African Journal of Agricultural Research Vol. 7(35), pp. 4848-4857, 11 September, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.1287

Review

Irrigation water and microbiological safety of fresh produce; South Africa as a case study: A review

Oluwatosin A. Ijabadeniyi[1]* and Elna M. Buys[2]

[1]Department of Biotechnology and Food Technology, Durban University of Technology, South Africa.
[2]Department of Food Science, University of Pretoria, South Africa.

Accepted 23 May, 2012

Irrigation water is perhaps the leading pre-harvest source of contamination of fresh produce in the world. In this review, the impact of contaminated surface irrigation water on bacterial contamination of fresh produce was examined. Some practical solutions to prevent or reduce this challenge were also considered. In South Africa, fruit and vegetables are produced on a large scale by commercial farmers who depend on surface water for their cultivation. However, the surface water, that is, rivers- has been reported to be heavily contaminated with *Escherichia coli* and feacal coliforms. There is a concern that contaminated surface water used for irrigation may contaminate fresh vegetables which may also have a negative effect on the export of vegetables to the EU and USA. Consumption of vegetables contaminated with foodborne pathogens presents a public health risk especially in countries like South Africa that has more than 5 million people with immune-system compromised diseases such as HIV and tuberculosis. Other groups of people that may be negatively affected because of the contaminated surface water are those who are directly and indirectly associated with the production of fresh vegetables such as pickers, handlers, packers and farmers that participate in the production of vegetables during pre-harvest and post-harvest. Prevention of contamination of fresh produce from both pre-harvest and post-harvest sources especially irrigation water still remains the only effective way to protect the public. However, for this to occur, every stakeholder in the production industry must have a culture of food safety.

Key words: Irrigation water, pathogens, fresh produce.

INTRODUCTION

Outbreaks of food infections associated with consumption of ready-to-eat vegetables have been increasing (IFT, 2007; Pezzoli et al., 2008; Fynn, 2009; Schreck, 2009). In September 2006, pre-packaged fresh spinach was recalled by the Food and Drug Administration (FDA) in the United States of America (USA) as a result of an *Escherichia coli* outbreak in California, USA. Also, in the same month, fresh tomatoes consumed at restaurants in the USA were responsible for an outbreak of *Salmonella* Typhimurium. In addition, there was an *E. coli* O157:H7 outbreak linked to lettuce from Taco Bell restaurants in the northern USA (IFT, 2007).

The increase in outbreaks of foodborne illnesses due to fresh produce is as a result of 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). According to Alzamora et al. (2000), yearly consumption of fresh fruits and vegetables in the USA increased by 20 pounds per person from 1988 to 1996 mostly because of the belief that fruits and vegetables are healthful. Changes in production and processing methods; agronomic, harvesting; distribution and consumption patterns and practices are other factors that have also contributed to the increase (Hedberg et al., 1999; Beuchat and Ryu, 1997).

*Corresponding author. E-mail: tosynolu@yahoo.com, oluwatosini@dut.ac.za.

Other reasons given by the Food and Agriculture Organisation (FAO) and World Health Organization (WHO) (2006) for increased foodborne infection/ poisoning outbreaks are: microbial adaptation; increase in international trade; increase in susceptible population and increase in travel; change to a lifestyle of convenience and consumer demands regarding healthy food with no chemical preservatives and with an extended shelf life; changes in human demographics and behaviour.

Irrigation water is one of the sources of contamination of fresh produce. The surface water that is used for irrigation of fruits and vegetables constitute public health risk because informal settlement around the dams and rivers pollute them with waste and sewage. SAWQG (1996) also reported that irrigation water used in agriculture in South Africa (SA) is mostly untreated water while home gardeners have access to treated water of high quality.

The Berg River used for irrigation of vegetables in SA has also been reported to fall below the European Union (EU) microbiological standard allowed for food production according to the *Cape Times* (Britz et al., 2007). The *Landbouweekblad* magazine, of 24 August 2007, reported that the water in Loskop Dam contained poisonous heavy metals and *E. coli* as a result of mines and municipalities dumping wastes in the rivers that feed the dam.

This problem of the contamination of irrigation water and subsequently, of vegetables might lead to a suspension of exports to the EU and USA, leading in turn to lost markets, reduction of foreign exchange earnings and job losses. This should be discouraged from happening because South Africa's local and export trade in fresh and processed fruit and vegetables is steadily growing. Exports from the Western Cape Province in particular have grown to R8 billion (WESGRO, 2006). Furthermore, consumption by South Africans of vegetables contaminated with foodborne pathogens might lead to outbreaks of foodborne illnesses, bearing in mind that a large proportion (that is, more than 5 million) of the citizens have immune system compromised diseases such as HIV and tuberculosis (Suarez, 2009). Immune-compromised people, elderly people, pregnant women and children are reported to be the most vulnerable to foodborne diseases (CDC, 2006).

Apart from a fear of the safety of consumers from contaminated vegetables as a result of contaminated irrigation water, there is concern over the safety of pickers, handlers, packers and farmers that participate in the production of vegetables during pre-harvest and post-harvest. It has been reported that young children from families of farming communities are the most vulnerable to *Salmonella* infection as a result of sewage irrigation (Ait and Hassani, 1999; FDA/CFSAN, 2001). This review therefore seeks to add to body of knowledge on irrigation water and food safety since there are few reports available especially in Africa. Importance of vegetables or produce from point of view of economy and healthy living will also be considered. Finally, ways by which contamination of produce can be prevented will be discussed.

IMPORTANCE OF FRUITS AND VEGETABLES

Fresh and minimally-processed vegetables and fruits provide most of our daily requirements for vitamins, minerals and fibre and their role in reducing the risk of lifestyle associated illnesses such as heart disease, diabetes and cancer has resulted in a further increase in their desirability and consumption. FDA and WHO have recommended 5–9 servings of fruits and vegetables to be taken daily because correct fresh produce intake alone could save 2.7 million lives per year (Johnston et al., 2006). As a result of this recommendation, fruit and vegetable consumption increased by 29% per capita in the USA between 1980 and 2000 (Matthews, 2006). Also, in SA, the Department of Health is promoting the consumption of fruits and vegetables through its '5-a-Day' eating programme, namely, consumption of at least five portions of vegetables and fruit every day (Badham, 2010).

