Ozonation & Shelf-life

Overview:

Ozone is a natural gas composed of three oxygen atoms that has some remarkable properties. It has a strong ability to oxidize and reduce substances, which makes it incredibly useful for sanitizing, controlling fungi, and extending the shelf life of fresh fruits and vegetables. Furthermore, ozone can effectively reduce contaminants in crops and even lower pesticide and mycotoxin levels in food and animal feed.

The great thing about ozone is that it doesn't leave any residue after it's used, making it a safe and environmentally friendly choice for sanitizing in the food industry. Depending on the type of food and how it's being used, ozone can be applied as a gas, in the form of ozonated water, or as an ozone mist.

In this section, we'll introduce you to ozone technology in the postharvest and food industries. We'll discuss the different types of ozone generators currently available and their applications. We'll also explore the potential uses of ozone in postharvest scenarios, using specific examples of our projects involving fresh figs, strawberries, tangerines, and other fresh produce. Additionally, we'll highlight the advantages, limitations, and future prospects of ozone in agriculture and the food industry.'

Overall, ozone is a powerful tool that can help ensure the safety and quality of our food supply while minimizing environmental impact. Understanding its applications and potential benefits can be valuable for students studying in high school or college, especially those interested in fields like agriculture, food science, or environmental sustainability.

What is ozone and how is it produced for research purposes?

Ozone is a natural gas made up of three oxygen atoms (Figure 1). It has a high oxidation/reduction potential, which means it can effectively sanitize and control contaminants in the food industry. Ozone has a pungent odor and a molecular weight of 48. It is less stable at higher pH values and decomposes into oxygen over time. However, ozone is considered safe and environmentally friendly. Depending on the food and its use, ozone gas, ozonated water, or ozone mist can be employed.

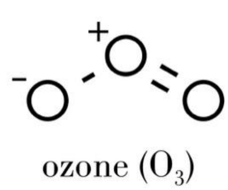

Figure 1. Ozone structure

There are different types of ozone generators available, each with its own design and applications. Here are some common types:

1. **Corona discharge ozone generators:** These generators use a corona discharge method to produce ozone. They pass air or oxygen through a high-voltage electrical field, which splits oxygen molecules and creates ozone. Corona discharge ozone generators are mostly used for water treatment, air purification, and industrial purposes.

2. **UV ozone generators:** UV ozone generators use ultraviolet light to convert oxygen molecules into ozone. They have a UV lamp that emits UV-C radiation, triggering the conversion process. UV ozone generators are commonly used for small-scale applications like residential air purifiers.

3. **Cold plasma ozone generators:** Cold plasma ozone generators generate ozone by subjecting oxygen molecules to a cold plasma field, mainly through techniques like dielectric barrier discharge. These generators are suitable for industrial odor control, water treatment, and wastewater purification.

4. **Electrolytic ozone generators:** Electrolytic ozone generators produce ozone through electrolysis. They pass an electric current through water with dissolved oxygen, resulting in ozone production. These generators are used in small-scale applications like personal water purifiers or spa treatments.

The choice of ozone generator depends on factors like required ozone concentration, cost, portability, and application.

In our research studies, we used our custom design ozone generator. Specifically, we designed a low-cost ozone generator based on incomplete corona discharge (Figure 2). As mentioned earlier, a corona is a specific type of electrical discharge that happens within a gas-filled space. It occurs when there is an incomplete breakdown of the electrical field between two electrodes, causing a partial discharge. This typically happens when the electrical field conditions are uneven or non-uniform.

This ozone generator was built for our laboratory experiments. It operated on a 12V DC power source, which was converted into a higher DC voltage to produce enough energy for ozone generation. The generator was able to quickly generate ozone on the output electrodes. Figure 2 shows the concept of the high voltage generator we used for ozone production.

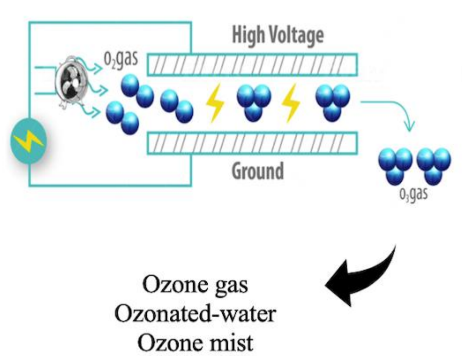

Figure 2. Illustration of the high voltage generator used in our ozone generator.

