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Sharmin Zaman , Ashfaq Aziz , Md. Abubakkar Siddique , Abdul Khaleque , Latiful Bari *

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Review

Use of Non-Chlorine Sanitizer in Improving the Quality and Safety of Marketed Fresh Salad Vegetables

Sharmin Zaman [1], Ashfaq Aziz [1], Abubakkar Siddique [2] M.A. Khaleque [3] and Md Latiful Bari [1]*

[1] Center for Advanced Research in Sciences, University of Dhaka, Dhaka-1000, Bangladesh
[2] WAFFEN Research Laboratory Limited, Blue Moon Gram Tower (7th Floor), 167/24, Matikata, ECB Chattar, Kalshi, Mirpur, Dhaka-1206, Bangladesh.
[3] Department of Biochemistry and Microbiology, North South University, Bashundhara, Dhaka-1229, Bangladesh
* Correspondence: author: latiful@du.ac.bd

Abstract:The safety of vegetable food is compromised by various factors, including the inefficient or excessive use of sanitizers. Instances of individuals falling ill after consuming raw vegetables have been reported, with outbreaks of diseases caused by pathogens on fresh vegetables becoming increasingly prevalent globally, attracting significant media coverage and impacting the economic viability of vegetable cultivation. Measures to enhance food safety in postharvest horticultural produce involve controlling microbial proliferation and minimizing cross-contamination. Sanitizers were utilized in the food safety arsenal for a variety of purposes, including pathogen elimination and microbe reduction, hand, tools, and vegetable contact surface cleaning, and produce shelf life extension. Choosing an appropriate sanitizer for all vegetables is difficult due to a lack of knowledge on which sanitizers are ideal for the many types of vegetables grown on farms under different environmental circumstances. Although chlorine-based sanitizers, such as sodium or calcium hypochlorite, have been widely used for the past 50 years, recent research has revealed that chlorine reacts with an organic compound in fresh vegetables to produce trihalomethane, a carcinogen precursor, and as a result, many countries have prohibited the use of chlorine in all foods. As a result, horticulture research groups worldwide are exploring for non-chlorine, ecologically friendly sanitizers for the vegetable industry. They also want to understand more about present procedures in the vegetable business for employing alternative sanitizers, as well as the efficacy and potential dangers to the food safety of fresh salad vegetables. This review-cum-research paper presented detailed information on non-chlorine sanitizers, such as their efficacy, benefits, drawbacks, regulatory requirements, and the need for additional research to lower the risk of marketed salad vegetable food safety.

Keywords: non-chlorine sanitizer; food safety; common fresh salad vegetables

Introduction

Consumers today prefer safer, fresher, and healthier options in their daily diets, and vegetables are becoming a more important "healthy" group than animal proteins, complex carbohydrates, or sweeter alternatives like fruits (Mir et al., 2018; Akoachere et al., 2018; Sagoo et al., 2003). Fresh vegetables, including cucumber, tomato, carrot, capsicum, lettuce, green chili, and onion, are frequently used as salad items in Asian countries and are an essential part of a healthy diet. The demand for ready-to-eat or ready-to-cook foods also means that cutting, peeling, and dicing vegetables is an increasingly common practice, significantly raising food safety risks. Bacteria (such as *Aeromonas spp., Bacillus cereus, Clostridium botulinum, Clostridium perfringens, E. coli* (pathogenic and non-pathogenic), *L. monocytogenes, Pseudomonas spp., Salmonella spp., Shigella spp., S. aureus, and Yersinia enterocolitica*), virus (such as Hepatitis A, Rotavirus and Norovirus) and parasites (such as *Cryptosporidium parvum, Cyclospora cayetanensis, Giardia lamblia,* and *Toxoplasma gondii*) are the food

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safety concern microorganisms. Table 1 provides the lists of microorganisms responsible and specific vegetables that contributed to the foodborne outbreaks.

Table. Selected vegetable pathogens linked with outbreaks.

Bacteria	Selected Vegetables	References
Clostridium botulinum	carrots	Marshall et al., 2014
Shiga-Toxigenic *Escherichia coli*	Lettuce, Tomato	Mazaheri et al., 2014; Tahir et al., 2022
Listeria monocytogenes	Lettuce, tomato	Shenoy et al., 2017; Honjoh et al., 2016
Salmonella spp.	Lettuce, tomato	Ceuppens et al., 2014; Bartz et al., 2015
Shigella spp.	Lettuce, salad vegetables	Guchi et al., 2010
Staphylococcus aureus	Lettuce, tomato, carrot	Wei et al., 2016; Colombari et al., 2007; Denayer et al., 2017
Yersinia enterocolitica	Carrots, cucumber, lettuce, tomatoes	Rimhanen et al., 2009;Islam et al., 2015; MacDonald et al., 2012
Viruses		
Hepatitis A and Norovirus	Lettuce	Coudray-Meunier et al., 2015; Donnann et al., 2012
Protozoa		
Cryptosporidium spp. *and Cyclospora* spp	Lettuce	Utaaker et al., 2017; Buss et al., 2016

Plant pathogenic fungi are mainly responsible for the spoilage of vegetables, known as quality deterioration. Table 2 summarizes the microorganisms that cause postharvest spoilage of selected fresh vegetables.