However, unlike in the USA, where they are generally consumed by the majority of the population, fruits and vegetables are seldom consumed by economically and socially deprived communities in developing countries (Chada and Oluoch, 2003). Instead dietary intakes consist of plant-based staple foods (Chada and Oluoch, 2003). In contrast to what obtains in poor communities in most developing countries, the majority of the population generally consume vegetables and fruits in SA (FAO, 2006). Also according to the report, vegetables are referred to as 'poor people's food' in some countries of southern Africa (FAO, 2006).

Apart from health benefits derive from consumption of vegetables, South Africa also exports fresh fruits and vegetables to US and Europe. Ndiame and Jaffee (2005) reported that 73% of fruits and vegetables exported to the USA in terms of the African Growth and Opportunity Act (AGOA) were from SA. SA is the largest third world supplier of fruits and vegetables to the European Union (EU) with a 31% of imported fruit market share (Ndiame and Jaffee, 2005). Several countries in sub-Saharan Africa export vegetables but three, Cote d'Ivoire, Kenya and SA, account for nearly 90% of the trade in the region for the international market with SA being the leading exporter (Ndiame and Jaffee, 2005).

For some produce, especially fruits, SA ranks between number one and number 20 among the world's fresh produce exporting countries in terms of monetary value (FAO, 2004). According to a 2006 agriculture sector brief report on fruit processing, the fruit industry is very important to the South African economy contributing 20% of total agricultural production (WESGRO, 2006). SA was ranked the 2nd largest southern hemisphere exporter of deciduous fruit, apples and pears, and stone fruit, nectarines, peaches and plums, after Chile. For citrus fruit, SA was ranked 3rd in the world after Spain and the USA. Apart from the exported fresh fruit, 20% is consumed locally, while the remaining 20% is processed into juices (WESGRO, 2006).

After consideration of the economic importance of fresh vegetables in SA, it is essential to elaborate on the pathogens that may contaminate them during pre-harvest which may later predispose them to become causative agents of infectious diseases to both local and international consumers.

FOOD PATHOGENS ASSOCIATED WITH VEGETABLES

Vegetables are among the food groups implicated with greater frequency in recent years as causative agents of enteric diseases (Beuchat, 2006). All types of produce have the potential to harbour pathogens (Brackett, 1999). *Shigella* spp, *Salmonella* spp, enterotoxigenic and enterohemorrhagic *Escherichia coli, Campylobacter* spp, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Bacillus cereus*, *Clostridium botulinum,* viruses and parasites such as *Giardia lamblia, Cyclospora cayetanensis*, and *Cryptosporidium parvum* are of public health concern (Beuchat, 1996; Ortega et al., 1997; De Roever, 1998; Beuchat, 2002). Most of these pathogens have been associated with foodborne illnesses (Beuchat, 2002).

According to Beuchat (1998), the occurrences of pathogens in vegetables vary. The prevalence of *Campylobacter* is <3%, whereas the prevalence of *Salmonella* is higher, between 4 and 8%. *E. coli* O157:H7 and *L. monocytogenes* were more frequently isolated from vegetables compared to *Salmonella* (ECSCF, 2002). Also, recently (May 2011), cucumbers contaminated with pathogenic strains of *E. coli* cause the death of about 16 people in Europe. The outbreak is considered the third –largest involving *E. coli* in recent world history, and it is reported to be the deadliest (Grieshaber and Cheng, 2011).

Factors responsible for the emergence and prevalence of produce-linked outbreaks must be clearly understood for effective control and prevention. According to Tauxe et al. (1997), such factors include the following:

(i) Changes in the produce industry such as intensification and centralization of production;
(ii) Wider distribution of produce over greater distances;
(iii) Introduction of minimally processed produce; and
(iv) Increased importation of fresh produce.

Other factors include changes in consumer habits, for example, the increased consumption of meals outside the home, increased popularity of salad bars and increased consumption of fresh fruits and vegetables and fresh fruit juices. Tauxe et al. (1997) also reported on the some additional factors such as the increased size of at-risk population (elderly people, children, immuno-compromised people), enhanced epidemiology surveillance, improved methods to identify and track pathogens and lastly, emerging pathogens with low infection dose. The recent May, 2011 food infection outbreak has also shown that increase in antibiotic resistant strains of bacterial pathogens on produce may predispose them to cause outbreaks (Grieshaber and Cheng, 2011).

Reported outbreaks of foodborne illnesses as a result of the consumption of fresh produce will therefore vary from the developed countries to the developing countries. From the responsible factors stated above, developed countries such as USA and those in Europe may have higher reported cases of foodborne outbreaks. For example, these countries have enhanced epidemiology surveillance in place unlike countries from the developing world.

In the USA alone, 164 foodborne outbreaks due to fresh produce (excluding salads) were reported to the CDC from 1973 to 1997 (Beans et al., 1997; Tauxe et al., 1997). The mean number of produce-associated outbreaks nearly tripled from 4.0 per year from 1973 through to 1982 to 11.8 per year from 1993 through to 1997 (Beans et al., 1997; Tauxe et al., 1997). However, no foodborne outbreak due to fresh produce has been reported in most developing countries. According to the FDA (2009), the increase of reported produce-borne outbreaks in developed countries such as the USA is mainly due to improved surveillance that is lacking in most developing countries. The United Kingdom (UK) is another country where the surveillance of foodborne illness is extensive and because of this, a significant proportion of outbreaks have also been associated with fresh produce (Brandl, 2006). Salad, vegetables and fruit caused 6.4 and 10.1% of foodborne outbreaks in the periods of 1993–1998 and 1999–2000 respectively in England and Wales (Brandl, 2006).