Fruits used in our ozone studies:

For our ozone studies, we selected fresh figs and strawberries as the fruits to investigate and analyze. We made this choice because fresh figs and strawberries are delicate crops that are vulnerable crops that spoil quickly. When fully ripe, figs and strawberries become soft and easily affected by different types of molds, such as Alternaria rot (caused by various *Alternaria* species) and gray mold (caused by *Botrytis cinerea*), as well as bruising. Due to this susceptibility after harvest, the market life and storage period of these fruits are limited. Typically, within 5 to 10 days after harvest, depending on the maturity at harvest and storage conditions, signs of decay and shriveling start to appear.

Fresh figs and strawberries are delicate fruits that cannot withstand washing without being damaged. Additionally, the presence of water during the washing process may trigger the germination of fungal spores on the fruit's surface. These fruits have a relatively short shelf-life and are associated with a smaller market size. Within just one week after harvest, they can become inedible due to factors such as weight loss, shriveling, color change, and fungal growth. As a result, producers are actively looking for methods to reduce weight loss and prolong the shelf life of fresh figs and strawberries. By achieving these goals, producers can increase their profits when selling these fruits.

Why did we use ozone?

After fruits are harvested, they tend to deteriorate quickly, making it crucial to preserve them effectively. One way to achieve this is by applying certain chemicals to the fruits, which can potentially extend their shelf life and maintain their quality. However, there are limitations to using chemicals to extend the shelf-life of fresh products. Some disinfection methods, like Infrared (IR) and Ultraviolet (UV) irradiation, chlorine dioxide (ClO_2) fogging, and sulfur dioxide (SO_2) fumigation, can be used for fresh fruits. However, these methods come with safety concerns. Chlorine dioxide fogging can negatively impact human health, so workers need to take precautions when handling stock solutions or fumigating figs. The toxicity of sulfur dioxide increases with temperature, and there are worries about the rates of SO_2 fumigation and chemical residues on the final product. Irradiation is an expensive method, and some customers have doubts about consuming irradiated foods. Therefore, alternative technologies are necessary to enhance the quality, safety, profitability, and consistency of fresh products.

Ozone plays an important role in keeping fresh fruits and vegetables free from germs, preventing fungal growth, and making them last longer. Researchers used ozone to disinfect agricultural products such as fresh kiwifruits and dried figs. In our ozone studies, we investigated whether ozonated-air (OA) could help reduce the loss of weight and volume and retain a good appearance in fresh figs and strawberries.

Results of our ozone-based study on extending the shelf life of fresh fruits:

In our study, we investigated how ozonated-air (OA) affects the overall quality of two types of figs (Kadota and Mission) and Monterey strawberries. We wanted to see if treating the fruits with OA

would make any impact on their weight, size, appearance, firmness, skin changes, microbial quality, and taste. We measured these factors before applying the OA treatment, right after the treatment, and on days 7 and 14 during the cold storage period.
In our experiment, we examined various concentrations of ozonated-air (OA) and different exposure times (which refers to the duration the fruit is in contact with OA). We discovered that using OA at a concentration of 15 ppm for an exposure time of 3 hours yielded the most favorable outcomes. When we treated fig samples with 15 ppm OA for 3 hours, we observed a 25.8 % reduction in weight loss, a 32.5 % decrease in shriveling, improved appearance, fewer brown spots, and less fungal growth compared to the control group.

(1)

(2)