Table 2. Summary of microorganisms that cause postharvest spoilage of selected fresh produce.

Vegetable crop	*Scientific name*	Type of Microorganism
Lettuce	*Aeromonas & Pectobacterium spp. (bacterial soft rot)*	Bacteria
Tomato	Lactic acid bacteria	Bacteria
Lettuce & Tomato	*Xanthomonas*	Bacteria
Carrot, Lettuce, & Tomato	*Pseudomonas* (bacterial spot)	Bacteria
Carrot, Cucumber, Lettuce & Onion	*Erwinia* (soft rot),	Bacteria
Cucumber, Onion, & Tomato,	*Bacillus*	Bacteria
Carrot	*Thielaviopsis basicola (black root rot)*	Fungi
Cucumber	*Pythium (cottony rot)*	Fungi
Tomato	*Phytophthora*	Fungi
Cucumber, & Tomato	*Penicillium (blue mold) & Rhizopus*	Fungi
Onion, & Tomato	*Aspergillus niger (black rot)*	Fungi
Carrot, Lettuce, & Tomato	*Sclerotinia* (white rot, white mold)	Fungi
Carrot, Lettuce, Onion, Tomato	*Geotrichum*	Fungi
Capsicum, Cucumber, Onion, & Tomato	*Collectotrichum (Anthracnose)*	Fungi

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Capsicum, Carrot, Cucumber, & Tomato	*Rhizopus spp. (storage rot, rhizopus rot)*	Fungi
Carrot, Cucumber, Lettuce, Onion & Tomato	*Botrytis spp. (neck rot, grey mold)*	Fungi
Capsicum, Carrot, Cucumber, Onion, Tomato,	*Fusarium (soft rot, dry rot) & Alternaria spp. (black rot)*	Fungi

All of these vegetables have the potential to pick up pathogenic microorganisms while being harvested on the field, handled afterward, processed and packaged in the pack house, or transported and distributed to stores. The agroecology of the geographical locations, genetic diversity, agronomic practices, and environmental responses in different farm production stages all influence the level of microbial contamination. Following the postharvest process, human activity and the environmental responses of the vegetable-packing plants can also increase the risk of contamination. The vast majority of studies reported in the published literature claimed that contamination happens mostly before harvesting, either through contaminated manure, sewage, irrigation water, and wastewater from livestock operations or directly from wild and domestic animals, or during harvesting, transport, processing, distribution, at the pack house, and marketing, or even at home (Eraky et al. 2014; Rahman et al. 2014; Pagadala et al. 2015; Maffei et al. 2016). Vegetable food safety risks in connection to agroecology during farm production and the environment of vegetable-packaging facilities during postharvest operations can be significant, and this field of study is just beginning. As mentioned in the literature, vegetables can also become infected at the retail or consumer levels, and this can happen through direct contamination, contact with contaminated soil or water, symptomatic and asymptomatic employees, or cross-contamination with other foods (Lambertini et al., 2016). This risk, however, is completely determined by regional food safety culture, which is also a new area of study. Figure 1 depicts the typical annual average microbiological quality and safety indicator microorganisms discovered in different salad vegetables in Bangladesh from 2010 to 2022, where almost all the parmeters are above the acceptable limit set by the regulatory agencies.