According to Chang and Fang (2007), risk associated with the consumption of fresh produce because of the possibility of foodborne infections is a problem in both industrialized nations and developing countries. In a survey carried out on spring onions, lettuce and cabbage cultivated with poor quality irrigation water in Ghana, Amoah et al. (2006) found them to be heavily contaminated with faecal coliform (between 4.0×10^3 to 9.3×10^8 MPN/g). The lettuce, cabbage, and spring onions were also contaminated with an average of 1.1, 0.4, and 2.7, helminth eggs g^{-1}, respectively. The eggs were identified as those of *Ascaris lumbricoides*, *Ancylostoma duodenale*, *Schistosoma heamatobium*, and *Trichuris trichiura* (Amoah et al., 2006). These studies have given rise to a growing awareness that fresh or minimally processed fruit and vegetables can be sources of disease-causing bacteria, viruses, protozoa, and

Table 1. Outbreaks of bacterial infections associated with fruits, unpasteurized fruit and vegetables (Wood et al., 1991; Mahbub et al., 2004; Nuorti et al., 2004; Bowen et al., 2006; CDC, 2006; IFT, 2007; Greene et al., 2008; Pezzoli et al., 2008; Schreck, 2009; Flynn, 2009).

Bacteria	Year	Country	Vegetables source
Bacillus cereus	1973	USA	Seed sprouts
C. botulinum	1987	USA	Cabbage
	1991	USA	Apple cider
	1995, 2002	USA	Lettuce
E. coli 0157: H7	1996	USA	Apple juice
	1997	Japan	Radish sprouts
	1997	USA	Alfalfa sprouts
	2002, 2006	USA	Spinach
E. coli (enterotoxigenic)	1993	USA	Carrots
L. monocytogenes	1979	USA/Canada	Celery, lettuce, tomato, cabbage
Salmonella			
S. miami	1954	USA	Watermelon
S. typhimurium	1974, 2009	USA	Apple cider
S. oranienburg	1979	USA	Watermelon
S. saintpaul	1988	UK	Mungbean sprouts
S. chester	1989–1990	USA	Cantaloupes
S. javiana	1990	USA	Tomatoes
S. poona	1991	USA/Canada	Cantaloupes
S. montevideo	1993	USA	Tomatoes
S. bovismorbificans	1994	Sweden/Finland	Alfalfa sprouts
S. hartford	1995	USA	Orange juice
S. stanley	1995	USA	Alfalfa sprouts
S. montevideo	1996	USA	Alfalfa sprouts
S. typhi	1998–1999	USA	Mamey
S. mbandaka	1999	USA	Alfalfa sprouts
S. senftenberg	2007	UK	Prepacked basil
S. newport	2007	USA	Tomatoes
Shigella flexneri	1998	UK	Fruit salad
	1986	USA	Lettuce
	1994	Norway	Lettuce
S. sonnei	1998	USA	Parsley
	1995	USA	Scallions
	1970	Israel	Vegetables
Vibrio cholera	1991	USA	Coconut
Yersinia pseudotuberculosis	2003	Norway	Iceberg lettuce

helminths (Steele and Odumeru, 2004). The continuous rise in the number of outbreaks of foodborne illness linked to fresh fruit and vegetables challenges the notion that enteric pathogens are defined mostly by their ability to colonize the intestinal habitat (Brandl, 2006).

Outbreaks of foodborne illnesses as a result of consumption of fruits and vegetables are given in Table 1. Having looked at different bacterial pathogens that may cause foodborne illnesses if ingested with vegetables, it is appropriate to discuss ways by which they might likely come in contact with vegetable production during pre- harvest and post-harvest.

SOURCES OF CONTAMINATION OF FRUITS AND VEGETABLES WITH PATHOGENS

Contamination of fruits and vegetables can be divided into pre-harvest and post-harvest contamination (Beuchat and Ryu, 1997; Beuchat, 2002). Pre-harvest and post-harvest sources of pathogenic microorganisms on fruits and vegetables are given in Table 2. Potential pre-harvest sources include soil, faeces, irrigation water, water used to apply fungicides and insecticides, dust, insects, inadequately composted manure, wild and domestic animals, human handling, among others

Table 2. Sources of pathogenic microorganisms on fresh fruit and vegetables (Beuchat, 1997; Steele and Odumeru, 2004; Johnston et al., 2006; Beuchat, 2006).

Preharvest	Postharvest
Faeces	Faeces
Soil	Human handling (workers, consumers)
Irrigation water	Harvesting equipment
Water used to apply fungicides, insecticides	Transport containers (field to packing shed)
Green or inadequately composted manure	Wild and domestic animals (including fowl and reptiles)
Air (dust)	Insects
Wild and domestic animals (including fowl and reptiles)	Air (dust)
Insects	Wash and rinse water
Human handling	i) Sorting, packing, cutting, and further processing equipment
	ii) Ice
	iii) Transport vehicles
	iv) Improper storage (temperature, physical environment)
	v) Improper packaging (including new packaging technologies)
	vi) Cross-contamination (other foods in storage, preparation, and display areas)
	vii) Improper display temperature
	viii) Improper handling after wholesale or retail purchase

(Beuchat and Ryu, 1997; Beuchat, 2002). Post-harvest sources include faeces, human handling, harvesting equipment, transport containers, wild and domestic animals, insects, dusts, rinse water, ice, transport vehicles, processing equipment, among others (Beuchat and Ryu, 1997; Beuchat, 2002, 2006).

A study of soil and domestic animal faeces indicated that *Listeria* spp is more often present during July to September than other months in the USA (MacGowan et al., 1994; Beuchat and Ryu, 1997). Wild birds and animals can also be sources responsible for the distribution of *L. monocytogenes* to fruits and vegetables because 23% of samples collected from wild bird feeding grounds were positive for *L. monocytogenes* (Weiss and Seeliger, 1975).

