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Review Paper

A review of microbiological safety of fruits and vegetables and the introduction of electrolyzed water as an alternative to sodium hypochlorite solution

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Over the past few years, food safety has become and continues to be the number one public concern. Considerable progress to strengthen food safety systems has been achieved in many countries, highlighting the opportunities to reduce and prevent food-borne disease. However, unacceptable rates of food-borne illness still remain and new hazards continue to enter the food supply chain. Contaminations in food and agricultural products may occur in every stage of the food supply chain, from the field to the table, that is production, harvesting, processing, storage and distribution, calling for proper decontamination and insuring food safety at each of these stages using an effective antimicrobial agent. Several commercial products are available for this purpose, however, most of available products are seriously hindered by a number of work and environmental safety limitations calling for the development of a new product which is both safe for environment and workers. In this accord, the use of acidic electrolyzed water (AEW), a new concept developed in Japan, which is now gaining popularity in other countries has been introduced. The principle behind its sterilizing effect is still explored, but it has shown to have strong and significant bactericidal and virucidal and moderate fungicidal properties. Some studies have been carried out in Japan, China, Korea, Canada, Europe and the USA on its pre- and post-harvest application in the field of food processing. This review provides an overview of microbiological safety of food and agricultural produces, points out the burdens of food borne diseases; highlights the drawbacks of currently employed sanitizers and introduces electrolyzed water as a novel non-thermal food sanitizer with potential of application in agriculture and food industry.

Key words: Microbiological food safety, electrolyzed water, agriculture produce.

INTRODUCTION

Post harvest microbial control is one of the most important post harvest practices for control of food borne diseases and maintains the quality of fresh produce at post-harvest stage. Control of post-harvest food-borne diseases in food products has been the subject of extensive study. It is important to note that food safety must be ensured at each post-harvest processing step, including handling, washing of raw materials, cleaning of utensils and pipelines, and packaging. Despite advances in hygiene, consumer knowledge, food treatment and processing and the use of microbial safety monitoring

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programs and food quality assurance such as HACCP, food borne diseases mediated by pathogenic microorganisms still represent a significant threat to public health worldwide. *Escherichia coli*, *Salmonella typhimurium*, *Staphylococcus aureus*, *Listeria monocytogenes*, and *Enterococcus faecalis* and other emerging food-borne pathogens have been reported as common food borne pathogens that can pose a high health risk often with lethal consequences.

Serious outbreaks have been reported in Canada, USA, the UK, Japan and some other parts of the world necessitating more effort for microbial food control. 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 (Al-Haq et al., 2005) and require an effective control/decontamination to ensure safety of the ultimate food consumer.

To achieve this control, cleaning and sanitizing using effective sanitizer have been pointed out as important elements of the hygiene practices in a food and agricultural industry. Chlorine rinses are generally used during processing (fruits, vegetables, meat, poultry, etc.) for pathogen reduction. Other various processes have been proposed as alternatives for eliminating or substantially decreasing bacterial populations. These includes sodium bisulfite (Krahn, 1977), sulfur dioxide (Bolin et al., 1977), organic acids (Adams et al., 1989), calcium chloride (Izumi and Watada, 1994; 1995), acidified sodium chlorite (Allende et al., 2009; Liao, 2009) and ozone (Nagashima and Kamoi, 1997). However, these processes have been found not to be completely acceptable due to chemical residues, discoloration of food produce where they are applied, high cost and limited effectiveness.

Chlorine sanitizers on the other hand are therefore the most commonly used chemical sanitizer to date. Although chlorine sanitizers are popular and has been intensively used in food industry, increasing public health concerns about the possible formation of chlorinated organic compounds such as chloramines and trihalomethanes and the emergence of new more tolerant pathogens, have raised doubts in relation to the use of chlorine especially by the fresh-cut industry (Singh et al., 2002). The prolonged exposure to chlorine vapors have been reported to result in the irritation to the skin and respiratory tract of workers (Beuchat, 1998). Additionally, the safety and efficacy of chlorine might eventually be the reason of the implementation of restrictions by regulatory agencies in USA (Sapers, 2001). Future regulatory restrictions on the use of chlorine are likely and will require the development of functional alternatives.

One recent discovery sought to be a promising alternative is the possibility of using electrolyzed oxidizing water (acidic electrolyzed water) as a sanitizer, a result of a new concept developed in Japan (Al-Haq and Sugiyama, 2004). This paper therefore provides in depth review of microbiological safety of food and agricultural produces, highlights the burden imposed by food borne diseases, both in terms of rates of human morbidity and premature mortality and the economic and social costs imposed on the community. It further introduces a novel non-thermal post-harvest microbial control using electrolyzed water as alternative to chlorine sanitizers that is commonly used in food industry.

GENERAL ASPECTS OF MICROBIOLOGICAL SAFETY OF FOOD AND AGRICULTURAL PRODUCE

Ensuring food safety to protect public health and promote economic development remains a significant challenge in both developing and developed countries. Considerable progress to strengthen food safety systems has been achieved in many countries, highlighting the opportunities to reduce and prevent food-borne disease. However, unacceptable rates of food-borne illness still remains and new hazards continue to enter the food supply chain.