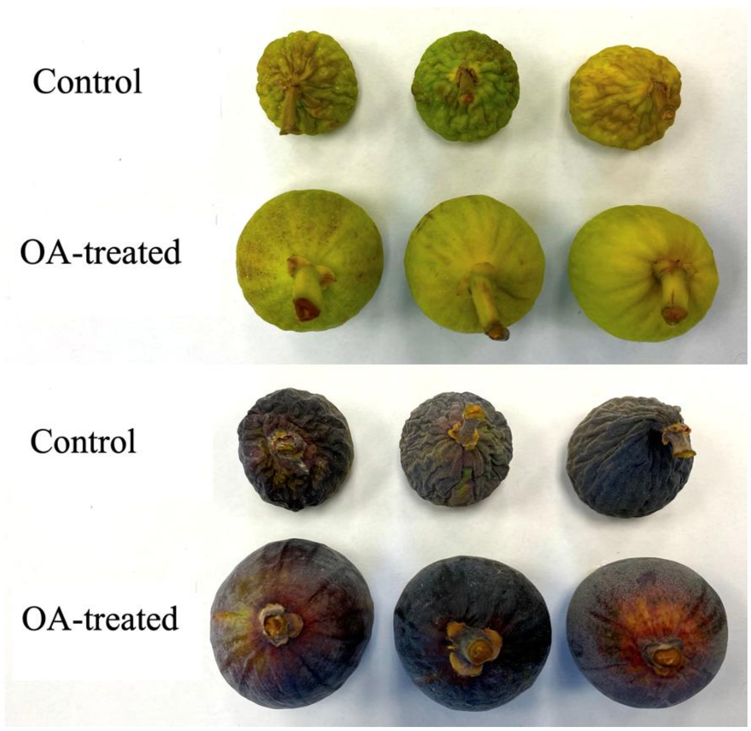

Figure 3. Effect of ozonated-air (OA) on weight and volume loss of fresh figs. Control (Top) and OA-treated (Bottom) Kadota figs (1) and Mission figs (2) during 21 days of storage at 4ºC

Figure 3 demonstrates the impact of ozonated-air on the aging characteristics of figs and the overall quality of two different fig varieties after being stored for 21 days. In both images 1 and 2, the top row represents the control samples that were not treated with OA and were refrigerated for 21 days. Conversely, the bottom row displays the fig samples that were treated with OA and then stored in the same refrigerator for 21 days. Clearly, the ozone-treated samples maintained their quality and remained suitable for consumption, while the control samples significantly deteriorated and were no longer edible.

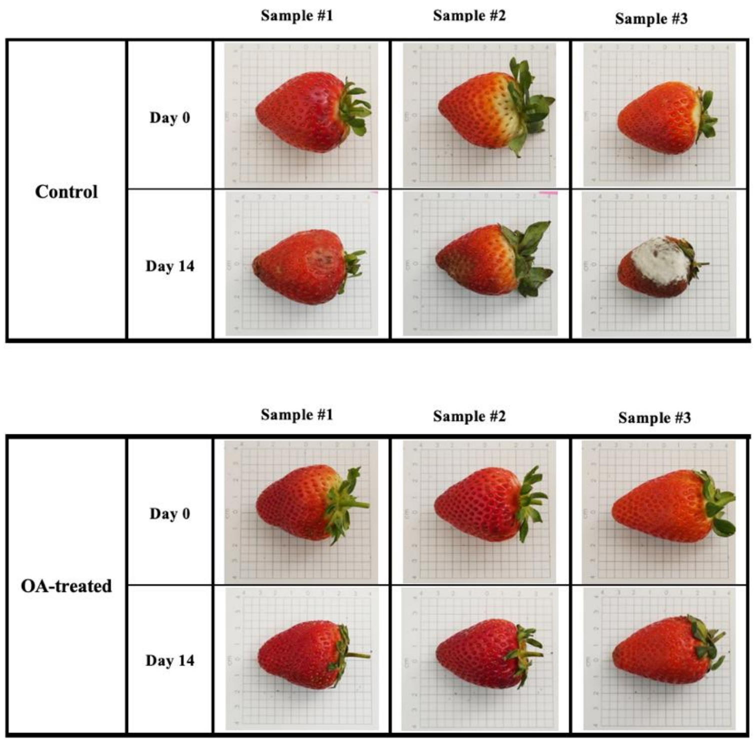

Figure 4. Effect of ozonated-air (OA) on weight and volume loss of fresh strawberries. Control (Top) and OA-treated (Bottom) strawberry samples during 14 days of storage at 4ºC.

Similarly, the strawberries treated with 3 hours of ozonated-air (OA) at a concentration of 15 ppm showed positive outcomes. As you can see in Figure 4, compared to the control strawberries, the OA-treated ones demonstrated a 5% less reduction in weight, 15% less shriveling, improved appearance, fewer dark spots, and lower fungal growth. After 14 days, the OA-treated strawberries exhibited increased firmness, although there was no notable difference in redness compared to the control strawberries.

To measure how consumers perceive and accept a product, it is necessary to conduct sensory tests with a group of trained evaluators known as a sensory panel. A sensory panel is a group of trained people who evaluate the taste, smell, appearance, texture, and overall sensory qualities of food. The sensory panel assess the overall quality of both figs and strawberries and based on their evaluations, the strawberries and figs treated with OA were preferred as they looked better and tasted better. They were sweeter, had a more pleasant taste, and strawberries emitted a better aroma.