Duffy et al. (2005) showed that irrigation water is the leading pre-harvest and post-harvest source of contamination of produce. From a total of 22 *Salmonella* isolates found in environmental samples (irrigation water, soil, packing shed equipment), 16 isolates were from irrigation water and 6 from packing shed equipment. Contaminated irrigation and surface run-off waters, according to Beuchat and Ryu (1997) and Ibenyassine et al. (2006), can also be sources of pathogenic microorganisms that contaminate fruits and vegetables in the field. Apart from irrigation water, the use of sewage as a fertilizer could also be a source of pathogens. MacGowan et al. (1994) found 84–100% of sewage samples to be contaminated with *L. monocytogenes* or *L. innocua* during a two-year sampling period. *Salmonella,* Ascaris ova and *Entamoeba coli* cysts were isolated from more than 50% of irrigation water samples contaminated with raw sewage or primary treated chlorinated effluents (Wang et al., 1996).

In summarizing this section, it must be emphasized that fruits and vegetables can become contaminated with foodborne pathogens in various ways during production, harvest, processing, transportation, in retail and food service and even at home (Harris et al., 2003).

QUALITY OF SOUTH AFRICAN SURFACE WATER

The deterioration of the quality of the South African surface water resources is one of the major threats the country is faced with (Sigge and Fitchet, 2009). The Minister of Water Affairs and Forestry has stated that bacteriological contamination and pollution of the surface water, originating from the absence of poorly maintained sanitation facilities, is widespread in the country (Vuuren, 2009b).

Increasing rates of urbanization, industrialization and population growth have led to stress on water resources and pollution. According to Vuuren (2009a), one of the major sources of faecal pollution of surface water is the fact that during the last two decades many un-serviced informal settlements have developed near rivers. Another major contributor to the menace is the failing sewage disposal systems of a large number of villages, towns and cities.

The rivers in the urban areas regularly measure Hundreds of thousands or ten millions of *E. coli* organisms per 100 ml water. The Jukskei River in the Gauteng Province was reported in 2003 to measure 13 million cfu/100 ml of *E. coli*, while the Umungeni River was contaminated with 1.1×10^6 cfu/100 ml of *E. coli*. The

Berg River below the confluence with the Stiebeuel River in Franschhoek measured 9.2 × 10^4 cfu/100 ml of *E. coli* while the storm water ditches joining the Berg River from the informal settlement of Mbekweni at Paarl measured 2.4 × 10^9 cfu/100 ml of *E. coli* in 2004 (Barnes, 2003). These data show that some South African rivers and streams are unacceptably polluted.

Sources of irrigation water

The common sources of irrigation water used in South Africa are large reservoirs, farm dams, rivers, ground water, municipal supplies and industrial effluent (SAWQG, 1996). According to Bihn and Gravani (2006), irrigation water in agriculture can be diverse, ranging from potable to surface water from sources such as rivers to treated and untreated municipal water.

There is no evidence that reclaimed water is a known source of irrigation water in SA (SAWQG, 1996). WHO recommended that <1000 faecal coliforms/100 ml must be in reclaimed water before it can be used for irrigation (WHO, 1989). The USA Environmental Protection Agency (EPA) also has guidelines for water reclamation and agricultural which states that faecal coliforms should not be detected in the water in at least 50% of samples (EPA, 2000; Lambertini et al., 2008).

Irrigation water and pathogen transfer

The microbial quality of irrigation water is important because poor quality water can introduce pathogens into produce during pre-harvest and post-harvest. Indirect or direct contamination of produce by water or water aerosols containing pathogens has been long recognized as a potential hazard (FDA/CFSAN, 2001; WHO, 2003).

Though direct evidence of foodborne illness due to contamination of edible horticultural commodities during commercial production is limited, compelling epidemiological evidence involving these crops shows possibility of contamination through some production practices (Brackett, 1999). Practices such as the use of animal waste or manure, faecally contaminated agricultural water for irrigation or pesticide/crop management application and farm labour personal hygiene all leads to direct contamination (Brackett, 1999).

Brackett (1999) suggested that only clean, potable water should be used for irrigation of fruits and vegetables after planting. However, this approach fails to take into account many aspects of water availability, water conservation programmes, irrigation method, geographic diversity, crop diversity, temporal factors, and the significant difficulty inherent in water monitoring for microbial content during production (FDA, 2001). Polluted irrigation and contaminated manure have been implicated In the outbreaks of enterohemorrhagic *E. coli* O157:H7 infections. The infections were associated with lettuce and other leaf crops and they are occurring with increasing frequency (Mahbub et al., 2004).

Infectious doses of pathogens in irrigation water

Analyses of some river waters in SA have been reported to contain high levels of pathogens that exceed infectious doses (Britz et al., 2007). According to Britz (2005), accidental ingestion of such water, even if diluted, could cause serious infections among the population. The number of viruses that are able to cause infection is low compared with bacteria (Barnes, 2003). Also, some microbes infect the host immediately while others infect on a cumulative basis and thus the infection takes a long period to manifest (Legnani and Leoni, 2004). Water-borne pathogens are also able to form microfilms and ingestion of these microfilms or clusters poses a much higher risk of infection because the number of colonies in clusters or microfilms is very likely to exceed the infectious dose of the pathogen (Jamieson et al., 2005).

Infectious doses of pathogens are not the same everywhere. For example, they are lower in developing countries such as SA where a large percentage of the exposed population is immune-compromised because of malnourishment, old age or suffering from HIV/AIDS or tuberculosis (Barnes, 2003). This factor further increases the importance of reducing pathogens in irrigation water in SA since a large percentage of the population has a much higher risk of infection (Barnes, 2003).

FACTORS AFFECTING PREVALENCE OF PATHOGENS IN PRODUCE AFTER IRRIGATION

According to Stine et al. (2005), the factors that affect the transfer of pathogens from contaminated irrigation water to fresh produce are the type of crop, the irrigation method and the number days between the last irrigation event and harvest.

Results of a survey of *Salmonella, Shigella,* and enteropathogenic *E. coli* on vegetables done in the USA confirmed that the frequency with which target pathogens could be isolated from irrigation water was inversely correlated with crop height (FDA/CFSAN, 2001). Plants, such as spinach and cabbage, had a higher frequency of confirmed positive isolation of pathogens than taller chilli peppers or tomatoes.

