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Review

Applications of Electrolyzed Water in Agriculture & Food Industries

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Microbial control of postharvest diseases has been extensively studied and appears to be a viable technology. Food safety must be ensured at each postharvest processing step, including handling, washing of raw materials, cleaning of utensils and pipelines, and packaging. Several commercial products are available for this purpose. The time is ripe for developing new techniques and technologies. The use of electrolyzed water (EW) is the product of a new concept developed in Japan, which is now gaining popularity in other countries. Little is known about the principle behind its sterilizing effect, but it has been shown to have significant bactericidal and virucidal and moderate fungicidal properties. Some studies have been carried out in Japan, China, and the USA on the pre- and postharvest application of EW in the field of food processing. EW may be produced using common salt and an apparatus connected to a power source. As the size of the machine is quite small, the water can be manufactured on-site. Studies have been carried out on the use of EW as a sanitizer for fruits, utensils, and cutting boards. It can also be used as a fungicide during postharvest processing of fruits and vegetables, and as a sanitizer for washing the carcasses of meat and poultry. It is cost-effective and environment-friendly. The use of EW is an emerging technology with considerable potential.

Keywords: Electrolyzed water, acidic, alkaline, basic, oxidized, reduced, food safety, postharvest, environment friendly

1. Introduction

It is of utmost importance to maintain the quality of fresh produce at postharvest stage. Microbial control of postharvest diseases in food products has been the subject of extensive study. Research into and development of postharvest technologies are on a fast track. Until recently, the economic and political implications of a safe food supply were underestimated. Worldwide, there are 1.5 billion cases of food-borne illness each year; these illnesses rank among the most common forms of disease in the world. More than 3 million deaths from food-borne illness are recorded per year. In the last 25 years, at least 30 new infectious agents associated with food- and water-borne illnesses have been recognized.

Food safety must be ensured at each postharvest processing step, including handling, washing of raw materials, cleaning of utensils and pipelines, and packaging. Bacterial contamination of food-processing surfaces such as stainless steel, glass, cast iron, polypropylene, and Formica, resulting in food spoilage or transmission of disease, has been extensively reported (Abrishami *et al.*, 1994; Blackman and Frank, 1996; Helke *et al.*, 1995; Zhao *et al.*, 1998). Bacterial contamination can also occur on non-food-contact surfaces such as ceramic tiles, vitreous china, stainless steel, and glassware (found in bathrooms and laundries, microbiological testing laboratories, swimming pools, and medical facilities) if these surfaces are not completely sanitized. These contaminated surfaces can serve as reservoirs of pathogens and transfer disease via hand-to-surface contact (Emori and Gaynes, 1993).

Many commercial disinfecting cleaning agents, such as potassium persulphate, isopropanol, hydrogen peroxide, sodium dichloroisocyanurate, ethanol and phenol derivatives (Aarnisalo *et al.*, 2000), quaternary ammonium compounds, and chlorine (Tuncan, 1993), have been shown to be effective against food-borne pathogens in suspension tests. However, microorganisms attached to surfaces are less susceptible to chemical sanitizers than their free-living counterparts because sanitizers have a limited ability to penetrate the protective layer of microbial polymers (Frank and Koffi, 1990; Lee and Frank, 1991).

Chlorine rinses are generally used during processing (fruits, vegetables, meat, poultry, etc.) for pathogen reduction. Various other processes have been proposed as alternatives for eliminating or substantially decreasing bacterial populations. These include treatment with trisodium phosphate (Vareltzis *et al.*, 1997; Xiong *et al.*, 1998), cetylpyridinium chloride (Xiong *et al.*, 1998), hydrogen peroxide (Lillard and Thomson, 1983), gamma irradiation (Katta *et al.*, 1991), microwave irradiation (Goksoy *et al.*, 2000), and chilling (Vivien *et al.*, 2000). However, most of

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these processes have been found not to be completely acceptable due to chemical residues, discoloration of chicken carcasses, high cost or limited effectiveness. Therefore, the development of effective sanitizers to reduce or eliminate bacterial populations on food, food-processing surfaces, non-food contact surfaces (e.g. floors), *etc.*, is an ongoing subject of interest.

Although several commercial products are available, research is still being conducted into new techniques and technologies. One recent discovery is the possibility of using electrolyzed water as a sanitizer. This is the result of a new concept developed in Japan (Al-Haq and Sugiyama, 2004). There is evidence that electrolyzed water can work better than water and chlorine solutions as a sanitizer of meats, some fresh produce, cutting boards and utensils. It appears that the process allows better access to the uneven surfaces of fruits and vegetables. This is currently a topic of interest in the USA, Canada, Japan, and other developed countries. Electrolyzed water has been introduced to food industries as a novel disinfecting agent.

The first reported use of electrolyzed water was in the production of tofu (Isobe, 2003); basic electrolyzed water (BEW) was used for this purpose. Acidic electrolyzed water (AEW or AcEW), which is a popular disinfectant, has been determined to have a strong bactericidal effect on most known pathogenic bacteria. Table 1 presents a summary of studies of the effect of AEW on various microorganisms. It acts as a flash disinfectant, although not for *Bacillus, Mycobacterium* and fungi (Iwasawa and

Table 1. Studies conducted to know the effect of AEW on various microorganisms.

	Organism	Reference
	Bacteria	
1	*Bacillus cereus*	Kim *et al.* (2000a,b, 2001), Park *et al.* (2002a)
2.	*Campylobacter jenuni*	Kim *et al.* (2000a,b, 2001), Park *et al.* (2002a)
3.	*Enterobacter aerogenes*	Park *et al.* (2002b)
4.	*Erwinia carotovora*	Robbs *et al.* (1995)
5.	*Escherichia coli* O157:H7	Albrich *et al.* (1986), Bari *et al.* (2003), Kim *et al.* (2002b), Len *et al.* (2000, 2002), Koseki *et al.* (2003, 2004a), Park *et al.* (2004), Venkitanarayanan *et al.* (1999a,b), Yang *et al.* (2003), Yoshida *et al.* (2001)
6.	*Listeria monocytogenes*	Aarnisalo *et al.* (2000), Bari *et al.* (2003), Blackman & Frank (1996), Frank & Koffi (1990), Kim *et al.* (2002b), Park *et al.* (2004), Venkitanarayanan *et al.* (1999a,b), Yang *et al.* (2003), Zhao *et al.* (2001)
7.	*Psudomonos salanacearum*	Matsuoka & Kawasaki (1994)
8.	*Salmonella* Enteritidis	Bari *et al.* (2003), Koseki *et al.* (2004), Stan *et al.* (2003), Venkitanarayanan *et al.* (1999a)
9.	*Salmonella typhimurium*	Suzuki *et al.* (2002b), Yang *et al.* (2003)
10.	*Staphylococcoccus aureus*	Park *et al.* (2002b), Suzuki *et al.* (2002a)
11.	*Streptococcus*	Hotta *et al.* (1994)
12.	*Xanthomonas*	Lazarovits *et al.* (2004)
13.	Others	Moriyama *et al.* (2002), Nakagawa *et al.* (1998), Suzuki (1996), Tagaki *et al.* (1997)
	Fungi	
14.	*Aspegillus*	Buck *et al.* (2002), Hara *et al.* (2003c), Suzuki *et al.* (2002b)
15.	*Botrytis*	Buck *et al.* (2002)
16.	*Burkholderia glumae*	Oomori *et al.* (2000b)
17.	*Botryosphaeria*	Al-Haq *et al.* (2000, 2001a, 2002a)
18.	*Cladosporium*	Buck *et al.* (2002)
19.	*Colletotrichum*	Al-Haq *et al.* (2003a,b)
20.	*Curvularia*	Buck *et al.* (2002)
21.	*Fusarium*	Grech & Rijkenberg (1992)
22.	*Helminthosporium*	Buck *et al.* (2002)
23.	*Magnaporthe*	Tamaki *et al.* (2001)
24.	*Monilinia*	Al-Haq *et al.* (2001b, 2002b)
25.	*Penicillium*	Buck *et al.* (2002)
26.	*Phytophthora*	Grech & Rijkenberg (1992)
27.	*Tilletia indica*	Bonde *et al.* (1998, 1999a,b), Bonde & Nester (2002)
28.	Others	Schoerner & Yamaki (1997, 1999a,b); Fujiwara *et al.* (1998a,b)
29.	**Viruses**	Iwasawa (1993), Kawasaki *et al.* (2003), Shimizu (1994)
30.	**Algae, Protozoans, Nematodes**	Grech & Rijkenberg (1992)