How does ozone impact the fruits, leading to the retention of overall quality?

To study effect of ozone on the epidermis, which is the outermost layer of the fruit's skin, we used scanning electron microscopy (SEM) imaging technique. SEM imaging provides high-resolution, three-dimensional images of the fruit's outer layer, revealing details such as cell structure and surface features. SEM imaging helped us understand how ozone treatments affected fruit quality, and preservation.

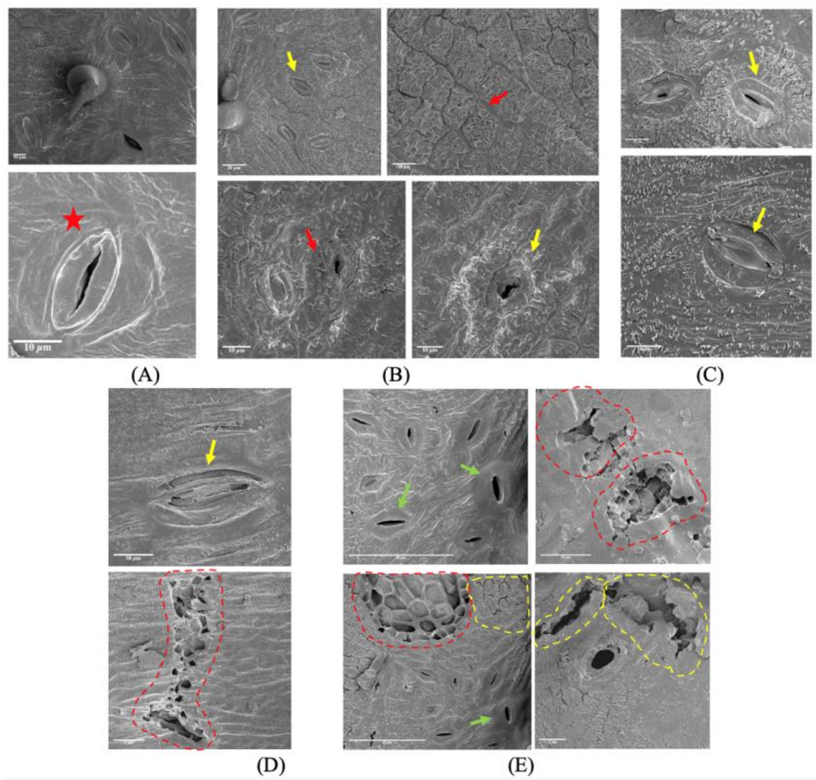

Figure 5. SEM images of Kadota figs on Day 0 (A): normal stomata and peristomatal rim (red star), immediately after OA-treatment (B): wax platelets with irregular and undulated edges (red arrows), deformed or occluded stomata (yellow arrows), OA-treated on Day 7 (C), OA-treated on Day 14 (D): microcracks (yellow dashed lines) and cell wall disassembly (red lines), and control on Day 14 (E): open stomata (green arrows) observed by scanning electron microscope.

Figure 5 demonstrates the differences observed through SEM imaging between the control and OA-treated figs. The epidermis of the figs was affected by ozone treatment, specifically impacting the stomata (pores) and epicuticular wax crystals. This resulted in blockage or deformation of the stomata and irregular shapes in the wax platelets. Despite the effects of OA treatment on the fruit's epidermis, the self-assembly properties of the epicuticular wax layer aided in the recovery from oxidative damage caused by ozone by Day 7. After 14 days of cold storage, noticeable microcracks and cell wall disassembly were observed on the fruit surface, particularly in the control samples. These changes led to significant water and weight loss, decreased shelf life, and increased susceptibility to fungal infection.