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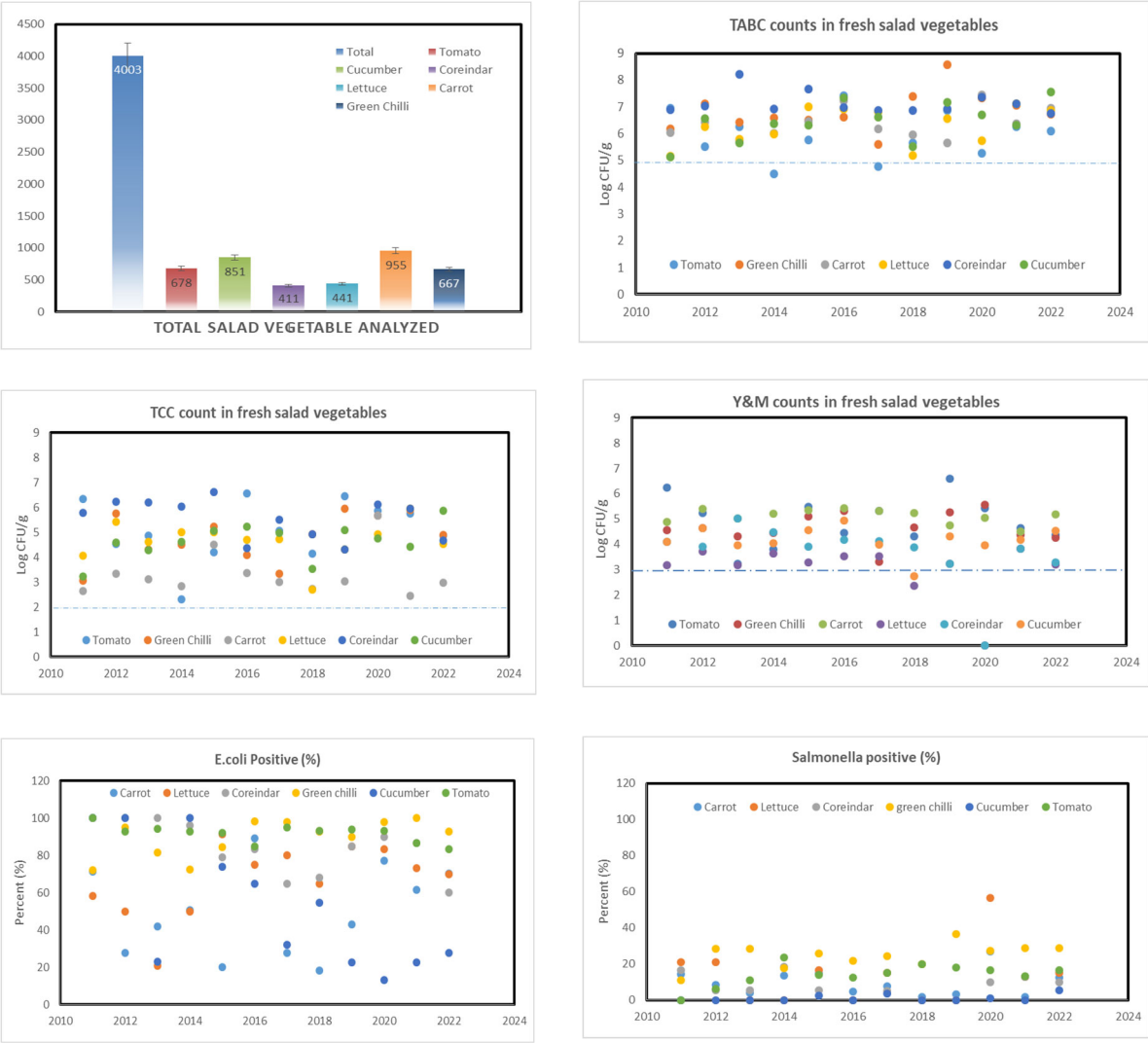

Figure 1. Indicators of microbiological quality (total aerobic bacteria, total coliform bacteria, total yeast, and mold) and safety (E. coli and Salmonella) were distributed on an annual basis in salad vegetables such as tomato, cucumber, carrot, coriander leaf, green chili, and lettuce in Bangladesh between 2011 and 2022.

Use of Sanitizers

The most common reasons to use sanitizer are: 1) To eliminate any bacteria or pathogens and lower microbial load; 2) To control microbiological hazards from human sources; 3) To maintain a safe environment; 3) To control product cross-contamination; 4) To reduce fungi's ability to propagate; 5) To disinfect and/or clean the processing facility, machinery, and any surfaces that come into contact with the vegetable crop; 6) To make sterile water; 7) To sterilize water-holding vessels; 8) To maintain the product's cleanliness; and 9) To increase shelf life (Jing et al., 2020).

Although various microbial agents are available for sanitizing fresh produce, their efficacies differ, and none can eliminate pathogens without compromising sensory quality. Recent research has also demonstrated that chlorine is ineffective at reducing pathogens, and the creation of chlorine byproducts harms human health. As a consequence, there is considerable interest in developing a chlorine substitute that is both safer and better for the environment. On the other hand, various non chlorine sanitizers including, calcined calcium, hydrogen peroxide, ozone, peroxyacetic acid, organic acid, natural antimicrobial agents, or combinations of these and other physical sanitization techniques have been seen in the literature for washing fresh salad vegetables to improve the quality

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and safety of these vegetables, however, it's vital to remember that the efficiency of any sanitizer, chlorine or non-chlorine, depends on factors such as concentration, contact time, and application method. Proper handling and sanitation practices are crucial regardless of the type of sanitizer used to ensure the safety and quality of fresh salad vegetables. Additionally, regulatory guidelines and specific industry requirements should be considered when selecting and implementing sanitization methods. The disadvantages and advantages of chlorine based sanitizers and non-chlorine sanitizers are summarized in Table 3.