Nakamura, 1999a). It has also been reported to suppress fungal rot in fruits (Table 1). Studies have shown that AEW is highly effective in reducing or eliminating food-borne pathogens on kitchen boards and on various food products, such as fish, poultry, fruits, and vegetables, on which it reduced populations of pathogens to undetectable levels. A summary of applications of AEW at pre- and postharvest stages in the agriculture and food industries is presented in Table 2.

2. Electrolyzed Water

2.1 History

Water electrolysis technology was first used around 1900 in the soda industry, including in the production of sodium hypochlorite (Japan Soda Industry Association, 1982). In 1980, the technology was introduced into the market as sanitary supervision of stored water in an automatic dispenser (Iseki *et al.*, 2002). With improvement and miniaturization of the equipment, electrolysis technology has been applied in various fields and is now regarded as a promising non-thermal treatment for hygiene control (Yoshida, 2003).

2.2 Terminology

Acidic electrolyzed water (AEW) has been classified as functional water; some scientists use the term electrolyzed oxidizing water (EO water). Similarly, alkaline electrolyzed water (AlEW) has been referred to as electrolyzed reducing (ER) water or basic electrolyzed water (BEW). Scientists have given various names to the water collected from the anode, a few of which are listed in Table 3. As some Japanese scientists believe that oxidation-reduction potential (ORP) is not the principle behind the sterilizing effect of AEW, they prefer the term AEW or EO water. In this article, therefore, the terms AEW and BEW have been used.

2.3 Generation of Electrolyzed water

Electrolyzed water is generated in a cell containing inert positively charged and negatively charged electrodes separated by a septum (membrane or diaphragm) (Fig. 1). The current passing through the electrolyzed-water generator and voltage between the electrodes are set at 8~10 amperes and 9~10 volts, respectively. A saturated NaCl (or $KCl/MgCl_2$) solution and tap water from the laboratory supply line are simultaneously introduced into the

Table 2. Application of AEW at pre- and postharvest stages in agriculture and food industries.

Application	References
Pre-harvest applications	
Seed disinfection	Bonde *et al.* (1999), Bonde & Nester (2002), Stan *et al.* (2003), Yoshida *et al.* (2003)
Crop disinfection/pre-harvest disease control	Matsuo (1995a,b), Matsuo & Takahashi (1997a,b), Matsuoka & Kawasaki (1994), Matsuoka *et al.* (1994), Tamaki *et al.* (2001)
Irrigational water for microbial control	Grech & Rijkenberg (1992), Buck *et al.* (2003)
Spraying as fungicide to control plant diseases	Buck *et al.* (2003), Fujiwara *et al.* (1998a,b), Kang *et al.* (2002), Schoerner & Yamaki (1997, 1999a,b), Yamaki & Schoerner (1995)
Applications of electrolyzed water	Kubota (1996)
Post-harvest applications	
Decontamination by ice cubes of EO water	Koseki *et al.* (2002)
Disinfection cutting boards, etc.	Abrishami *et al.* (1994), Venkitanarayan *et al.* (1999a,b)
Disinfecting fresh leafy Vegetables (cabbage, cilantro, spinach, lettuce)	Izumi (1999), Izumi & Ebihara (2001), Koseki & Itoh (2000a,b,c;e 2001a,b, 2002), Koseki *et al.* (2001, 2002, 2003), Park *et al.* (2001), Koseki *et al.* (2004a), Ueno *et al.* (1999), Wang *et al.* (2004), Yang *et al.* (2003)
Fish	Ueno *et al.* (1999)
Food sanitation management	Kato (1999), Suzuki (1996, 1999)
Inactivation of food related pathogens (bacteria)	Kim *et al.* (2000a,b; 2001), Koseki *et al.* (2004b), Park *et al.* (2004), Suzuki *et al.* (2002b), Venkitanarayan *et al.* (1999a,b)
Postharvest application to control fungal decay	Al-Haq *et al.* (2000, 2001a,b; 2002a,b,c; 2003a,b), Al-Haq & Sugiyama (2004), Koseki *et al.* (2004b), Schoerner & Yamaki (1997, 1999a,b), Yamaki (1998), Yamaki & Schoerner (1995, 1996, 1997)
Postharvest application to control bacterial decay	Isobe (2002), Izumi (1999), Koseki & Itoh (2000a,b; 2001), Koseki *et al.* (2001, 2002), Park *et al.* (2002a)
Poultry	Park *et al.* (2002a)

equipment. The display indicators (amperes, volts, pH/ ion meters) are continuously observed until the machine stabilizes. The cell electrolyzes the water, resulting in two types of water, possessing different properties, which may be collected from their respective outlets:

(a) An electrolyzed basic solution (BEW, or ER water or AlEW) from the cathode stream (pH 11.4, ORP-795 mV), which has strong reducing potential.

(b) An electrolyzed acid solution (AEW, or EO water or AcEW) from the anode stream (pH 2.5, OPR > 1,100 mV, chlorine base reactants 10 to 90 ppm), which has a strong bactericidal effect (Anonymous, 1997).

The pH and ORP are recorded by a pH/ion meter. The pH, ORP, and free chlorine concentration of electrolyzed water manufactured from tap water has been found to be nearly identical to that produced from distilled water (Bonde *et al.*, 1999). AEW and BEW are collected in separate containers. Electrolyzed water is usually prepared just before use, but studies have been conducted into the possibilities of preserving the water in darkness (Len *et al.*, 2002) and converting it into ice cubes for later use (Koseki *et al.*, 2002). Some scientists have also used electrolyzed neutral water (Hirano and Ueda, 1997), which has a pH near 7, for disinfection of food materials.

Formulae for the anodic and cathodic reactions are summarized in Figs. 2 and 3.

2.4 Types of Electrolyzed Water-Producing Machines

Various types of electrolyzed water-producing machines are available in the market. As the country that introduced this technology, Japan is the biggest manufacturer of such machines. Sumida (1998) mentioned four models, *viz.* type I, type II, type 1S, and type 3, which produced AEW of pH 2.3～3.5, 2.5～3.5, 3.0～4.0, and 5.0～6.0, respectively.

Generally speaking, machines can be divided into two types: those containing a diaphragm (septum or membrane) produce AEW with a pH between 2 and 3, while those without a septum produce neutral water at pH 6.8, because HCl formed at the anode side neutralizes the

Table 3. Various names used by scientists for the AEW.