According to FDA/CFSAN (2001), other factors that may cause the persistence of pathogens are plant surface hydrophobility and contours. In another study, during a seven-month microbiological survey of vegetables, higher total coliform counts were recorded when the sprinkler irrigation water source was used compared to drip irrigation water source (FDA/CFSAN, 2001).

Control of pathogens in irrigation water

The four major ways by which the introduction of pathogenic microorganisms into irrigation water can be controlled according to Buck et al. (2003) are;

(i) Knowing the origin and distribution of irrigation water,
(ii) Knowing the history of the land,
(iii) Maintaining irrigation wells, and
(iv) Monitoring all irrigation sources for human pathogens.

Other measures that may be more successful at minimizing contamination of surface and ground water are proper design, construction and protection of wellheads. Periodic microbial monitoring of wells, using *E. coli* as an indicator of recent or persistent faecal contamination is also recommended (Allen et al., 1990; FDA/CFSAN, 2001). The feasibility and performance of various methods of on-farm water treatment are not available (FDA/CFSAN, 2001).

Apart from the use of a good water source with the reduced possibility of pathogen contamination, factors that determine the risk of infection such as type of crop, irrigation method and days between the last irrigation event and harvest should be understood (Stine et al., 2005). This will aid in the development of irrigation water quality standards and risk assessment for enteric bacteria and viruses associated with fresh produce (Stine et al., 2005). Surface or drip irrigation, for example, reduces the rate of contamination of produce with bacterial pathogens compared to spray irrigation. It is therefore essential for farmers to employ drip irrigation for vegetables that will be consumed raw. In a study carried out by Solomon et al. (2002), the number of plants that tested positive following a single exposure to *E. coli* O157:H7 through spray irrigation (29 of 32 plants) was larger than the number that tested positive following drip irrigation (6 of 32 plants). But regardless of the irrigation method used, produce can become contaminated; therefore, the irrigation of food crops with water of unknown microbial quality should be avoided (Solomon et al., 2002).

Control and prevention measures against fresh produce contamination

The inability of sanitizers to completely decontaminate pathogens after coming in contact with produce during pre-harvest has been reported by many authors (Nguyen-the and Carlin, 1994; Hagenmaier and Baker, 1998; Solomon et al., 2002; Ijabadeniyi et al., 2011). In spite of the addition of a sanitizer, higher microbial concentrations have been reported after harvest of fresh produce to be influenced by post-harvest processing, importation and seasonal variations (Ailes et al., 2008). The prevention of foodborne diseases related to fresh produce could therefore occur only by preventing initial contamination (Beuchat, 2006). According to Zhu et al. (2009), effective and preventive measures are important to avoid contamination of fresh produce. Such measures should include environmental and family health improvement, good personal hygiene and safe food handling practices (Zhu et al., 2009).

Other practical methods should also be employed to reduce, eliminate or prevent multiplication of pathogens on produce. According to De Roever (1998), proper sanitation at all levels in the fresh produce chain, namely, from farm-to-fork should be made mandatory. Also for the preventive measures to be effective, a collaborative approach among the industry, federal and international partners must be used (Unnevehr, 2000; Bowen et al., 2006).

This safety initiative should include the avoidance of the use of untreated manure as fertilizers; proper sanitary systems and hand-washing facilities for farm workers; use of clean equipment and transportation vehicles; good hygiene in the processing facilities and in the kitchen; and measures to prevent cross-contamination (De Roever, 1998). To prevent cross- contamination, persons with an infection should not be allowed to handle produce or equipment since they may transmit the infection to other workers and may contaminate the produce. Also cold storage and transportation should be employed to discourage the amplification of pathogens (De Roever, 1998).

All stakeholders in the produce industry, namely, growers, harvesters, packers, processors, preparers and even consumers along the food chain from farm-to-fork should be educated on proper way of produce handling (Balsevich et al., 2003; Berdegué et al., 2005). This will include the prevention of cross-contamination, the temperature at which different produce should be stored or kept and their shelf life (De Roever, 1998; Satcher, 2000).

Proper consumer handling of fresh produce has also been canvassed by Bruhn (2006) because many consumers believe that produce is already clean and further washing is not important. The following improper food-handling practices, for example, infrequent hand-washing, poor hand-washing techniques, inadequate cleaning of kitchen surfaces, involvement of pets in the kitchen, and frequent touching of the face, mouth, nose and/or hair which Jay (1997) observed, may predispose produce to risk during its preparation by consumers and they should be warned against such practices (Li-Cohen and Bruhn, 2002).

Other measures that have been recommended are the implementation of Good Manufacturing Practices (GMP) programme in the produce industry (Bihn and Gravani, 2006). Good Agricultural Practices (GAPs) for irrigation water have also been recommended to ensure the safety of fresh produce. According to Bihn and Gravani (2006), a good agricultural practices farm food safety plan should include the following sections:

i) Irrigation practices,
ii) Manure use,
iii) Worker health, hygiene and training,
iv) Toilet and hand-washing facilities,
v) Field and packing-house sanitation,
vi) Pesticide use,
vii) Animal and pest management,
viii) Post-harvest handling,
ix Crisis management,
x) Recall and traceback,
xi) Farm biosecurity,
xii) Record keeping.

2) Specialty and niche markets may need to add the following sections:

i) Direct marketing,
ii) Farm market protocols,
iii) Pick your own/u-pick operations.

3) Petting zoos including animal health. The summarized recommendations according to Bihn and Gravani (2006) are as follows:

(i) If surface water is used for irrigation, it should be tested for *E. coli* on a regular schedule to monitor microbiological quality and any changes that may occur due to unusual contamination events,
(ii) Drip or surface irrigation should be used when possible to prevent direct wetting of the plant or ripe fruit or vegetable,
(iii) Potable water should be used for mixing topical sprays,
(iv) If well water is used, producers should be sure that the well is capped and properly constructed. Wells should be tested at least once a year to monitor microbiological quality.