Table 3. The disadvantages and advantages of chlorine based sanitizers and non-chlorine sanitizers.

Factors	Chlorine-based sanitizers	Non-chlorine sanitizers
Reduced Chemical Residue	Can leave behind chemical residues that may affect the taste and safety of vegetables	Can effectively sanitize vegetables without leaving harmful residues.
Gentler on Produce	Can sometimes be harsh on delicate salad vegetables, potentially causing discoloration or off-flavors.	Often gentler and less likely to affect the appearance or taste of the vegetables
Effective Pathogen Reduction	Can be effective in pathogen reduction but the creation of chlorine byproducts harms human health.	Can effectively reduce pathogens and no such byproduct occurred which harms human health.
Organic Compliance	Doesn't adhere to organic standards,	Align more closely with organic certification requirements
Versatility	May not be suitable for certain sensitive vegetables.	Often be used across a wider range of vegetables without adverse effects.
Reduced Environmental Impact	Can have environmental implications, including the formation of harmful disinfection byproducts.	No environmental implications, impact and no formation of harmful byproducts
Consumer Preferences	May not prefer by some consumers because causes harm to environment	May prefer due to perceived health and environmental benefits

Generally, the ideal sanitizing agent should possess two key qualities: an adequate level of antimicrobial activity and little to no impact on the product's sensory quality. Consumer demands for safe and ecologically friendly products would increasingly influence sanitizer selection for both domestic and international use. There is a lack of information on a suitable alternative, more environmentally friendly sanitizers, their efficacy on various products, and their market acceptance. The US Environmental Protection Agency (EPA) has registered and authorized nearly 4000 antimicrobial sanitizers, including 275 distinct active components (Yeomans et al., 2021). Choosing the best sanitizer for specific vegetables (cucumber, tomato, carrot, capsicum, lettuce, green chili, and onion) might be challenging, given a lengthy list. The most commonly used sanitizers in the food business are chlorine-based, which include sodium or calcium hypochlorite, acidified chlorite, electrolyzed water, and others; they have been tested on a variety of fresh produce and are effective against a wide range of pathogens (Praeger et al., 2018). However, chlorine can interact with organic matter in the natural environment to produce halogenated byproducts like trihalomethanes or haloacetic acids (Praeger et al., 2018). Because these byproducts are carcinogenic and unfriendly to the environment, using chlorine to wash fresh vegetables has been prohibited in countries such as Belgium, Switzerland, and the Netherlands for safety reasons (Aaliya et al., 2021). As a result, Table

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4 includes a number of substitute sanitizers proven to improve the safety and quality of salad vegetables, such as calcinated calcium, aqueous chlorine dioxide (ClO_2), ozone, hydrogen peroxide, peroxyacetic acid, organic acid, and plant bioactive compounds or essential oils.

Table 4. List of various applicable non-chlorine sanitizers for washing fresh salad vegetables.

