatile compound contents, loss of firmness and color changes. The optimization of ozone processing conditions must be assessed for particular food commodities, once the quality may be affected. However, varietal characteristics, maturity at the time of harvest are the major factors that determine the composition of fruits and vegetables which in turn affect the optimum dose of ozone required for treatment. All equipment that could come into contact with ozone gas during food preservation must be resistant to corrosion to ozone such as stainless steel (Sleeper and Henry 2007). Also, US Occupational Safety and Health Administration (OSHA), has stipulated that ozone exposure shall not exceed 0.1 ppm by volume during normal working conditions (8 h daily). It warrants precautionary measures to avoid over-exposure to ozone during work. The advantages of ozone-based food preservation methods could not be realized without effective and economical ozone generation system since ozone oxidation is a complex process leading to formation of reactive oxygen species and the half-life of ozone too is short (Greene et al. 2012). Finally the apprehension of the consumers with respect to the perceived toxic properties of the ozone further diminishes its acceptability with the consumers. Hence, comprehensive information regarding the utility of the ozone-based technologies and its potential benefits is mandatory to achieve consumer's acceptance.

Conclusion

Ozone has been a promising technology in the food industry. Since the use of ozone does not involve very high temperature it is an energy saving model. Also, ozone is produced *in situ* hence the storage costs of disinfectants are saved while following this technique. Even though ozone generator may involve initial capital costs for the small-scale businesses the advantages far outweigh the costs in the long run. Nevertheless, it is pertinent to design detailed product-wise feasibility studies regarding the application of ozone and compare it with other methods of food preservation in vogue. Considerable research efforts are underway at a number of universities and research institutes that are investigating the agricultural applications of ozone; Tamil Nadu Agricultural University, Coimbatore, India, AINIA Centro Technológico, Valencia, Spain, Ecole d'ingéniers de Purpan, Toulouse, France, Purdue University, USA, Ohio State University, USA among others. Further intense research efforts are needed to study the use of ozone in preserving food products where infection due to moulds, bacteria and infestation due to insects are rampant. Despite the proven benefits of ozone in obtaining high-quality, safe to eat foods specific treatment conditions have to be standardized for each food product. Many critiques have been raised against the use of ozone in food products as it is considered a potential irritant and sometimes as a poisonous gas at high concentrations. Nevertheless, ozone is a safe disinfectant under controlled conditions. Ozone quickly decomposes to O_2 with little residual effect and hence its effects are short-lived and it is suited for use in preservation of most food materials. However, reduction in microbial and fungal load without compromising the organoleptic and nutritional qualities could not be achieved by ozonation alone. Some combination application of ozonation with pasteurization, UV, high-pressure processing, membrane processing and freezing may be very effective in microbial inhibition and shelf life extension and of food products. Meanwhile, consumer's acceptance, cost-effectiveness, legal aspects and safety, and efficacy should also be taken into consideration in future studies.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abeysinghe, D.C, X. Li, W.S. Sun, C.H. Zhang, K.S Zhou, Chen, and C Zhou. 2007. "Bioactive Compounds and Antioxidant Capacities in Different Edible Tissues of Citrus Fruit of Four Species." *Food Chemistry* 104:1338–44.

Aday, M. S., and C. Caner. 2014. "Individual and Combined Effects of Ultrasound, Ozone and Chlorine Dioxide on Strawberry Storage Life." *LWT-Food Science and Technology* 57:344–51.

Aguayo, E., V.H. Escalona, and F. Artes. 2006. "Effect of Cyclic Exposure to Ozone Gas on Physicochemical, Sensorial and Microbial Quality of Whole and Sliced Tomatoes." *Postharvest Biology and Technology* 39:169–77.

Alexopoulos, A, S Plessas, V Ceciu, Lazar, I Mantzourani, C. Voidarou, and E. Bezirtzoglou. 2013. "Evaluation of Ozone Efficacy on the Reduction of Microbial Population of Fresh Cut Lettuce (*Lactuca Sativa*) and Green Bell Pepper (*Capsicum Annuum*)." *Food Control* 30:491–96.

Ali, A., M.K. Ong, and C.F. Forney. 2014. "Effect of Ozone Pre-Conditioning on Quality and Antioxidant Capacity of Papaya Fruit during Ambient Storage." *Food Chemistry* 142: 19–26. doi: 10.1016/j.foodchem.2013.07.039

Almeida, F. D. L., R.S. Cavalcante, P.J. Cullen, J.M. Frias, P. Bourke, F.A. Fernandes, and S. Rodrigues. 2015. "Effects of Atmospheric Cold Plasma and Ozone on Prebiotic Orange Juice." *Innovative Food Science & Emerging Technologies* 32:127–35.

An, J., M. Zhang, and Q. Lu. 2007. "Changes in Some Quality Indexes in Fresh Cut Green Asparagus Pretreated with Aqueous Ozone and Subsequent Modified Atmosphere Packaging." *Journal of Food Engineering* 78: 340–44. doi: 10.1016/j.jfoodeng.2005.10.001

Antos, P., B. Piechowicz, J. Gorzelany, N. Matłok, D. Migut, R. Józefczyk, and M. Balawejder. 2018. "Effect of Ozone on Fruit Quality and Fungicide Residue Degradation in Apples during Cold Storage." *Ozone: Science & Engineering* 1–5. doi: 10.1080/01919512.2018.1471389.

Badiani, M., J. Fuhrer, A.R. Paolacci, and G.G. Sermanni. 1995. "Deriving Critical Levels for Ozone Effects on Peach Trees [*Prunuspersica (L) Batsch*] Grown in Open-Top Chambers in Central Italy". *8th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region*, Rhodes, Greece: Inst Lebensmittel technologie Analytische Chemie.

Baranovskaya, V.A., O.B. Zapol'skii, I.Y. Ovrutskaya, N.N. Obodovskaya, E.E. Pschenichnaya, and O.I. Yushkevich. 1979. "Use of Ozone Gas Sterilization during Storage of Potatoes and Vegetables." *Konservnaja I Ovoshecesushil'naya Promyshlennost* 4:10–12.

Barry, M.C., K. Hristovski, and P. Westerhoff. 2014. "Promoting Hydroxyl Radical Production during Ozonation of Municipal Wastewater." *Ozone: Science & Engineering* 36:229–37.

Barth, M.M., C. Zhou, J. Mercier, and F.A. Payne. 1995. "Ozone Storage Effects on Anthocyanin Content and Fungal Growth in Blackberries." *Journal of Food Science* 60 (6):1286–88.