Few attempts have also been made to apply Hazard Analysis Critical Control Point (HACCP) principles during production of fresh produce, that is, sprouted seeds, shredded lettuce and tomatoes but complete validation of the HACCP plans has not yet been accomplished (NACMCF, 1999). According to Bihn and Gravani (2006), the problem of too many variables, such as weather, wild animals, irrigation water, soil and several other factors that are not easily controlled are responsible for a lack of validation and difficulty in the implementation of HACCP in the production of produce. However, for the measures stated above to work and to lead to the reduction of episodes of foodborne illness, there must be a behavioural change on the part of food producers, food processors, food retailers, food service personnel and even consumers (McCabe-Sellers and Beattie, 2004). According to Yiannas (2009), achieving food safety success in this changing environment involves going beyond traditional training, testing and inspectional approaches to managing risks. It requires a better understanding of organizational culture and the human dimensions of food safety. To improve the food safety performance of a retail establishment or a foodservice establishment, an organization with thousands of employees, or a local community, the way people do things or their behaviour must be changed (Yiannas, 2009). A good behaviour or attitude to food safety is the foundation of having food safety culture. According to Powell et al. (2011), maintaining a food safety culture means that operators and staff know the risks associated with the products or meals they produce, know why managing the risks is important, and effectively manage those risks in a demonstrable way. This culture can best be created by application of best science with the best management or behavioural science. In addition communicating systems including compelling, rapid, relevant, reliable and repeated food safety messages using multimedia must be applied (Seward and Baron, 2012, Powell et al., 2011; Yiannas, 2009).

CONCLUSION

In concluding this review, it must be emphasized that prevention of contamination of fresh produce from both pre-harvest and post-harvest sources especially irrigation water still remains the only effective way to protect the public. However for this to occur, every stakeholder in the produce industry must have a culture of food safety that is, safety of produce becomes everybody’s business and responsibility. While producers and processors ensure they do not cut costs at the expense of food safety which can be detrimental to the business; customers and consumers also have the responsibility of maintaining food hygiene practices such as hand and produce washing and handling of fresh cut at the prescribed temperature.

REFERENCES

Ailes EC, Leon JS, Jaykus l, Johnston LM (2008). Microbial concentrations on fresh produce are affected by postharvest processing, importation and season, J. Food Protect. 71:2389- 2397.
Ait A, Hassani L (1999). *Salmonella* infection in children from the waste-water spreading zone of Marrakesh city (Morocco), J. Appl. Microbiol. 87:536–539.
Allen EA, Hoch HC, Steadman JR, Stavely RJ (1990). Influence of leaf surface features on spore deposition and the epiphytic growth of phytopathogenic fungi in: Microbial Ecology of leaves, Eds Andrews J.H, Hirano, S. S. Madison, Wis, pp. 87-110.
Altekruse SF, Swerdlow DL (1996). The changing epidemiology of foodborne diseases, Am. J. Med. Sci. 311:23–29.
Alzamora SM, Lopez-Malo A, Tapla MS (2000). Overview In: Minimally processed fruits and vegetables: Fundamental aspects and applications. Alzamora SM, Tapia MS, Lopez-Malo A (eds). Galthersburg, Md: Aspen.
Amoah P, Drechsel P, Abaidoo, RC, Ntow WJ (2006). Pesticide and Pathogen Contamination of Vegetables in Ghana’s Urban Markets, Arch. Environ. Contam. Toxicol. 50:1- 6.
Badham J (2010). 5-a-Day” eating programme i.e consumption of at least 5 portions of vegetables and fruit every day. http://www.ifava.org/about_member_details.asp?id=12&member_con