Sanitizer	Allowable Levels	Advantages	Disadvantages	Rinse Step	Additional Comments	References
Calcinated Calcium (CCA)	Use 1g powder/10L water (giving a concentration of 0.01% and pH about 11) and 40 s wash	Calcinated calcium (CCa) is safe and eco-friendly, produced from marine waste (scallop shells)	If not dissolve properly may contribute residues on the vegetable surface. Can be affected by organic load in wash water	Yes	effective at lower dose, high pH , less contact time, available and cheap	Ahmed et al., 2019; Bari et al., 2002
Aqueous Chlorine di oxide (ClO_2)	ClO_2 5 mg/L, 60 s overhead spray and brush roller system at 25 °C.	Easy to handle, inexpensive; It can be used in the form of spray, immerse or washing; Concentration and contact can be maintained; Easy to adopt in industrial washing lines	Produce surface properties can affect ClO_2 accessibility to microbes; Residual moisture after the water rinsing can promote microbial growth;	yes	Not suitable for dried foods ; Relatively less effect on microbial internalization	Praeger et al., 2018; Banach et al. (2017).
Hydrogen Peroxide (H_2O_2)	Typical concentration used: (0.04–2%); Environmentally friendly. Declared GRAS by FDA.	Breaks down easily, no harmful by-products; Higher temperatures could produce better reduction	Higher concentrations can cause browning or bleaching in certain products and can be corrosive and irritating. Unstable degrades fast	No	Commercially available at 31-70%, but 30-50% is most common. Dilute (3%) solutions are available to consumers.	McWatters 2002; Olmez 2009
Ozone (O_3)	No regulatory limit but typically used at 2-10 ppm for up to 5 min; Activity reduced in presence of organic load	Declared GRAS by FDA. Environmentally friendly; Effective at low concentrations; No harmful end products.	Has to be generated on-site; unstable and highly reactive; Corrosive to equipment; OSHA requirements on employee exposure.	No	Solubility in water increases at lower temperatures and pH. Does not work as well at higher pH.	Ramos et al. 2013; Picchioni 1996; Martin-Diana 2005; Anino 2006; Alexandre 2011
Organic acids (acetic acid, citric acid, lactic acid, and tartaric acid, oxalic acid, ascorbic acid, and phytic acid).	1% oxalic acid, 0.03% phytic acid, 0.5% CA 0.5% lactic 2 min or 2% acetic acid for 15 min	Organic acids have been used as sanitizers for fresh produce. The FDA recognizes organic acids as GRAS,	Their usefulness against microorganisms is generally low and requires high concentrations for long periods. Sensory quality might also be affected with 5-15 min treatment	No	Effective at higher conc, depends on water quality and costly; Antimicrobial efficacy is dependent on the microorganism strain and acid type.	Ramos et al. (2013); (Olmez 2009); Akbas (2007)
Peroxyacetic Acid	Strong oxidizing agent; Use 80 ppm- 150 ppm; 2 min on fruits and vegetables; Can	Environmentally friendly and less corrosive to equipment; Works at a wide range of pH values and temperatures;	Cost more than chlorine; Vinegar odor; losses its effectiveness in the presence of metals (copper); High	No	Store in a well-ventilated area; Concentrated peroxyacetic acid is a safety hazard.	Uddin et al.2021; Neo et al (2013); Shan Yu 2013; Gombas 2017; Vandekinderen 2007

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	work well in cooler temperatures;	Effective against biofilms ; Not as sensitive to organic load as chlorine.	concentrations damage produce and can shorten shelf life.			
Plant extracts (bioactive compounds)	Grape stem extract, 2.5% solution; 2 min, and dried for 30 min could reduce pathogen by 2.0 -4.0 log CFU/g in lettuce; oregano aqueous extract for 2 min; green tea extract 60% GTE for 5 min; Essential Oil (Cypriot Oregano), 0.1% for 10 min	The antibacterial activity could be due to the damage of cytoplasmic membrane, inhibition of synthesis of nucleic acids, cell wall components, and cell membrane (Bernard et al. 1997; Borges et al. 2013; Wu et al. 2013).	fewer effects than chemical sanitizers and non-economic efficiency; unpleasant aroma; longer durations;	no	Store in dark place; since sensitive to light, volatile nature; higher concentration (0.5%) resulted in softer fruits;	Vázquez-Armenta, et al., 2017; Poimenidou et al. 2016; Ascimento, & São josé, 2022; Xylia et al., 2022

GARS= Generally recognized as safe; GTE=green tea extract;

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Calcinated Calcium (Green Agrowash®):

Calcinated calcium is a baked & pyrolysis product of waste shell aggregate into a fine, odorless, natural, environmentally beneficial, and biodegradable powder. The Japan Standard of Food Additive (JSFA) has approved using this shell powder with microparticles in food. This powder is sparingly soluble in water and possesses antibacterial and antifungal activities, which is proven effective in killing bacteria and fungus and removing contaminants from the fruits and vegetables' surface (Zaman et al., 2021; Bari et al., 2002). One gram of powder in 10 L tap water or (0.01% solution) is recommended for 40-60s wash followed by clean water wash was able to eliminate pathogens and remove other contaminants from the surface of the vegetable. However, using more than the suggested concentration can leave a white stain on stainless steel or glass surfaces. Since calcinated calcium is made from natural ingredients, it is readily accessible, inexpensive doesn't harm the environment, and isn't toxic to humans or animals.

Hydrogen Peroxide

Hydrogen peroxide, also called hydrogen dioxide, can be used as a sanitizer of fruits and vegetables as a liquid or gas. It is considered "generally recognized as safe" or GRAS by FDA and EPA and is environmentally friendly because it breaks down to oxygen and water. It is affected by the organic load in the wash water but not by pH. The FDA has approved using hydrogen peroxide as a sanitizing solution on fresh produce at levels not exceeding 59 ppm. Recently, it has become more common to use hydrogen peroxide in combination with acetic acid (PAA) than to use it alone**.** Hydrogen peroxide causes cells to die by altering osmotic pressure, leading to the loss of cell wall integrity. This compound is cheap, easy to prepare, fast acting for bacteria, and can kill spores. Hydrogen peroxide must be used cautiously due to its instability in water, high allergenicity, and loss of effectiveness if not stored under the right conditions.