Bazarova, V.I. 1982. "Use of Ozone in Storage of Apples." *Food Science and Technology Abstracts* 14:1653.

Beltrán, D., M.V. Selma, A. Marin, and M.I. Gil. 2005a. "Ozonated Water Extends the Shelf Life of Fresh-Cut Lettuce." *Journal of Agricultural and Food Chemistry* 53:5654–63.

Beltrán, D., M.V. Selma, J.A. Tudela, and M.I. Gil. 2005b. "Effect of Different Sanitizers on Microbial and Sensory Quality of Fresh-Cut Potato Strips Stored under Modified Atmosphere or Vacuum Packaging." *Post-Harvest Biology and Technology* 37:37–46.

Beltran, F.J. 2004. *"Ozone Reaction Kinetics for Water and Wastewater System"*. 31–44. UK: CRC Press.

Bermudez-Aguirre, D., and Barbosa-Canovas. 2013. "Disinfection of Selected Vegetables under Non-Thermal Treatments: Chlorine, Acid Citric, Ultraviolet Light and Ozone." *Food Control* 29: 82–90. doi: 10.1016/j.foodcont.2012.05.073

Beuchat, L.R. 1992. "Surface Disinfection of Raw Produce." *Dairy, Food and Environmental Sanitation* 12 (1):6–9.

Botondi, R., F. De Sanctis, N. Moscatelli, A.M. Vettraino, C. Catelli, and F. Mencarelli. 2015. "Ozone Fumigation for Safety and Quality of Wine Grapes in Post-Harvest Dehydration." *Food Chemistry* 188:641–47.

Casani, S., M. Rouhany, and S. Knochel. 2005. "A Discussion Paper on Challenges and Limitations to Water Reuse and Hygiene in the Food Industry." *Water Research* 39 (6):1134–46.

Castanha, N., M. D. Da Matta Junior, and P.E.D. Augusto. 2017. "Potato Starch Modification Using the Ozone Technology." *Food Hydrocolloids* 66:343–56.

Castillo, A., K.S. McKenzie, L.M. Lucia, and G.R. Acuff. 2003. "Ozone Treatment for Reduction of Escherichia Coli 0157: H7and Salmonella Serotype Typhimurium on Beef Carcass Surfaces." *Journal Food Protection* 66 (5):775–79.

Çatal, H., and S. İbanoğlu. 2014. "Effect of Aqueous Ozonation on the Pasting, Flow and Gelatinization Properties of Wheat Starch." *LWT-Food Science and Technology* 59:577–82.

Chauhan, O. P., P. S. Raju, N. Ravi, A. Singh, and A.S. Bawa. 2011. ""Effectivenessof Ozone in Combination with Controlled Atmosphere on Quality Characteristics Including Lignification of Carrot Sticks."." *Journal of Food Engineering* 102 (1):43–48.

Chen, H.C., S.O. Chang, and S.T. Ing. 1987. "A Study on the Sterilization Effect of Ozone and Its Application for

Marine Food Processing." *Journal of the Fisheries Society of Taiwan* 14:79–89.

Chen, H.U., and I.C. Lao. 1997. "Washing Process during the Manufacture of Dark Fleshed Fish Surimi: The Effects of Washing Methods and Conditions on the Color and Gel-Forming Ability of Surimi Prepared from Layanscad (*Decapterusmacarellus*)." *Food Science of Taiwan* 24:56–67.

Choi, L.H., and S.S. Nielsen. 2005. "The Effects of Thermal and Non Thermal Processing Methods on Apple Cider Quality and Consumer Acceptability." *Journal of Food Quality* 28:13–29.

Choi, M., Q. Liu, S. Lee, J. Jin, S. Ryu, and D. Kang. 2012. "Inactivation of Escherichia Coli O157: H7, *Salmonella Typhimurium* and *Listeria Monocytogenes* in Apple Juice with Gaseous Ozone." *Food Microbiology* 32:191–95.

Coke, A.L. 1993. "Mother Nature's Best Remedy: Ozone." *Water Conditioning and Purification* (October):48–51.

Cox, J.P., J.M. Cox, and R.W. Cox. 1995. "Hyperpasteurization of Food." U.S. Patent No. 5,431,939.

De Souza, L.P., Lê Faroni, Rita D.'Antonino, F.F Heleno, P.R Cecon, T.D.C Gonçalves, G.J Da Silva, and L.H.F Prates. 2018. "Effects of Ozone Treatment on Post Harvest Carrot Quality." *LWT - Food Science and Technology* doi: 10.1016/j.lwt.2017.11.057.

De Souza Sartori, J.A., C.F.F. Angolini, M.N. Eberlin, and C. L. De Aguiar. 2017. "Criegee Mechanism as a Safe Pathway of Color Reduction in Sugarcane Juice by Ozonation." *Food Chemistry* 225:181–87.

Desvignes, C., M. Chaurand, M. Dubois, A. Sadoudi, J. Abecassis, and V. Lullien-Pellerin. 2008. "Changes in Common Wheat Grain Milling Behavior and Tissue Mechanical Properties following Ozone Treatment." *Journal of Cereal Science* 47:245–51.

Dietrich, M. G, R.C Andaluri, Smith, and R. Suri. 2017. "Combined Ozone and Ultrasound for the Removal of 1,4-Dioxane from Drinking Water." *Ozone: Science & Engineering* doi: 10.1080/01919512.2017.1321981.

Dubois, M., D. Canadas, A.G. Despres-Pernot, C. Coste, and A. Pfohl-Leszkowicz. 2008. "Oxygreen Process Applied on Nongerminated and Germinated Wheat: Role of Hydroxamic Acids." *Journal of Agric Food Chemistry* 56:1116–21.

Dubois, M., C. Coste, A.G. Despres, T. Efstathiou, C. Nio, E. Dumont, and D. Parent-Massin. 2006. "Safety of Oxygreen, an Ozone Treatment on Wheat Grains. Part 2. Is There a Substantial Equivalence between Oxygreen-Treated Wheat Grains and Untreated Wheat Grains?." *Food Additives and Contaminants* 23:1–15.

EPRI. 1999. "Membrane Filtration and Ozonation of Poultry Chiller Overflow Water: Study of Membrane Treatment to Reduce Water Use and Ozonation for Sanitation at a Poultry Processing Plant." *Technical Report* 114435, Palo Alto,

Evans, F.L. 1972. *Ozone in Water and Wastewater Treatment*, 1–185. Michigan: Ann Arbor Science Publishers.

