REVISÃO
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Microbiological safety aspects of mangoes (*Mangifera indica*) and papayas (*Carica papaya*): a mini-review

Aspectos de segurança microbiológica de manga (*Mangifera indica*) e papaya (*Carica papaya*): mini revisão

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ABSTRACT

This review describes several aspects related to microbiological safety in mangoes and papayas, such as incidence, outbreaks, internalisation and growth/survival of bacterial pathogens. Mangoes and papayas are often served sliced in food establishments in fresh pieces at salad bars, deli counters and as pulp juice. In general, these products do not undergo any process to eliminate pathogenic microorganisms before consumption, and a long shelf life could theoretically provide time for these microorganisms to multiply without affecting the organoleptic qualities of the fruit, thereby increasing the risks of food-borne illness. The data presented in this review show that low temperatures can impede microbial growth, but not completely inhibit such growth in mangoes and papayas. Highest growth rates were observed in the range between 22 and 37ºC. In the last 20 years, several outbreaks of salmonellosis caused by these fruits or by food made with these fruits have been reported. The control of the temperature in the fruit washing water is important to prevent the internalisation of *Salmonella* spp. The implementation of strategies such as Good Agricultural Practices, Good Manufacturing Practices and Hazard Analysis Critical is important, as these methods can eliminate or significantly reduce microbial contamination.

KEYWORDS: Mango; Papaya; Safety; Pathogens; bacterium

RESUMO

Esta revisão descreve diversos aspectos relacionados à segurança microbiológica em manga e mamão papaya como; incidência, surtos, internalização e crescimento/sobrevivência de patógenos bacterianos nestas frutas. Mangas e papayas são frequentemente servidas fatiadas em estabelecimentos alimentícios como pedaços frescos, em misturas para saladas, expostas em balcões e como polpas de frutas. No geral, estes produtos não passam por qualquer processo para eliminar microrganismos patogênicos antes do seu consumo e uma vida longa de prateleira poderia teoricamente fornecer tempo para que estes microrganismos se multipliquem sem afetar as qualidades organolépticas destas frutas e assim aumentar o risco de doenças de origem alimentar. Os dados apresentados nesta revisão mostram que baixas temperaturas podem diminuir o crescimento de microrganismos mas não inibi-los em mangas e papayas. Os melhores crescimentos foram observados na faixa de 22–37ºC. Nos últimos 20 anos diversos surtos de salmonelose nestas frutas ou produtos feitos com as mesmas foram relatados. O controle da temperatura da água de lavagem de frutas é importante para prevenir a internalização de *Salmonella* spp. A implementação de estratégias como Boas Práticas Agrícolas, Boas Práticas de Produção e Análise Crítica de Pontos de Controle são importantes já que podem eliminar ou reduzir significantemente a contaminação microbiana.

PALAVRAS- CHAVE: Manga; Papaya; Segurança; Patógenos; bactérias

INTRODUCTION

The consumption of fresh produce, an important source of nutrients, vitamins and fibre for humans, is steadily increasing worldwide. The World Health Organisation (WHO) and the Food and Agricultural Organisation (FAO) recommend a minimum of 400 g of fruit and vegetables per day for the prevention of chronic diseases, such as heart disease, cancer, diabetes and obesity, and for the prevention and alleviation of several micronutrient deficiencies, especially in less developed countries[1,2].

From 1980 to 2004, global fruit and vegetable production increased. This resulted in higher food industry profits and export rates, but also in more frequent disease outbreaks and spoilage problems[2,3,4].

Mango *(Mangifera indica* Linn) and papaya (*Carica papaya*) are tropical fruits of great economic importance and some of the most commonly eaten fruits in tropical countries around the world[5]. According to the FAO in 2013, India leads the world production of papaya with 5,544,000,00 tonnes, followed by Brazil (1,582,638,000 tonnes), Nigeria (773,000,000 tonnes) and Mexico (764,514,000 tonnes). India also has the highest mango production (18,002,000,000 tonnes), followed by Indonesia (2,058,607,000 tonnes), Mexico (1,901,871,000 tonnes), Pakistan (1,658,562,000 tonnes) and Brazil (1,163,000,000 tonnes)[6,7].

At all stages of production, harvesting and processing, fruits and vegetables can become contaminated with microorganisms capable of causing human diseases[8].

Fresh produce, such as fruit and salad, is often consumed raw without undergoing processing, such as cooking, to inactivate harmful microorganisms. In addition, further cutting, slicing or peeling causes tissue damage, which releases nutrients and facilitates microbial growth, putting consumers at risk of infection by contaminating organisms[9,10]. Mangoes and papayas are often served sliced in food establishments at salad bars and deli counters and as raw pulp juice. Preventing fruit and vegetable contamination with pathogenic microorganisms is complex because pathogens are normally present in the soil and may therefore be present on the surfaces of fruits and vegetables at harvesting[8].

Strategies for limiting microbiological contamination of frits

according to Kokkinakis and Fragkiadakis[11], Strawn et al.[12], and Estrada-Acosta et al.[13], implementation of good agricultural practices (GAPs) and good manufacturing practices (GMPs) enhances the safety of fresh produce and its value throughout the food chain. This also facilitates the implementation of Hazard Analysis Critical Control Points (HACCP), which have been developed to identify specific risks related to food processing and as risk control measures. Generally, HACCP programs are a proactive way to limit food safety risks.

On an international level, GAPs and GMPs are described in the Codex Alimentarius Commission's code of hygienic practice for fresh fruits and vegetables[14]. This code helps to control microbial, chemical and physical hazards associated with all stages of fruit and vegetable production (i.e. environmental hygiene, agricultural input requirements, water for primary production, manure, biosolids and other natural fertilisers, soil, indoor facilities associated with growing and harvesting, personnel health, hygiene and sanitary facilities, equipment associated with growing and harvesting, handling, storage and transport, cleaning, maintenance and sanitation of premises and harvesting equipment).

Meanwhile, the HACCP is a tool to assess hazards and establish control systems that focus on prevention rather than rely mainly on end-product testing; it consists of seven principles as described by the Codex Alimentarius[15].

To minimise the risk associated with microbial hazards of fruits, producers and processors have access to several detailed codes, guidelines and regulations, such as "The guide to minimise the microbial food safety hazards for fresh fruits and vegetables, Guidance for industry (FDA)[16]" "Microbiological hazards in fresh fruits and vegetables (FAO/WHO)[17]"; "Microbiological Risk Assessment (Codex)[18] and Microbial Risk Assessment Guideline (FSIS/USDA)[19]".