Consumers are becoming increasingly concerned over food quality and safety arising from the globalization of trade in food, intensive agriculture, environmental pollution and natural and manmade disasters. Such concerns have now been articulated via higher quality and safety standards required by markets, with producers under greater pressure to meet such standards in their efforts to build consumers' confidence. For the developing countries, quality and safety management systems, product certification and standardization regarding food safety and quality are still in their infancy and need immediate attention (Choi, 2008). The potential of the agriculture and food industry, strong policy strategies on food quality and safety are absolutely imperative, with focus given on a holistic approach and a farm-to-table approach, as an effective means of reducing food hazards.

Contamination and hazards in food and agricultural products may occur in every stage of the food supply chain, from the field to the table. Moreover, food and feed are distributed over far greater distances than before, creating the conditions necessary for widespread outbreaks of food-borne illness. The problem is that food safety incidents become known to the general public after a damaging breakout. It is also very difficult to pin down exactly where the produce became contaminated in the food supply chain because of the difficulty in testing for microbial contamination.

Burden of food-borne diseases

Food-borne risks to human health can arise from hazards that are biological, chemical or physical in nature. Microbiological food safety is a complex, fundamental issue of continuing concern. Contributing to this

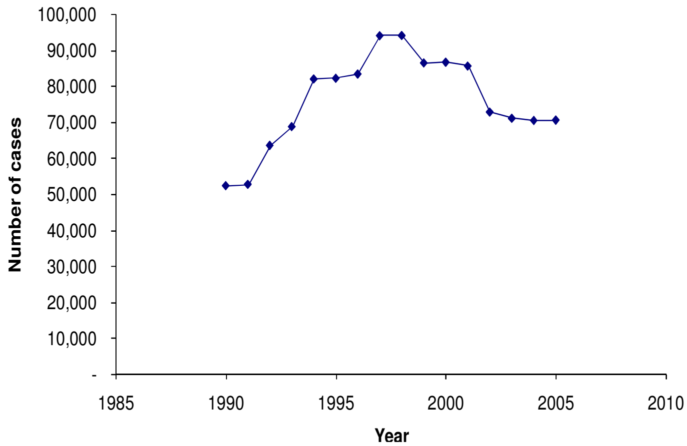

Figure 1. Food poisoning notifications – annual totals England and Wales, 1982 to 2005. Source: Author, using data obtained from: www.hpa.org.uk/infections/topics_az/noids/food_poisoning.htm.

complexity and the emergence of food safety issues are ongoing changes in demographics, geographic origin of food, food production and processing, food consumption patterns, and microorganisms themselves. Food-borne disease remains a real and alarming problem in both developed and developing countries, causing human suffering and significant economic losses.

Food-borne illness is not a simple problem in need of a solution; it is a complex combination of factors that must be managed on a continual basis. Aside from the inherent ability of pathogens themselves to evolve, pathogens' victims and the microbial environment play a role in the changing nature of food-borne illness, opening new niches and creating new vulnerabilities. No matter how sophisticated and complex a system is developed, food safety management is never finished or complete, because change is constant. Food-borne illness caused by microorganisms is a large and growing public health problem.

Most countries with systems for reporting cases of food-borne illness have documented significant increases over the past few decades in the incidence of diseases caused by microorganisms in food, including pathogens such as *Salmonella*, *Campylobacter jejuni* and enterohaemorrhagic *E. coli*, and parasites such as *cryptosporidium*, *cryptospora*, and *trematodes*. The global incidence of foodborne disease is difficult to estimate. It has been estimated that up to one third of the population of developed countries may be affected by food-borne diseases each year, and the problem is likely to be even more widespread in developing countries, where food and water-borne diarrhea diseases kill an estimated 2.2 million people each year, most of them children (FAO and WHO, 2006). A great proportion of these cases can be attributed to contamination of food and drinking water.

In the USA, 76 million cases of food-borne illness, resulting in 325,000 hospitalizations and 5,000 deaths, are estimated to occur each year (WHO, 2007). While less well documented, developing countries bear the brunt of the problem due to the presence of a wide range of food-borne diseases, including those caused by parasites. The high prevalence of diarrhoeal diseases in many developing countries suggests major underlying food safety problems. For instance, it was is reported that approximately 1.8 million children in developing countries (excluding China) died from diarrhoeal disease in 1998, caused by microbiological agents, mostly originating from food and water (WHO, 2002).

Food-borne diseases not only significantly affect people's health and well-being, but they also have economic consequences for individuals, families, communities, businesses and countries. These diseases impose a substantial burden on health-care systems and markedly reduce economic productivity. Poor people tend to live from day to day, and loss of income due to foodborne illness perpetuates the cycle of poverty. Some data on the economic consequences of food contamination and food-borne disease are available. In some studies in the USA 1995, it was estimated that the annual cost of the 3.3 to 12 million cases of foodborne illness caused by seven pathogens was US $6.5 to 35 billion. The medical costs and the value of the lives lost during just five foodborne outbreaks in England and Wales in 1996 were estimated at UK£ 300 to 700 million. The cost of the estimated 11,500 daily cases of food poisoning in Australia was calculated at AU$ 2.6 billion annually (WHO, 2002). The most recent comprehensive study by Scharff (2010) finds that the cumulative cost to Americans of foodborne illnesses is $152 billion annually; the cost per case for an individual is $1,850 on average.