Ozone:

Ozone is also considered to have vigorous antimicrobial activity. It is highly reactive and has high penetrability (Ramos et al., 2013). Ozone generation/production has lower running costs, and it is GRAS. The effect of ozonated waters with different concentrations and contact times on fresh-cut produce's quality attributes and the microbial population was studied (Kim, 2012). Ozone does not produce any hazardous disinfection byproducts and decomposes into non-toxic products. Gaseous ozone is more effective against pathogenic and non-pathogenic microorganisms than aqueous ozone. However, gaseous ozone could be hazardous, toxic, and reactive in this form (Martin-Diana 2005; Añino, 2006; Alexandre, 2011).

Organic Acids:

Fresh fruit has been sanitized using organic acids like citric acid, acetic acid, and lactic acid as well as combinations with phosphoric acid and sulfuric acid. These substances can't stain or emit odors and aren't corrosive to stainless steel, making them more natural ingredients in food. On the negative side, yeasts, fungi, Gram-positive bacteria, and others are not destroyed by organic acids. Although organic acids are deemed GRAS by the FDA, their effectiveness against microorganisms is typically low and needs high concentrations for extended periods of time. Fresh and freshly cut vegetables have been sanitized using organic acids and acid compound sanitizers. In order to maintain the physical and chemical properties of many fresh-cut products and to stop microbial development, organic acids are crucial sanitizers. According to Ibrahim et al. (2009), decontaminating leaves of some particular veggies with 5% citric acid resulted in a noticeably lower microbial count than washing them with water. The ideal form of organic acid had no negative effects on flavor or taste, and it had no negative effects on the ecosystem. Fresh-cut fruit can have their shelf life extended by citric acid because it prevents food quality from deteriorating and the spread of disease. However, using these acids at greater concentrations may lead to a quality loss in some freshly cut leafy veggies due to off-odor and texture damage. It has also been investigated how citric acid and ethanol treatment in order affects the quality and microbial reduction of organic vegetables. As a result, an

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organic acid-based disinfectant has been developed using a combination of technologies in place of chlorine.

Chlorine dioxide: Fresh fruit can be effectively protected from bacterial, fungal, and viral contamination by using the oxidizing gas ClO_2 (Praeger et al., 2018; Sun et al., 2019). ClO_2 is effective across a wide pH range and does not create any toxic byproducts or change the nutritive or olfactory qualities of food products. (pH 3–8). However, using ClO_2 to wash fresh product in gaseous and aqueous forms has benefits and drawbacks, which are listed in Table 5.

Table 5. Chlorine dioxide (ClO_2) application in the aqueous and gaseous form: advantages and disadvantages.

Aqueous ClO_2, (Praeger et al., 2018)	
Advantages	**Disadvantages**
Easy to handle, inexpensive	Produce surface properties can affect ClO_2 accessibility to microbes
It can be used in the form of a spray, immerse or washing	Cross-contamination of wash water
Concentration and contact can be maintained	Water rinsing is required after the treatment
Easy to adopt in industrial washing lines	Residual moisture after the water rinsing can promote microbial growth
	Not suitable for dried foods
	Relatively less effect on microbial internalization
Gaseous ClO_2, (Sun et al., 2019)	
Advantages	**Disadvantages**
Higher antimicrobial activity	Needs onsite generation
It can be applied as batch treatment or continuous treatment	Needs technical knowledge
High accessibility to microbes, irrespective of surface barriers	laborious to perform, expensive
No water rinsing is required after the treatment	Explosive at higher concentration
It can impact microbial internalization	Challenging to maintain concentration and contact time
No issue of cross-contamination of wash water	Challenging to implement at the industry scale

Natural plant extracts:

