ARTICLE IN PRESS

Food Control xxx (xxxx) xxx

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Review

Food safety issues in fresh produce supply chain with particular reference to sub-Saharan Africa

O. Charles Aworh

Department of Food Technology, University of Ibadan, Nigeria

ARTICLE INFO

Keywords:
Fruits and vegetables
Food-borne diseases
Food decontamination
Post-harvest handling
Digital technology

ABSTRACT

Developing countries including those of sub-Saharan Africa (SSA) bear the greatest burden of food-borne illnesses. Animal-source foods and fresh fruits and vegetables are the leading cause of food-borne diseases in SSA. Pathogenic bacteria, viruses and chemical contaminants including pesticide residues and calcium carbide used for artificial fruit ripening are the primary agents of food-borne illnesses due to fresh produce in SSA. Small, resource-poor farmers account for the bulk of agricultural production in SSA and advocacy, capacity building in food safety and the application of good agricultural practices and good hygienic practices will reduce fresh produce contamination. Improved post-harvest handling practices, transport and market infrastructure including cold chains, the establishment of simple packinghouses where fresh produce is prepared for the market, developing regulations for the informal food sector, greater capacity to enforce existing regulations and the certification of food management systems will improve food safety throughout the fresh produce supply chain in SSA. The adoption of new, sophisticated and more effective technologies of fresh produce decontamination is hampered by technical and economic constraints. Africa has the fastest-growing number of mobile phone users in the world and mobile phones and internet can improve food quality and safety in SSA and overcome the constraint of access to market information and promote the inclusion of smallholder farmers in SSA in national, regional and global markets.

1. Introduction

Food safety is a major concern because food systems may have adverse impacts on nutrition and health through food-borne diseases, naturally occurring toxicants, zoonotic infections, indiscriminate use of agro-chemicals, exposure to pesticides and other chemicals, antimicrobial resistance and other factors related to food and agriculture. Even though food safety is a growing, major concern in the industrialized, high-income countries, the most damaging effects of unsafe foods are felt in developing countries that bear the greatest burden of food-borne illnesses. Poverty is pervasive in most parts of SSA with dire consequences for nutrition and health. For example, it is estimated that about 70% of the population of Nigeria (Africa's most populous nation with a population of about 200 million) live below the poverty line (Canagarajah & Thomas, 2001; Oshewolo, 2010). Protein-energy malnutrition in children and micronutrient deficiencies (the hidden hunger), especially vitamin A, iodine, iron and zinc deficiencies, are important public health problems with severe consequences for productivity, intellectual development, maternal and infant morbidity and mortality (Aworh, 2015). Food-borne illnesses perpetuate the cycle of poverty because of their debilitating effects on health and productivity and premature death. The health consequences of food-borne illnesses are more damaging to the malnourished, children, pregnant women and the elderly with weak immune systems resulting in a vicious cycle of morbidity and mortality (WHO, 2015). Food-borne illnesses constrain agricultural development in developing countries and reduce access to export markets that are subject to international regulatory requirements of the World Trade Organization such as the Sanitary and Phytosanitary (SPS) Measures and Technical Barriers to Trade (TBT) Agreement. Food-borne illnesses may also have adverse effects on the hospitality and tourism industry that contributes significantly to the economy of many African countries and is an important source of foreign exchange. Even though difficult to quantify in monetary terms, there is no doubt that food-borne illnesses have substantial adverse impacts on the economy of SSA. It is estimated that the annual cost of treating food-borne diseases in SSA is at least $10.5 billion with an annual loss to GDP due to food-borne diseases and health incapacitation of workers estimated at $15 billion. The annual economic loss from deaths due to food-borne

E-mail addresses: oguguaaworh@gmail.com, ocawo51@yahoo.co.uk, charles.aworh@mail.ui.edu.ng.

https://doi.org/10.1016/j.foodcont.2020.107737
Received 11 September 2020; Received in revised form 23 October 2020; Accepted 31 October 2020
Available online 4 November 2020

diseases in SSA is estimated at about $39 billion (Grace et al., 2018).

Epidemiological data on food-borne illnesses in developing countries including those of SSA are very limited because food-borne illnesses are often unreported and in many cases unrecognized as such and attributed to other factors. Food-borne disease surveillance is weak or absent and it is not mandatory that food-borne illnesses be reported in many countries of SSA (Grace et al., 2018). The tropical climate of SSA promotes the proliferation of pests and disease organisms increasing the challenges of food safety. Many parts of SSA rely heavily on ecosystem services for water and sewage water and sludge are used in agricultural production. Peri-urban vegetable producers in West Africa often use sewage water for irrigation (Kitinoja, Saran, Roy, & Kader, 2011). Infrastructural deficits including lack of potable water, poor food handling and storage conditions, poor sanitation and hygiene result in food contamination leading to illnesses. Lack of regulations that cover the informal food sector and poor capacity to enforce regulations adversely affect food safety in SSA. The WHO Foodborne Disease Burden Epidemiology Reference Group (FERG) report of 2015 documented estimates of the global burden of food-borne diseases caused by 31 bacteria, viruses, parasites, toxins and chemicals. The report included commissioned studies in four countries namely Albania, Japan, Thailand and Uganda where the study covered both water-borne and food-borne illnesses and data were collated from surveillance sources on acute diarrhea, cholera, dysentery, brucellosis, hepatitis E, typhoid fever, parasitic infections and chemical hazards. The 31 food-borne hazards were responsible for approximately 600 million cases of illnesses, 420,000 deaths and 33 million Disability Adjusted Life Years (DALYs) in 2010 with the greatest burden per population, on the basis of child and adult mortality, in Africa followed by South-East Asia and the Eastern Mediterranean (WHO, 2015). The most frequent causes of food-borne illnesses responsible for 230,000 deaths globally in 2010 were diarrheal disease agents particularly norovirus and *Campylobacter* species. Others were enteropathogenic *Escherichia coli*, enterotoxigenic *E. coli*, shiga-toxin producing *E. coli*, non-typhoidal *Salmonella enterica*, *Shigella* spp., *Vibrio cholerae*, *Cryptosporidium* spp., *Entamoeba histolytica* and *Gardia* species. Non-typhoidal *Salmonella enterica* in particular was a major cause of food-borne deaths globally, with Africa most severely affected. Other major causes of food-borne deaths were *Salmonella typhi*, *Taenia solium*, hepatitis A virus and aflatoxin. Other notable bacteria responsible for food-borne illnesses highlighted in the FERG report include *Listeria monocytogenes*, *Mycobacterium bovis*, *Salmonella paratyphi*, *Bacillus cereus* and *Clostridium botulinum* (WHO, 2015).