Intervention methods to extend shelf-life and enhance safety

the best method to eliminate pathogens from produce is to prevent contamination in the first place. However, this is not always possible, and the need to wash and sanitise many types of produce remains of paramount importance to prevent disease outbreaks[20] and increase shelf life. As a result, different treatment methods can be applied to fresh produce, such as chemical, physical, controlled atmosphere storage and modified atmosphere packaging.

Chemical methods

Calcium-based solutions. Calcium treatments have been used to extend the shelf life of fruits and vegetables. Calcium helps to maintain the vegetable cell wall integrity by interacting with pectin to form calcium pectate[21]. One of the most used compounds is calcium lactate, which has antibacterial properties due to its ability to uncouple microbial transport processes [22].

Chlorine (hypochlorite) chemicals are often used to sanitise produce and surfaces in produce processing facilities as well as to reduce microbial populations in water used for cleaning and packaging operations. However, there are safety concerns about the production of chlorinated organic compounds and their impacts on human and environmental safety. Liquid chlorine and hypochlorites are generally used in the 50 to 200 ppm concentration range, with a contact time of 1 to 2 min to sanitise produce surfaces and processing equipment[20].

Chlorine dioxide is a strong oxidising agent and a safe bactericide; it generates only a small amount of trihalomethans (THMs) as a byproduct[23]. The Food and Drug Administration[24] has allowed the

use of aqueous chlorine dioxide in washing fruits and vegetables. A maximum of 3 ppm is allowed for contact with whole produce [20].

Electrolyzed water. There are two types of electrolysed water with sanitising properties: acidic electrolysed water, or electrolysed oxidising water (AEW), and neutral electrolysed water (NEW). These solutions are conventionally generated by electrolysis of aqueous sodium chloride, and an electrolysed acidic solution (AEW) or an electrolysed basic solution (NEW) is produced at the anode and cathode, respectively[22]. Recently, the use of electrolysed water as a sanitising agent for fresh produce has received considerable attention in microbial load reduction[25].

Hydrogen peroxide is a colourless gas at room temperature. Because of its high oxidation potential, it has high bacteriostatic and bactericidal properties and has gained interest as a potential disinfectant in the fresh produce industry because of its strong oxidising power. It does not react with the organic compounds present in perishables to produce carcinogenic compounds and breaks down into water and oxygen. It has gained the status of Generally Regarded as Safe (GRAS) in 1986 for some of the food commodities[25].

Ozone is efficient in reducing pathogens on fresh produce because of its strong oxidising capacity. However, using ozone as a disinfectant has disadvantages, including its instability and reactivity with organic materials. Thus, the effective elimination of microorganisms may require high concentrations, which may, in turn, cause sensory defects in fresh produce[2]. The effectiveness of ozone treatment on microbial loads depends on several factors, such as product type, target microorganism, initial microbial load level, physiological state of the bacterial cells and zone physical state, which may explain the diversity of published results[26].

Quaternary ammonium compounds, commonly called “QAC”, are cationic surfactants that are able to penetrate food contact surfaces more readily than other sanitisers[22]. The mode of action of these compounds against bacterial cells involves a general perturbation of lipid bilayer membranes[27]. Although they are not approved for direct food contact, QAC may only partly be useful when applied to whole produce, since the product must be peeled prior to consumption[20].

Organic acids (e.g. lactic, citric, acetic or tartaric acid). The antimicrobial action of organic acids is due to a pH reduction of the environment, disruption of membrane transport and/or permeability, anion accumulation or reduction in internal cellular pH[20]. Organic acids have a potential to reduce microbial populations on fresh vegetables[27].

Physical methods

Irradiation

Gamma-ray, X-ray and electron beams are called ionizing radiations, because they are capable of producing ions, electronically charged atoms or molecules. They have the same mechanisms in terms of their effects on foods and microrganisms[22]. Irradiation is an alternative treatment which is effective in decreasing microbial counts on ready-to-eat vegetables[28].

Steam jet-injection

Application of heat treatment is the most used method for stabilising foods not involving any chemicals, based on its capacity to destroy microorganisms and inactivate enzymes. However, heat can impair many organoleptic properties of foods and reduce the contents or bioavailability of some nutrients[29]. Short-time steam processing can be used as an alternative to chlorine in sanitising fresh-cut lettuce; such treatment can significantly reduce antioxidant levels, especially ascorbic acid concentration, and, to a lower extend, carotenoid levels[30]. From a safety point of view, steam treatment can keep the mesophilic load as low as chlorine treatment[30].

Temperature

Control of temperature is a key point in microbial growth control. Either refrigerating or heating can be applied to control or reduce microbial load, respectively. Furthermore, the air temperature can also be reduced to delay microbial proliferation. However, this method should be used as complementary technique as, on its own, it is not effective enough to ensure product safety[31]. The hygiene and temperature of water used during the handling of produce are of primary importance. Immersion of warm whole or fresh-cut produce in cool process solutions may induce infiltration of the solution (including contaminating microorganisms) into the product through openings in the peel, such as stem-end vascular tissue, lenticels, stomata, puncture wounds or other physical disruptions[20].

Ultrasound is a nonthermal technology using sonic waves and requires the presence of a liquid medium for power transmission[32,22]. The inactivation of microorganisms through ultrasound is a complex process, and a number of factors influence its efficiency[32].

Ultraviolet light is one alternative to decrease pathogenic bacterial levels on fresh produce; the maximum effect of the use of ultraviolet C (UV-C) light is obtained at a wavelength at 254 nm[33,34]. A dose in the range from 0.5 to 20 Jm-2 leads to lethality by directly altering microbial DNA through dimer formation, thereby eliminating the risk of microbially induced disease[33]. Most commonly, UV-C is applied to fresh fruits and vegetables, since it acts directly or indirectly as an antimicrobial agent[22].

Cold Atmospheric Plasma (CAP) is an emerging antimicrobial technology for decontaminating infected surfaces. The treatment uses non-thermal ionised gases (cold gas plasmas)[22] that are produced by the excitation of gas with electrical discharges at room temperature and atmospheric pressure[35]. This treatment shows significant potential for sanitation of fresh produce[2].

Modified atmosphere packaging (MAP) involves the modification of the internal atmosphere composition of a package by reducing the amount of oxygen (O_2) and replacing it by carbon dioxide (CO_2) and/or nitrogen (N_2)[22]. The MAP can be achieved passively (the package is sealed under normal air conditions) or actively (the package is flushed with a gas mixture before being closed)[21]. In combination with low temperatures, MAP could be used as a mild preservation technique to enhance the safety of minimally processed products[36].