Name Given	Abbreviation used	References
Acid Oxidizing Water	AOW	Shimada *et al.* (2000)
Acidic Electrolyzed Water	AEW, AcEW, AcE water	Al-Haq *et al.* (2000), Bari *et al.* (2003), Buck *et al.* (2002, 2003), Bonde & Nester (2002), Bonde *et al.* (1999), Isobe (2002, 2003), Iwasawa (1993), Iwasawa & Nakamura (1999a/b), Koseki & Itoh (2001a,b; 2002), Koseki *et al.* (2001, 2002, 2003, 2004a,b), Oomori *et al.* (2002a,b), Tosa & Yamasaki (2000), Wang *et al.* (2004), Yoshida *et al.* (2002, 2003)
Aqua Oxidation water		Iwasawa *et al.*, (1993a.b)
Chlor-aqueous Solution		Nakagawa *et al.* (1998), Suzuki (1999)
Electrolyzed NaCl solution		Hotta *et al.* (194), Suzuki *et al.* (2002b)
Electrolyzed Oxidizing Water	EO water	Al-Haq *et al.* (2001a,b; 2002a,b,c; 2003a,b), Hayashibara *et al.* (1994), Hsu (2003), Kim *et al.* (2000a,b, 2001), Len *et al.* (2000, 2002), Shimada *et al.* (2000), Park *et al.* (2004), Venkitanarayanan *et al.* (1999a,b), Yamanaka (1995), Yamanaka *et al.* (1995)
Electronically generated Chlorine Water		Grech & Rijkenberg (1992)
Electronically Prepared Chlorine Water	EPCW	Kato (1999)
Electrolyzed Strong Acid Aqueous Solution	ESAAS	Abe (1999), Hayashi *et al.* (1997), Kumon (1999)
Electrolyzed Strong Acid Water	ESAW	Fujiwara *et al.* (1998a,b)
Functional water		Iwasawa & Nakamura (1999b), Kumon (1997), Nishimoto *et al.* (1996), Yamaki (1998), Yamaki & Shoerner (1995)
Redox Water		Sumida (1998)
Sterilox water		Selkon *et al.* (1999), Shetty *et al.* (1999)
Strong Ionized water		Shiba & Shiba (1995)
Superoxide water		Selkon *et al.* (1999), Tanaka *et al.* (1996)

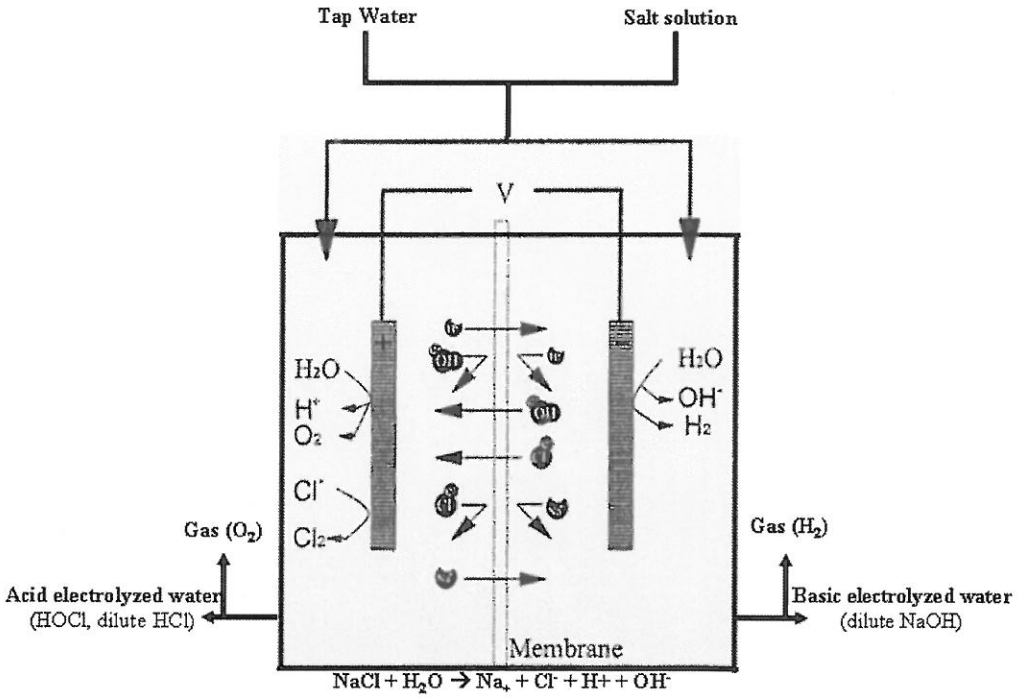


Fig. 1. Schematic of electrolyzed water generator and resulting compounds.

NaOH at cathode side (Hirano and Ueda, 1997).

Al-Haq and Sugiyama (2004) state that the machine used most commonly in published reports is the ROX-20 TA (Fig. 4, Hoshizaki Electric Inc., Toyoake, Aichi, Japan). This has been used in studies reported by Koseki and Itoh (2000a, b, c, d, 2001); Koseki *et al.* (2001, 2002); Kim *et al.* (2000b, 2001); Park *et al.* (2001, 2002a, b); Venkitanarayanan *et al.* (1999a, b) and many others. A machine manufactured by Remotex (Remote Co., Toshima-ku, Tokyo) was used by Yamaki (1998) and Yamaki and Schoerner (1995, 1996, 1997). Al-Haq *et al.* (2000, 2001a, b, 2002a, b, c, 2003a, b) used a machine manufactured by Mitsubishi Electric Engineering Co., Japan (Fig. 5), on which it is possible to set the desired pH by adjusting the control knobs (Fig. 5), allowing production of electrolyzed neutral water (ENW). ENW, or neutral oxidizing water (NOW), is produced using a non-septum machine and usually has a pH of 5.0～5.5, an ORP of approximately 830 mV and a FAC of approximately 80 ppm. In Japan, more than 20 companies manufacture electrolyzed water machines.

2.5 Uses of AEW in agriculture and food industries

AEW is used in the medical, dental, food-processing, agriculture, and dairy industries. It is widely used for disinfection purposes in Japanese hospitals and dental clinics. A brief account of its uses in the agriculture and food industries has been summarized in Tables 2 and 4. AEW has mostly been used for microbial control, but in some studies both AEW and BEW have been used (Table 5).

2.6 Advantages of AEW

Disinfection with AEW is more convenient than conventional chlorine disinfection for the following reasons:

1) It can be produced on-site.
2) It is produced by simple electrolysis using pure water with no added chemicals except for a dilute salt solution (NaCl or KCl or $MgCl_2$); it therefore has less adverse impact on the environment (Kim *et al.*, 2000b; Koseki *et al.*, 2002).
3) Its use reduces the cost and hazards associated with the handling, transportation, and storage of concentrated chlorine solution.
4) It is more environment-friendly. In some machines, if the pH is set lower than 5.0, chlorine gas (Fig. 6) is produced in addition to other species of FAC (*e.g.* HOCl and OCl^- ions) (Al-Haq *et al.*, 2001b, 2002a). In such cases the operator must protect himself from chlorine fumes. Otherwise, the machines are safe for the environment as well as for the operator (Bonde *et al.*, 1999).
5) To reduce health concerns about the use of chlorinated water, AEW can be modified to reduce the available chlorine concentration while maintaining its effectiveness against microbes (Kim *et al.*, 2000 b).
6) It reverts to normal water after use, without releasing large amounts of harmful gases such as chlorine (Bonde *et al.*, 1999).
7) Some researchers claim that AEW kills microorganisms physically, and that microorganisms do not acquire resistance.
8) After the initial cost of the electrolysis apparatus, operational expenses are minimal (Bonde *et al.*, 1999).