The trends of food-borne disease

Food-borne diseases in developed countries

The 1990s saw rapid increases in the incidence of food poisoning in the developed world, and finally a call to action to reverse this trend. Figure 1 gives a representative example of food poisoning trends in Europe. The number of food poisoning notifications reached a peak in 1997/1998 and has since declined, but remains in excess of 70,000 per year (Figure 1). Although the number of cases recorded is in the thousands, the true burden of food poisoning is likely to be millions of cases per year, as most cases go unreported.

The 2003 WHO report stated that about 40% of reported food-borne outbreaks in the WHO European region over the previous decade were caused by food consumed in private homes. The report cites several factors as "critical for a large proportion of food-borne diseases" including use of contaminated raw food ingredients, contact between raw and cooked foods, and poor personal hygiene by food handlers. According to the UK Food Standards Agency up to half of the annual 9.4 million cases of infectious intestinal diseases (IID) are food poisoning, equating to 4.7 million cases per year (FSA, 2000). In the USA, the Centre for Diseases Control and Prevention (CDC) reported that, although significant declines in the incidence of certain foodborne pathogens have occurred since 1996, these declines all occurred before 2004. Comparing 2007 with 2004 to 2006, the estimated incidence of infections caused by *Campylobacter*, *Listeria*, *Salmonella*, *Shigella, E. coli* O157, *Vibrio*, and *Yersinia* did not decline significantly, and the incidence of Cryptosporidium infections increased. The incidence of Campylobacter, Salmonella, Shigella, and *E. coli* O157 infections remains highest among children aged <5 years, and necessitates the need for urgent food microbial control (CDC, 2007). OzFoodNet (2006) reported 115 foodborne disease outbreaks giving an overall rate of 5.6 outbreaks per million population in Australia.

These outbreaks affected 1,522 persons, hospitalized 146 persons but did not result in any death. This compares with rates of outbreak reported in other developed countries. Using data from 2000 to 2004, Hall et al (2008) estimated the annual community incidence rates per 100,000 populations as 262, 1,184, and 23 for salmonellosis, campylobacteriosis and *E. coli* (STEC) respectively. New Zealand reported a rate of 35 foodborne outbreaks per million population for 2006 (Population and Environmental Health Group, 2007). The most frequently notified etiological agents were *Campylobacter* and *Salmonella*.

Food-borne diseases in developing countries

In developing countries, it is often difficult to establish whether a disease outbreak is waterborne or foodborne or involves direct faecal-oral transfer. Most diseases that are spread by water are also spread through faecal contamination or person-to-person contact and in contaminated food. In rural areas where sanitation facilities are often inadequate, once a pathogen gets into a community, faecal-oral spread can be rapid and extensive. It is likely that the proportion of infections which are foodborne (relative to other modes of spread, for example faecal-oral transmission not involving food) is lower in developing compared with developed countries because of the frequent and more varied opportunities for other modes of transmission, and because the zoonotic agents (particularly *Salmonella* and *Campylobacter*) which are especially associated with foodborne infections in developed countries are less important relative to other enteric pathogens in low income communities, where sanitation and water are inadequate.

The overall rates of food-borne infection, however, are likely to be higher in developing compared with developed countries. Because keeping food hot or cold is usually not practical, pathogens may be able to grow in home-prepared foods and those sold in food service operations and street vendors. In most developing countries, the foodborne disease incidences go unrecorded and make it difficult to estimate the trends.

Reasons for the observed increased incidences of food-borne illness

The increased incidence of food-borne disease due to microbiological hazards is the result of a multiplicity of factors, all associated with our fast-changing world. Demographic profiles are being altered, with increasing proportions of people who are more susceptible to microorganisms in food (WHO, 2002). Changes in farm practices, more extensive food distribution systems and the increasing preference for meat and poultry in developing countries all have the potential to increase the incidence of foodborne illness. Extensive food distribution systems raise the potential for rapid, widespread distribution of contaminated food products.

Changes in food production result in new types of food that may harbour less common pathogens. Intensive animal husbandry technologies, introduced to minimize production costs, have led to the emergence of new zoonotic diseases, which affect humans (WHO, 2002). Safe disposal of manure from large-scale animal and poultry production facilities is a growing food safety problem in much of the world, as manure frequently contains pathogens. Changes in eating patterns, such as a preference for fresh and minimally processed foods, the increasingly longer interval between processing and consumption of foods and the increasing prevalence of eating food prepared outside the home all contribute to the increased incidences of foodborne illness ascribed to microbiological organisms.

The emergence of new pathogens and pathogens not previously associated with food is a major public health concern. *E. coli* O157:H7 was identified for the first time in 1979 and has subsequently caused illness and deaths (especially among children) owing to its presence in ground beef, unpasteurized apple cider, milk, lettuce, alfalfa and other sprouts, and drinking-water in several countries. *S. typhimurium* DT104 has developed resistance to five commonly prescribed antibiotics and is a major concern in many countries because of its rapid spread during the 1990s (WHO, 2002).