tact=1.
Balsevich F, Berdegue JA, Flores L, Manville D, Reardon T (2003). Supermarkets and produce quality and safety standards in Latin America. Am. J. Agric. Econ. 85:1147-1154.
Barnes JM (2003). The impact of water pollution from formal and informal urban development along the Plankenbrug River on water quality and health risk. PhD Thesis, University of Stellenbosch, South Africa.
Beans NH, Goulding JS, Daniel MT, Angelo FJ (1997). Surveillance for foodborne disease outbreaks-United States, 1997-1992, J. Food Protect. 60:1265-1286.
Berdegué JA, Balsevich F, Flores L, Reardon T (2005). Central American supermarkets' private standards of quality and safety in procurement of fresh fruits and vegetables, Food Policy. 30:254-269.
Beuchat LR, Ryu J (1997). Produce handling and processing practices, Emerg. Infect. Dis. 3:1-9.
Beuchat LR (1996). Pathogenic microorganisms associated with fresh produce, J. Food Protect. 59:204-206.
Beuchat LR (2002). Ecological factors influencing survival and growth of human pathogens on raw fruits and vegetables, Microbes Infect. 4:413-423.
Beuchat LR (2006). Vectors and conditions for pre-harvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. Br. Food. J. 108:38- 53.
Bihn EA, Gravani RB (2006). Role of good agricultural practices in fruit and vegetable safety. In: Microbiology of Fresh Produce (Edited by K.R. Matthews). Washington DC: ASM Press. pp. 21-28.
Bowen A, Fry A, Ruchards G. Beuchat LR (2006). Infections associated with cantaloupe consumption: A public health concern, Epidemiol. Infect. Control. 134:675-685.
Brackett RE (1999). Incidence, contributing factors, and control of bacterial pathogens in produce, Postharvest. Biol. Technol. 15:305-311.
Brackett RE (2009). Ensuring Food Safety: Tracking and resolving the *E. coli* spinach outbreak. http://www.fda.gov/NewsEvents/Testimony/ucm110926.htm. Brandl MT (2006). Fitness of human enteric pathogens on plants and implications for food safety. Ann. Rev. Phytopathol. 44:367-392.
Britz JT, Barnes J, Buys EM, Ijabadeniyi OA, Minnaar A, Potgieter N, Sigge GO, Ackerman A, Lotter M, Taylor, MB, van Zyl W, Venter I, Netshikweta R (2007). Quantitative investigation into the link between irrigation water quality and food safety: *A review.* WRC Report (K51773). http://academic.sun.ac.za/foodsci/pub_books.htm.
Britz TJ (2005). Impact of polluted irrigation water on agricultural products. Invited Speaker. Imbizo of the Cape Winelands District Municipality. April 2005, Wellington, Western Cape Province, South Africa.
Bruhn C (2006). Consumer handling of fresh produce from supermarket to table. In: Microbial Hazard Identification in Fresh Fruits and Vegetables (Edited by J. James). New Jersey: John Wiley & Sons, pp. 95-109.
Buck JW, Walcott R, Beuchat LR (2003). Recent trends in microbiological safety of fruits and vegetables. http://www.apsnet.org/online/feature/safety/.
CDC (2006). Surveillance for foodborne –disease outbreaks in US, 1998-2002. Http://www.cdc.gov/mmwr/preview/mmwrhtml/ss5510a1.htm?_cid=ss5510a1_e.
Chada ML, Oluoch MO (2003). Home-based vegetable gardens and other strategies to overcome micronutrient malnutrition in developing countries, Food. Nutr. Agric. 32:17-21.
De Roever C (1998). Microbiological safety of evaluations and recommendations on fresh produce, Food Control. 9:321-347.
Duffy EA, Lucia LM, Kells JM, Castillo A, Pillai SD, Acuff G, R (2005). Concentration of *E. coli* and genetic diversity and antibiotic resistance profiling of *Salmonella* isolated from irrigation water, packing shed equipment, and fresh produce in Texas. J. Food. Protect. 68:70-79.
ECSCF (European Commission Scientific Committee on Food) (2002). Risk Profile on the microbiological contamination of fruits and vegetables eaten raw. European Commission Scientific Committee on Food. http://ec.europa.eu/food/fs/sc/scf/out125_en.pdf
EPA (Environmental Protection Agency) (2000). Optimisation of a new method for detection of viruses in groundwater. National groundwater and contained land centre project NC/99/40/2000. http://aem.asm.org/cgi/content/full/74/10/2990.
FAO (Food and Agricultural Organization) (2004). Key statistics of Food and Agricultural External Trade. http://www.fao.org/es/ess/toptrade/trade.asp
FAO (Food and Agricultural Organization) (2005). AQUASTAT. Country profile South Africa. http://www.fao.org/ag/agl/aglw/aquastat/countries/index.stm.
FAO (Food and Agricultural Organization) (2006). Spotlight on fruit and vegetable. www.fao.org/ag/magazine/0606sp2.htm
FDA (Food and Drug Administration) (2001). Secondary direct food additives permitted in food for human consumption, Federal Register, 66: 33929-33930.
FDA (2009). Safe Practices for food processors. http://www.fda.gov/Food/ScienceResearch/ResearchAreas/SafePraSafePr for FoodProcesses/ucm091265.htm.
FDA/CFSAN, (2001). Production practices as risk factors in microbial food safety of fresh and fresh-cut produce. http://ucgaps.ucdavis.edu/documents/Preharvest_Factors_and_Risk2041.pdf.
Flynn D (2009). Cantaloupe recalled for *Salmonella.* http://www.foodsafetynews.com/2009/10/cantaloupe-recalled-for salmonella/.
Greene SK, Daly ER, Talbot E A, Demma LJ, Holzbauer S, Patel NJ, Hill TA, Walderhaug MO, Hoekstra RM, Lynch MF, Painter JA (2008). Recurrent multistate outbreak of *Salmonella* Newport associated with tomatoes from contaminated fields. Epidemiol. infect. 136:157-165.
Grieshaber K, Cheng M, (2011). Outbreak in Europe blamed on 'super-toxic' strain. http://beta.news.yahoo.com/outbreak-europe-blamed-super-toxic-strain-183404464.html
Hagenmaier RD, Baker RA (1998). Microbial population of shredded carrot in modified atmosphere packaging as related to irradiation treatment. J. Food. Sci. 63:162-164.
Harris LJ, Farber JN, Beuchat LR, Parish ME, Suslow TV, Garrett EH, Busta FF (2003). Outbreaks associated with fresh produce: Incidence, growth and survival of pathogens in fresh and fresh- cut produce, Comprehensive. Rev. Food Sci. Food Safety. 2:78-141.
Hedberg CW, MacDonald KL Osterholm MT (1999. Changing epidemiology of foodborne disease: A Minnesota perspective. Clin. Infect. Dis. 18:671–682.
Ibenyassine K, Aitmhand R, Karamoko Y, Cohen N, Ennaji MM (2006). Use of repetitive DNA sequences to determine the persistence of enteropathogenic *Escherichia coli* in vegetables and in soil grown in fields treated with contacted irrigation water. Lett. Appl. Microbiol. 43:528-533.
IFT (2007). Food Forecast 2007. Institute of Food Technologists. http://www.ift.org/cms/?pid=1001537 &printable=1. Ijabadeniyi AO, Buys EM, Minnaar A (2011). Effect of attachment time followed by chlorine washing on the survival of inoculated *Listeria monocytogenes* on tomatoes and spinach. J. Food Qual. 34:133-141.
Jamieson R, Joy DM, Lee H, Kostaschuk R, Gordon R (2005). Transport and deposition of sediment-associated *Escherichia coli* in natural streams. Water Res. 39:2665-2675.
Jay JM (1997). Do background microorganisms play a role in the safety of fresh foods. Trends. Food Sci. Technol. 8:421-424.
Johnston LM, Moe CL, Moll D, Jaykus L (2006). The epidemiology of produce-associated outbreaks of food borne disease. In: Microbial hazard identification in fresh fruits and vegetables. Edited by J. James. John Wiley and sons publishers, New Jersey. pp. 38-52.
Lambertini E, Spencer SK, Bert, PD, Loge FJ, Kieke BA, Borchadt MA (2008). Concentration of enteroviruses, adenoviruses and noroviruses from drinking water by use of glass wool filters, Appl. Environ. Microbiol. 78:2990-2996.
Legnani PP, Leoni E (2004). Effect of processing and storage conditions on the microbiological quality of minimally processed vegetables. Int. J. Food Sci. Technol. 39:1061-1068.
MacGowan AP, Bowker K, McLauchlin J, Bennet PM, Reeves DS(1994). The occurrence and seasonal changes in the isolation of *Listeria* sp in shop bought food stuffs, human faeces, sewage and