Fruits and vegetables are important components of diets, adding a variety of colors, unique flavors and a range of textures. They contribute to food security and play critical roles in nutrition, health and general wellbeing of people (Aworh, 2015, 2018). The WHO 2004 report on a Global Strategy on Diet, Physical Activity and Health recommended increased consumption of fruits and vegetables, with a minimum daily intake of 400 g of fruits and vegetables for a healthy lifestyle (Smith & Eyzaguirre, 2007; WHO, 2004). Even though commercial fruit and vegetable production in Africa is among the lowest in the world and African countries have low fruit and vegetable consumption with poverty a major factor (Hall, Moore, Harper, & Lynch, 2009), animal-source foods and fresh fruits and vegetables are the leading cause of food-borne diseases in SSA (Grace, 2015). The high moisture content of these food commodities and their high nutrient content promote microbial growth including pathogenic bacteria.

There is the need to focus on food safety along the value chain and not just in the household and institutions in SSA where food-borne diseases are likely to increase due to increased consumption of animal-source foods and fresh produce and lengthening and broadening value chains (Grace, 2015). Reliable information on hazards, risks and mitigation including process control and critical control points along the value chain are needed. There is also the need for capacity to advocate for food safety and respond to food safety needs in addition to improved infrastructure and marketing skills (Grace et al., 2018). Efficient post-harvest handling of perishable produce requires the integration into one carefully controlled system, of all operations and stages involved in the movement of the produce from the farm gate to the retail outlet (Aworh, 2014). Small, resource-poor farmers account for up to 90% of agricultural production in many parts of SSA and the fresh produce supply chain evolved in response to the food production pattern characterized by a large number of peasant farmers with small, often less than 1 ha, non-contiguous holdings (Aworh, 2014). Market preparatory practices (packinghouse operations) including washing with water treated with chlorine or other disinfectants, chemical treatment with fungicides and bactericides, and protective packaging are lacking making fresh produce prone to contamination by spoilage organisms as well as those responsible for food-borne diseases (Aworh, 2014). The objective of this paper is to highlight food safety issues associated with fresh produce with particular emphasis on the fresh produce supply chain in SSA and recommend interventions that can minimize food-borne illnesses due to fresh produce and strengthen the fresh produce supply chain in SSA including leveraging digital technology.

2. Characteristics of fresh produce supply chain

The need to maintain good agricultural practices throughout the production system cannot be overemphasized. The application of good agricultural practices is considered as the most important control measure to assure the safety of fresh produce, followed by the application of good hygienic practices and the certification of food safety management systems (Van Boxstael et al., 2013). Microbial contamination of fresh produce may begin right in the field. Untreated manure when used in growing fruits and vegetables may harbor large populations of pathogenic microorganisms including *L. monocytogenes*, *E. coli* O157:H7, *Salmonella* spp., *Mycobacterium* spp., *Brucella* spp., *Bacillus anthracis*, *Yersinia enterocolitica*, *Clostridium perfringes* and *Klebsiella* spp. (Pell, 1997). Other sources of contamination of fresh produce on the farm include contaminated irrigation and wash water (Sivapalasingam, Friedman, Cohen, & Tauxe, 2004). Microbial contamination of produce in the field is more likely in SSA where growing conditions are often unhygienic and protective practices such as the use of plastic mulch (thin plastic sheets used primarily to control weeds and conserve water) that prevents fresh fruits and vegetables from coming in contact with soil-borne microorganisms are lacking. Harvesting methods in SSA predispose fruits to microbial contamination and often involve violently shaking tree branches so that the fruits fall to the ground or hitting them with sticks or similar objects leading to harvest injuries that promote infection. Harvesting fruits from tall trees by severing them at the point of attachment to the stalk with a sickle or knife attached to a long pole with the provision of some form of cushioning for falling fruits to prevent them from falling to the ground or the use of ladders and picking bags is recommended for better quality produce and to minimize microbial contamination (Aworh, 2014).

The typical traditional supply chain for fresh fruits and vegetables in Nigeria, Uganda and most parts of SSA consists of three main stages (Apolot et al., 2020; Aworh, 2014). In the first stage, small farmers offer their small harvests to traders in the village markets or first assembly points. The second stage involves the movement of the accumulated produce along the supply chain to secondary collection centers. The produce is then moved in the third stage to central wholesale markets in urban centers. Transportation of fresh produce from the farm gate to the primary and secondary collection centers is primarily as head loads or by means of farm animals, wheel barrows, carts, bicycles, motorcycles, and motor vehicles of all sorts (Apolot et al., 2020; Aworh, 2014). At the collection centers, fresh fruits and vegetables are often heaped together in piles in the open without any form of protection. From these centers, the produce is transported by road to urban central wholesale markets mainly in open non-refrigerated trucks with capacities ranging from less than 10 tons to up to 30 tons (Apolot et al., 2020; Aworh, 2014; Berinyuy & Fontem, 2011). Smaller units are transported in ‘kombi’ buses and 'pick-ups' (Aworh, 2014). The common practice in fresh produce supply chain in SSA is to transport produce in bulk or packed in raffia or bamboo baskets, wooden containers or salvaged fiberboard cartons and other improvised containers previously used to package imported or locally manufactured products (Apolot et al., 2020; Aworh, 2014). There is the critical need for improved packaging systems, refrigerated transport and cold chains for perishable produce in SSA for better produce quality and food safety (Kader, 2010; Kitinoja et al., 2011). The traditional raffia or bamboo basket which is the most common and cheapest container for conveying fresh fruits and vegetables in many parts of SSA offers little protection to the produce and is not conducive to efficient handling and transportation of fresh produce. The use of rigid crates made from polypropylene, high-density polyethylene or similar plastics is recommended for fresh fruits and vegetables in SSA. Rigid plastic crates, especially of the stack/nest design, have unique advantages that make them very suitable as transport containers for fresh produce. They are lightweight and strong, practically impermeable to moisture, have good stack stability and smooth surfaces that can be easily cleaned and sanitized, reducing contamination by microorganisms responsible for spoilage and food-borne diseases (Aworh, 2014).