Active packaging has been defined as a packaging system actively changing the condition of the package to improve food safety, extend shelf life, enhance sensory properties and maintain the quality of the products[37]. There are different concepts of active food packaging, including oxygen scavengers, carbon dioxide absorbers and emitters, moisture absorbers, ethylene scavengers, ultraviolet (UV) barriers and other mechanisms delivering antioxidant, flavouring or antimicrobial activity[38,39]. Substances responsible for the active function can be obtained in a separate container, for instance in a small paper sachet, or be directly incorporated in the packaging material[39]. The substances that can be added are diverse ranging from organic acids, enzymes, bacteriocins, fungicides, natural extracts and ions to ethanol[39,40]. Currently, active packaging with ethylene scavengers, moisture and liquid absorbers as well as with antimicrobial effects is used in commercial fruit distribution[41].

There are different technologies to reduce/eliminate the microorganisms present in fresh-cut fruits and vegetables. However, none of these sanitising methods can control all the parameters that maintain the quality and shelf-life of MPFVs. Therefore, the use of combined methods is crucial[22].

In this review, the main focus was on the incidence, outbreaks, growth/survival and internalisation of bacterial pathogens in mangoes and papayas.

METHOD

Search strategy

The search for data on the incidence, outbreaks, growth/survival and internalisation of bacterial pathogens in mangoes and papayas was conducted from 1986 to 2016. Electronic searches were conducted using the following scientific bases: Web of Science, PubMed, Science Direct, Scopus and data from the "Centers for Disease Control-CDC-USA". The keywords used were incidence, isolation, prevalence, detection, growth, behaviour, survival, fruits, papayas, mangoes, internalisation, fruits, microbiological, quality, safety, outbreak.

RESULTS

Incidence

From farm to table, there are multiple opportunities for fresh produce to become contaminated by *Salmonella*, *Escherichia coli* O157:H7, *Campylobacter jejuni*, *Vibrio cholerae*, parasites and viruses that may contaminate raw manure or unpotable water as well as animals or potentially tainted surfaces, including human hands. In addition, pathogens such as *Listeria monocytogenes*, *Bacillus cereus* and *Clostridium botulinum* are naturally present in the soil[42] and may also be a problem.

An important consideration when addressing safety issues is the incidence of pathogens and outbreaks associated with particular food products[9].The following studies show the incidence of bacterial pathogens in mangoes and papayas.

One hundred and fifty samples of fresh fruits and vegetables, collected over a period of 12 months from various localities in Karachi, Pakistan, were screened for *Listeria monocytogenes*. Two out of thirty samples of papaya were positive for this pathogen[43].

The microbiological quality of street-sold fruits in San José, Costa Rica, was analysed over a two-year period from March 1990 to March 1993. Researchers evaluated the presence of *Salmonella* spp., *Shigella* spp., *Escherichia coli* and faecal coliforms in several foods. The results showed that *E. coli* was present in more than 10% of the mango and papaya samples, while *Salmonella* spp. and *Shigella* spp. could not be isolated from these fruits[44].

Thirty samples of ripe papaya (*Carica papaya*) slices were collected in Calcutta, India, from itinerant roadside vendors over a three-month period. *Salmonella* and *Vibrio cholerae* results were positive in one sample each, and low levels of coagulase-positive *Staphylococcus aureus* were detected in 17% of the samples[45].

Bordini et al.[46] analysed 100 mango samples produced in the Northeastern region of Brazil from September 2001 to May 2002 and marketed in the state of São Paulo. The authors did not observe the presence of *Salmonella* in any of the 33 samples of mangoes destined for export. However, *Salmonella* was detected in 2 out of 67 samples destined for the internal market.

The prevalence and quantity of *Salmonella* spp., *Salmonella* Typhi and *Salmonella* Typhimurium were identified in sliced fruits from hawker stalls and hypermarkets in Kuala Lumpur, Malaysia. *Salmonella* spp. and *Salmonella* Typhi were found, respectively, in six and three out of twenty samples of papaya and in two and one out of twenty samples of mango from hawker stalls[47].

A total of 125 samples of fresh produce were collected from major supermarkets and local markets across Singapore and characterised with respect to microbiological quality. *Salmonella* and *E. coli* O 157:H7 were absent in only ten mango samples[48].

Outbreaks

Foodborne illness is a major public health concern worldwide in terms of the number of persons affected and the entailed economic costs[2]. According to the WHO[49] , in the year 2010, 31 foodborne global hazards caused 600 million foodborne illnesses and 420,000 deaths worldwide. Foodborne diarrhoeal disease agents caused 230,000 deaths, particularly non-typhoidal *Salmonella enterica*.

In the USA, in 2013, the Centers for Disease Control and Prevention (CDC) reported 818 foodborne disease outbreaks, resulting in 13,360 illnesses, 1,062 hospitalisations, 16 deaths and 14 food recalls (CDC, 2013)[50]. In the developing world,2epidemiological data on foodborne diseases remain scarce. Even the most visible foodborne outbreaks often go unrecognised, uninvestigated or unreported and may only be visible if connected to major public health or economic impacts[49].

According to the Brazilian Ministry of Health[51], from 2007 to 2016, 6.848 outbreaks were related to the consumption of

contaminated food, with 121.283 illnesses, 17.517 hospitalisations and 111 deaths. Fruits and food were responsible for 0.6% of the outbreaks, while the number of non-identified foods related to the total of the outbreaks is still as high as 66.9%.

The following reported outbreaks are related to the consumption of mango and papaya contaminated by bacteria. A large outbreak of food poisoning occurred in September 1996 and involved at least 116 workers at a shipyard in Jurong, Singapore. Four samples of cut watermelon, pineapple, papaya and honeydew melon were tested positive for *Salmonella weltevreden*[52]. In 1998, an outbreak caused by S. Oranienburg, with nine cases and three hospitalisations, occurred in a private home in Washington state and was associated with the consumption of fresh imported mangoes purchased from a particular grocery chain[53]. In December 1999, the first reported outbreak of salmonellosis with mangoes in the United States occurred. Seventy-eight patients from 13 states were infected with *Salmonella* Newport. Fifteen patients were hospitalised and two died. The mangoes had been imported from a single farm in Brazil[54]. Another outbreak in 2001 of *S. enterica*, associated with the consumption of imported mangoes from Peru, occurred in the United States. The serotype was *Saintpaul*; 26 cases were reported[55]. In 2003, an outbreak due to the consumption of mangoes contaminated with *S. saintpaul* in a restaurant/delicatessen occurred in California, US, with 17 cases[56]. During the period from October 2006 to January 2007, an outbreak with 26 cases of *Salmonella* Litchfield infection occurred in Australia. This was the first Australian *Salmonella* outbreak associated with the consumption of papaya[57]. A total of 106 individuals were infected with *Salmonella* Agona in 25 states in the US from January 1 to August 25, 2011; no deaths were reported. This outbreak was related to eating fresh, whole imported papayas from Mexico[58].