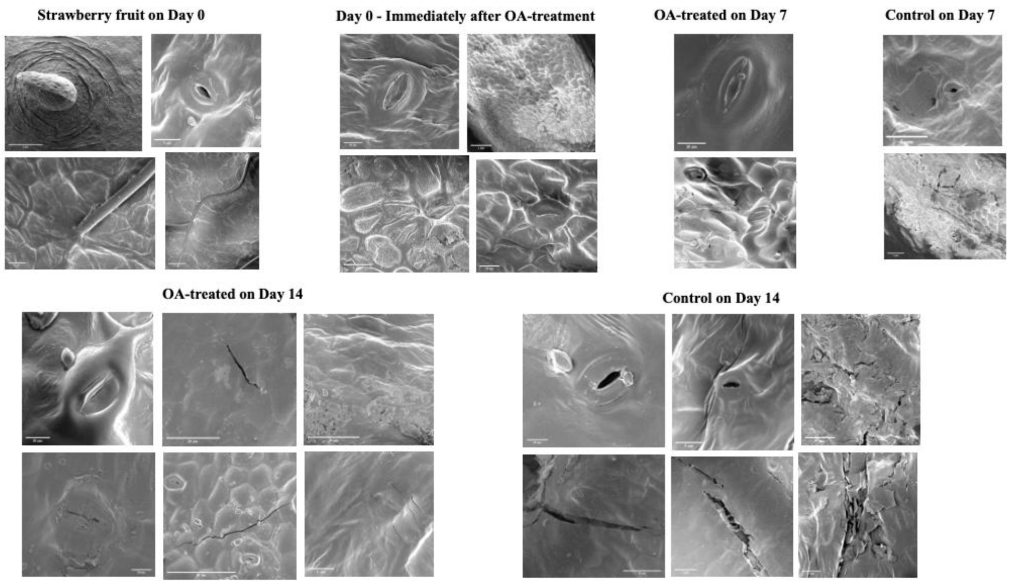

Figure 6. SEM images of OA-treated and control strawberries on days 0, 7, and 14 observed by scanning electron microscope.

In Figure 6, SEM images revealed that ozone treatment did not have an impact on the epidermis of strawberries. On Day 14, only some small microcracks were observed on the strawberries treated with ozone, but they were more abundant and larger in size in the control samples. Different fruits respond differently to ozone treatment due to variations in their physiological properties.

This study highlights the effectiveness of ozone treatment in minimizing volume and weight loss, while improving overall fruit quality for both figs and strawberries. It should be noted that this study is the first of its kind to investigate the changes in the epidermis of figs and strawberries during storage. If you're interested in learning more about the application of ozone on fruits, please refer to our listed publications.

Are there any limitations to the use of ozone technology?

Ozone technology has several limitations that should be considered. These limitations include instability and rapid decomposition, potential health effects, corrosive properties, limited penetration capabilities, impact on nutrient content, and dependency on factors such as dosage, time, and temperature. Figure 7 illustrates both the advantages and limitations of ozone technology.

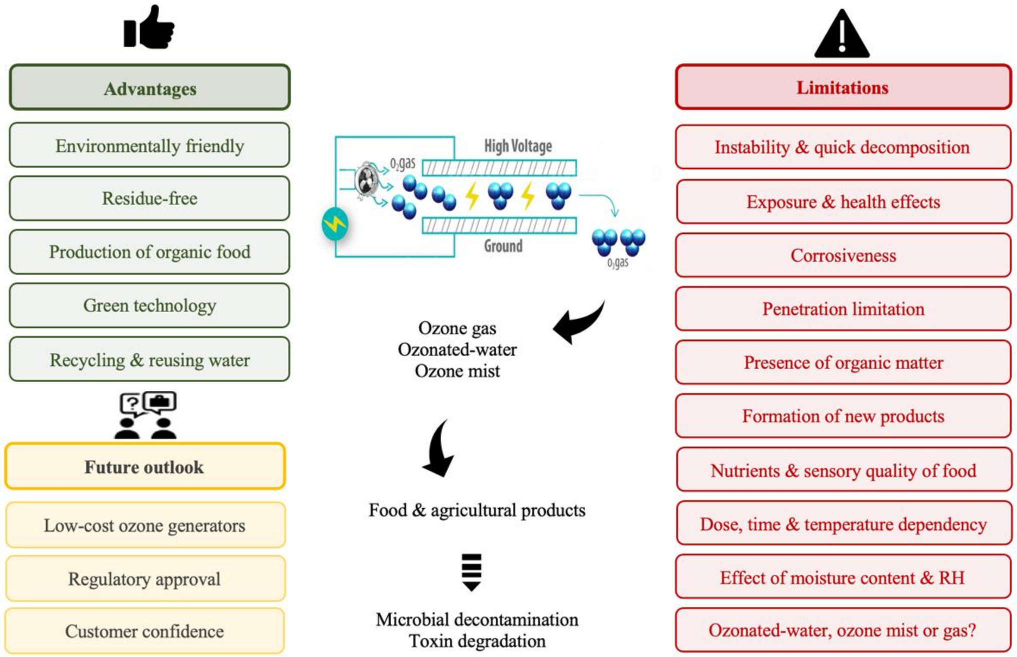

Figure 6. Advantages, limitations, and future outlook of ozone technology.