The central wholesale market occupies a prime position in fresh produce supply chain in Nigeria and other parts of SSA and it is here that the price levels of commodities are determined to a large extent by market players (Aworh, 2014). Regrettably, these markets are often in very poor shape. They are, invariably, badly located, heavily congested, badly maintained and lack the physical facilities and essential infrastructure including electricity and potable water from municipal sources and waste disposal facilities to handle the large volume of produce that pass through them. Market transactions are often carried out in the open exposing the produce to the elements. Market stalls, where they exist, are badly designed and constructed and they lack modern storage facilities (Apolot et al., 2020; Aworh, 2014; Berinyuy & Fontem, 2011). Since potable water is often lacking, practices such as wetting leafy vegetables with water or placing them in a bucket of water to control moisture loss and wilting as is common in Nigeria, Uganda, Swaziland and many parts of SSA, though desirable for maintaining freshness, may lead to contamination with water-borne disease organisms (Apolot et al., 2020; Masarirambi, Mavuso, Songwe, Nkambule, & Mhazo, 2010). Other players in the fresh produce supply chain are retailers that buy from wholesale markets with some having permanent stalls, or direct from farmers and sell their produce direct to motorists on major inter-city highways thus bypassing middlemen, and street hawkers that operate largely in the cities during the period of glut (Aworh, 2014). A large number of operatives-farmers, traders and middlemen/transporters-with little knowledge of proper post-harvest handling practices and food safety are involved in fresh produce supply chains in SSA. Advocacy, capacity building and improved market infrastructure are crucial to promoting food safety and reducing food-borne illnesses due to fresh produce in developing countries (Kitinoja et al., 2011). Grower and central packinghouses where fresh produce are subjected to market preparatory treatments that promote keeping quality and food safety including sorting and grading, washing with water treated with chlorine or other disinfectants, precooling, chemical treatment with fungicides and bactericides, hot water dips, waxing and protective packaging are an important integral component of fresh produce supply chain in industrialized countries. The need for packinghouses in fresh produce supply chain in SSA cannot be overstressed and these need not be as sophisticated as the packinghouses in developed countries (Aworh, 2014; Kader, 2010; Kitinoja et al., 2011). Small farmers should be organized into cooperatives that could invest in and manage packinghouses and storage facilities, facilitate transportation to markets, act as a common selling unit for the members and distribute profits as appropriate (Kader, 2005; Kitinoja et al., 2011).

3. Microbial contamination of fresh produce

Pathogenic bacteria are considered the most important food safety issue for fresh produce, followed by food-borne viruses, pesticide residues and mycotoxins (Van Boxstael et al., 2013) and there has been growing concern over the increase in outbreaks of food-borne illnesses caused by fresh produce since the 1970s (Sivapalasingam et al., 2004). Table 1 lists the most common microbial agents responsible for food-borne diseases due to fresh produce and the nature of the diseases with diarrhea a common feature. An evaluation of outbreaks of food-borne illnesses associated with fresh produce in the US reported to the Centers for Disease Control and Prevention (CDC) from 1973 through 1997 revealed that 190 produce-associated outbreaks were implicated in 16,058 illnesses, 598 hospitalizations and eight deaths. Multiple produce items that included salad, mixed fruits and mixed vegetables were associated with 55% of the outbreaks and single produce items accounted for 45% of the outbreaks with lettuce, melon (particularly watermelon and cantaloupe), seed sprouts, apple or orange juice and berries (particularly strawberry and raspberry) the most common cause of single produce outbreaks. *Salmonella* was the most important bacterium responsible for the illnesses. Others were *E. coli* O157:H7, *Shigella*, *Campylobacter*, non-O157 *E. coli*, *Bacillus cereus*, *Yersinia enterocolitica* and *S. aureus*. Viral infections were due to hepatitis A virus and norovirus (Sivapalasingam et al., 2004). Parasites were responsible for 16 out of 103 of the outbreaks attributed to a specific etiological agent. Eight (50%) were due to *Cyclospora cayetanensis*, a coccidian parasite, five to *Giardia lamblia* and three to *Cryptosporidium parvum* (Sivapalasingam et al., 2004). Nineteen out of some of the outbreaks of food-borne diseases due to fresh produce reported between 2013 and 2016 in USA (11 outbreaks), UK (4 outbreaks), Australia (3 outbreaks) and New Zealand (1 outbreak) involved a variety of produce including rock melon, lettuce, cucumber, clover sprouts, mung bean sprouts, watercress etc. with *Salmonella* spp., *E. Coli*, *L. monocytogenes* and hepatitis A virus among the causative microorganisms (Wadamori, Gooneratne, & Hussain, 2017). *C. cayetanensis* was responsible for two of the major outbreaks of food-borne illnesses due to salad mix and coriander in USA in 2013 and 2014 (Wadamori et al., 2017).

Some of the reported outbreaks of food-borne illnesses due to fresh produce are linked to fresh produce exported from developing countries such as hepatitis A outbreak in the US in 2003 linked to the importation of green onions from Mexico (Wheeler et al., 2005), *Salmonella*

Table 1
Common microbial agents responsible for food borne diseases due to fresh produce.