During August 2012, a multistate outbreak of *Salmonella* Braenderup in the USA occurred due to the consumption of imported mangoes from Mexico. A total of 127 persons were infected; 33 were hospitalised, but no deaths were reported. From July to August 2012, a similar strain of *S. braederup* caused 21 illnesses in Canada; the infection was linked to mangoes from Mexico[59]. In 2013, a multistate (4) outbreak occurred in the USA due to the consumption of papaya contaminated with S. Thomson, resulting in 13 cases, 6 hospitalisations and 1 death[60]. In 2014, two outbreaks due to the consumption of mango contaminated with *Salmonella* were reported in the USA, one multistate and the other in the state of Connecticut, each with four illnesses and one hospitalisation[61].

All cited outbreaks were caused by *Salmonella* spp. Other pathogens, such as *L. monocytogenes*, are not sufficiently established as relevant fruit juice-borne pathogens in the scientific literature, as compared to *Salmonella* and *E. coli* O157:H7. However, this pathogen is of concern in fresh fruits and fruit juices, due to its ability to survive under a variety of adverse conditions. The reason why there are no reports of listerioses linked to the consumption of fruit or fresh juices, in contrast to the variety of outbreaks related to other enteropathogens, is unclear[3].

Internalisation

Physical barriers, such as skin or rind, do not necessarily prevent the contamination of produce, because cutting and slicing eliminate this protection and microbes can invade the internal tissue. In addition, bacterial microorganisms from contaminated washing water can enter fruits and vegetables under certain conditions[45,62]. Mangoes and papayas are tree fruits with similar processing procedures on the farm[57]. For example, at least three salmonellosis outbreaks may have been caused by the same mechanism through the immersion of warm papaya/mango in cooler water, resulting in a pressure difference between the produce core and the surrounding water, which allowed *Salmonella* present in the water to enter the fruit, generally through the area around the stem[54,55,57].

Growth/survival

The survival and/or growth of pathogens on fresh produce is influenced by the organism, produce item and environmental conditions in the field and thereafter, including storage conditions. In general, pathogens will survive, but not grow on the uninjured outer surface of fresh fruits or vegetables, partly due to the protective character of the plant´s natural barriers (for example, cell walls and wax layers). In some cases, pathogen levels will decline on the outer surface[9]. One exception is the study conducted by Bordini et al.[46], which reported that the number of *Salmonella* present on mango rind surfaces depended on the storage temperature; at 22ºC, an increase up to 2.30 logs was observed, while at 8ºC, no significant variation occurred.

Microorganisms can grow and survive on mangoes and papayas, as shown in the following studies. The ability of five strains of enteropathogenic bacteria (*Shigella sonnei*, *S. flexneri*, *S. dysenteriae*, *Salmonella derby* and *S. typhi*) to survive and grow on sliced jicama, papaya and watermelon was investigated. Small increases in the numbers of *Shigella* species occurred on inoculated papaya after storage for only 2 h at 25–27ºC, and an increase of about 1.4 in 6 hours at room temperature was observed for *S. typhi* inoculated on this fruit. Both microorganisms could grow on papaya stored at temperatures of 22–27ºC[63].

Castillo and Escartin[64] studied the survival of *Campylobacter jejuni* on sliced watermelon and papaya. The populations on papaya cubes inoculated with this microorganism survived for at least 6 h. The percentage of survivors at 6 hours of storage ranged from 7.7 to 9.4. Decreases in count were substantial at 2 h of storage.

Yegeremu et al.[65] studied the fate of *Salmonella* species and *E. coli* in fresh-prepared orange, avocado, papaya and pineapple juices. They observed that *S. typhimurium* and *S. choleraesuis* could proliferate in papaya juice when stored at ambient temperatures. *Salmonella typhimurium* reached counts as high as 10^9 CFU/mL in 24 h, steadily increasing until 48 h. *Salmonella choleraesuis* reached its maximum count (10^8 CFU/ml) at 24 h, with a slight decrease thereafter. Counts of both *Salmonella* species increased by one log unit in 24 h at 4ºC, but did not exceed 10^5 CFU/ml throughout the storage time.

Penteado and Leitão[66,67] investigated the growth of *L. monocytogenes* and *S. enteritidis* in papaya pulp. For *L. monocytogenes*, maximum populations of about 5, 4 and 7 log units were reached at temperatures of 10, 20 and 30ºC, respectively, at the end of the incubation periods. Generation times (g) of 15.05, 6.42 and 1.16 were obtained and decreased as the temperatures increased. The same authors observed maximum populations of 10^8 CFU/g for 24- and 48-hr incubation periods and generation times of 16.61, 1.74, and 0.66 hrs at incubation temperatures of 10, 20 and 30ºC, respectively.

Mutaku et al.[68] evaluated the growth potential of *E. coli* O 157:H7 in fresh juices of papaya, pineapple and avocado. In papaya juice, counts of the test strains increased at varying rates at both storage temperatures, ambient (20–25ºC) and refrigeration (4ºC).

Bordini et al.[46] studied *Salmonella enterica* behaviour in mangoes stored at temperatures of 8 and 22ºC for 24 and 144 h and observed that mean population numbers increased in the rind, stem, middle and blossom end of the fruits at 22ºC, over a period of 24 h, with values of 0.53, 1.16, 1.47 and 1.36 logs, respectively. With an incubation period of 144 h, the values were 1.84, 1.74, 2.30 and 2.30, respectively. At an incubation temperature of 8ºC, the increase in the number of bacteria was smaller: 0.59 log in the stem end, 0.82 log in the middle side and 0.80 log in the blossom end after 24 h of incubation and 0.21, 0.22 and 0.47 log, respectively, after 144 h. At the rind surface, there was a decrease in the number of bacteria: 0.41 log MPN/g after 144 h.

Strawn and Danyluk[69] reported growth of *Salmonella* on cut mangoes stored at 23 ± 2ºC and survival at 4 ± 2ºC, regardless of initial inoculum concentrations. Population level was a factor at 12 ± 2ºC, with *Salmonella* growth only at the high (5 log CFU/g) and medium (3 log CFU/g) inoculum levels. *Escherichia coli* O157:H7 grew rapidly on fresh-cut papayas at 23 ± 2ºC and 12 ± 2ºC and survived throughout the shelf life of cut, refrigerated papayas. Similarly, *Salmonella* grew rapidly on fresh-cut papayas at 23 ± 2ºC and 12 ± 2ºC and survived throughout the shelf life of refrigerated fresh-cut papayas (4 ± 2ºC). Inoculum levels had no effect on *Salmonella* behaviour in cut papaya. Both microorganisms can survive on frozen cut mangoes and papayas for at least 180 days.