MICROBIOLOGICAL SAFETY OF FRUITS AND VEGETABLES

Overview of produce-related human infections

Fresh produce has become one of our most desirable

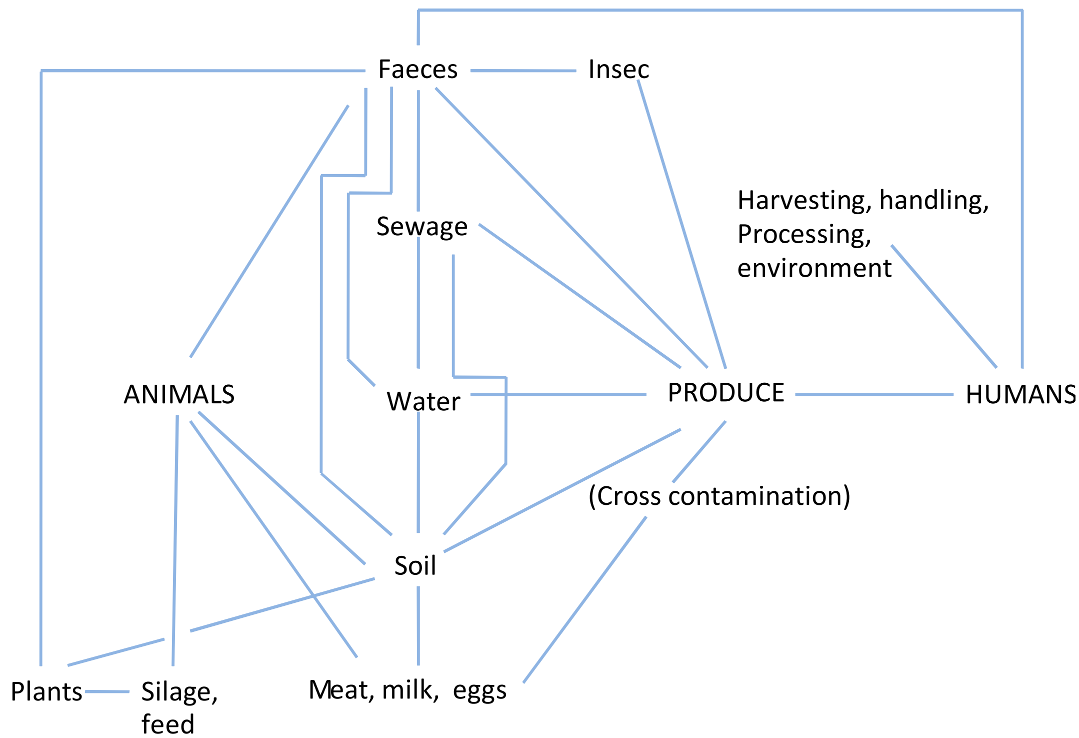

Figure 2. Mechanism by which raw fruits and vegetables may become contaminated with pathogenic microorganisms.

foods because today's consumer perceives it as being healthy, tasty, convenient, and fresh. All of these characteristics are strong selling points to a busy and health-conscious consumer. The fruit and vegetable industry has experienced solid growth over the past 10 years as illustrated by increasing consumption of these produce. Several reasons for the increase in produce-related human infections have been proposed. These include changes in dietary habits, including a higher per capita consumption of fresh or minimally processed fruits and vegetables, and the increased use of salad bars and meals eaten outside the home (Altekruse and Swerdlow, 1996).

The increase in the consumption of fresh fruits and vegetables has been paralleled by an increase in the number of foodborne illnesses attributed to fresh produce (Adrenne et al., 2001) and this has made some consumers worry about the safety of eating fresh produce. Changes in production and processing methods, sources of produce, and the emergence of pathogens not previously associated with raw produce have enhanced the potential for foodborne illness outbreaks associated with raw fruits and vegetables (Hedberg et al., 1994).

The end result of these changes is an increased exposure of the general public to fruits and vegetables, which has exacerbated potential problems with contamination by human pathogens.

Sources and mechanism of contamination of fruits and vegetables

Fruits and vegetables can become contaminated with microorganisms capable of causing human diseases while still on the plant in fields or orchards, or during harvesting, transport, processing, distribution and marketing, or in the home. Beuchat (1996) suggested the potential mechanisms by which pathogenic microorganisms can contaminate fruits and vegetables as shown in Figure 2. Potential pre-harvest sources of contamination include soil, feces, irrigation water, water used to apply fungicides and insecticides, dust, insects, inadequately composted manure, wild and domestic animals, and human handling (Beuchat, 1996).

Post-harvest sources of contamination include feces, human handling, harvesting equipment, transport containers, wild and domestic animals, insects, dust, rinse water, ice, transport vehicles, and processing equipment (Burnett and Beuchat, 2001). As raw agricultural products, fresh produce should be expected to harbor a wide variety of microorganisms including some pathogenic varieties. After all, with the exception of greenhouse operations, produce is still grown out doors and animals, birds, and insects can all carry human pathogens.

Bacteria such as *Clostridium botulinum*, *Bacillus cereus* and *L. monocytogenes*, all capable of causing illness, are normal inhabitants of many soils, whereas Salmonella, *Shigella*, *E. coli* and *Campylobacter* reside in the intestinal tracts of animals, including humans, and are more likely to contaminate raw fruits and vegetables through contact with faeces, sewage, untreated irrigation water or surface water.