Ozone gas quickly decomposes into oxygen, especially in water. When ozone dissolves in water, it forms oxygen and reactive hydroxyl radicals. The decomposition rate depends on factors like organic solutes, pH, temperature, and ventilation. Ozone must be generated near its application point and kept constant due to its instability.

Ozone is highly reactive and can react with organic substances, including the human body. Safety precautions are crucial when working with ozone or being in an ozone-exposed environment. It primarily affects the respiratory system and can cause acute or chronic toxicity (Figure 7). Symptoms include throat and eye irritation, cough, dizziness, and headaches. Limiting contact with ozone is important due to associated health problems. Specific concentration limits and exposure times are set by regulatory agencies. When using ozonated water, precautions should be taken to prevent ozone gas release into the air.

Ozone is highly corrosive, and metal equipment cannot be used in ozone fumigation systems. The use of ozone in food processing plants can lead to metal rusting and the release of metal pieces in food, therefore rubber or plastic containers should be used instead but require regular inspection for damage. It is important to use special ozone-resistant equipment for ozonation purposes to prevent corrosion. Without proper precautions, storage and processing equipment can corrode within two months when exposed to high ozone concentrations.

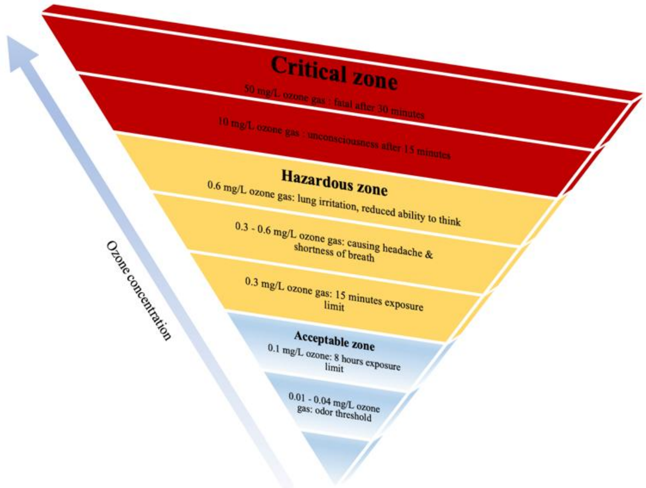

Figure 7. Health effect zones of ozone gas.

Using ozone treatment in food can lead to the formation of new substances and affecting its nutritional quality, therefore, more research is needed to understand the potential creation of unknown products.

The effectiveness of ozone treatment in food depends on ozone concentration, exposure time, and temperature. High temperatures above 50°C can speed up ozone decomposition, but they negatively affect food quality. Optimal ozonation is typically done at room temperature by adjusting exposure time and ozone concentration. Longer exposure times are more effective in degrading mycotoxins than higher ozone concentrations. It is important to find the right balance to maximize mycotoxin degradation without compromising food quality.

What advancements can we expect in the future of ozone technology?

In the future, we can expect more affordable and versatile ozone generation systems. Advancements in manufacturing technology are making ozone generators cost-effective, energy-efficient, and low-maintenance. However, reducing their cost further and making them more compact and adaptable to different voltage ranges are areas of focus for future development. These improvements will expand the application of ozone technology in various industries.

Ozone gas is approved as a safe antimicrobial agent for food by the Food and Drug Administration (FDA) and European countries. However, its use is regulated as a pesticide by the Environmental Protection Agency (EPA). Ozone generators and ultraviolet (UV) light systems are considered pest control devices and must be registered with the EPA.

Also, consumer attitudes towards ozone-treated products are uncertain, as new technologies like food irradiation are often perceived as risky. Media and advertisements play a role in educating the public about the benefits of ozone technology. Researchers and scientists must share their knowledge with policymakers and the public to increase awareness. Future research is needed to evaluate the acceptability, safety, and effectiveness of ozone treatment in reducing mycotoxins and ensuring the safety of ozone-treated food products.