Fahnrich, A., V. Mavrov, and H. Chmiel. 1998. "Membrane Processes for Water Reuse in the Food Industry." *Desalination* 119:213–16.

Faitel'berg-Blank, V.R., E.V. Bykove, A.V. Orlova, L.G. Ostapenko, and V.A. Stepanenko. 1979. "Improvement of Keeping Quality of Potatoes and Onions by Means of Ionized Air." *Vestn.S'kh. Nauki* 4:110–12.

Fawell, J. 2000. "Risk Assessment Case Study: Chloroform and Related Substances." *Food Chemistry Toxicology* 38: S91–S95.

FDA. 2001. "Hazard Analysis and Critical Control Point (HACCP): Procedures for the Safe and Sanitary Processing and Importing of Juice: Final Rule." *Federal Register* 66: 6137–202.

Fisher, C. W., D. Lee, B.A. Dodge, K.M. Hamman, J.B. Robbins, and S.E. Martin. 2000. "Influence of Catalase and Superoxide Dismutase on Ozone Inactivation of Listeria Monocytogenes." *Applied and Environmental Microbiology* 66 (4):1405–09. doi:10.1128/AEM.66.4.1405-1409.2000.

Forney, C.F., J. Song, P.D. Hildebrand, L. Fan, and K.B. McRae. 2007. "Interactive Effects of Ozone and 1-Methylcyclopropene on Decay Resistance and Quality of Stored Carrots." *Postharvest Biology and Technology* 45: 341–48. doi: 10.1016/j.postharvbio.2007.03.006

Fournaud, J., and R. Lauret. 1972. "Influence of Ozone on the Surface Microbial Flora of Beef during Refrigeration and Thawing." *Technologia Alimentari* 6:12.

Fundo, J.F., F.A. Miller, A. Tremarin, E. Garcia, T.R. Brandão, and C.L. Silva. 2018. "Quality Assessment of Cantaloupe Melon Juice under Ozone Processing." *Innovative Food Science & Emerging Technologies* 47: 461–66. doi: 10.1016/j.ifset.2018.04.016

Gabriel'yants', M.A., L.N. Teplova, T.I. Karpova, R.A. Kozlova, and G.F. Makarova. 1980. "Storage of Hard Rennet Cheeses in Cold Stores with Ozonization of Air." *Kholodil'nayaTekhnika* 5:35–37.

Garud, S.R., B.S. Priyanka, N.K. Rastogi, M. Prakash, and P.S. Negi. 2018. "Efficacy of Ozone and Lactic Acid as Nonthermal Hurdles for Preservation of Sugarcane Juice." *Ozone: Science & Engineering* 40: 198–208. doi: 10.1080/01919512.2017.1415802

Gelman, A., O. Sach, Y. Khanin, V. Drabkin, and L. Glatman. 2005. "Effect of Ozone Pretreatment on Fish Storage Life at Low Temperature." *Journal of Food Protection* 68:778–84.

Gil, M., M.V. Selma, F. López-Gálvez, and A. Allende. 2009. "Fresh-Cut Product Sanitation and Wash Water Disinfection: Problems and Solutions." *International Journal of Food Microbiology* 134:37–45.

Gorman, B.M., J.N. Sofos, J.B. Morgan, G.R. Schmidt, and G. C. Smith. 1995. "Evaluation of Hand-Trimming, Various Sanitizing Agents, and Hot Water Spray-Washing as Decontamination Interventions for Beef Brisket Adipose Tissue." *Journal of Food Protection* 58:899–907.

Gozé, P., L. Rhazi, L. Lakhal, P. Jacolot, A. Pauss, and T. Aussenac. 2017. "Effects of Ozone Treatment on the Molecular Properties of Wheat Grain Proteins." *Journal of Cereal Science* 75:243–251.

Gozé, P., L. Rhazi, A. Pauss, and T. Aussenac. 2016. "Starch Characterization after Ozone Treatment of Wheat Grains." *Journal of Cereal Science* 70:207–13.

Graham, D.M. 1997. "Use of Ozone for Food Processing." *Food Technology* 51:121–37.

Greene, A.K, B. Zeynep, Guzel-Seydium, and Atif Can Seydim. 2012. ""Chemical and Physical Properties of Ozone." In *Ozone in Food Processing*, Eds., 19–32. UK: Wiley-Blackwell.

Guzel-Seydim, Z.B., A.K. Greene, and A.C. Seydim. 2004. "Use of Ozone in the Food Industry." *LWT-Food Science and Technology* 37:453–60.

Hampson, B.C., and S.R. Fiori. 1997. “Applications of Ozone in Food Processing Operations.” *Proceedings of 1997 IOA PAG Conference*, Lake Tahoe, NV, pp. 261–67.

Haraguchi, T., U. Shimizu, and K. Aiso. 1969. “Preservation of Ozone on Fish.” *Bulletin of the Japanese Society of Scientific Fisheries* 35:915–19.

Hill, A. G., and R.G. Rice. 1982. “Historical Background, Properties and Applications.” In *Ozone Treatment of Water for Cooling Application*, Ed., 1–37. Michigan: Ann Arbor Science Publishers.

Hoigné, J., and H. Bader. 1977. “The Role of Hydroxyl Radical Reactions in Ozonation Processes in Aqueous Solutions.” *Water Research* 10: 377–86. doi: 10.1016/0043-1354(76)90055-5

Holmstrup, M., J. G. Sørensen, L.H. Heckmann, S. Slotsbo, P. Hansen, and L.S. Hansen. 2011. “Effects of Ozone on Gene Expression and Lipid Peroxidation in Adults and Larvae of the Red Flour Beetle (*Tribolium Castaneum*).” *Journal of Stored Products Research* 47:378–84.

Horvath, M., L. Bilitzky, and J. Huttner. 1985. ““Fields of Utilization of Ozone.” In *Ozone*, ed., 257–316. New York: Elsevier Science Publishing Co., Inc.

Horvitz, S., and M.J. Cantalejo. 2012. “Effects of Ozone and Chlorine Postharvest Treatments on Quality of Fresh Cut Red Bell Peppers.” *International Journal of Food Science and Technology* 47: 1935–43. doi: 10.1111/j.1365-2621.2012.03053.x

Huber, M.M., S. Canonica, G.Y. Park, and U. Von Gunten. 2003. “Oxidation of Pharmaceuticals during Ozonation and Advanced Oxidation Processes.” *Environmental Science and Technology* 37:1016–24.

Ibanoglu, S. 2002. “Wheat Washing with Ozonated Water: Effects on Selected Flour Properties.” *International Journal of Food Science and Technology* 37:579–84.