Potential food-borne illness outbreaks associated with consumption of fruits and vegetables

Fresh produce can be a vehicle for the transmission of bacterial, parasitic and viral pathogens capable of causing human illness and a number of reports refer to raw vegetables harboring potential foodborne pathogens (Nguyen-the and Carlin, 1994; Beuchat, 1996). *L. monocytogenes* (Schlech et al., 1983), *Salmonella* (Doyle, 1990), and *E. coli* (Nguyen-the and Carlin, 1994) have been isolated from raw vegetables, which can become contaminated while growing or during harvesting, post-harvest handling, or distribution. Table 1 shows examples of pathogens that have been isolated from various fruits and vegetables and are involved in outbreaks of foodborne disease reported to date.

List of foods and pathogenic microorganism indicated in Table 1 is just a representative; many other fresh and minimally processed ready-to-eat fruits and vegetables have been implicated with outbreaks in a number of developed countries. The incidence of foodborne outbreaks caused by contaminated fresh fruit and vegetables has increased in recent years (Mukherjee et al., 2006). The pathogens most frequently linked to produce-related outbreaks include bacteria (*Salmonella, E. coli, L. monocytogenes, S. aureus*), viruses (Norwalk-like, *hepatitis* A), and parasites (Cryptosporidium, Cyclospora) (Tauxe et al., 1997), with *Salmonella* and *E. coli* O157:H7 being the leading causes of produce-related outbreaks in the USA (Olsen et al., 2000).

Fresh produce and sprouts have been implicated in a number of documented outbreaks of illness in countries such as Japan (Nat'l. Inst. Inf. Dis., 1997; Gutierrez, 1997) and EU (Emberland et al., 2007; Pezzoli et al., 2007). In the U.S. between 1995 and 1998, there were nine outbreaks of foodborne illness caused by *Salmonella* or *E. coli* O157:H7 due to consumption of fresh vegetable sprouts (National Advisory Committee on Microbiological Criteria for Foods, 1999). These outbreaks involved more than 1234 cases in Missouri, Michigan, California, Washington, Arizona, and Nevada, and in most cases, alfalfa or clover seed were implicated as the initial inoculum source. Also, later in September 2006, an *E. coli* O157:H7 outbreak affected 26 US States which involved about 200 cases of illness, including some of Hemolytic Uremic Syndrome (HUS) and resulted in three deaths (FDA, 2006). Data indicated that fresh spinach grown in three Californian counties was the source of the bacterium. The potential for widespread outbreaks of human infection caused by consumption of raw produce was also dramatically realized during the summer of 1996 in Japan where more than 6000 cases of *E. coli* O157:H7 infections were reported (Guiterrez, 1997).

The largest outbreak resulted in four deaths and affected more than 4000 school children in and around Sakai City. Raw radish sprouts that had been prepared in central kitchens appear to have transmitted the pathogen, although the mechanism of sprout contamination was not determined. Sprout-related disease outbreaks have also been reported in the United Kingdom, Finland, Denmark, Sweden, and Canada and have involved alfalfa, cress, radish, and mungbean sprouts (Puohiniemi et al., 1997; Taormina et al., 1999; Taylor et al., 2002). Fresh fruit and vegetables may therefore pose a food safety risk because they are consumed raw and are susceptible to be contaminated by fecal material and soil on the farm (Mukherjee et al., 2004).

DECONTAMINATION METHODS CURRENTLY USED TO ENSURE MICROBIOLOGICAL FOOD SAFETY OF FRESH PRODUCE

There are a variety of methods used to reduce populations of microorganisms on whole and fresh-cut produce. Each method has distinct advantages and disadvantages depending upon the type of produce, mitigation protocol, and other variables. The best method to eliminate pathogens from produce is to prevent contamination in the first place. However, this is not always possible and the need to wash and sanitize many types of produce remains of paramount importance to prevent food-borne disease outbreaks. It should be noted that washing and sanitizing are unlikely to totally eliminate all pathogens after the produce is contaminated.

Therefore, it is important to use washing and sanitizing protocols that are efficient. Sanitization has been defined by FDA (1998) as the art of treat cleaning the produce by a process that is effective in destroying or substantially reducing the numbers of microorganisms of public health concern, as well as other undesirable microorganisms, without adversely affecting the quality of the product or its safety for the consumer. This definition addresses two crucial matters; the need to maintain produce quality while enhancing safety by reducing populations of pathogenic microorganisms of public health significance that might theoretically exist on the produce. The user safety is equally an important issue and can not be overlooked when considering an effective sanitizer in ensuring microbial food safety.

Efficacy of the method used to reduce microbial populations is usually dependent upon the type of treatment, type and physiology of the target micro-organisms, characteristics of produce surfaces (cracks,

Table 1. Examples of pathogens associated with fruits and vegetables involved in outbreaks of food-borne disease.