Microbial agent	Nature of Disease
Norovirus	Vomiting and diarrhea
Hepatitis A virus	Hepatitis A liver infection
Campylobacter spp	Inflammatory and sometimes bloody diarrhea, Guillain-Barre syndrome
Enteropathogenic *Escherichia coli* (EPEC)	Diarrhea
Enterotoxigenic *Escherichia coli* (ETEC)	Profuse, watery diarrhea
Shiga toxin-producing *E. coli* (STEC) e.g. O157:H7 and other non-O157 STEC	Diarrhea, hemolytic uremic syndrome, end-stage renal disease
Non-typhoidal *Salmonella enterica*	Diarrhea, invasive salmonellosis
Salmonella typhi	Typhoid fever, liver abscesses and cysts
Salmonella paratyphi	Paratyphoid fever, liver abscesses and cysts
Staphylococcus aureus	Acute intoxication
Listeria monocytogenes	Sepsis, central nervous system infection, neurological sequelae
Shigella spp	Diarrhea, often bloody
Bacillus cereus	Acute intoxication
Yersinia enterocolitica	Diarrhea
Cryptosporidium parvum	Diarrhea
Giardia lamblia	Diarrhea
Cyclospora cayetanensis	Diarrhea

senftenberg outbreak in 2008 in the US linked to imported peppers from Mexico (Behravesh et al., 2011) and shiga toxin-producing *E. coli* O104: H4 outbreak in 2011 in France and Germany linked to sprouted fenugreek seeds imported from Egypt (EFSA, 2011). High prevalence of *S. aureus*, *E. coli*, *Enterobacter* sp., *Klebsiella* sp., *S. typhi*, *Serratia* sp., *Providencia* sp. and *Pseudomonas aeruginosa* was reported in 120 samples of different types of fresh produce including salad vegetables, fruits and sprouts from street vendors in India with *P. aeruginosa* the most antibiotic resistant of the contaminating microorganisms (Viswanathan & Kaur, 2001). The emergence of antimicrobial resistant bacterial strains is a major public health problem with microorganisms developing resistant strains against common antibiotics such as penicillin and vancomycin and diseases such as tuberculosis, once considered to be eradicated, re-emerging (Pruden, Pei, Storteboom, & Carlson, 2006). Vegetable samples (550) from different markets of Kalaburagi, India had high populations of *E. coli*, *Salmonella* sp. and *Shigella* sp., and among the most highly contaminated vegetables (50% or more) were chilli, dill, capsicum, spinach, parsley, peas and cauliflower (Gundappa & Gaddad, 2016). Salad vegetables including carrot, cucumber, tomato and lettuce from different markets and shops of Dhaka City, Bangladesh had high populations of *S. aureus*, *E. coli* and *Listeria* spp. (Rahman & Noor, 2012).

Even though reliable data are scanty, it is clear that microbial contamination of fresh produce is widespread in SSA. An evaluation of 13 out of 37 food-borne disease outbreaks from various parts of Kenya involving a total of 926 people reported to the Kenyan Ministry of Health from 1970 to 1993 and confirmed to be due to known etiological agents indicated that the foods involved in the outbreaks included milk and milk products, meat and meat products, maize flour, bread scones and other wheat products, vegetables and lemon pie pudding (Ombui, Kagiko, & Arimi, 2001). The microorganisms responsible for some of the food-borne diseases were *S. aureus* (five outbreaks), *Clostridium perfringes* (one outbreak) and *Clostridium botulinum* (two outbreaks). *S. aureus* (two outbreaks), *B. cereus* (one outbreak) and *Salmonella* spp. (three outbreaks) were tentatively diagnosed as being responsible for some of another twenty food-borne disease outbreaks involving 518 people reported in Kenya between 1970 and 1993 (Ombui et al., 2001). Specimens collected in 239 out of 327 food-borne disease outbreaks reported from 2013 to 2017 to the South African National Institute for Communicable Diseases indicated the presence of pathogenic microorganisms including *Salmonella* spp. (11%), *E. coli* (11%), *B. cereus* (10%), *C. perfringes* (3%) and *L. monocytogenes* (3%) in 132 food samples collected (Shonhiwa, Ntshoe, Essel, Thomas, & McCarthy, 2019). In a systematic review of literature from Nigeria on food-borne hazards covering a total of 860 titles and abstracts, only 15% of the studies were considered as good quality and most of them focused only on assessing food-borne hazard prevalence in foods without considering the health and economic impact (Grace et al., 2018). Fruits and vegetables dominated the studies and a vast majority of them reported the presence of bacteria responsible for food-borne diseases in fresh fruits and vegetables sold in Nigerian markets with a high prevalence of *Bacillus* species. *Salmonella* spp., *Proteus* spp. and *S. aureus* (6–52% of positive samples) were among the other microorganisms responsible for food-borne diseases reported in various fruits including watermelon, pineapple and papaya in Nigerian markets. *L. monocytogenes* was also reported to be present in different vegetables (Grace et al., 2018).

4. Chemical contamination of fresh produce

There is no doubt that contamination due to the use of chemicals in food and agriculture has been a major concern from the standpoint of food safety for decades. A wide range of chemicals including insecticides and fungicides are used for pest control in fresh produce. Contact insecticides are commonly classified as pyrethroid, organochlorine, organophosphate and carbamate insecticides depending on their chemical nature (Table 2). Some of these chemicals like aldicarb, DDT and hexachlorobenzene have been banned because of their toxicity and damaging effects on the environment. Pyrethrins (natural insecticides from chrysanthemum flowers) and pyrethroids (synthetic pyrethrins) are generally considered as among the safest insecticides (Ray & Fry, 2006). Four percent (4%) of 103 produce-associated outbreaks of food-borne illnesses attributed to a specific etiological agent reported to the CDC in the US from 1973 through 1997 were caused by chemicals and poisons with aldicarb, an insecticide and nematicide (Table 2), accounting for 50% of them. The aldicarb food-borne disease outbreaks were due to contamination of watermelon that led to 53 persons becoming ill and of cucumber (Sivapalasingam et al., 2004). The use of pesticides is strictly regulated in developed economies and in international trade and a maximum residue level (MRL) specified for each pesticide is permitted in foods including fresh produce for food safety (Bhilwadikar, Pounraj, Manivannan, Rastogi, & Negi, 2019).