Barbosa et al.[70] inoculated mango slices with *S. aureus* and *L. monocytogenes* (10^7 CFU/g), and the viable cell numbers exhibited a reduction of only one log unit after six days of storage for *S. aureus*, while being constant at 10^7 CFU/g for *L. monocytogenes* over the same period.

Penteado et al.[71] studied the growth of *S. enteritidis* and *L. monocytogenes* in mangoes pulp at different temperatures and incubation times. At 25ºC, the authors observed an increase of about 4.8 cycles log^{-1} after 48 h of incubation and a maximum population of 7.6 log units for *S. enteritidis*, while *L. monocytogenes* exhibited an increase of about 6 cycles log^{-1}, with a maximum population of 8.6 log for the same temperature and period of incubation. At 10ºC, no growth could be observed for *S. enteritidis*. For *L. monocytogenes*, an increase of about 4 cycles log^{-1} was observed, with a maximum population of 7 log units after 200 h. At 4ºC, both bacterial populations survived for eight days. At -20ºC, *S. enteritidis* was able to survive for five months, while *L. monocytogenes* could still be recovered after eight months.

Ma et al.[72] studied the behaviour of *Salmonella* spp. on fresh-cut tropical fruits, such as dragon fruit, banana, starfruit, mango, pineapple, guava and wax apple, at 28 and 4ºC at four inoculum levels: 0.1, 1.0, 2.0 and 3.0 log CFU/g. The population of *Salmonella* in mango remained equal to the initial inoculum level after six days of storage at 4ºC for all fruits tested. At 28 ± 2ºC/two days, there were increases of 0.11, 0.51 and 0.56 for inoculation levels of 0.1, 2.0 and 3.0, respectively, and a decrease of -0.39 for the inoculation level of 1.0 log CFU/g.

Table 1 shows the important factors to consider when conducting a bacterial growth study in fresh mango and papaya, including inoculation, storage conditions, incubation temperature and time, type of microorganism and pH. Along with storage temperature, pH is cited as the principal determinant of bacterial growth on fresh fruits. Many acidic fruits do not support the growth of human pathogens and even inactivate them[73,74].

The chemical and biochemical composition of mango varies with cultivation, variety and stage of maturity. The major constituents of the pulp are water, carbohydrates, organic acids, fats, minerals, pigments, tannins, vitamins and flavour compounds[76,77].

Fruits can be divided in two groups: those with pH ≤ 4 (high-acid fruits), where the growth of microbial pathogens is unlikely to occur, and those with a pH above 4 (low-acid fruits), where microbial growth is more likely (*e.g.* mango and papaya)[8]. Variation in pH exists among varieties, growing conditions and processing methods[77], as in the case of the Dashehari mango cultivar. During ripening, the pH rose from 3.0 to 5.2[78], demonstrating the importance of determining pH when conducting a growth study.

Papaya has low acidity when compared to other tropical fruits, which is a nutritional advantage, as it allows its consumption by people sensitive to fruit acids; however, this low acidity is a problem faced by processors, because high pH values favour enzymatic activity and microbial growth[79].

As shown in Table 2, variation in pH occurs in both fruits, depending on the variables mentioned, which is of paramount importance when conducting studies related to the behaviour of microorganisms in this food.

DISCUSSION

Mangoes and papayas are good substrates for pathogen growth and survival when stored in a variety of temperatures. Considering they are frequently manipulated, sliced and served in restaurants, hotels and at home (alone, mixed with other foods and as pulp juice) and remain exposed for hours on restaurant tables, normally at room temperature, these fruits could be considered as potential vehicles for foodborne diseases.

Possible microbiological contamination could be reduced if mangoes and papayas were cooked before consumption. This process is

Table 1. Growth and survival of pathogenic bacteria on mango and papaya.

Pathogen	Fruit type	pHo-pHf	Method of inoculation	Storage conditions	Temp. (°C)	Initial counts	Incub. Time	Final counts	Unit	Comments	Reference
Salmonella Typhi	Papaya cubes	5.69	Spot inoculation, cells suspended in saline solution, 1 drop	12 cm^2 cubes, inoculated stored in covered glass trays	25-27	2.9	6 h	4.3	CFU/cube	nd	63
Shigella (three species)	Papaya cubes	5.69	Spot inoculation, cells suspended in saline solution, 1 drop	12 cm^2 cubes, inoculated, stored in covered glass trays	25-27	1.9-2.2	6 h	3.8-4.4	CFU/cube	*S. sonnei* *S. flexneri* *S. dysenteriae*	63
Campylobacter jejuni	Papaya cubes	5.6-5.0	Spot inoculation cells suspended in saline solution, 0.02 ml inoculated per cube	24 cm^2 cubes. Stored in sterile stainless-steel trays with cover	25-29	2.8	6 h	1.7	CFU/cube	Serotype Penner 50	64
Salmonella typhimurium	Papaya juice	5.7-4.69	Inoculated with overnight broth culture	Inside screw cap bottles	4 37	3.99	24 h 48 h 24 h 48 h	5.2 4.43 9.15 9.23	CFU/mL	100 ml water/400 ml papaya. Steamed before inoculation100°C/10 min/ papaya fresh ripened	65
Salmonella choleraesuis	Papaya juice	5.7-4.69	Inoculated with overnight broth culture	Inside screw cap bottles	4 37	3.52	24 h 48 h 24 h 48h	4.45 4.08 8.66 8.18	CFU/mL	100 ml water/400 ml papaya. Steamed before inoculation100°C/10 min/ papaya fresh ripened	65
E. coli (25922)	Papaya juice	5.7-4.69	Inoculated with overnight broth culture	Inside screw cap bottles	4 37	3.52 2.70	24 h 48 h 24 h 48 h	4.45 4.08 9.36 9.40	CFU/mL	100 ml water/400 ml papaya. Steamed before inoculation100°C/10 min/ papaya fresh ripened	65
E. coli (9637)	Papaya juice	5.7-4.69	Inoculated with overnight broth culture	Inside screw cap bottles	4 37	2.78	24 h 48 h 24 h 48 h	2.54 2.53 9.1 9.4	CFU/mL	100 ml water/400 ml papaya. Steamed before inoculation100°C/10 min/ papaya fresh ripened	65
Salmonella Enteritidis	Papaya pulp	4.87	Bacterial suspension diluted in 0.1% peptone water	50 g pulp, inoculated and stored in Erlenmeyer flasks	10 20 30	2.58 2.42 2.54	168 h 48 h 24 h	4.46 8.68 8.81	CFU/g	Pulps pasteurised (80°C/1 min) before inoculation tests	66
Listeria monocytogenes	Papaya pulp	4.87	Bacterial suspension diluted in 0.1% peptone water	50g pulp, inoculated and stored in Erlenmeyer flasks	10 20 30	2.45 2.59 2.61	168 h 48 h 24 h	4.84 4.43 7.36	CFU/g	Pulps pasteurised (80°C/1min) before inoculation tests	67
E. coli O 157:H7	Papaya fresh juice	5.17	Bacterial suspension at TSB + 0.6% yeast extract	250 ml juice inoculated and stored in screw-capped bottles	25	~3.3	96	9	CFU/ml	Four strains of *E. coli* O 157:H7 pH 4.5 after 120 hr/ juices steamed at 100°C/10min. before inoculation	68