Jamil, A., S. Farooq, and I. Hashmi. 2017. “Ozone Disinfection Efficiency for Indicator Microorganisms at Different pH Values and Temperatures.” *Ozone: Science & Engineering* 39: 407–16. doi: 10.1080/01919512.2017.1322489

Jaramillo-Sánchez, G. M., A.B. Garcia Loredo, E.V. Contigiani, P.L. Gómez, and S.M. Alzamora. 2017. “Inactivation Kinetics of Peroxidase and Polyphenoloxidase in Peach Juice Treated with Gaseous Ozone.” *International Journal of Food Science and Technology* 53: 347–55. doi: 10.1111/ijfs.13591

Jhala, R., K. Muthukumarappan, J.L. Julson, R.I. Dave, and A. K. Mahapatra. 2002. “Synergistic Effect of Ozone and Micrgard 300 for Controlling Listeria Monocytogenes in Ready-To-Eat Cooked and Cured Ham.” *ASAE Annual International Meeting/CIGR XVth World Congress, Paper Number* 026143:1–7.

Jodzis, S., and W. Patkowski. 2016. “‘Kinetic and Energetic Analysis of the Ozone Synthesis Process in Oxygen-Fed DBD Reactor. Effect of Power Density, Gap Volume and Residence Time.”.” *Ozone: Science & Engineering* 38:86–99.

Kaess, G., and J.F. Weidemann. 1968. “Ozone Treatment of Chilled Beef. I. Effect of Low Concentrations of Ozone on Microbial Spoilage and Surface Color of Beef.” *Journal of Food Technology* 3:325–34.

Kaess, G., and J.F. Weidemann. 1973. “Effects of Ultraviolet Irradiation on the Growth of Microorganisms on Chilled Beef Slices.” *Journal of Food Technology* 8:59–69.

Karaca, H. 2010. “Use of Ozone in the Citrus Industry.” *Ozone: Science & Engineering* 32: 122–29. doi: 10.1080/01919510903520605

Karaca, H., and Y.S. Velioglu. 2007. “Ozone Applications in Fruit and Vegetable Processing.” *Food Reviews International* 23 (1):91–106.

Kells, S.A., L.J. Mason, D.E. Maier, and C.P. Woloshuk. 2001. “Efficacy and Fumigation Characteristics of Ozone in Stored Maize.” *Journal of Stored Products Research* 37:371–82.

Khadre, M.A., A.E. Yousef, and J. Kim. 2001. “Microbiological Aspects of Ozone Applications in Food: A Review.” *Journal of Food Science* 66: 1242–52. doi: 10.1111/j.1365-2621.2001.tb15196.x

Kianmehr, P., and F. Kfoury. 2016. “Prediction of Methane Generation of Ozone-Treated Sludge from a Wastewater Treatment Plant.” *Ozone: Science & Engineering* 38 (6):465–71. doi:10.1080/01919512.2016.1213157.

Kim, J.G., A.E. Yousef, and S. Dave. 1999. “Application of Ozone for Enhancing the Microbiological Safety and Quality of Foods: A Review.” *Journal of Food Protection* 62 (9):1071–87.

Kirby, R.M., J. Bartram, and R. Carr. 2003. “Water in Food Production and Processing: Quantity and Quality Concerns.” *Food Control* 14:283–99.

Krivopishin, I.P., B.V. Emel’yanov, and B.A. Tregubov. 1977. “Method for Preservation of Eggs.” USSR patent no. 577009.

Kying, O.M., and A. Ali. 2016. “Effect of Ozone Exposure on Microbial Flora and Quality Attributes of Papaya (*Carica Papaya L*) Fruit.” *Journal of Agronomy and Agricultural Aspects JAAA* 2016(1):104

Ledakowicz, S., R. Żyłła, K. Paździor, J. Wrębiak, and J. Sójka-Ledakowicz. 2017. “Integration of Ozonation and Biological Treatment of Industrial Wastewater from Dyehouse.” *Ozone: Science & Engineering* 39: 357–65. doi: 10.1080/01919512.2017.1321980

Liangji, X. 1999. “Use of Ozone to Improve the Safety of Fresh Fruits and Vegetables.” *Food Technology* 53:58–61.

Liew, C.L., and R.K. Prange. 1994. “Effect of Ozone and Storage-Temperature on Post Harvest Diseases and Physiology of Carrots (*Daucus-Carota L.*).” *Journal American Society Horticultural Science* 119:563–67.

Loeb, B.L. 2011. “Ozone: Science & Engineering: Thirty-Three Years and Growing.” *Ozone: Science & Engineering* 33:329–42.

Lu, B., Y. Ren, Y.Z. Du, Y. Fu, and J. Gu. 2009. “Effect of Ozone on Respiration of Adult *Sitophilusorizae* (L.), *Tribolium Castaneum* (Herbst) and *Rhyzopertha Dominica* (F.).” *Journal of Insect Physiology* 55:885–89.

Luo, X., R. Wang, L. Wang, Y. Li, Y. Bian, and Z. Chen. 2014. “Effect of Ozone Treatment on Aflatoxin B1 and Safety Evaluation of Ozonized Corn.” *Food Control* 37:171–76.

Martinez-Sanchez, A., A. Allende, Y. Cortes-Galera, and M.I. Gil. 2008. “Respiration Rate Response of Four Baby Leaf. *Brassica* Species to Cutting at Harvest and Fresh-Cut Washing.” *Postharvest Biology and Technology* 47: 382–88. doi: 10.1016/j.postharvbio.2007.07.010

McEvily, A. J., R. Iyengar, and W.S. Otwell. 1992. “Inhibition of Enzymatic Browning in Foods and Beverages.” *Critical Reviews in Food Science and Nutrition* 32:253–73.

Mehlman, M. A., and C. Borek. 1987. “Toxicity and Biochemical Mechanisms of Ozone.” *Environmental Research* 42:36–53.

Mei, J., G. Liu, X. Huang, and W. Ding. 2016. “Effects of Ozone Treatment on Medium Hard Wheat (Triticum Aestivum L.) Flour Quality and Performance in Steamed Bread Making.” *CyTA Journal of Food* 14:449–56.

Mella, B, B.S De C, D Barcellos, Extralazon Da Silva Costa, and M. Gutterres. 2017: “Treatment of Leather Dyeing Wastewater with Associated Process of Coagulation-Flocculation/Adsorption/Ozonation.”Ozone: Science & Engineering, DOI:10.1080/01919512.2017.1346464.