Unfortunately, there is widespread indiscriminate use of chemicals in developing countries where legislations that regulate pesticide residues and other chemicals in foods are often simply not in place, are poorly enacted or not enforced. Many older, non-patented, more toxic, environmentally persistent and inexpensive pesticides are widely used in developing countries creating serious public health problems (Ecobichon, 2001). A review of pesticide residues in fruits and vegetables from Pakistan indicated that 50% were contaminated with organophosphate, pyrethroid and organochlorine pesticides and 50% of samples of tomato, apple, melon, mango, grapes and plum had residue levels above the MRLs (Syed et al., 2014). In Kuwait, residues of many pesticides including imidacloprid, deltamethrin, cypermethrin, malathion, acetamiprid, monocrotophos, chlorpyrifos-methyl and diazinon exceeding their MRLs were found in 21% of 150 samples of different commonly consumed fresh fruits and vegetables including strawberry, watermelon, apple, grapes, tomato, bell pepper, eggplant, cucumber, zucchini, cabbage, carrot and potato (Jallow, Awadh, Albaho, Devi, & Ahmad, 2017). Residue of aldrin, an organochlorine insecticide (Table 2) which has been banned in most countries, was found in one apple sample (Jallow et al., 2017). Similarly, pesticide residues exceeding the MRLs were found in 15% of 250 field samples of vegetables including brinjal, okra, green chilli, crucifers and cucurbits from

Table 2
Some potent contact insecticides and fungicides.

Insecticides				Fungicides
Pyrethroids	Organochlorines	Organophosphates	Carbamates	
Permethrin	Lindane	Dimethoate		Thiabendazole
Cypermethrin	Aldrin	Malathion	Carbaryl	Benomyl
Deltamethrin	Dieldrin	Chlorpyrifos	Propoxur	Imazilil (Enilconazole)
Resmethrin	Endrin	Profenofos	Aldicarb	Fludioxonil
Tetramethrin	Heptachlor	Trichlorfan (Metrifonate)	Methomyl	Pyrimethanil
Phenothrin	Endosulfan	Dichlorvos	Carbofuran	Tebuconazole
Cyphenothrin	Methoxyclor	Fenitrothion		Azoxystrobin
Fenpropathrin	Toxaphene	Diazinon		Dimethomorph
Fenvalerate	Chlordane			Hexachloro-benzene
	Dichloro-diphenyl-trichloroethane (DDT)			Chlorothalonil

Andaman Islands, India analyzed for the presence of a wide range of organochlorine, organophosphate and pyrethroid insecticides (Swarnam & Velmurugen, 2013). Pesticide residues exceeding the MRLs were found in 33% of market samples (320) of locally grown papaya and tomato and imported apples analyzed for pesticide residues, mainly organochlorines such as aldrin, heptachlor, DDT, methoxychlor, etc. in Accra, Metropolis, Ghana (Bempah & Donkor, 2011). High levels of pesticide residues and other chemical contaminants in foods have led to export restrictions with serious consequences for the economies of many developing countries. However, present knowledge does not permit accurate estimate of the health burden associated with chemicals in foods in developing countries (Grace, 2015).

A growing food safety concern with regards to fresh fruits in developing countries including SSA is the use of cheap, readily available calcium carbide for artificially ripening fruits (Islam, Mursalat, & Khan, 2016). When calcium carbide reacts with moisture, it produces acetylene and calcium hydroxide. Acetylene mimics ethylene which is produced naturally by fruits from methionine and stimulates ripening in climacteric fruits, and is used exogenously in controlled commercial ripening of fruits and degreening of citrus (Aworh, 2014). Calcium carbide is alkaline and can irritate the mucosal tissue of the abdominal region causing stomach disorder that has been reported after eating mangoes artificially ripened with calcium carbide (Islam et al., 2016). Industrial grade calcium carbide may contain impurities such as arsenic and phosphorus that may have adverse effects on the health of those applying calcium carbide to fruits including dizziness, frequent thirst, irritation in mouth and nose, weakness, permanent skin damage, difficulty in swallowing, vomiting and skin ulcer. Direct exposure to acetylene may result in reduced oxygen supply to the brain and prolonged hypoxia (Islam et al., 2016). Other adverse health effects associated with the use of calcium carbide in artificial fruit ripening include mood disturbances, mental confusion, memory loss and cerebral edema (Asif, 2012).

Mycotoxins are a leading cause of food-borne diseases most commonly associated with grains, nuts and dried plant food products and there is limited knowledge regarding mycotoxins in fresh produce, e.g. altenariol in tomatoes (Van Boxstael et al., 2013). However, some studies indicate the potential presence of mycotoxin producing fungi on fruits and vegetables and it is feared that the food safety risks associated with mycotoxins in fresh produce may be greater than presently recognized and that the trend of using less fungicides might increase mold growth in fresh produce with potentials for mycotoxin contamination (Van Boxstael et al., 2013).

5. Control of microbial and chemical contamination of fresh produce

Food safety control measures in fresh produce should be throughout the supply chain as contamination can occur at various points and a thorough understanding of the source of contamination and the major contributory factors is critical for success (Bhilwadikar et al., 2019). Management practices that reduce risks of contamination of fruits and vegetables after harvest by pathogenic bacteria include sorting, precooling, chlorination of wash water, refrigerated shipping and refrigerated storage (Aworh, 2014). Even though some psychrotrophic pathogenic bacteria such as *L. monocytogenes* can grow at temperatures as low as −1.5 °C, refrigeration is a very important means of controlling pathogenic microorganisms in fresh produce and the need for cold chains for fresh produce in SSA cannot be overstressed (Kader, 2010; Kitinoja et al., 2011).