Continue

Continuation

Salmonella enterica	Mangoes	4.49	Immersion in water with the inoculum	Inside sterile plastic bags	8	1.91 S[1] 0.76 M[2] 0.5 B[3] 1.7 R[4]*	24	2.5 S[1] 1.58 M[2] 1.3 B[3] 1.29* R[4]	CFU/g *MPN/g	Different portions of the mango (Stem-S, Middle-M, Blossom-B and Rind-R)	46
							144	2.29 S[1] 0.98 M[2] 0.97 B[3] 0.7* R[4]			
					22	1.91 S 0.76 M 0.5 B 1.7 R*	24	3.07 2.23 1.86 2.23			
							144	3.65 3.06 2.8 3.5*			
Salmonella	Mangoes slices	nd	Inoculation by drops on the fruit surface of bacterial suspension diluted in 0.1% peptone water	Samples inoculated and placed into sterile stomacher bags	12	4.5	24 hr 28 d	5.9 0.6	CFU/g	Cocktail of *S. serovars. S. Michigan, S. Montevideo, S. Munchen, S. Newport, S. Saintpaul Mangoes cv Tommy Atkins (ripe)*	69
					23	2.9	24 h 7 d	6.0 2.4			
E. coli O157:H7	Mangoes slices	nd	Drops inoculation on the fruit surface of bacterial suspension diluted in 0.1% peptone water	Samples inoculated and placed into sterile stomacher bags	12	4.6	24 hr 28 d	4.5 1.5	CFU/g	Cocktail of four strains Mangoes cv Tommy Atkins (ripe)	69
					23	2.9	24 h 7 d	4.7 4.0			
	Papayas cubes	nd	Drop inoculation on the fruit surface of bacterial suspension diluted in 0.1% peptone water	Samples inoculated and placed into sterile stomacher bags	12	3.9	24 h 28 d	5.0 4.3	CFU/g	Cocktail of four strains Papayas cv Red Lady (ripe)	69
					23	2.6	24 h 7 d	6.0 6.3			
Salmonella	Papayas cubes	nd	Drop inoculation on the fruit surface of bacterial suspension diluted in 0.1% peptone water	Samples inoculated and placed into sterile stomacher bags	12	4.1	24 h 28 d	5.2 3.5	CFU/g	Cocktail of *S serovars. S. Michigan, S.Montevideo, S. Munchen, S. Newport, S. Saintpaul Papayas cv Red Lady (ripe)*	69
					23	2.6	24 h 7 d	6.2 6.6			
S. aureus	Mangoes cv Tommy Atkins slices	4.30-4.0	Immersion of slices in 0.1% peptone with cell suspension	Packed in polystyrene trays covered with PVC film	5	7.0	12 d	5.0	CFU/g	Mangoes at mature-green stage	70
L. monocytogene	Mangoes cv Tommy Atkins slices	4.30-4.29	Immersion of slices in 0.1% peptone with cell suspension	Packed in polystyrene trays covered with PVC film	5	7.0	12 d	6.0	CFU/g	Mangoes at mature-green stage	70

Continue

Continuation

Salmonella Enteritidis	Mango pulp	5.16	Bacterial suspension diluted in 0.1% peptone water	50 g pulp, inoculated and stored in Erlenmeyer flasks	25	2.8	24 h	4.94	CFU/g	Pulps pasteurised (80ºC/1min) before inoculation tests	71
							48 h	7.6			
	Mango pulp	5.16	Bacterial suspension diluted in 0.1% peptone water	50 g pulp, inoculated and stored in Erlenmeyer flasks	25	2.79	24	6.14	CFU/g	Pulps pasteurised (80ºC/1min) before inoculation tests	71
							48 h	8.6			
Listeria monocytogenes	Mango slices	4.19	Bacterial suspension diluted in 0.1% peptone water	10g, inoculated, packed in polystyrene trays covered with PVC film	5	2.3	1 d	-4.0	CFU/g	Cocktail of six strains	75
					13	2.3	6 d	7.7			
					25	2.3	4 d	6.8			
	Papaya slices	5.99	Bacterial suspension diluted in 0.1% peptone water	10g, inoculated, packed in polystyrene trays covered with PVC film	5	2.2	5 d	-4.0	CFU/g	Cocktail of six strains	75
					13	2.2	6 d	4.2			
					25	2.2	4 d	7.6			
S. aureus	Mango slices	4.19	Bacterial suspension diluted in 0.1% peptone water	10g, inoculated, packed in polystyrene trays covered with PVC film	5	3.5	1 d	-3.5	CFU/g	Cocktail of four strains	75
					13	3.5	6 d	5.4			
					25	3.5	4 d	8.1			
	Papaya slices	5.99	Bacterial suspension diluted in 0.1% peptone water	10g, inoculated, packed in polystyrene trays covered with PVC film	5	2.5	6 d	4.4	CFU/g	Cocktail of four strains	75
					13	2.5	6 d	5.3			
					25	2.5	4 d	6.1			
Salmonella	Mango (cv Palmer)	nd	Spot inoculated with 1 cell suspension	Fruit cubes packaged in sterilised bags	28	0.1	2 d	0.21	CFU/g	Cocktail 3 serotypes (*S. Newport*, *S. Saintpaul S. rnteritdis*)	72
						1.0		0.61			
						2.0		2.51			
						3.0		3.56			

S[1] = Stem end; M[2] = Middle; B[3] =Blossom end; R[4]= Rind

usually effective in the elimination of any potentially pathogenic organisms, rendering these fruits safe to be consumed. However, mangoes and papayas are commonly eaten in a raw state, and the possible presence of pathogens on their surface or inside the fruits can be problematic during the manipulation process or even in the case of internalisation, which would allow the growth/survival of foodborne pathogens in these foods and pose a problem for the consumers. Pathogen internalisation into those fruits is a process that should be controlled with attention to the quality and temperature of the water applied in washing these fruits.

The first step to prevent contamination is to respect the preventive measures included in the GAPs, GMPs and HACCP.