soil from urban sources, Int. J. Food .Microbiol. 21:325- 334.
Mahbub I, Michael PD, Sharad CP, Patricia M, Xiuping J (2004). Persistence of enterohemorrhagic *Escherichia coli* 0157:H7 in soil and on leaf lettuce and parsley grown in fields treated with contaminated manure composts or irrigation water. J. Food Protect. 67:1365-1370.
Matthews KR (2006). Microorganisms associated with fruits and vegetables. In: Microbiology of Fresh Produce. Edited by K.R. Matthews. ASM Press. Washington DC pp. 1-21.
McCabe-Sellers B, Beattie S (2004). Emerging trends in food borne illness surveillance and prevention J. Am. Diet. Assoc. 104:1708-1717.
NACMCF (National Advisory Committee on Microbiological Criteria for Foods) (1999). Microbiological safety evaluations and recommendations on fresh produce. Food Control. 10:117-143.
Ndiame D, Jaffe SM (2005). Fruits and vegetables: Global trade and competition in fresh and processed product markets. In: Global agricultural trade and developing countries. Edited by Aksoy, M.A and Beghin, J.C. World Bank, pp. 237-257.
Nguyen-the C, Carlin F (1994). The microbiology of minimally processed fresh fruits and vegetables Critical. Rev. Food Sci. Nutr. 34:371-401.
Nuorti JP, Niskanen T., Hallanvuo S, Mikkola J (2004). A widespread outbreak of *Yersinia pseudotuberculosis* 0:3 infection from iceberg lettuce. J. Infect. Dis. 189:766-774.
Ortega, YR. Roxas CR, Gilman, RH, Miller NJ, Cabrera L., Taquiri C, Sterling CR (1997). Isolation of *Cryptosporidium parvum* and *Cyclospora cayetanensis* from vegetables collected in markets of an endemic region in Peru. Am. J. Trop. Med. Hyg. 57:683- 686.
Pezzoli L, Elson R, Little CL, Yip H (2008). Packed with *Salmonella*-Investigation of an intestinal outbreak of *Salmonella* infection linked to contamination of pre-packed basil in 2007. Food borne pathogens dis. 5:661-668.
Powell DA, Jacob CJ, Chapman BJ (2011). Enhancing food safety culture to reduce rates of foodborne illness. Food Control., *22:*817–822.
Satcher D (2000). Food safety: A growing global health problem. J. Am. Med. Assoc. 283:1817-1823.
SAWQG .South African Water Quality Guidelines (1996). Agricultural Water Use: Irrigation. 2nd Edition. p. 180.
Schreck S (2009). Cantaloupe recalled for possible *Salmonella* contamination. Http://www.foodpoisonjournal.com/admin/trackback/134463.
Seward R, Baron M (2012). Assessing the food safety culture of a manufacturing facility, Institute. Food Technol. 66:1- 9
Sigge G, Fitchet T (2009). Food Safety in the Limelight, South Afri. Food Rev. 36:14-16.
Solomon EB, Potenski CJ, Matthews KR (2002). Effect of irrigation method on transmission to and persistence of *Escherichia coli* O157:H7 on lettuce. J. Food Protect. 65:673- 676.
Steele M, Odumeru J (2004). Irrigation water as source of food borne pathogens on fruit and vegetables, J. Food Protect. 67:2839-2849.
Stine SW, Inhong S, Choi CY, Gerba CP (2005). Application of microbial risk assessment to the development of standards for enteric pathogens in water used to irrigate fresh produce. J. Food Protect. 68:913- 918.
Suarez R (2009). TB thrives among South Africa's HIV population. http://www.pbs.org/newshour/bb/africa/jan-june09/southafricatb_03-24.html.
Tauxe R, Kruse H, Hadberg C, Potter CM, Madden J, Wachsmuth K (1997). Microbial hazards and emerging issues associated with produce. A preliminary report to the National Advisory Committee on microbiological criteria for foods, J. Food Protect. 60:1400-1408.
Unnevehr LJ (2000). Food safety issues and fresh food product exports from less developed Countries, Agric. Econ. 23:231- 240.
Vuuren L (2009a). New water framework counts every drop. The Water Wheel. 8:28-30.
Vuuren L (2009b). The state of water in South Africa: Are we heading for a crisis. The Water Wheel 8:31-33.
Wang G, Zhao T, Doyle MP (1996). Fate of enterohemorrhagic *Escherichia coli* O157:H7 in bovine feces, Appl. Environ. Microbiol. 62:2567-2570.
Weiss J, Seeliger HP (1975). Incidence of *Listeria monocytogenes* in nature Appl. Microbiol. 29:29-32.
WESGRO (2006). Fruit processing sector brief. Western Cape Trade and Investment Promotion Agency, pp.. 36-40.
WHO (World Health Organisation) (2006). WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater: 2, Wastewater Use in Agriculture. World Health Organization, Geneva. Switzerland. pp. 1-176.
WHO (World Health Organization) (2003). The present state of food borne disease in QECDcountries.http://www.who.int/foodsafety/publications/foodborne disease/en/ OECD%20Final%20for%20WEB.pdf
WHO (World Health Organisation) (1989). Health guidelines for the use of wastewater in agriculture and aquaculture. Geneva, Switzerland: World Health Organisation. Technical Report Series. p. 778.
Wood RC, Hedberg C, White K. (1991). A multistate outbreak of *Salmonella* Javiana infections associated with raw tomatoes. In: CDC Epidemic Intelligence Service, 40th Annual Conference, Atlanta, USA. pp. 69-200.
Yiannas F (2009). Food Safety culture. Creating a behavior-based food safety management system. Edited by Doyle, M. P. Springer Science, New York. p. 95.
Zhu Y, Gu L, Yu J, Yang J, Zhai X (2009). Analysis on the Epidemiological characteristics of *E. coli* 0157: H7 infection in Xuzhou, Jiangsu, China. J. Nanjing Med. Univ. 23:20-24.