Post-harvest chemical treatment is one of the effective ways of decontaminating fresh produce. Sodium hypochlorite, commonly used at concentrations of 50–200 ppm, is the most widely used disinfectant for washing fresh produce (Bhilwadikar et al., 2019). Adding sodium hypochlorite to water in a wash tank is recommended as a simple, effective means of controlling pathogenic bacteria in fresh fruits and vegetables in SSA (Aworh, 2014). Apart from the fact that it is more effective against pathogenic bacteria than other chlorine-based antimicrobials and does not produce toxic byproducts from the breakdown of pesticides like chlorine solutions, gaseous chlorine dioxide, a potent oxidizing agent, has potentials for reducing pesticide residues in fresh fruits and vegetables as well (Bhilwadikar et al., 2019). Fumigation with gaseous chlorine dioxide reduced pesticide levels in grapes sprayed with tebuconazole by 65%, azoxystrobin by 51%, dimethomorph (E) by 39% and dimethomorph (Z) by 41%, all levels below their MRLs, after storage for 27 days at 0 °C (Wei, Chen, Tiemur, Wang, & Wu, 2018). A variety of other chemicals including hydrogen peroxide, peroxyacetic acid, benzalkonium chloride, organic acids, acidified sodium chlorite, sodium bicarbonate and sodium hydroxide, calcium-based solutions, potassium permanganate, essential oils and other washing solutions are useful in decontaminating fresh produce and their efficacy, mode of action, limitations, current use and future potentials have recently been extensively reviewed (Bhilwadikar et al., 2019). Electrolyzed water, a well-known disinfectant in the food industry whose disinfecting properties are due to chlorine, and ozone, a powerful oxidizing agent, are effective in destroying pathogenic microorganisms and reducing pesticide residues in fruits and vegetables (Bhilwadikar et al., 2019).

Ionizing radiation from radioactive isotopes such as cobalt (^{60}Co) and caesium (^{137}Cs), x-rays and accelerated electrons from machines operating at energy levels of not more than 5 and 10 MeV respectively have been used for commercial food preservation since the 1970s and there is now little concern about the safety of food irradiated within the acceptable dose range (Monk, Beuchat, & Doyle, 1995). Food irradiation is useful in inactivating specific pathogenic or spoilage microorganisms and for insect disinfestation in fresh produce and has the advantages of not heating up the produce or leaving toxic residues. Most of the damaging effects of ionizing radiation on microorganisms are due to ion pairs and free radicals such as hydroxyl (·OH) and hydrogen (·H) which are produced when the rays collide with water and other food molecules. Hydroxyl and hydrogen radicals are strong oxidizing and reducing agents respectively and they can react with each other or with dissolved oxygen producing hydrogen peroxide and peroxide radical ($\cdot HO_2$) respectively (Aworh, 2014; Bhilwadikar et al., 2019). Irradiation may also be effective in removing pesticide residues in fresh produce especially in aqueous solutions as compared to dry treatments (Bhilwadikar et al., 2019). However, undesirable effects such as abnormal ripening and excessive softening may result when fruits and vegetables are irradiated, especially at high doses. Irradiation is now in use in many countries for the control of spoilage and pathogenic microorganisms, insects and parasites in foods based on the principles of the Codex General Standard for Irradiated Foods (CODEX STAN 106–1983) and the relevant provisions of the agreements of the World Trade Organization including the Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures. Even though commercial scale application of food irradiation has been carried out in South Africa since the 1980s and a study commissioned by the International Atomic Energy Agency (IAEA) between 1995 and 1999 demonstrated the potentials of food irradiation in Africa, widespread adoption of the technology in SSA is constrained by social, technical and economic factors (IAEA, 2002).

Modern techniques such as food irradiation, cold plasma, electrolyzed water, ozone, high hydrostatic pressure, pulsed light, ultraviolet light and ultrasound are more effective in the destruction of pathogenic microorganisms and the removal of pesticide residues from fresh produce (Bhilwadikar et al., 2019). However, their industrial use in developing countries is limited by the high installation and maintenance cost, and lack of requisite expertise. The use of hurdle technology in which a combination of techniques is deployed to produce synergy is more appropriate for effective decontamination of microorganisms and pesticides in fresh produce to reduce treatment cost and enhance food safety in developing countries (Bhilwadikar et al., 2019).

6. Leveraging digital technology in strengthening fresh produce supply chain

Digital technology has been adopted in precision agriculture for managing and optimizing crop production, increasing the efficiency of agricultural extension services, providing solutions to information problems that limit access for small-scale farmers and for developing new approaches to agricultural supply chain management. Digital technology can have profound positive impact on agriculture outcomes in developing countries by improving market transparency, enhancing farm productivity, improving rural households' food security, strengthening logistics and optimizing supply chain management, and improving food quality and safety as has been demonstrated in studies in parts of SSA including Uganda, Niger, Ethiopia, Rwanda, Ghana, Kenya, South Africa, Zambia, Namibia, Mali and Nigeria (Deichmann, Goyal, & Mishra, 2016). The use of mobile phones has revolutionized information dissemination in developing countries and Africa has the fastest-growing number of mobile phone users in the world. For example, in Nigeria, mobile phone penetration has shown nearly linear growth since 2012 reaching 83% in 2016 (Forenbacher, Husnjak, Cvitic, & Jovovic, 2019). This revolution offers new opportunities for farmers and agricultural production in SSA and even poor farmers now have access to mobile phones and can benefit from short messaging service (sms) or "texting" that offers access to weather, market and price information that can increase farmers' income (Deichmann, Goyal & Misra, 2016). By creating efficient linkages between production and market, and overcoming the constraint of access to market information, mobile phones and the internet can reduce reliance on market intermediaries and promote the inclusion of resource-poor, smallholder farmers that are often marginalized in national, regional and even global markets (Awuor, Kimeli, Rabah, & Rambim, 2013; Deichmann, Goyal & Misra, 2016).