Mendez, F., D. E. Maier, L. J. Mason, and C. P. Woloshuk. 2003. “Penetration of Ozone into Columns of Stored Grains and Effects on Chemical Composition and Processing Performance.” *Journal of Stored Products Research* 39: 33–44. doi: 10.1016/S0022-474X(02)00015-2

Miguel, N., M. Lanao, P. Valero, R. Mosteo, and M.P. Ormad. 2016. “*Enterococcus Sp*. Inactivation by Ozonation in Natural Water: Influence of H2O2 and TiO2 and Inactivation Kinetics Modeling.” *Ozone: Science & Engineering* 38: 443–51. doi: 10.1080/01919512.2016.1204223

Miller, G. W., R.G. Rice, C.M. Robson, R.L. Scullin, W. Kuhn, and H. Wolf. 1978. “.An Assessment of Ozone and Chlorine Dioxide Technologies for Treatment of Municipal Water Supplies.” US Environmental Protection Agency Report No. EPA-600/2-78-147. Washington, DC: US Government printing Office.

Minas, I.S., G. Tanou, M. Belghazi, D. Job, G.A. Manganaris, A. Molassiotis, and M. Vasilakakis. 2012. “Physiological and Proteomic Approaches to Address the Active Role of Ozone in Kiwi Fruit Post-Harvest Ripening.” *Journal of Experimental Botany* 63: 2449–64. doi: 10.1093/jxb/err418

Mohammadi, H., S.M. Mazloomi, M.H. Eskandari, M. Aminlari, and M. Niakousari. 2017. “The Effect of Ozone on Aflatoxin M1, Oxidative Stability, Carotenoid Content and the Microbial Count of Milk.” *Ozone: Science & Engineering* 39: 447–53. doi: 10.1080/01919512.2017.1329647

Mustafa, M. G. 1990. “Biochemical Basis of Ozone Toxicity.” *Free Radical Biology and Medicine* 9:245–65.

Muthukumar, A., and M. Muthuchamy. 2013. “Optimization of Ozone in Gaseous Phase to Inactivate Listeria Monocytogenes on Raw Chicken Samples.” *Food Research International* 54 (1):1128–30.

Nadas, A., M. Olmo, and J.M. Garcia. 2003. “Growth of *Botrytis Cinerea* and Strawberry Quality in Ozone Enriched Atmospheres.” *Journal of Food Science* 68: 1798–802. doi: 10.1111/j.1365-2621.2003.tb12332.x

Naito, S., and Y. Sannomiya. 1985. “Ozone Treatment of Dried Cuttlefish for Storage.” *Annual Report of the Food Research Institute, Aichi Prefectural Government* 26:104–12.

Naito, S., and H. Takahara. 2006. “Ozone Contribution in Food Industry in Japan.” *Ozone: Science & Engineering* 28: 425–29. doi: 10.1080/01919510600987347

Najafi, M. B. H., and M. H. Khodaparast. 2009. “Efficacy of Ozone to Reduce Microbial Populations in Date Fruits.” *Food Control* 20:27–30.

Nakamura, H., M. Oya, T. Hanamoto, and D. Nagashio. 2017. “Reviewing the 20 Years of Operation of Ozonation Facilities in Hanshin Water Supply Authority with respect to Water Quality Improvements.” *Ozone: Science & Engineering* 39: 397–06. doi: 10.1080/01919512.2017.1352413

Nash, B. 2002. “Ozone Effective in Preserving Seafood Freshness.” Marine Extension News, North Carolina Sea Grant, Spring Issue.

Nieto, J.C., F. Jiménez-Colmenero, and Ma.C Peláez. 1984. “Effect of Ozone on Bacterial Flora in Poultry during Refrigerated Storage.” *International Journal of Refrigeration* 7:389–92.

Nishijima, W., T. Okuda, S. Nakai, and M. Okada. 2014. “A Green Procedure Using Ozone for Cleaning-In-Place in the Beverage Industry.” *Chemosphere* 105:106–11.

Noronha, M., T. Britz, V. Mavrov, H.D. Janke, and H. Chmiel. 2002. “Treatment of Spent Process Water from a Fruit Juice Company for Purposes of Reuse: Hybrid Process Concept and On-Site Test Operation of a Pilot Plant.” *Desalination* 143:183–96.

Novak, J.S., and J.T.C. Yuan. 2004a. “Increased Inactivation of Ozone-Treated *Clostridium Perfringens* Vegetative Cells and Spores on Fabricated Beef Surfaces Using Mild Heat.” *Journal Food Protection* 67:342–46.

Novak, J.S., and J.T.C. Yuan. 2004b. “The Fate of Clostridium Perfringensspores Exposed to Ozone And/Or Mild Heat Pretreatment on Beef Surfaces Followed by Modified Atmosphere Packaging.” *Food Microbiology* 21:667–73.

Nunes, M.C.N., J.P. Emond, M. Rauth, S. Dea, and K.V. Chau. 2009. “Environmental Conditions Encountered during Typical Consumer Retail Display Affect Fruit and Vegetable Quality and Waste.” *Postharvest Biology and Technology* 51: 232–41. doi: 10.1016/j.postharvbio.2008.07.016

O’Donnell, C., B.K. Tiwari, P.J. Cullen, and R.G. Rice. 2012. *Ozone in Food Processing*. West Sussex, UK: BlackWell Publishing Ltd, John Wiley & Sons.

Obadi, M., K.X. Zhu, W. Peng, A.F. Ammar, and H.M. Zhou. 2016. “Effect of Ozone Gas Processing on Physical and Chemical Properties of Wheat Proteins.” *Tropical Journal of Pharmaceutical Research* 15:2147–2154.

Obadi, M., K.X. Zhu, W. Peng, A. Noman, K. Mohammed, and H.M. Zhou. 2018. “Oil Characterization of Whole Grain Flour as Affected by Ozone Gas.” *Journal of Cereal Science* 79:527–533.

Ölmez, H., and M.Y. Akbas. 2009. “Optimization of Ozone Treatment of Fresh-Cut Green Leaf Lettuce.” *Journal of Food Engineering* 90:487–94.

Ong, K.C., J.N. Cash, M.J. Zabik, M. Siddiq, and A.L. Jones. 1996. “Chlorine and Ozone Washes for Pesticide Removal from Apples and Processed Apple Sauce.” *Food Chemistry* 55:153–60.

Ou-Yang, X.K., S.M. Liu, and M. Ying. 2004. “Study on the Mechanism of Ozone Reaction with Parathion-Methyl.” *Safety and Environmental Engineering* 11:38–41.