Agent	Implication/suspected food	Reference
Bacilus cereus	Alfalfa sprouts, cress sprouts, cucumbers, mustard sprouts, soyabeans sprouts	Buck et al. (2003)
Campylobacter jejuni	Green onions, lettuce, mushroom, potato, parsley, pepper, spinach	CDC (1998), Buck et al. (2003)
Clostridium botulinum	Cabbage, mushroom, pepper	Buck et al. (2003)
Cryptosporidium	Apple cider	CDR (1991)
Cyclospora	Raspberries	Herwaldt et al. (1997)
E. Coli O157:H7	Alfalfa sprouts, radish sprouts, apple juice, apple cider, cilantro, cress sprouts, lettuce	Buck et al. (2003), WHO (1996), CDR (1997)
Hepatitis A virus	Iceberg lettuce, raspberries, strawberries	Rosenblum et al (1990), Niu et al (1992)
Salmonella	Alfalfa sprouts, artichokes, beet leaves, celery, cabbage, cantaloupe, cauliflower, chili, cilantro, egg plant, endive, fennel, green onions, lettuce, mungbean sprouts, mustard cress, orange juice, parsley, pepper, salad greens, spinach, strawberries, tomato, watermelon	Buck et al. (2003), Mahon et al. (1997)
Shigella	Celery, cantaloupe, lettuce, parsley, scallions, mixed salad	Buck et al. (2003), Dunn et al. (1995)
Vibrio cholerae	Cabbage, coconut milk, lettuce	Shuval et al. (1989), Buck et al. (2003)
Aeromonas	Alfalfa sprouts, asparagus, broccoli, cauliflower, celery, lettuce, pepper, spinach.	Buck et al. (2003)
Listeria monocytogenes	beans sprouts, Cabbage, chicory, cucumber, eggplant, lettuce, mushroom, potatoes, radish, salad vegetables, tomato	Buck et al. (2003)
staphylococcus	Alfalfa sprouts, carrot, lettuce, onions sprouts, parsley, radish	Buck et al. (2003)

crevices, hydrophobic tendency, and texture), attachment of cells to produce surfaces, formation of resistant biofilms and internalization of microorganisms, exposure time and concentration of sanitizer, pH, and temperature. It should be noted that the concentration/level of sanitizers or other intervention methods may be limited by unacceptable sensory impact on the produce. Additionally, the remaining microbial load could grow rapidly, reaching similar values to those of unwashed products. Hence, maintenance of this reduction during storage is as important as initial microbial reductions after washing (Ragaert et al., 2007).

Chemical sanitizers such as sodium hypochlorite (Adams et al., 1989), chlorine dioxide (Kim et al., 2009), sodium bisulfite (Krahn, 1977), sulfur dioxide (Bolin et al., 1977), organic acids (Adams et al., 1989), calcium chloride (Izumi and Watada, 1994; 1995), acidified sodium chlorite (Allende et al., 2009; Liao, 2009) and ozone (Nagashima and Kamoi, 1997) have been shown to reduce microbial populations on fresh produce. Among these sanitizers, chlorine-based chemicals, particularly liquid chlorine and hypochlorite, are probably the most widely used sanitizers for decontaminating fresh produce (Francis and O'Beirne, 2002). Although Chlorine is currently the sanitizing agent most used by the fresh-cut industry, chlorine sanitizer has faced a number of drawbacks for its application in food industry to date. Washing produces with chlorinated water has been traditionally applied to decontaminate vegetables, but several reports have questioned its efficacy (Adams et al., 1989; Beuchat, 1999; Li et al., 2001; Nguyen-the and Carlin, 1994; Zhang and Farber, 1996).

Increasing public health concerns about the possible formation of chlorinated organic compounds, such as chloramines and trihalomethanes and the emergence of new more tolerant pathogens, have raised doubts in relation to the use of chlorine by the fresh-cut industry (Singh et al., 2002) and called for the development of new promising sanitizer. Trihalomethanes were reported to be a cause of tumors in rodents and linked to a higher rate of cancer, and classified as possible human carcinogens by the United States Environmental Protection Agency (EPA) (Kim et al., 2000b). Yet, another concern about applying chlorine or chlorine-containing compound as a disinfecting agent is that the prolonged exposure to chlorine vapors can result in the irritation to the skin and respiratory tract of workers (Beuchat 1998). Additionally, the safety and efficacy of chlorine might eventually be the reason of the implementation of restrictions by regulatory agencies in USA (Sapers, 2001).

In some European countries including Germany, The Netherlands, Switzerland and Belgium the use of chlorine in RTU products is prohibited (Nguyen-the and Carlin, 1994). Future regulatory restrictions on the use of chlorine are likely and will require the development of functional alternatives. Such sanitizer with equivalent or superior disinfecting effect possessing advanced properties to overcome the disadvantages of chlorine usage is inevitable and in urgent need. One recently discovered alternative is a possibility of using Acidic electrolyzed water (AEW) as a sanitizer in food industry. This is the result of a new concept thought to be first developed in Japan (Al-Haq and Sugiyama, 2004), which is now gaining popularity in other countries. Acidic electrolyzed water is believed to be one of potential alternatives to chlorine sanitizer for microbial decontamination and its sanitization effect is very promising.