Traceability has become an important feature of the global food supply chain with the growing food safety concerns and the globalization of food production and distribution. Traceability helps to minimize the production and distribution of poor quality and unsafe foods, minimizing the need for recalls and issues relating to bad publicity and liability (Aung & Chang, 2014). Food chain integrity is not just limited to food quality and safety concerns but issues such as origin fraud also come into play. Traceability is a tool to comply with legislation and to meet food safety and quality requirements of international trade in a transparent manner within food chains and increase consumer confidence (Aung & Chang, 2014). Small farmers in developing countries who want access to international markets but lack the necessary resources to trace their products from the farm gate to the market now increasingly rely on cooperatives and aggregators who are leveraging ICTs to improve traceability (Deichmann, Goyal & Misra, 2016). This underscores the need for small, resource-poor farmers in SSA to be organized into cooperatives to be able to adopt new technological innovations. The use of ICT in agriculture in SSA is constrained by poor awareness of the impact that ICT can make, the lack of the requisite software and technological infrastructure and the perceived high cost of ICT adoption (Awuor et al., 2013). While the use of mobile phone is now widespread in most of SSA, internet access remains low. Internet access can have even greater impact on agriculture and rural development, food quality and safety in SSA, and there is the critical need to encourage its spread (Deichmann et al., 2016). Substantial investment is needed to adapt and use ICT for sustainable agricultural productivity, food quality and safety in SSA and this will require public-private partnership (Awuor et al., 2013).

7. Conclusion

Food-borne illnesses due to microbial and chemical contamination are a major public health concern in SSA and animal-source foods and fresh fruits and vegetables are the primary sources. Poor handling practices along the fresh produce supply chain from farm to market and from rural to urban areas, poor infrastructure including transport and market infrastructure, and lack of refrigeration capacity in a tropical environment promote the growth of pathogenic organisms with adverse consequences for food safety and public health. Adoption of good agricultural and health practices and improved post-harvest handling will promote food safety throughout the fresh produce supply chain. Mobile phone and internet can improve food quality and safety and overcome the constraint of access to market information by smallholder farmers that account for the bulk of agricultural production in SSA.

Declaration of competing interest

I assert that there is no conflict of interest on my part regarding the manuscript entitled "Food safety issues in fresh produce supply chain with particular reference to sub-Saharan Africa" submitted for consideration for publication in Food Control.

References

Apolot, M. G., Acham, H., Ssozi, J., Namutebi, A., Masanza, M., Kizito, E., et al. (2020). Postharvest practices along supply chains of *Solanum aethiopicum* (shum) and *Amaranthus lividus* (Linn) leafy vegetables in Wakiso and Kampala Districts, Uganda. *African Journal of Food, Agriculture, Nutrition and Development, 20*, 15978–15991.

Asif, M. (2012). Physico-chemical properties and toxic effect of fruit-ripening agent calcium carbide. *Annals of Tropical Medicine and Public Health, 5*, 150–156.

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control, 39*, 172–184.

Aworh, O. C. (2014). *Lesser-Known Nigerian Fruits and Vegetables: Post-Harvest Handling, Utilization and Nutritional Value*. Ibadan, Nigeria: Ibadan University Press.

Aworh, O. C. (2015). Promoting food security and enhancing Nigeria's small farmers' income through value-added processing of lesser-known and under-utilized indigenous fruits and vegetables. *Food Research International, 76*, 986–991.

Aworh, O. C. (2018). From lesser-known to super vegetables: The growing profile of African traditional leafy vegetables in promoting food security and wellness. *Journal of the Science of Food and Agriculture, 98*, 3609–3613.

Awuor, F., Kimeli, K., Rabah, K., & Rambim, D. (2013). ICT solution architecture for agriculture. In P. Cunningham, & M. Cunningham (Eds.), *IST-africa 2013 Conference Proceedings*. www.IST-Africa.org/Conference2013.

Behravesh, C. B., Mody, R. K., Jungk, J., Gaul, L., Redd, J. T., Chen, S., et al. (2011). 2008 outbreak of *Salmonella* Saintpaul infections associated with raw produce. *New England Journal of Medicine, 364*, 918–927.

Bempah, C. K., & Donkor, A. K. (2011). Pesticide residues in fruits at the market level in Accra, Metropolis, Ghana, a preliminary study. *Environmental Monitoring and Assessment, 175*, 551–561.

Berinyuy, J. E., & Fontem, D. A. (2011). Evaluating post harvest opportunities and constraints to utilization and marketing of African leafy vegetables in Cameroon. *African Journal of Food, Agriculture, Nutrition and Development, 11*, 4647–4663.

Bhilwadikar, T., Pounraj, S., Manivannan, S., Rastogi, N. K., & Negi, P. S. (2019). Decontamination of microorganisms and pesticides from fresh fruits and vegetables: A comprehensive review from common household processes to modern techniques. *Comprehensive Reviews in Food Science and Food Safety, 18*, 1003–1038.

Canagarajah, S., & Thomas, S. (2001). Poverty in a wealthy economy: The case of Nigeria. *Journal of African Economies, 10*, 143–173.

Deichmann, U., Goyal, A., & Mishra, D. (2016). *Will digital technologies transform agriculture in developing countries? Policy Research working paper 7669*. World Bank Group. http://econ.worldbank.org.

Ecobichon, D. J. (2001). Pesticide use in developing countries. *Toxicology, 160*, 27–33.

EFSA. (2011). European food safety Authority. Shiga toxin-producing E. coli (STEC) O104:H4 2011 outbreaks in Europe: Taking stock. *EFSA Journal, 9*, 1–22.

Forenbacher, I., Husnjak, S., Cvitic, I., & Jovovic, I. (2019). Determinants of mobile phone ownership in Nigeria. *Telecommunications Policy, 43*(7), Article 101812. https://doi.org/10.1016/j.telpol.2019.03.001

Grace, D. (2015). Food safety in low and middle income countries. *International Journal of Environmental Research and Public Health, 12*(9), 10490–10507. https://doi.org/10.3390/ijerph120910490

Grace, D., Alonso, S., Mutua, F., Roesel, K., Lindahl, J., & Amenu, K. (2018). *Food safety investment Expert Advice: Burkina Faso, Ethiopia, Nigeria*. Nairobi, Kenya: International Livestock Research Institute.