Palou, L., C.H. Crisosto, J.L. Smilanick, J.E. Adaskaveg, and J. P. Zoffoli. 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* 24:39–48.

Pandiselvam, R., V. Chandrasekar, and V. Thirupathi. 2017. “Numerical Simulation of Ozone Concentration Profile and Flow Characteristics in Paddy Bulks.” *Pest Management Science* 73: 1698–702. doi: 10.1002/ps.4516

Pandiselvam, R., A. Kothakota, V. Thirupathi, S. Anandakumar, and P. Krishnakumar. 2017b. “Numerical Simulation and Validation of Ozone Concentration Profile in Green Gram (*Vigna Radiate*) Bulks.” *Ozone: Science & Engineering* 39:54–60.

Pandiselvam, R., S. Sunoj, M.R. Manikantan, A. Kothakota, and K.B. Hebbar. 2017a. “Application and Kinetics of Ozone in Food Preservation.” *Ozone: Science & Engineering* 39: 115–26. doi: 10.1080/01919512.2016.1268947

Pandiselvam, R., S. Sunoj, and D. Uma. 2016. “Development of Multivariate Regression Model for Quantification of Proximate Content in *Vigna Radiata* Using Fourier Transform–NIR Spectroscopy.” *Poljoprivredna Tehnika* 41:61–70.

Pandiselvam, R., and V. Thirupathi. 2015. “Reaction Kinetics of Ozone Gas in Green Gram (*Vigna Radiate*).” *Ozone: Science & Engineering* 37: 309–15. doi: 10.1080/01919512.2014.984158

Pandiselvam, R., V. Thirupathi, and S. Anandakumar. 2015. “Reaction Kinetics of Ozone Gas in Paddy Grains.” *Journal of Food Process Engineering* 38: 594–600. doi: 10.1111/jfpe.2015.38.issue-6

Pandiselvam, R., V. Thirupathi, V. Chandrasekar, A. Kothakota, and S. Anandakumar. 2018. “Numerical Simulation and Validation of Mass Transfer Process of Ozone Gas in Rice Grain Bulks.” *Ozone: Science & Engineering* 40:191–97.

Pandiselvam, R., V. Thirupathi, and P. Vennila. 2016. “Fourier Transform–Near Infrared Spectroscopy for Rapid and Nondestructive Measurement of Amylose Content of Paddy.” *Poljoprivredna Tehnika* 41:93–100.

Paranjpye, R.N., M.E. Peterson, F.T. Poysky, and M.W. Eklund. 2008. “Incidence, Growth, and Inactivation of Listeria Monocytogenesin Cooked and Peeled Cold-Water Shrimp.” *Journal of Aquatic Food Product Technology* 17:266–84.

Pathapati, S.S., A.L. Mazzei, J.R. Jackson, P.K. Overbeck, J.P. Bennett, and C.M. Cobar. 2016. “Optimization of Mixing and Mass Transfer in In-Line Multi-Jet Ozone Contactors Using Computational Fluid Dynamics.” *Ozone: Science & Engineering* 38:245–52.

Patil, S., and P. Bourke. 2012. “Ozone Processing of Fluid Foods.” In *In Novel Thermal and Non-Thermal Technologies for Fluid Foods*, edited by, 225–61. London, United Kingdom: Elsevier.

Peleg, M. 1976. “Review Paper: The Chemistry of Ozone in the Treatment of Water.” *Water Research* 10:361–65.

Perez, A.G., C. Sanz, J.J. Rios, R. Olias, and J.M. Olias. 1999. “Effects of Ozone Treatment on Postharvest Strawberry Quality.” *Journal of Agricultural and Food Chemistry* 47:1652–56.

Poretti, M. 1990. “Quality Control of Water as Raw Material in the Food Industry.” *Food Control* 1:79–83.

Powell, J., C. Anne, R. Moor, and J.A. Gow. 1979. “Comparison of EC Broth and Medium A-1 for the Recovery of Escherichia Coli from Frozen Shucked Snow Crab.” *Environ Microbiol* 37:836–40.

Qi, S.Q., Y.Q. Mao, X.F. Guo, X.M. Wang, H.W. Yang, and Y.F.F. Xie. 2017. “Evaluating Dissolved Ozone in a Bubble Column Using a Discrete-Bubble Model.” *Ozone: Science & Engineering* 39:44–53.

Quero-Pastor, M., C. Garrido-Perez, A. A. Merino, M. Jose, and Q. Alonso. 2016. “Toxicity and Degradation Study of Clofibric Acid by Treatment with Ozone in Water.” *Ozone: Science & Engineering* 38 (6):425–33. doi:10.1080/01919512.2016.1203288.

Raila, A., A. Lugauskas, D. Steponavicius, M. Ralliene, A. Steponaviciene, and E. Zvicevicius. 2006. “Application of Ozone for Reduction of Mycological Infection in Wheat Grain.” *Annals of Agricultural and Environmental Medicine* 13:287–94.

Ravesi, E.M., J.J. Licciardello, and L.D. Racicot. 1988. “Ozone Treatment of Fresh Fish Atlantic Cod.” *Gadusmorhus, Marine Fisheries Review* 49:37–42.

Ravi, P., T. Venkatachalam, and M. Rajamani. 2015. “Decay Rate Kinetics of Ozone Gas in Rice Grains.” *Ozone: Science and Engineering* 37: 450–55. doi: 10.1080/01919512.2015.1040912

Reagan, J.O., G.R. Acuff, D.R. Buege, M.J. Buyck, J.S. Dickson, C.L. Kastner, J.L. Marsden, J.B. Morgan, R. Nickelson, G.C. Smith, et al. 1996. “Trimming and Washing of Beef Carcasses as a Method of Improving the Microbiological Quality of Meat.” *Journal of Food Protection* 59:751–56.

Restaino, L., E.W. Frampton, J.B. Hemphill, and P. Palnikar. 1995. “Efficacy of Ozonated Water against Various Food-Related Microorganisms.” *Applied and Environmental Microbiology* 61:3471–75.

Rice, R. G. 1986. ““Application of Ozone in Water and Waste Water Treatment.” In *Analytical Aspects of Ozone Treatment of Water and Waste Water*, edited by R. G. Rice and M. J. Browning, 7–26. Chelsea, MI: Lewis Publishers.

Rice, R. G., C. M. Robson, G.W. Miller, and A.G. Hill. 1981. “Uses of Ozone in Drinking Water Treatment.” *Journal of the American Water Works Association* 73:44–57.