In recent years, acidic electrolyzed water comes under the spotlight as one of the advanced technologies for non-thermal food processing. Acidic electrolyzed water known as denkaisui in Japan is gaining popularity as a sanitizer in the food industry to reduce or eliminate bacterial populations on food products, food-processing surfaces, and non–food contact surfaces. In Japan, the Ministry of Health, Labor and Welfare approved AEW as a food additive in year 2002 (Yoshida et al., 2004). EW generators also have been approved for use in the food industry by the U.S. Environmental Protection Agency (Park et al., 2002). Two types of acidic electrolyzed water have been approved in Japan as indirect food additive in the food industry. These are the Strongly Acidic Electrolyzed Water (StAEW) and Slightly Acidic Electrolyzed Water (SAEW). The strongly acidic electrolyzed water (StAEW) is prepared by electrolysis of an aqueous solution of sodium chloride at a concentration of 0.2% or lower in an electrolytic cell with a diaphragm between a cathodic side and an anodic side. StAEW is produced from the anodic side and has a pH of 2.7 or lower, an available chlorine concentration (ACC) of from 20 to 60 mg/l, and an oxidation-reduction potential (ORP) of 1000 mV or higher.

A number of studies have confirmed strong antibacterial activity of StAEW against food-borne pathogens both in vitro (Kim et al., 2000a, b; Nakajima et al., 2004; Park et al., 2004) and on fruits and vegetable surfaces (Deza et al., 2003; Sharma and Demirci, 2003). On the other hand, a slightly acidic type of electrolyzed water (SAEW) is prepared by electrolyzing an aqueous dilute solution of hydrochloric acid at a concentration of 2 to 6% in an electrolytic cell without a separating diaphragm (Gómez-López et al., 2007; Koide et al., 2009; Deza et al., 2005, 2007). Slightly acidic electrolyzed water can also be produced from StAEW generator type by electrolysis of dilute NaCl solution in a cell with a separating membrane, and part of the product formed at the anode is then redirected into the cathode chamber during electrolysis (Pernezny et al., 2005; Guentzel et al., 2008; Al-Haq and Sugiyama, 2004). However, this is not common method and is seldom used. SAEW has a near neutral pH of 5 to 6.5 and an available chlorine concentration of 10 to 30 mg/l. It is known that this contains much un-dissociated hypochlorous acid than StAEW and show an excellent sanitization efficacy against several types of food pathogens. SAEW is reported to have strong antimicrobial effect against most viable bacteria cells, pathogenic and non-pathogenic bacteria and spore, virus and fungus both *in vitro* and on different food and agricultural produces and is considered more applicable to the food industry because of its mild pH.

Previous studies have demonstrated that SAEW possess similar bactericidal activity as that of StAEW against cells of several food pathogens and spores (Hotta and Suzuki, 1999; Oomori et al., 2000; Suzuki et al., 2002). There is evidence that acidic electrolyzed water can work better than water and chlorine solutions as a sanitizer of meats, fresh produce, cutting boards and utensils and it appears that the process allows better access to the uneven surfaces of fruits and vegetables (Al-Haq et al., 2005). Electrolyzed water has been reported to have strong bactericidal effects on most pathogenic and non-pathogenic bacteria *in vitro* (Kim et al. 2000a; Venkitanarayanan et al., 1999 a, b). It has strong bactericidal effect against cells suspensions of food-borne pathogens of major public health concern including *E. coli O157*, *S. aureus*, *C. jejuni*, *Salmonella enteritidis, S. typhimurium* and *Listeria monocytogens* (Venkitanarayanan et al., 1999a, b; Kim et al., 2000a, b; Fabrizio and Cutter, 2003; Park et al., 2004; Liao et al., 2007) achieving ≥ 5 log CFU/ml (Ayebe et al., 2006; Deza et al., 2005) for only ≤ 0.5 min of contact. Electrolyzed water has also effectively reduced the level of pathogens from different fresh food and agricultural produce. For instance, Koseki and Isobe (2007) extensively studied and reviewed the application of StAEW for inactivation of pathogens on fresh fruits and vegetables. In their study, Koseki and Isobe (2007) concluded that, although the efficacy of StAEW as a sanitizing agent was dependent on the kind of produce treated, it could be sufficiently effective to offer an alternative to conventional sanitizers, such as sodium hypochlorite solution (150 ppm).

Other studies (Bari et al., 2003; Izumi et al., 1999; Kim et al., 2003; Udompijitkul et al., 2007) have previously demonstrated that StAEW is effective in reducing the microbial load from fresh produce. For instance, one of the old studies by Izumi (1999) demonstrated that electrolyzed oxidizing water is usable for cleaning fresh-cut carrots, bell peppers, spinach, Japanese radish and potatoes. The precut produces, treated with EO water (pH 6.8, 20 mg/L free chlorine) by dipping, rinsing or dipping/blowing, showed a bacterial reduction of up to 2.6 log CFU/g. Recent studies by Issa-Zacharia et al. (2010) have demonstrated that SAEW treatment significantly reduced the total aerobic mesophilic bacteria from Chinese celery, lettuce and daikon sprouts by ≥ 2.5 log CFU/g relative to un-treated samples and the population of *E.coli* and *Salmonella* spp. were also significantly reduced by ≥ 2.7 log CFU/g and ≥ 2.9 log CFU/g, respectively from each of tested samples of Chinese celery, lettuce and daikon sprouts following a SAEW treatment.