Studies have shown that the application of preventive measures, such as washing hands, good personal hygiene, appropriate use of sanitary facilities, treated manure (fertilisers), quality of the irrigation water, avoiding flooding events, cleaning and sanitising of equipment, can reduce microbial contamination on fresh produce.

Himathongkham and Riemann[86] showed that treatment of dry chicken manure with ammonia results in a significant reduction of *Salmonella typhimurium*, *E. coli* O 157:H7 and *Listeria monocytogenes*.

In cooling and storage facilities, contamination can be reduced with the use of ozone; treatment of cold rooms has been reported to be effective in significantly reducing *Listeria monocytogenes*[87].

Zhou et al.[88] studied the effect of ultrasound in combination with chlorine on the reduction of *Escherichia coli* O 157:H7 populations on lettuce coring knives; the results of these treatments with redesigned coring knives may provide practical options for minimising microbial safety hazards of lettuce processed by core-in-field operations.

According to Park et al.[89], microbial contamination of produce is influenced by farm management and environmental factors. Specifically, contamination seems to be strongly influenced by the time since last irrigation, worker personal hygiene and field use prior to planting.

Rodrigues et al.[90] mentioned that preventive measures on lettuce farms, such as microbial quality and method of composting manure as well the source and quality of irrigation waters and washing waters, are of utmost importance in accordance with the obtained microbiological results. The authors also demonstrated that the fertiliser control program and the water used for irrigation and washing were important factors to be controlled in the production chain of organic lettuce in order to ensure food safety and a high hygiene status. With regards to irrigation and rinsing water, the results showed the importance of using water from safe sources.

Monagham and Hutchison[91] showed that the numbers of generic *Escherichia coli* isolated from workers' hands declined with increasing thoroughness of hand-washing treatments. As reported by Park et al.[89], contamination with generic *E. coli* was significantly reduced with an irrigation lapse time of > five days as well as by several factors related to field workers, including the use

Table 2. pH values of mangoes and papayas.

Fruit	pH	Comments	References
Mangoes var. Tommy Atkins	4.49	Central portion of the mango	46
Mango pulp (variety Palmer)	5.16	Ripe	66
Manga "Ubá"	3.90-4.29	-	80
Manga cv. Haden	4.28	Pulp	81
Mangoes cv "Tommy Atkins"	4.30	Mature-green stage	38
Mangoes cv Golden	5.39-6.14	Pulp, homogenised in distilled water, different maturity stages	82
Mango cv. Haden	2.4-4.5	Mix of pulps of the same maturity stage; pH increase with maturity	44
Mangoes	3.9-4.6	-	83
Papaya cv. "Maradol" red	5.5	Partially ripe	84
Papaya (*Carica papaya*)	6.4-6.8	Ripe	15
Ripe papaya	5.69	Surface pH	32
Papaya pulp	4.87	Ripe	35
Papaya Formosa cv. Tainung 01	5.06-5.10	Stage 4 (51-75% yellow colour)/fruit juice	47
	4.1	75% ripe/fruit	85
Papaya	5.17	Fresh/juice	37
	5.2-5.7	-	83

of portable toilets, training to use portable toilets and the use of hand-washing stations.

Increased microbial load and pathogen prevalence in lettuce production was revealed for high temperature, flooding of lettuce fields, application of contaminated organic fertiliser, irrigation with water of inferior quality and large distances between the field and toilets, showing the importance of controlling the composting process of organic manure and the quality of the irrigation water, to improve and/or maintain the safety of lettuce during primary production[92].

As stated by Bracket[93], it should be remembered that a systems approach in maintaining sanitation and quality should be taken. All steps, from production through consumption, will affect the microflora. Applying proper sanitary procedures and insisting on utmost hygiene are indispensable. However, employing a good HACCP program is also necessary to assure safety, as the use of HACCP helps to minimise the potential hazards that may be associated with fresh-cut produce processing[93,94].

The application of HACCP to control enteric pathogens in processed crops was reviewed by Leifter et al.[95]. As mentioned by Hurst[96], HACCP is the most comprehensive, science-based program for reducing pathogen contamination in fruit and vegetable products.

CONCLUSION

Therefore, the implementation of strategies such as Good Agricultural Practices, Good Manufacturing Practices and Hazard Analysis Critical can eliminate or significantly reduce microbial contamination on fresh mangoes and papayas.

REFERENCES

1. Food and Agricultural Organization of the United Nations - FAO. FAO statistical yearbook 2013: world food and agriculture. Rome: FAO; 2013.
2. Olaimat AN, Holley RA. Factors influencing the microbial safety of fresh produce: a review. Food Microbiol 2012;32(1):1-19. https://doi.org/10.1016/j.fm.2012.04.016
3. Tribst AAL, Sant'Ana AS, Massaguer PR. Review: microbiological quality and safety of fruit juices: past, presente and future perspectives. Crit Rev Microbiol. 2009;35(4):310-39. https://doi.org/10.3109/10408410903241428
4. Brazilian Fruit Yearbook 2015. Santa Cruz do Sul: Gazeta Santa Cruz; 2015[cited 2016 Feb 02]. Avalaible from: http://www.grupogaz.com.br/tratadas/eo_edicao/4/2015/03/20150301_106c8c2f1/flip/#4
5. Tharanathan RN, Yashoda HM, Prabha TN. Mango (*Mangifera indica L.*), "The king of fruits": an overview. Food Rev Int. 2006;22(2):95-123. https://doi.org/10.1080/87559120600574493
6. Oliveira JG, Vitória AP. Papaya: nutritional and pharmacological characterization, and quality loss due to physiological disorders: an overview. Food Res Int. 2011;44(5):1306-13. https://doi.org/10.1016/j.foodres.2010.12.035
7. Food and Agriculture Organization of the United Nations - FAO. Faostat. Rome: FAO; 2013[cited 2016 Feb 02]. Available from: http://faostat3.fao.org/download/Q/QC/E
8. Beuchat LR. Surface decontamination of fruits and vegetables eaten raw: a review. Rome: World Health Organization; 1998[cited 2016 Feb 02]. Available from: http://apps.who.int/iris/bitstream/10665/64435/1/WHO_FSF_FOS_98.2.pdf
9. Harris LJ, Farber JN, Beuchat LR, Parish ME, Suslow TV, Garret EH et al. Outbreaks associated with fresh produce: incidence, growth, and survival of pathogens in fresh and fresh-cut produce. Compr Rev Food Sci Food Saf. 2003;2(s1):78-141. https://doi.org/10.1111/j.1541-4337.2003.tb00031.x