Natural goods are increasingly being looked into as alternatives to conventional sanitizing agents in the washing processes for fresh produce. Essential oils (EOs) and hydrosols from aromatic plants are examples of natural plant extracts that are generally accepted as safe (GRAS) for use in the food industry and are also covered by EC Regulation No. 1334/2008 on flavorings and certain food ingredients with flavoring properties for use in and on foods (D'Amato, et al., 2018; European Commission, 2008). Numerous EOs and other natural extracts, such as sage, Greek oregano, eucalyptus, and rosemary, have been used to preserve fresh produce and barely processed vegetables. (Tzortzakis et al., 2010, 2016; Chrysargyris et al., 2021; Xylia et al., 2021). Furthermore, no variations in lowering *E. coli* O157: H7 and total coliforms in lettuce and spinach were discovered after washing with water and tannin solutions. (Engels et al. 2012). While washing spinach and lettuce samples in aqueous oregano extract for two minutes reduced *E. coli* O157:H7 counts by 2.1 log CFU g^{-1} and 3.7–4.0 log CFU g^{-1}, respectively, when coupled with Citrox® (a product containing citric acid and phenolic compounds) (Poimenidou et al. 2016). These findings suggested that plant extracts can successfully decrease the pathogenic load in fresh vegetables. Edible coatings with natural antimicrobial agents are becoming more popular as possible treatments to lessen the adverse effects of processing fresh vegetables. However, using natural edible coatings for freshly cut vegetables has not attracted attention, and no vegetable businesses have yet to wash or preserve fresh-cut vegetables

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using a natural antimicrobial agent due to fewer side effects than chemical sanitizers and non-economic efficiency. Plant extracts should also be kept in the dark because they are typically volatile and light-sensitive. Vegetables may become softer when plant extracts are in greater concentrations (0.5%). Washing fresh organic produce offered at a higher price can be done with natural detergents. The need for natural food preservation techniques, such as using natural antimicrobials and their combination with other obstacles, without adverse effects on the consumer or the environment, has been brought on by consumers' increasing demand for fresh and freshly cut produce (Tiwari et al., 2009). Essential oils are natural antimicrobial agents; however, it is practically difficult to use these oils because of their hydrophobic, volatile, and unstable nature (Deng et al., 2020).

Green tea extract: Green tea extract (GTE; 60%) was shown by Randazzo et al. (2017) to exhibit a rise in antiviral activity with increasing pH. The cytoplasmic membrane damage, nucleic acid synthesis suppression, cell wall component inhibition, and cell membrane damage could contribute to the antibacterial activity (Borges et al., 2013; Wu et al., 2013). Temperature, concentration, and contact time all impacted GTE's reaction. For lettuce and spinach, using 60% GTE also successfully lowered the bacterial count by 1.5 logs after 30 minutes of exposure. A non-economic and occasionally greater dosage of GTE may result in an unpleasant odor and soften the vegetables because it requires longer times, less effectiveness, and a higher concentration than chemical sanitizers.

Table 6. Efficacy of non-chlorine-based sanitizers in reducing bacterial pathogens from fresh salad vegetables' surface.

Vegetables	Non-chlorine sanitizers (Conc & contact time)	Microorganisms	Maximum reduction (log CFU/g)	Complete reduction /Number of samples	References
Lettuce	Peracetic Acid (PAA); (100 mg/L; 5 min at 65 rpm)	*E. coli* O157:H7,	2.2	0/6	Singh et al., 2018
		S. Typhimurium DT104	6.8	6/6	
		L. monocytogenes,	2.4	0/6	
	Lactic acid (2%; 5 min at 65 rpm)	*E. coli* O157:H7,	1.7	0/6	
		L. monocytogenes,	1.7	0/6	
	Calcinated calcium: 0.01% for 40-60 sec	*Escherichia coli*	2.1	3/3	Feroz et al., 2013
	Hydrogen peroxide (H_2O_2); (2% for 90 sec)	*E.coli* O157:H7	4.3	0/3	Lin et al., 2002
		S. Enteritidis	4.3	0/3	
	Aquous Ozone (O_3); (3 ppm for 5 min)	*E. coli* O157:H7,	5.9	0/5	Rodgers et al., 2004
		Listeria monocytogenes	5.9		
	ClO_2 3 ppm, 5 min	*E. coli* O157:H7,	5.8		
		Listeria monocytogenes	6.0		
	Plant extract (grape stem extract, 25 mg/ml)	*E.coli* O157:H7	0.7	0/5	Vázquez-Armenta, et al., 2017
		S. enterica	1.0	0/5	
		L. monocytogenes	0.8	0/5	
Tomato	PAA at 100 mg/L; 5 min@65 rpm (Laboratory scale)	*E. coli* O157:H7,	5.5	3/6	Singh et al., 2018
		S. Typhimurium DT104	6.8	6/6	
		L. monocytogenes	2.4	0/6	
	Lactic acid (2%); 5 min@65 rpm	*E. coli* O157:H7,	2.4	0/6	
		S. Typhimurium DT104	4.8	0/6	
		L. monocytogenes	2.3	0/6	
	ClO_2 5 mg/L, 60 s (Commercial scale)	*Salmonella spp.*	4.9	0/15	Chang et al., 2012