The advantages of acidic electrolyzed water over chlorine sanitizers have been clearly indicated. For both type of acidic electrolyzed water, the main merit for inactivation of pathogenic microorganisms relies on their less adverse impact on the environment (Kim et al., 2000a, b). Strong acidic electrolyzed water (StAEW) is environment friendly because it is generated by electrolysis of only water and a dilute salt solution (Kim et al., 2000a, b; Koseki et al., 2002; Koseki et al., 2004; Park et al., 2002) and when it comes into contact with organic matter, or is diluted by tap water, it becomes ordinary water again. StAEW has been reported to be safer to the user (Mori et al., 1997; Al-Haq et al., 2005; Huang et al., 2008) since no concentrated chemicals are required during its production. It is more effective, less dangerous and less expensive than most traditional preservation methods such as glutaraldehyde (Sakurai et al., 2002, 2003), sodium hypochlorite and acetic acid (Ayebah et al., 2005). Compared with other conventional disinfecting techniques, StAEW reduces cleaning times, is easy to handle, has very few side effects, and is relative cheap (Bonde et al., 1999; Tanaka et al., 1999) since the raw materials, water and sodium chloride, are found virtually everywhere (Venczel et al., 1997).

Chemicals used for cleaning and disinfection are expensive and represent an operating expense. However, with StAEW, once the initial capital investment is made to purchase an electrolyzed water generator, the only operating expenses are water, salts and electricity to run the unit (Walker et al., 2005). StAEW can be generated *on-site* (Len et al., 2000), and reverts to normal water after use (Al-Haq et al. 2005; Bonde et al., 1999), hence there is no need for special handling, storage, or transportation of concentrated chemicals that are a potential health hazard (Al-Haq et al., 2005; Nakagawara et al., 1998). Because of its nonselective antimicrobial properties, StAEW does not promote the development of bacterial resistance (Al-Haq et al., 2005, Vorobjeva et al., 2003).

The use of StAEW on various food commodities did not negatively affect the organoleptic properties of color, scent, flavor, or texture as reported in previous studies (Achiwa and Nishio, 2003; Al-Haq et al., 2005; Kim et al., 2003; Mahmoud, 2007). As a non-thermal method, the use of StAEW does not result in changes in ingredients, texture, scent, flavor, etc., which are brought about by heat-treatment (Yoshida et al., 2004). For instance, the use of StAEW on various food commodities (for example rice, tofu, wheat noodles, fish etc.) did not negatively affect the organoleptic properties of color, aroma, flavor, or texture (Hara et al., 2003a, b; Kobayashi et al., 1996).

The main disadvantage of StAEW reported to date is that, the solution rapidly loses its antimicrobial activity with time as a result of chlorine loss (Koseki and Itoh, 2001; Koseki and Isobe, 2007) especially if it is not continuously supplied with H^+, HOCl and Cl_2 by electrolysis (Kiura et al., 2002) at its lower pH of 2.5. However, the invention of slightly acidic type of electrolyzed water (SAEW) with a near neutral pH and low available chlorine concentration, presents a solution to this drawback of StAEW sanitization effectiveness. SAEW is reported to be more stable on storage as chlorine loss is significantly reduced at pH 5 to 6.5 and therefore, factor responsible for the bactericidal effect of SAEW is more stable than the corresponding factor in StAEW (Deza et al., 2003; Horiba et al., 1999). Its superior preservative ability over StAEW was further confirmed by Suzuki et al. (2005b), Issa-Zacharia et al. (2009c) and Koide et al. (2009). This gives SAEW more promising application especially in areas where on site production and application would not be practical.

Previous studies have demonstrated that SAEW at low chlorine concentration (10 to 30 mg/l) possess similar or higher bactericidal activity than that of sodium hypochlorite solution (100 to 200 mg/l) (Cao et al., 2008; Deza et al., 2005; Kim et al., 2000a, b; Issa-Zacharia et al., 2009c), which could allow the food industry to reduce the amount of chlorine used and would help to improve the safety of both products and workers. Moreover, due to its near-neutral pH value of 5 to 6.5 and low chlorine concentration (10 to 30mg/l), SAEW does not contribute as aggressively to the corrosion of processing equipment or irritation of hands (Abadias et al., 2008). As a result of low chlorine concentration there is little corrosion of metal surfaces due to oxygen or chlorine and the safety of the working environment is high. Furthermore, sterile seawater can be generated by electrolyzing filtered seawater and adding HCl solution (2 to 6%) in a non-diaphragm electrolytic cell (Doi, 2002), so that electrolyzed sterile seawater would have a potential for disinfection of fish and seafood retaining their taste and odor with the natural salt in seawater.

A number of studies on the application of electrolyzed water in food industry have been carried out in developed countries including Japan, USA, Russia, (Al-Haq et al., 2005) and none has been carried out in developing countries to date. This opens up a challenge and a potential area of research for food industries in developing countries. It is the high time for the food industry in both developed and developing countries to explore the use of electrolyzed water for microbial control as an alternative to chlorine sanitizer that has brought a lot of safety attention in its application.

CONCLUSION

Owing to the particular concern of microbial food safety not only because of the high prevalence of food-borne illness and other hazards associated with food, but also because of the considerable economic and social costs, an effective and environmentally friendly antimicrobial agent in food industry is highly required. Electrolyzed water therefore seems to be an available alternative to sodium hypochlorite for microbial control in food and agricultural produces and its potential need to be more explored.

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