1. Generation of free radicals, active oxygen, and hydrogen peroxide

$$H_2O = H^+ + {}^\bullet OH + e^-$$
$${}^\bullet OH + {}^\bullet OH = H_2O_2$$
$$H_2O = {}^\bullet O + 2H^+ + 2e^-$$
$$O_{2^-} = 2O + e^-$$

2. Generation of ozone gas

$$3H_2O = O_3 + 6H^+ + 6e^-$$
$${}^\bullet O + O_2 + O_3,\ O + O_2 = O_3$$
$$O_2 + H_2O = O_3 + 2H^+ + 2e^- \ (E^o = 2.07\ V)$$

3. Generation of oxygen gas

$$2H_2O = O_2 + 4H^+ + 4e^-$$
$$4OH^- = O_2 + 2H_2O + 4\ e^-$$
$$H_2O_2 = O_2 + 2H^+ + 2e^-$$
$$2Cl_2 + 2H_2O = 4H^+ + 4Cl^- + O_2$$

4. Generation of oxygen gas and chlorine gas

$$2Cl^- + O_3 + 2H^+ = O_2 + Cl_2 + H_2$$
$$2Cl^- + 2O_3 = 3O_2 + Cl_2 + 2e^-$$

5. Generation of chlorine gas and dissolved chlorine

$$2Cl^- = Cl_2(g) + 2e^- \ (E^o = 1.359V)$$
$$2HOCl + 2H^+ + 2e^- = Cl_2 + 2H_2O \ (E^o = 1.63V)$$
$$Cl_2(g) = Cl_2(aq)$$

6. Generation of hypochlorous acid and hypochloric acid

$$Cl_{2(aq)} + H_2O = HCl\ (=H^+ + Cl^-) + HOCl$$
$$Cl^- + H_2O = HOCl + H^+ + 2e^-$$
$$2Cl^- + H_2O = HOCl + HCl + 2e^-$$
$$2Cl^- + H_2O_2 = 2HOCl + 2e^-$$
$$ClO^- + H_2O = HOCl + OH^-$$

7. Generation of hypochlorite ion, etc.

$$Cl_{2(aq)} + 2OH^- = ClO^- + Cl^- + H_2O$$
$$Cl_{2(aq)} + H_2O = ClO^- + Cl^- + 2H^+$$
$$HOCl = ClO^- + H^+$$
$$2HOCl\ ClO^- = ClO_3^- + 2Cl^- + 2H^+$$

Fig. 2. Reaction formulae at anodic side.

1. Generation of hydrogen gas

$$2H_2O + 2e^- = H_2 + 2OH^- \ (E^o = -0.828\ V)$$
$$2H_2O = H_2 + 2{}^\bullet OH$$

2. Generation of hydrogen and sodium hydrate

$$2Na^+ + 2H_2O + 2e^- = H_2 + 2NaOH$$
$$2Na + 2H_2O = H_2 + 2NaOH$$
$$Na^+ + OH^- = NaOH$$

3. Generation of hydroxide ion and separation of sodium

$$Na^+ + e^- = Na$$
$$2\,{}^\bullet OH + 2e^- = 2OH^-$$
$$O_2 + 2H_2O + 4e^- = 4OH^-$$

Fig. 3. Reaction formulae at cathodic side.

Thus, the use of electronically generated chlorine is quite cost-effective. Grech and Rijkenberg (1992) calculated the cost of various methods of chlorination and reported that the unit cost (USA) per kilogram of chlorine (100% free available) produced was $1.60 for liquefied chlorine gas, $2.70 for sodium hypochlorite solution (15%, w/v), $2.87 for dry calcium hypochlorite (70%, w/v), $3.64 for TCIA tablets, and 34 cent for electronically generated chlorine.

9) As a non-thermal method, the use of AEW does not result in changes in ingredients, texture, scent, flavor, *etc.*, which are brought about by heat-treatment (Yoshida, 2003).



Fig. 4. The most commonly used electrolyzed water-producing apparatus.

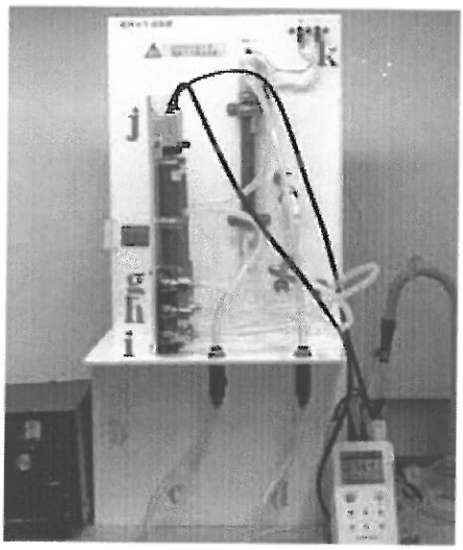


Fig. 5. Equipment used for manufacturing AEW by Al-Haq *et al.* (2000 ; 2001a, b ; 2002a, b, c ; 2003a, b).
a) electricity generator, b) NaCl solution tank, c) ACE water outlet, d) ER water outlet, e) pH/ion meter, f) water supply line, g) Alkali/pH flow control, h) NaCl/voltage flow control, i) water flow control, j) pH and ORP electrodes, and k) sterilox cell.

10) The cytotoxicity of AEW is less than that of a conventional disinfectant.

2.7 Disadvantages of AEW

1) It may rust some metals.
2) Its effectiveness is reduced by the presence of protein (Bonde *et al.*, 1999; Iwasawa and Nakamura, 1999) because chlorine reacts with protein (Shimada *et al.*, 1997).
3) Among water-electrolyzing machines, some models, if operated at pH<5, produce pungent chlorine gas that causes discomfort for the operator (Al-Haq *et al.*, 2001b, 2002a).
4) The initial purchase of the equipment may be costly.
5) With time, the bactericidal activity of AEW is reduced due to chlorine loss (Koseki and Itoh, 2001).
6) AEW contains free chlorine, which can be phytotoxic to plants and damage plant tissue (Grech and Rijkenberg, 1992; Schubert *et al.*, 1995).

2.8 Principle of antimicrobial activity of AEW

The antimicrobial mechanism of AEW is not yet fully understood (Suzuki and Watanabe, 2000). AEW may contain chlorine gas (Cl_2), HOCl, and OCl^- ions, all of which contribute to FAC, *i.e.* uncombined chlorine radicals (FAC is sometimes referred to as available chlorine concentration, ACC). Some researchers believe that the antimicrobial activity of AEW is due to the presence of chlorine species, while others believe that the low pH is responsible. A few studies have suggested that this activity is due to its high ORP. Some scientists say that it is a mixture of all these reasons. The fact remains, however, that AEW possesses strong bactericidal and virucidal and moderate fungicidal properties.

Chlorine is generated at the anode (oxidizing or acidic water), and hydrogen (H_2) at the cathode (reducing or alkaline water) (Fig. 1). Cl_2 reacts with the water to form HOCl and HCl. At the low pH of AEW, HOCl, which is a very weak but effective sanitizer, undergoes virtually no hydrolysis to the much less effective hypochlorite ion (OCl^-) (Kohno, 1996a,b; White, 1992). Hotta (1995) and Kohno (1996b) suggested that the bactericidal action of

Table 4. Studies conducted on various food commodities.