Rivas, A., D. Rodrigo, A. Martínez, G.V. Barbosa-Cánovas, and M. Rodrigo. 2006. “Effect of PEF and Heat Pasteurization on the Physical-Chemical Characteristics of Blended Orange and Carrot Juice.” *LWT-Food Science and Technology* 39:1163–70.

Rodoni, L., N. Casadei, A. Concellón, A.R. Chaves Alicia, and A.R. Vicente. 2009. “Effect of Short-Term Ozone Treatments on Tomato (*Solanum Lycopersicum L.)* Fruit Quality and Cell Wall Degradation.” *Journal of Agricultural and Food Chemistry* 58: 594–99. doi: 10.1021/jf9029145

Rudavskaya, A.B., and E.V. Tishchenko. 1978. “Effect of Ozonization on the Quality and Keeping Characteristics of Retail Eggs.” *Tovarovedenie* 11:43–46.

Sandhu, H.P.S., F.A Manthey, and S. Simsek. 2011. “Quality of Bread Made from Ozonated Wheat (*Triticum Aestivum* L.) Flour.” *Journal of the Science of Food and Agriculture* 91: 1576–84. doi: 10.1002/jsfa.4350

Sarig, P., T. Zahavi, Y. Zutkhi, S. Yannai, N. Lisker, and R. Ben Arie. 1996. “Ozone for Control of Post-Harvest Decay of Table Grapes Caused by *Rhizopus Stolonifer*.” *Physiological and Molecular Plant Pathology* 48:403–15.

Savi, G. D., K. C. Piacentini, K.O. Bittencourt, and V.M. Scussel. 2014. “Ozone Treatment Efficiency on *Fusarium Graminearum* and Deoxynivalenol Degradation and Its Effects on Whole Wheat Grains (*Triticum Aestivum* L.)

Quality and Germination." *Journal of Stored Products Research* 59:245–253.

Schneider, F., A.S. Ruhl, U. Hübner, and M. Jekel. 2016. "Removal of Residual Dissolved Ozone with Manganese Dioxide for Process Control with UV254." *Ozone: Science & Engineering* 38: 79–85. doi: 10.1080/01919512.2015.1079121

Schrank, S.G., W. Gebhardt, H.J. José, R.F. Moreira, and H.F. Schröder. 2017. "Ozone Treatment of Tannery Wastewater Monitored by Conventional and Substance Specific Wastewater Analyses." *Ozone: Science & Engineering* 39:159–87.

Sharpe, D., L. Fan, K. McRae, B. Walker, R. MacKay, and C. Doucette. 2009. "Effects of Ozone Treatment on *Botrytis Cinerea* and *Sclerotinia Sclerotiorum* in Relation Horticultural Product Quality." *Journal of Food Science* 74: M250–M257. doi: 10.1111/j.1750-3841.2009.01234.x

Sheldon, B.W., and A.L. Brown. 1986. "Efficacy of Ozone as a Disinfectant for Poultry Carcasses and Chill Water." *Journal of Food Science* 51:305–09.

Shiler, G.G., N.N. Eliseeva, and L.N. Chebotarev. 1978. "Use of Ozone and Ultraviolet Radiation for the Inactivation of Mould Spores." 20th International Dairy Congress:616.

Shiler, G.G., N.N. Eliseeva, V.I. Volodin, L.N. Chebotarev, and L.S. Matevosyan. 1983. "Method of Ozonizing Rooms for Ripening and Storing Cheeses." USSR patent no. SU1022688A.

Shunmugam, G., D.S. Jayas, N.D.G. White, and W.E. Muir. 2005. "Diffusion of Carbon Dioxide through Grain Bulks." *Journal of Stored Products Research* 41:131–44.

Shynkaryk, M. V., T.I. Pyatkovskyy, A.E. Yousef, and S.K. Sastry. 2016. "Gaseous Ozone Treatment of Baby Spinach within the Existing Production Chain for Inactivation of Escherichia Coli O157: H7." *Journal of Food Engineering* 191:10–18.

Silva, J., M.N. Pereira, and V.M. Scussel. 2018. "Ozone Gas Antifungal Effect on Extruded Dog Food Contaminated with *Aspergillus Flavus*." *Ozone: Science & Engineering* (Accepted) doi: 10.1080/01919512.2018.1481361.

Singla, R., A. Ganguli, and M. Ghosh. 2011. "An Effective Combined Treatment Using Malic Acid and Ozone Inhibits Shigella Spp. On Sprouts." *Food Control* 22 (7):1032–39.

Sleeper, W., and D. Henry. 2007. "Durability Test Results of Construction and Process Materials Exposed to Liquid and Gas Phase Ozone." *Ozone: Science & Engineering* 24 (4):249–60. doi:10.1080/01919510208901616.

Smith, J.S., and S. Pillai. 2004. "Irradiation and Food Safety." *Food Technology* 58:48–54.

Steenstrup, L.D., and J.D. Floros. 2004. "Inactivation of E. Coli 0157: H7in Apple Cider by Ozone at Various Temperatures and Concentrations." *Journal of Food Processing Preservation* 28:103–16.

Stephan, R., D. Althaus, S. Kiefer, A. Lehner, C. Hatz, C. Schmutz, M. Jost, N. Gerber, A. Baumgartner, H. Hächler, et al. 2015. "Foodborne Transmission of Listeria Monocytogenes via Ready-To-Eat Salad: A Nationwide Outbreak in Switzerland, 2013–2014." *Food Control* 57: 14–17. doi: 10.1016/j.foodcont.2015.03.034

Strittmatter, R. J., B. Yang, and D.A. Johnson. 1996. "Ozone Application for Cooling Tower Water." *ASHRAE Journal* 38:27–34.

Suslow, T.V. 2001. "Water Disinfection: A Practical Approach to Calculating Dose Values for Preharvest and Postharvest Applications." Publication 7256, University of California, Agriculture and Natural Resources. Retrieved from http://vric.ucdavis.edu. Accessed on 16- 01-2017.

Ternes, T.A., J. Stüber, N. Herrmann, D. McDowell, A. Ried, M. Kampmann, and B. Teiser. 2003. "Ozonation: A Tool for Removal of Pharmaceuticals, Contrast Media and Musk Fragrances from Wastewater?." *Water Research* 37:1976–82.

Tiwari, B.K., K. Muthukumarappan, C.P. O'Donnell, and P.J. Cullen. 2008a. "Kinetics of Freshly Squeezed Orange Juice Quality Changes during Ozone Processing." *Journal of Agriculture Food Chemistry* 56:6416–22.