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	PAA 80 mg/L, 60 s (Commercial scale)	*Salmonella spp.*	5.5	15/15	Chang et al., 2012
	Calcinated calcium for 1 min 0.01%	*E. coli* O157:H7	7.6	0/3	Bari et al., 2002
		Salmonella spp.	7.4		
		L. monocytogenes	7.5		
	H_2O_2; 5% for 2 min, 60 ºC;	*Salmonella spp.*	2.6	0/3	Sapers et al., 2006
		E.coli	1.4		
		L. monocytogenes	2.5		
	Aquous O_3; 0.45 ppm for 10 min	*Salmonella spp.*	4.5	0/6	Xu et al., 2004
	Green tea extract 60%; 5 min	*E.coli*	5.66 ±0.1	3/3	Nascimento, & São josé, 2022
		S. enteriditis	5.23±0.12	0/3	
Cucumber	Peracetic Acid (PAA) 0.5%	*S. typhimurium*	2.66 ± 0.20	0/12	Li et al., 2020
		L. monocytogenes	1.28 ± 0.35		
	Lactic acid (2%)	*S. Typhimurium*	2.14 ± 0.26		
		L. monocytogenes	0.75 ± 0.43		
	Calcinated calcium (0.01 % for 1 min)	*E.coli*	3.62 ± 0.1	3/3	Ahmed et al., 2019
	H_2O_2; 0.5% for 2 min	*S. Typhimurium*	2.63 ± 0.19	0/12	Li et al., 2020
		L. monocytogenes	1.16 ± 0.40		
	Aquous O_3; 2% for 5 min	-	-	-	-
	ClO_2; 100 ppm	*E.coli*	2.61± 0.1	0/5	Chung et al., 2011
	Green tea extract 60%; 5 min	*S. enterica*	2.0 ± 0.1	0/4	Xylia et al., 2022
		L. monocytogenes	2.07 ± 0.1		
Carrot	Peracetic Acid (PAA) 40 ppm, 1 min;	*E.coli*	0.5	0/4	Ruiz-Cruz et al., 2007
		Salmonella spp.	1.5		
		L. monocytogenes	0.5		
	lactic acid (0.1%); 5 min	*E.coli* O157:H7	0.4	0/5	Gyawali et al., 2012
	Calcinated calcium (0.01% for 1 min)	*E. coli*	0.5	3/3	Amin et al., 2021
		Salmonella spp.	0.5	3/3	
	H_2O_2; 1.5% for 90 sec	*E.coli*	0.8	0/3	Augspole et al., 2013
	Aqueous O_3; 16.5 mg/L	*E.coli* O157:H7	1.85	0/3	Singh et al., 2002
	ClO_2: 20 mg/L	*E.coli* O157:H7	3.0	0/3	
	Plant Extract	-	-	-	-
Green chilli	Peracetic Acid (PAA)	-	-	-	-
	Lactic acid	-	-	-	-
	Calcinated calcium (0.01% for 1 min)	*E.coli*	0.5	0/3	Khadiza A. R. (2018)
		Salmonella spp.	0.5	0/3	
	H_2O_2; 0.5% for 2 min	*E.coli*	0.5	0/3	Khadiza A. R. (2018)
		Salmonella spp.	0.5	0/3	
	Aqueous O_3;	-	-	-	
	ClO_2;	-	-	-	-
	Plant extract	-	-	-	-
Coriander leaf	Peracetic Acid (PAA)	-	-	-	-
	Lactic acid	-	-	-	-
	Calcinated calcium (0.01% for 1 min)	*E.coli*	1.6±0.1	3/3	Khadiza A. R. (2018)
	H_2O_2	-	-	-	-
	Aqueous Ozone (O_3); 6% for 30 min	*E.coli*	2.5	0/3	Gibson et al., 2019
		S. Typhimurium	2.7	0/3	
	Aqueous ClO_2	-	-	-	-
	Plant extract	-	-	-	-

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Conclusions

According to the majority of studies, the biggest threats to the food safety of vegetables come from irrigation or wash water, then from how the produce is managed during the postharvest process. Microbial contamination is a significant factor in postharvest losses for fresh vegetables, and washing them in water lowers the number of microbes on their surface by one or two logs (1 log reduction being a 10-fold reduction). The quantity of total dissolved solids (such as soil, dirt, and debris) in the water, water temperature, the quality of the incoming water (such as pH and mineral content), the contact time with the produce, and the texture of the produce are all variables that influence the effectiveness of the sanitizer in vegetables (smooth or rough surface). Additionally, the majority of sanitizer effectiveness studies have only been conducted in laboratories; it is crucial to validate sanitizers in actual workplace settings. Furthermore, when determining the precise procedure (amount and mode of sanitizer delivery) to handle the vegetables, appropriate sanitation should consider the aforementioned factors.

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