Commodity	References
Alfalfa	Stan *et al.* (2003)
Bell Pepper	Izumi (1999)
Cabbage	Koseki *et al.* (2000a,b), Koseki & Itoh (2001b, 2002), Tosa & Yamasaki (2000)
Carrot	Izumi (1999), Izumi & Ebihara (2001), Izumi & Suzuki (2000)
Cilantro	Wang *et al.* (2004)
Cucumber	Fujiwara *et al.* (1998a,b), Izumi & Ebihara (2001), Koseki *et al.* (2004b), Schoerner & Yamaki (1999a), Yamaki (1998), Yamaki & Schoerner (1995)
Citrus	Grech & Rijkenberg (1992)
Japanese radish	Izumi (1999)
Lettuce	Izumi (1999), Koseki & Itoh (2000a,b; 2001a,b, 2002), Koseki *et al.* (2001, 2002, 2003, 2004), Park *et al.* (2001, 2002b), Yang *et al.* (2003)
Mandarin	Yamaki & Shoroener (1996)
Mango	Al-Haq *et al.* (2003a,b)
Melon	Schoerner & Yamaki (1997)
Peach	Al-Haq *et al.* (2001b, 2002b), Schoerner & Yamaki (1999b), Yamaki (1998), Yamaki & Schoerner (1997)
Pear	Al-Haq *et al.* (2000, 2001a, 2002a)
Potato	Izumi (1999), Izumi & Ebihara (2001)
Poultry meat	Park *et al.* (2002a)
Rice	Tamaki *et al.* (2001), Oomori *et al.* (2000), Yoshida *et al.* (2003)
Soybeans	Kang *et al.* (2002)
Spinach	Izumi (1999), Izumi & Ebihara (2001)
Strawberry	Koseki *et al.* (2004b)
Tomato	Bari *et al.* (2003), Matsuoka *et al.* (1994)
Wheat	Bonde *et al.* (1998, 1999a,b), Bonde & Nester (2002)

Table 5. Studies in which both AEW and BEW have been employed for microbial control.

Commodity	Organism	Reference
Peach	*Monilinia fructicola*	Al-Haq *et al.* (2002b)
Lettuce	*Escherichia coli* O157:H7	Koseki *et al.* (2004)
	Salmonella Enteritidis	

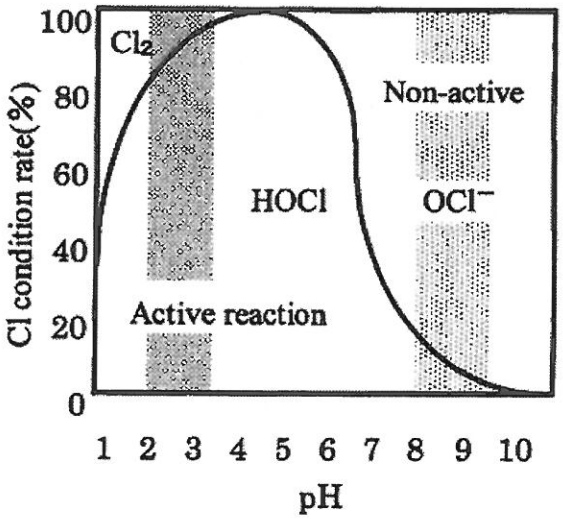


Fig. 6. Chlorine profile change with pH.

AEW is led by non-equilibrium HOCl, existing at low pH, in the electrolysis process. Studies have also suggested that hypochlorous acid (an undissociated form of chlorine) can penetrate microbial cell membranes and subsequently exert its antimicrobial action through the oxidation of key metabolic systems (Albrich *et al.*, 1986; Barrette *et al.*, 1989; Hurst *et al.*, 1991). Folkes *et al.* (1995) suggested that reactive HOCl supplies radical species such as hydroxyl radicals. White (1999) suggested that molecular Cl_2 (in equilibrium with HOCl), HOCl and FAC are the major contributors to the sanitizing effect of AEW. Park *et al.* (2001) suggested that the concentration of chlorine reactants in AEW is influenced by the amperage of the water generator, but other reports contend that the amount of HOCl produced during electrolysis is positively correlated with the amount of NaCl added (Anonymous, 1997; Al-Haq *et al.*, 2001b, 2002a). However, to reduce health concerns about chlorinated water, the manufacture of AEW can be modified to reduce the amount of HOCl produced while maintaining its effectiveness for microbial inactivation (Kim *et al.*, 2000b; Len *et al.*, 2000).

The pH value of AEW also plays a role in restricting microbial growth. Iwasawa *et al.* (2002) discussed the effect of pH on the bactericidal properties of AEW; Len *et al.* (2000) discussed the influence of amperage and pH on these properties. In addition, Len *et al.* (2002) discussed the effect of storage conditions and pH on chlorine loss in AEW.

Certain scientists have reported that a high ORP is responsible for the antimicrobial activity of AEW (Venkitanarayan *et al.*, 1999; Kim *et al.*, 2000b, 2001; Al-Haq *et al.*, 2002a). The ORP of a solution is an indicator of its ability to oxidize or reduce, with higher positive ORP values corresponding to greater oxidizing strength (Jay, 1996; McPherson, 1993; Robbs *et al.*, 1995). An ORP of +200 to +800 mV is optimal for growth of aerobic microorganisms, while a range of +200 to +400 mV is favored for growth of anaerobic microorganisms (Jay, 1996). A possible explanation for the high ORP of AEW is the oxygen released by the rupture of the weak and unstable bond between the hydroxy and chloric radicals (Anonymous, 1997). Kim *et al.* (2000b) mentioned that the ORP of the treatment solution was the primary factor affecting microbial inactivation. They agreed with reports by McPherson (1993) and Carlson (1991) concerning water disinfection applications, in which the ORP value of the solution was demonstrated to be a better indicator of disinfection properties than the concentration of residual (free) or total chlorine. McPherson (1993) also reported that ORP became a world standard in 1968 when a German Federal Health Office laboratory first proved that the killing rate of *E. coli* bacteria was dependent on ORP and not on residual chlorine. Carlson (1991) and Robbs *et al.* (1995) also noted that the killing of bacteria was not based on a defined chlorine reaction and that higher ORP values were required to kill all *E. coli* in a sample. Hence, a certain chlorine measurement alone cannot guarantee disinfection. However, the ORP provides a single measurement of total oxidation capability, regardless of the pH and the concentration of chlorine (Kim *et al.*, 2000b). Al-Haq *et al.* (2002a) suggested that ORP probably plays an influential role, in combination with low pH and FAC, in the disinfection of *B. berengeriana* on European pear.

A cascade of redox reactions occurs during electrolysis, producing many reactive and toxic compounds, such as ozone, and highly reactive and short-lived radicals such as O^-, Cl^-, and OH^- in AEW. These compounds contribute to the sanitizing effect of AEW (Shiba and Shiba, 1995).

A significant number of scientists believe that all three factors (chlorine, pH, and high ORP) contribute towards disinfection by AEW (Al-Haq *et al.*, 2002a). However, the presence of chlorine and a high ORP seem to be the main contributors to antimicrobial capacity. Some Japanese scientists believe that ORP is not the reason behind the sterilization effect of AEW and that it should be called AEW rather than EO water.