Tiwari, B. K., K. Muthukumarappan, C.P. O'Donnell, and P.J. Cullen. 2008b. "Modelling Color Degradation of Orange Juice by Ozone Treatment Using Response Surface Methodology." *Journal of Food Engineering* 88:553–60.

Tiwari, B. K., C.P. O'Donnell, N.P. Brunton, and P.J. Cullen. 2009a. "Degradation Kinetics of Tomato Juice Quality Parameters by Ozonation." *International Journal of Food Science and Technology* 44:1199–205.

Tiwari, B.K., C.P. O'Donnell, K. Muthukumarappan, and P.J. Cullen. 2009b. "Anthocyanin and Color Degradation in Ozone Treated Blackberry Juice." *Innovative Food Science and Emerging Technologies* 10:70–75.

Tiwari, B.K., C.P. O'Donnell, A. Patras, N. P. Brunton, and P. J. Cullen. 2009c. "Effect of Ozone Processing on Anthocyanins and Ascorbic Acid Degradation of Strawberry Juice." *Food Chemistry* 113:1119–26.

Torlak, E., and D. Sert. 2013. "Inactivation of Cronobacter by Gaseous Ozone in Milk Powders with Different Fat Contents." *International Dairy Journal* 32 (2):121–25.

Torlak, E., D. Sert, and P. Ulca. 2013. "Efficacy of Gaseous Ozone against Salmonella and Microbial Population on Dried Oregano." *International Journal of Food Microbiology* 165 (3):276–80.

Trombete, F., A. Minguita, Y. Porto, O. Freitas-Silva, D. Freitas-Sá, and S. Freitas. 2016. "Chemical, Technological, and Sensory Properties of Wheat Grains (*Triticum Aestivum L*) as Affected by Gaseous Ozonation." *International Journal of Food Properties* 19:2739–2749.

Tzortzakis, N., A. Borland, I. Singleton, and J. Barnes. 2007. "Impact of Atmospheric Ozone-Enrichment on Quality-Related Attributes of Tomato Fruit." *Postharvest Biology and Technology* 45:317–25.

Tzortzakis, N., I. Singleton, and J. Barnes. 2007. "Deployment of Low-Level Ozone-Enrichment for the Preservation of Chilled Fresh Produce." *Postharvest Biology and Technology* 43:261–70.

Tzortzakis, N., T. Taybi, R. Roberts, I. Singleton, A. Borland, and J. Barnes. 2011. "Low-Level Atmospheric Ozone Exposure Induces Protection against *Botrytis Cinerea* with Down-Regulation of Ethylene-, Jasmonate and Pathogenesis-Related Genes in Tomato Fruit." *Postharvest Biology and Technology* 61: 152–59. doi: 10.1016/j.postharvbio.2011.02.013

Varol, K., A. N. Koc, M.A. Atalay, and I. Keles. 2017. "Antifungal Activity of Olive Oil and Ozonated Olive Oil against *Candida Spp*. And *Saprochaete Spp*." *Ozone: Science & Engineering* 39: 462–70. doi: 10.1080/01919512.2017.1322490

Vieno, N.M., H. Harkki, T. Tuhkanen, and L. Kronberg. 2007. “Occurrence of Pharmaceuticals in River Water and Their Elimination in a Pilot-Scale Drinking Water Treatment Plant.” *Environmental Science & Technology* 41:5077–84.

Violleau, F., K. Hadjeba, J. Albet, R. Cazalis, and O. Surel. 2008. “Effect of Oxidative Treatment on Corn Seed Germination Kinetics.” *Ozone, Science and Engineering* 30:418–22.

Von Gunten, U. 2003. “”Ozonationof Drinking Water. Part I: Oxidation Kinetics and Product Formation.”.” *Water Research* 37:1443–67.

Whistler, P.E., and B.W. Sheldon. 1989. “Biocidal Activity of Ozone versus Formaldehyde against Poultry Pathogens Inoculated in a Prototype Setter.” *Poultry Science* 68:1068–73.

White, S. D., P.T. Murphy, C.J. Bern, and J.H. Van Leeuwen. 2010. “Controlling Deterioration of High-Moisture Maize with Ozone Treatment.” *Journal of Stored Products Research* 46:7–12.

Williams, R. C., S.S. Sumner, and D.A. Golden. 2005. “Inactivation of Escherichia Coli O157: H7and Salmonella in Apple Cider and Orange Juice Treated with Combinations of Ozone, Dimethyl Dicarbonate, and Hydrogen Peroxide.” *Journal of Food Science* 70 (4):M197–M201.

Wu, J.G., T.G. Luan, C.Y. Lan, W.H. Lo, and G.Y.S. Chan. 2007. “Removal of Residual Pesticides on Vegetables Using Ozonated Water.” *Food Control* 18:466–72.

Yamayoshi, T., and N. Tatsumi. 1993. “Microbiocidal Effect of Ozone Solution on Methicillin-Resistant *Staphylococcus Aureus*.” *Drugs Experimental Clinical Research* XIX (2):59–64.

Yan, S., X. Wu, J. Faubion, S.R. Bean, L. Cai, and Y.C. Shi. 2012. “Ethanol Production Performance of Ozone-Treated Tannin Grain Sorghum Flour.” *Cereal Chemistry* 89:30–37.

Yang, P.P.W., and T.C. Chen. 1979. “Effects of Ozone Treatment on Microflora of Poultry Meat.” *Journal Food Processing and Preservation* 3:177–85.

Yvin, J.C., A. Bailli, J.M. Joubert, and O. Bertaud. 2001. “Method and Installation for Making Flour from Ozone-Treated Grains.” French Patent FR2802390 (A1).

Yvin, J.C., and C. Coste. 1997. “Method and System for the Treatment of Seeds and Bulbs with Ozone.” US Patent 5703009.

Zambre, S.S., K.V. Venkatesh, and N. G. Shah. 2010. “Tomato Redness for Assessing Ozone Treatment to Extend the Shelf Life.” *Journal of Food Engineering* 96 (3):463–68.

Zhang, T., Y. Xue, Z. Li, Y. Wang, W. Yang, and C. Xue. 2016. “Effects of Ozone on the Removal of Geosmin and the Physicochemical Properties of Fish Meat from Bighead Carp (*Hypophthalmichthys Nobilis*).” *Innovative Food Science & Emerging Technologies* 34:16–23.

Zhao, J., and P.M. Cranston. 1995. “Microbial Decontamination of Black Pepper by Ozone and the Effect of the Treatment on Volatile Oil Constituents of the Spice.” *Journal of Science Food Agriculture* 68:11–18.