Gundappa, M., & Gaddad, S. M. (2016). Prevalence of Salmonella, Shigella and E. coli in vegetables of various markets in Kalaburagi (India). *Indian Journal of Natural Sciences, 35*, 10851–10858.

Hall, J. N., Moore, S., Harper, S. B., & Lynch, J. W. (2009). Global variability in fruit and vegetable consumption. *American Journal of Preventive Medicine, 36*, 402–409.

International Atomic Energy Agency of the United Nations. (2002). *Study of the impact of food irradiation on preventing Losses: Experience in Africa*. Vienna, Austria: IAEA.

Islam, M. N., Mursalat, M. M., & Khan, M. S. (2016). A review on the legislative aspect of artificial fruit ripening. *Agriculture & Food Security, 5*, 8. https://doi.org/10.1186/s40066-0057-5

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Ahmad, N. (2017). Monitoring of pesticide residues in commonly used fruits and vegetables in Kuwait. *International Journal of Environmental Research and Public Health, 14*(8), 833. https://doi.org/10.3390/ijerph14080833

Kader, A. A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. *Acta Horticulturae, 682*, 2169–2175.

Kader, A. A. (2010). Handling of horticultural perishables in developing vs. developed countries. *Acta Horticulturae, 877*, 121–126.

Kitinoja, L., Saran, S., Roy, S. K., & Kader, A. A. (2011). Postharvest technology for developing countries: Challenges and opportunities in research, outreach and advocacy. *Journal of the Science of Food and Agriculture, 91*, 597–603.

Masarirambi, M. T., Mavuso, V., Songwe, V. D., Nkambule, T. P., & Mhazo, N. (2010). Indigenous post-harvest handling and processing of traditional vegetables in Swaziland: A review. *African Journal of Agricultural Research, 5*, 3333–3341.

Monk, J. D., Beuchat, L. R., & Doyle, M. P. (1995). Irradiation inactivation of food-borne microorganisms. *Journal of Food Protection, 58*, 197–208.

Ombui, J. N., Kagiko, M. M., & Arimi, S. M. (2001). Foodborne diseases in Kenya. *East African Medical Journal, 78*, 40–44.

Oshewolo, S. (2010). Galloping poverty in Nigeria: An appraisal of government interventionist policies. *Journal of Sustainable Development in Africa, 12*, 264–274.

Pell, A. N. (1997). Manure and microbes: Public and animal health problem? *Journal of Dairy Science, 80*, 2673–2681.

Pruden, A., Pei, R., Storteboom, H., & Carlson, K. H. (2006). Antibiotic resistant genes as emerging contaminants: Studies in northern Colorado. *Environmental Science and Technology, 40*, 7445–7450.

Rahman, F., & Noor, R. (2012). Prevalence of pathogenic bacteria in common salad vegetables of Dhaka metropolis. *Bangladesh Journal of Botany, 41*, 159–162.

Ray, D. E., & Fry, J. R. (2006). A reassessment of the neurotoxicity of pyrethroid insecticides. *Pharmacology & Therapeutics, 111*(1), 174–193.

Shonhiwa, A. M., Ntshoe, G., Essel, V., Thomas, J., & McCarthy, K. (2019). A review of foodborne diseases outbreaks reported to the outbreak response unit, national institute for communicable diseases, South Africa, 2013-2017. *Abstracts/International Journal of Infectious Diseases, 79*(S1), 73. https://doi.org/10.1016/j.ijid.2018.11.186 .

Sivapalasingam, S., Friedman, C. R., Cohen, L., & Tauxe, R. V. (2004). Fresh produce: A growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. *Journal of Food Protection, 67*, 2342–2353.

Smith, I. F., & Eyzaguirre, P. (2007). African leafy vegetables: Their role in the world health Organization's global fruit and vegetables initiative. *African Journal of Food, Agriculture, Nutrition and Development, 7*, 1–8.

Swarnam, T. P., & Velmurugen, A. (2013). Pesticide residues in vegetable samples from the Andaman Islands, India. *Environmental Monitoring and Assessment, 185*, 6119–6127.

Syed, J. H., Alamadar, A., Mohammad, A., Ahad, K., Shabir, Z., Ahmed, H., et al. (2014). Pesticide residues in fruits and vegetables from Pakistan: A review of the occurrence and associated health risks. *Environmental Science and Pollution Research International*. https://doi.org/10.1007/s11356-014-3117-z

Van Boxstael, S., Habib, I., Jacxsens, L., De Vocht, M., Baert, L., Van De Pierre, E., et al. (2013). Food safety issues in fresh produce: Bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. *Food Control, 32*, 190–197.

Viswanathan, P., & Kaur, R. (2001). Prevalence and growth of pathogens on salad vegetables, fruits and sprouts. *International Journal of Hygiene and Environmental Health, 203*, 205–213.

Wadamori, Y., Gooneratne, R., & Hussain, M. A. (2017). Outbreaks and factors influencing microbiological contamination of fresh produce. *Journal of the Science of Food and Agriculture, 97*, 1396–1403.

Wei, J., Chen, Y., Tiemur, A., Wang, J., & Wu, B. (2018). Degradation of pesticide residues by gaseous chlorine dioxide on table grapes. *Postharvest Biology and Technology, 137*, 142–148.

Wheeler, C., Vogt, T. M., Armstrong, G. L., Vaughan, G., Weltman, A., Nainan, O. V., et al. (2005). An outbreak of hepatitis A associated with green onions. *New England Journal of Medicine, 353*, 890–897.

World Health Organization of the United Nations. (2004). *Global Strategy on diet, physical Activity and health*. Geneva, Switzerland: WHO.

World Health Organization of the United Nations. (2015). *WHO estimates of the global burden of Foodborne diseases. Food borne disease burden Epidemiology reference Group 2007-2015*. Geneva, Switzerland: WHO.