2.9 Principle of antimicrobial activity of BEW

BEW (also known as AlEW or ER water) has a pH greater than 11.3 and an ORP of −800 mV or less. Thus, it has strong reducing potential, which leads to reduction of free radicals in biological systems. It may also be useful in the treatment of organ malfunctions (Kim *et al.*, 2000b). BEW is recognized to have a surface-active effect due to the presence of dilute NaOH, dissolved hydrogen, and active hydrogen (Kikuchi, 2000; Shirahata, 2001; Yamanaka, 1995).

2.10 Factors affecting activity of AEW

Storage conditions: One of the limitations of AEW is its loss of bactericidal activity with time, which is caused by chlorine (Cl_2) loss (Koseki and Itoh, 2000) due to the evaporation of dissolved chlorine gas and ensuing HOCl decomposition (Fig. 6 and eq. 1).

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^- \quad (1)$$

The free chlorine content of AEW was found to drop significantly (by 80%) during 120 min of stirring, while the ORP remained constant, indicating the presence of other strong oxidants (Bonde *et al.*, 1999).

Len *et al.* (2002) reported that under open conditions, the chlorine in AEW was completely lost after 30 h when agitated and 100 h when not agitated. Storage lighting had no significant effect on chlorine loss. First-order kinetics based on chlorine evaporation are not applicable to closed conditions. The primary mechanism of chlorine loss under closed conditions may be the self-decomposition of chlorine in solution (White, 1999; Gordon, 1992), because chlorine evaporation is limited.

Light: Len *et al.* (2002) reported that the rate constant for chlorine loss remained almost the same regardless of lighting, indicating that the effect of diffused light on chlorine loss was small under open conditions. Previously, El Din *et al.* (2000) demonstrated that the chlorine decomposition rate for chlorinated water exposed to light was 5 to 8 times higher than the rate for chlorinated water stored in dark; however, the light conditions used in that study were much more intense (direct sunlight at 42～45℃) than the diffused light conditions (373 lux) used in the study carried out by Len *et al.* It was also found that lighting was a more important factor than agitation for chlorine loss under closed conditions. Under given experimental conditions, approximately 60% of chlorine was lost after 1400 h when diffused light was applied, whereas about 40% of chlorine was lost under dark conditions (Len *et al.*, 2002), which suggests that the diffused light induced the decomposition of chlorine during storage.

Agitation: Park *et al.* (2002b) reported that AEW treatment was less effective without agitation than with agitation, perhaps because of the limited ability of chlorine in AEW to penetrate attached microbial cell layers. Washing of inoculated surfaces in AEW with agitation at 50 rpm decreased the populations of *E. aerogenes* and *S. aureus* on different test surfaces to undetectable levels, while the control treatment resulted in a reduction of approximately 3 $\log_{10}$ CFU/cm^2 for both bacterial species. The observed reduction after the control treatment could be due to the removal of cells from inoculated surfaces through agitation. No viable cells of either species were observed in AEW after treatment. However, average counts of 4.6～4.9 $\log_{10}$ CFU/ml were recovered from the control solutions after treatment, suggesting that significant amounts of attached cells were removed from the inoculated surfaces during agitation (compared with approximately 2.5 $\log_{10}$ CFU/ml for the treatment without agitation). Without agitation, the TSB medium may react with AEW to form combined chlorine, reducing the local active chlorine concentration at or near the tested surfaces (Oomori *et al.*, 2000a). Complete inactivation of both species was observed on tested surfaces after AEW treatment with agitation, perhaps because (i) the cells removed from the surfaces during agitation were immediately inactivated in AEW, (ii) agitation facilitates the penetration of AEW into the remaining cells on the test surface, or (iii) the well-mixed AEW resulting from agitation allows chlorine to react with cells more efficiently (Park *et al.*, 2002b). For a better understanding of the chlorine-loss mechanism under open conditions, Len *et al.* (2002) calculated the rate constants and reported that the rate of chlorine loss increased by about 5 times when agitation was applied, probably due to the acceleration of interface mass transfer of chlorine gas. Agitation can accelerate mass transfer; however, it would not be expected to affect the decomposition of chlorine species via homogeneous reactions.

pH: The pH of AEW may also affect the rate of chlorine evaporation because the ratio of dissolved chlorine gas to HOCl in a solution is pH-dependent (White, 1999). The pH of AEW remained almost unchanged under all storage conditions in both open and closed environments (Len *et al.*, 2002). However, chlorine loss in AEW and chlorinated water was greatly reduced by increasing the pH (Len *et al.*, 2002). They further stated that as the pH increased from 2.5 to 4.0, significant decreases in k value (about 10-fold) were observed for both solutions. The decrease in H^+ concentration with increasing pH may shift the chemical equilibrium of eq. 1 towards the formation of HOCl, which is not volatile (Shimada *et al.*, 2000). The fraction of volatile dissolved Cl_2 gas would therefore decrease, resulting in a reduction of Cl_2 evaporation. AEW yielded larger k values than chlorinated water at the same pH, probably due to the different chemical environments of the two solutions (Len *et al.*, 2002). The form of available chlorine varies depending on the environmental pH (Nakagawa *et al.*, 1998). Theoretically, at pH values of 6.0 and 9.0, the predominant chlorine species in a solution is not dissolved Cl_2 gas but HOCl and OCl^- (White, 1999). It was therefore found that rates of Cl_2 loss due to the evaporation of dissolved Cl_2 gas at these pH values were not significantly different from each other, but were much less than those observed at acidic pH (Len *et al.*, 2002). There was almost no Cl_2 loss at pH 9.0. Len *et al.* (2002) stated that the observed small rates of Cl_2 loss at pH 6.0 and 9.0 could be due to the self-decomposition of chlorine species, as mentioned for chlorine loss under closed conditions. The change in chlorine profile with pH is shown in Fig. 6.

ORP: During 120 min stirring of AEW, the ORP remained constant, indicating the presence of other strong oxidants (Bonde *et al.*, 1999). The ORP of AEW was found to decrease during storage, consistent with the loss of oxidative chlorine (Len *et al.*, 2002). The effect of agitation was also clearly shown in the ORP profiles (Len *et al.*, 2002). The effect of lighting on chlorine loss was not clearly observed from the ORP profiles (Len *et al.*, 2002). ORP profiles obtained from closed conditions were similar to each other regardless of agitation and lighting, and only decreased slightly from about 1,100 to 1,085 mV (Len *et al.*, 2002).

Relationship between pH, ORP and FAC: Most of the published work in this area was done using the machine

shown in Fig. 4, which produces AEW with a pH of 2.6± 0.1. Al-Haq *et al.* (2002a) used a non-septum machine (Fig. 5) and reported a relationship between pH and ORP for AEW. The maximum ORP they observed was about 1200 mV at pH 2.5±0.1; the ORP remained in the range 1170±20 mV from pH 2.6 to 3.6.

3. Effects of AEW on microbes, food commodities and surfaces

3.1 Pre-harvest application of AEW: Effect on crops

Grech and Rijkenberg (1992) injected AEW into a citrus micro-irrigation system to control certain water-borne pathogens, *e.g. Phytophthora* spp., *Fusarium* spp., algae, and skin-forming bacteria. All of them were killed. Nematodes were found to resist free-chlorine levels in water up to 50 μg/ml. No chlorine-induced phytotoxicity was observed in field-grown plants. In greenhouse studies, treatment levels between 200 and 500 μg/ml significantly reduced propagules of *Phytophthora* in the soil and, in some cases, eradicated the pathogens.

3.2 Effect of AEW on bacteria

Park *et al.* (2002b) used initial populations of 8.0 $\log_{10}$ CFU/ml *E. aerogenes* and 8.04 $\log_{10}$ CFU/ml of *S. aureus*. Inactivation (reduction of >9 $\log_{10}$ CFU/ml) of *E. aerogenes* and *S. Aureus* occurred within 30 s of exposure to AEW containing approximately 25 or 50 mg/l of residual chlorine. *S. aureus* was more resistant than *E. aerogenes* to diluted AEW containing approximately 10 mg/l of residual chlorine. After 30 s of exposure to AEW containing approximately 10 mg/l of residual chlorine, the population of *E. aerogenes* decreased to an undetectable level; the surviving population of *S. aureus* was 3.9 $\log_{10}$ CFU/ml. Kim *et al.* (2000b) reported that a 60-s treatment with AEW containing 10 mg/l of residual chlorine was very effective in reducing the populations of *E. coli* O157: H7, *L. monocytogenes*, and *B. cereus* vegetative cells to undetectable levels. Zhao *et al.* (2001) found that most *E. coli* O157: H7 strains were very sensitive to chlorine and that a reduction of >7 $\log_{10}$ CFU/ml could be achieved with 0.25 mg/l of free chlorine.

3.3 Effect of AEW on test surfaces

Park *et al.* (2002b) used initial populations of 6.1 $\log_{10}$ CFU/cm^2 of *E. aerogenes* and *S. aureus* regardless of surface type (glass, stainless steel, glazed ceramic tile, unglazed ceramic tile, vitreous china). After immersion of the test surface in AEW for 5 min without agitation, the populations of *E. aerogenes* and *S. aureus* were reduced by 2.2 to 2.5 $\log_{10}$ CFU/cm^2 and by 1.7 to 1.9 $\log_{10}$ CFU/cm^2, respectively. Washing of inoculated surfaces with the control solution had only a minimal effect (a reduction of 0.1 and 0.3 $\log_{10}$ CFU/cm^2). No viable cells of *E. aerogenes* and *S. aureus* were detected in wash solutions immediately after treatment. However, >2 $\log_{10}$ CFU of viable cells/ml were recovered from the control wash solutions after treatment.

3.4 Effect of AEW on fungi

Effective postharvest and greenhouse disease management and the use of preventive fungicides are of considerable importance. Increasing concern about pesticides in the environment, potential worker safety issues, and fungicide resistance (LaMondia and Douglas, 1997; Yourman and Jeffers, 1999) indicate the need for alternative disease control measures. AEW is a potential alternative to fungicide in the control of foliar or postharvest diseases. Bonde *et al.* (1999) carried out a study to determine whether AEW could be used to stimulate germination of *Tilletia indica* spores, and observed that treatment of wheat seed for 20 min with AEW eliminated contamination by fungi such as *Aspergillus, Cladosporium,* and *Penicillium* spp.

AEW has wide fungicidal activity, which may facilitate its use as a contact fungicide on aerial plant surfaces and for general sanitation in greenhouses. It is currently used by some growers, in the form of a spray or as irrigational water, for arresting fungal growth on horticultural crops (Grech and Rijkenberg, 1992; Schoerner and Yamaki, 1997, 1999; Yamaki and Schoerner, 1995). Yamaki (1998) used it for controlling powdery mildew in cucumber and found that it apparently reduced powdery mildew for about two weeks from 18 days after planting. He also found that fungal decay was delayed for about two days in peaches treated with AEW and for one day in those treated with BEW, while control peaches started to decay the day after harvest. He reported that disease incidence was 70% in the control, 22% among BEW-treated peaches and 20% among AEW-treated peaches.

According to Bonde *et al.* (1992), AEW destroyed fungi such as *Aspergillus, Cladosporium,* and *Penicillium* at short to moderate time durations. This suggests that treatment with AEW may be a suitable replacement for NaOCl treatment in Karnal bunt disease.

Buck *et al.* (2002) treated 22 fungal species with AEW *in vitro* and reported that germination of all 22 fungal species was significantly reduced or prevented. All relatively thin-walled species (*e.g. Botrytis, Monilinia*) were killed by incubation times of 30 s or less. Thicker-walled, pigmented fungi (*e.g. Curvularia, Helminthosporium*) required 2 min or longer for germination to be reduced significantly. Dilution of AEW with tap water at ratios of 1: 4 and 1: 9 (AEW: tap water) decreased efficacy against *Botrytis cinerea.* The presence of Triton X-100 (all concentrations) and Tween 20 (1 and 10%) eliminated the activity of AEW against *B. cinerea.* AEW did not damage geranium leaf issue and inhibited lesion development by *B. cinerea* when applied up to 24 h post-inoculation.

Al-Haq *et al.* (2001b) used AEW for the control of brown rot in peaches. The fruits were inoculated with a spore suspension of 5×10^5 conidia/ml of *Monilinia fructicola* [(G. Wint.) Honey] applied as a drop on wounded and non-wounded fruits, or as a uniform spray-mist on non-wounded fruits. Fruit were immersed in tap water at 26℃ for 5 or 10 min (control), or treated with AEW of various ORP, pH, and FAC values. Following treatment, the fruits were held at 20℃ and 95% relative humidity for ≥10 d to simulate retail conditions. Disease incidence

Table 6. Electrolyzed water in food-product manufacturing.

Food Product	Reference
Bread	Kato *et al.* (2001), Onishi *et al.* (1999)
Rice	Kobayashi *et al.* (1996)
	Onishi *et al.* (2000)
Tofu	Hara *et al.* (2003b)
Wheat Noodles (Udon)	Hara *et al.* (2003a)

was determined as the percentage of the fruits showing symptoms of the disease, while severity was expressed as lesion diameter. AEW did not control brown rot in wound-inoculated fruits, but reduced disease incidence and severity in non-wounded inoculated peaches. Symptoms of brown rot were further delayed in fruit inoculated by a uniform spray-mist compared with non-wounded drop-inoculated peaches. Fruit treated with AEW and held for 8 d at 2℃ and 50% RH did not develop brown rot until they were transferred to a 20℃, 95% RH environment. The lowest disease incidence and severity occurred in fruit immersed in AEW for up to 5 min. AEW with pH 4.0, ORP 1,100 mV and FAC 290 mg/l delayed the onset of brown rot to 7 d, which is roughly the time spent on the market between packing house and consumer. No chlorine-induced phytotoxicity was observed in the treated fruit. This study revealed that AEW is an effective surface sanitizer, but delays rather than preventing disease development.

Al-Haq *et al.* (2002b) investigated the effectiveness of immersion in AEW on the control of Bot. rot in European pear (*Pyrus communis* L.), *cv.* La France. Four independent experiments were carried out. A wound was found necessary for infection. Wounded fruit were inoculated with 20 μL spore suspension of 5×10^5 conidia/ml of *Botryosphaeria berengeriana,* incubated for four hours, immersed in AEW, and held at 20℃, ≥90% RH (simulated retail conditions) for ripening and disease development. No chlorine-induced phytotoxicity was observed in the treated fruit. AEW was found to suppress disease incidence and severity. The minimum incidence and severity were recorded for a 10-min immersion period. This study also revealed that AEW is an effective surface sanitizer.

Al-Haq *et al.* (2003a) studied the effects of AEW on anthracnose of mango [*Mangifera indica* (L.)] caused by the fungus *Colletotrichum gloeosporioides.* Fruit were inoculated by applying a spore suspension of 5×10^5 conidia/ml of *Colletotrichum gloeosporioides* and immersed in AEW for varying periods. AEW proved ineffective in controlling anthracnose in wound-inoculated fruits but reduced disease incidence. Symptoms of anthracnose appeared later in fruit treated with AEW than in the control. The minimum disease incidence and severity were recorded for the AEW immersion periods of up to 30 min. This study revealed that EO water has an effect on *C. gloeosporioides,* as it suppressed the disease but did not control it.

3.5 Effect of AEW on cut vegetables

Izumi (1999) showed that AEW containing 15 to 50 ppm of available chlorine was effective in reducing microbial flora in several fresh-cut vegetables. Koseki *et al.* (2002) investigated the use of frozen AEW (in ice cubes, 2 to 3℃) to preserve fresh lettuce during storage in styrene-foam containers for 24 h. They monitored changes in chlorine concentration during storage with tap water ice, AEW ice, and a mixture of AEW and BEW ice cubes. The Cl_2 concentration increased by 3.9 ppm/h in the container packed with frozen AEW and 0.5 ppm/h for a mixture of AEW and BEW ice cubes; no increase in Cl_2 concentration was observed in the container packed with tap-water ice cubes.

3.6 Effect of AEW on meat and poultry

Park *et al.* (2002a) reported that complete inactivation of *Campylobacter jejuni* occurred in pure culture within 10 s after exposure to AEW or chlorinated water, both of which contained 50 mg/l of residual chlorine. Strong bactericidal activity was also observed in diluted AEW (containing 25 mg/l of residual chlorine) and the mean population of *C. jejuni* was reduced to less than 10 CFU/ml (detected only by enrichment for 48 h) after a 10-s treatment. Diluted chlorinated water (25 mg/l residual chlorine) was less effective than diluted AEW for inactivation of *C. jejuni.* AEW was further evaluated for its effectiveness in reducing *C. jejuni* on chicken during washing. AEW and chlorinated water proved equally effective: both achieved reduction of *C. jejuni* by about 3 $\log_{10}$ CFU/g on chicken, while treatment with deionized water as a control resulted in a reduction of only 1 $\log_{10}$ CFU/g. No viable cells of *C. jejuni* were recovered in AEW and chlorinated water after washing treatment, but high populations of *C. jejuni* (4 $\log_{10}$ CFU/ml) were recovered in the wash solution after the control treatment. It was further reported that AEW was not only effective in reducing the population of *C. jejuni* on chicken, but also could prevent cross-contamination of processing environments.

4. Applications of EW in Food Processing

Table 6 displays a summary of the few studies conducted on the use of AEW and/or BEW in the manufacture of food products. The use of BEW was found to increase the protein content of tofu (Hara *et al.,* 2003b). It was found that the texture of tofu prepared with BEW and AEW was softer than that of tofu prepared with tap water. No significant difference in free sugar content was observed in tofu prepared with EW compared to that

prepared with non-EW, but sensory panellists found that tofu prepared with BEW was sweeter than tofu prepared with tap water. Similarly, total carbonyl content, which is related to the substantial taste of tofu, was higher in tofu prepared with AEW and BEW than in tofu prepared with tap water. It was concluded that the eating quality of tofu may be modified by using EW, especially BEW.

According to Hara *et al.* (2003a), instrumental measurements and sensory tests of cooked Japanese noodles (*Udon*) showed that noodles made by kneading wheat flour with AEW were harder and springier than those made by kneading wheat flour with tap water. AEW imparts a favourable texture to the cooked noodles by promoting the dissolution of the gliadin and glutenin subunits that participate in the formation of the gluten matrix. In contrast, the use of BEW resulted in less springiness suggesting that it changed the gelatinization conditions of starch, which is a negative point. Gelatinization conditions were also changed when wheat starch was heated in EW. A decrease in the maximum and minimum viscosities when the noodles were heated in anode water suggested that the glycosidic linkages of starch molecules were partially hydrolyzed during heating at low pH. When wheat starch was heated in BEW, however, an increase in maximum viscosity and breakdown was observed, suggesting that heating at a high pH loosens hydrogen bonds, promoting the swelling and breaking of starch molecules. It is likely that when the noodles were cooked in EW, the decay of starch molecules caused the diffusion of large amounts of water into the noodles, resulting in a smaller difference between external and internal hardness. Thus, noodles cooked in EW were less springy than those cooked in tap water. In particular, the use of AEW decreased the springiness of the cooked noodles considerably, and stickiness was significantly increased compared with noodles cooked in tap water. We concluded that AEW was more effective than BEW in modifying the gelatinization conditions of wheat starch. In Japanese food, the springiness of cooked noodles is very important. The use of EW for cooking Japanese wheat noodles (*Udon*) may not be advisable, because the springiness of the cooked noodles deteriorates as a result.

According to Kobayashi *et al.* (1996) and Onishi *et al.* (2000), when weak BEW was used to cook aged rice grains, the cooked rice was found to be softer and stickier, which improved the texture. The quality of cooked rice immediately after cooking was improved by using BEW (Onishi *et al.*, 2000); it was observed that the texture was less hard and the stickiness considerably greater than cooked rice prepared with tap water, but the cooked rice prepared with BEW was found to spoil more quickly. It was further found that by adding a carbohydrate such as trehalose or a surfactant such as polyoxyethylene polyoxypropylene glycerinether monoglyceride to the soaking water, retrogradation of rice cooked with weak BEW could be retarded.

Hoshizaki Electric Inc., Japan, has obtained a US patent on a preparation method for flour dough, *e.g.* for bread. EW was used for kneading to enhance the quality of processed foods without using any food additives (Kato *et al.*, 2001). The crumb of bread made with weak AEW had higher elasticity than that of bread made with tap water, and the crumb of bread made with weak BEW was softer than that of bread made with tap water (Onishi *et al.*, 1999).

Sekihan, a Japanese food, consists of rice cooked with azuki beans. Azuki beans give a reddish color to the rice, which is why this dish is often prepared for celebrations in Japan. In fact, for Japanese people the phrase "Let's have sekihan," means that they intend to celebrate something. Kobayashi *et al.* (2004) studied the effectiveness of AEW and BEW in changing the color tone and astringency of sekihan. They found that the use of AEW resulted in a considerable reduction in astringency, but the color tone of the boiled azuki bean extract became faint. The use of BEW resulted in deeper color, and the color of the sekihan also became darker.

Conclusions

AEW treatment may be used as an effective method for reducing microbial contamination not only on food processing surfaces but also on non-food-contact surfaces such as ceramic tiles, floors, stainless steel, laboratory glassware, or medical or dental facilities. The complete inactivation of *S. aureus* and *E. aerogenes* in AEW after treatment indicated that AEW can also prevent cross-contamination from treatment solutions. AEW shows wide-ranging fungicidal activity, which may facilitate its use as a contact fungicide on aerial plant surfaces and for general sanitation in greenhouses.

As AEW is produced on-site and on demand for direct use, it can also reduce health hazards for workers by eliminating the need to handle concentrated chemicals. It may be useful as a food safety agent. Both AEW and BEW are useful in food manufacturing, depending on the food being produced. The use of EW is an emerging technology and the door is open to further research and development.

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