10. Berger CN, Sodha SV, Shaw RK, Griffin PM, Pink D, Hand P et al. Fresh fruit and vegetables as vehicles for the transmission of human pathogens. Environ Microbiol. 2010;12(9):2385-97. https://doi.org/10.1111/j.1462-2920.2010.02297.x

11. Kokkinakis E, Fragkiadakis GA. HACCP effect on microbiological quality of minimally processed vegetables: a survey in six mass catering establishments. Int J Food Sci Technol. 2007;42(1):18-23. https://doi.org/10.1111/j.1365-2621.2006.01179.x

12. Strawn LK, Schneider KR, Danyluk MD. Microbial safety of tropical fruits. Crit Rev Food Sci Nutr. 2011;51(2):132-45. https://doi.org/10.1080/10408390903502864

13. Estrada-Acosta M, Jiménez M, Chaidez C, León-Félix J, Castro-Del Campo N. Irrigation water quality and the benefits of implementing good agricultural practices during tomato (*Lycopersicum esculentum*) production. Environ Monit Assess. 2014;186(7):4323-30. https://doi.org/10.1007/s10661-014-3701-1

14. Codex Alimentarius. International Food Standards. CAC/RCP 53-2003. Code of hygienic practice for fresh fruits and vegetables. Rome: FAO; 2003.

15. Codex Alimentarius. International Food Standards.CAC/RCP 1-1969. Hazard analysis and critical control point (HACCP) system and guideline for its application. Rome: FAO; 2003.

16. U.S. Department of Health and Human Services. Food and Drug Administration. Center for Food Safety and Applied Nutrition. Guidance for industry: guide to minimise the microbial food safety hazards for fresh fruits and vegetables. Washington, DC: Center for Food Safety and Applied Nutrition; 1998 [cited 2017 Feb 6]. Available from: http://wcmorris.com/gap/files/prodguid.pdf

17. World Health Organization. Food and Agriculture Organization of the United Nations. Microbiological hazards in fresh fruits and vegetables: meeting report. Geneva: World Health Organization; 2008[cited 2017 Feb 6]. (Microbial risk assessment series. Pre-publication version). Available from: http://www.who.int/foodsafety/publications/micro/MRA_FruitVeges.pdf

18. Codex Alimentarius. International Food Standards. CAC/GL 30-1999. Principles and guidelines for the conduct of microbiological risk assessment. Amendments 2012, 2014. Rome: FAO; 2014.

19. U.S. Department of Agriculture/Food Safety and Inspection Service -FSIS/USDA Microbial risk assessment guideline: pathogenic microorganisms with focus on food and water. Washington, DC: U.S. Department of Agriculture; 2012 [cited 2017 Feb 6]. EPA publication, EPA/100/J12/001. Available from: https://www.fsis.usda.gov/wps/wcm/connect/d79eaa29-c53a-451e-ba1c-36a76a6c6434/Microbial_Risk_Assessment_Guideline_2012-001.pdf?MOD=AJPERES

20. Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garret EH, Farber JN et al. Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf. 2003;2(s1):161-73. https://doi.org/10.1111/j.1541-4337.2003.tb00033.x

21. Rico D, Martín-Diana AB, Barat JM, Barry-Ryan C. Extending and measuring the quality of fresh-cut fruit and vegetables: a review. Trends Food Sci Techol. 2007;18(7):373-86. https://doi.org/10.1016/j.tifs.2007.03.011

22. Ramos B, Miller FA, Brandão TRS, Teixeira P, Silva CLM. Fresh fruits and vegetables: an overview on applied methodologies to improve its quality and safety. Innov Food Sci Emerg Technol. 2013;20:1-15. https://doi.org/10.1016/j.ifset.2013.07.002

23. Chung CC, Huang TC, Yu CH, Shen FY, Chen HH. Bactericidal effects of fresh-cut vegetables and fruits after subsequent washing with chlorine dioxide. In Proceedings of International Conference on Food Engineering and Biotechnology, ICFEB 2011; 2011 May 2011; Bangkok, Thailand. Hong Kong: CBEES; 2011. p. 107-12.

24. U.S. Government Publishing Office. Eletronic code of federal regulations. Title 21: food and drugs. Part 173: Secondary direct food additives permitted in food for human consumption. Subpart D: specific usage additives. Chlorine dioxide. Washington, DC: U.S. Government Publishing Office; 2016[cited 2017 Fev 6]. Available from: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=d4e1a22de-727a4afaf0d5fb2b27a7d5d&ty=HTML&h=L&mc=true&r=SECTION&n=se21.3.173_1300

25. Joshi K, Mahendran R, Alagusundaram K, Norton T, Tiwari BK. Novel disinfectants for fresh produce. Trends Food Sci Technol. 2013;34(1):54-61. https://doi.org/10.1016/j.tifs.2013.08.008

26. Miller FA, Silva CLM, Brandão TRS. A Review on ozone-based treatments for fruit and vegetables preservation. Food Eng Rev. 2013;5(2):77-106. https://doi.org/10.1007/s12393-013-9064-5

27. Velázquez LdC, Barbini NB, Escudero ME, Estrada CL, Guzmán AMS. Evaluation of chlorine, benzalkonium chloride and lactic acid as saniters for reducing *Escherichia coli* O157:H7 and *Yersinia enterocolitica* on fresh vegetables. Food Control. 2009;20(3);262-8. https://doi.org/10.1016/j.foodcont.2008.05.012

28. Prakash A, Inthajak P, Huibregtse H, Caporaso F, Foley DM. Effects of Low-dose gamma irradiation and conventional treatments on shelf life and quality characteristics of diced celery. J Food Sci. 2000;65(6):1070-5. https://doi.org/10.1111/j.1365-2621.2000.tb09420.x

29. Rico D, Martín-Diana AB, Barry-Ryan C, Frias JM, Henehan GTM, Barat JM. Optimisation of steamer jet-injection to extend the shelflife of fresh cut lettuce. Postharvest Biol Technol. 2008;48(3):431-42. https://doi.org/10.1016/j.postharvbio.2007.09.013

30. Martín-Diana AB, Rico D, Barry-Ryan C, Frías JM, Henehan GTM, Barat JM. Efficacy of steamer jet-injection as alternative to chlorine in fresh-cut lettuce. Postharvest Biol Technol. 2007;45(1):97-107. https://doi.org/10.1016/j.postharvbio.2007.01.013

31. Meireles A, Giaouris E, Simões M. Alternative disinfection methods to chlorine for use in the fresh-cut industry. Food Res Int. 2016;82:71-85. https://doi.org/10.1016/j.foodres.2016.01.021

32. Otto C, Zahn S, Rost F, Zahn P, Jaros D, Rohm H. Physical methods for cleaning and disinfection of surfaces. Food Eng Rev. 2011;3(3-4):171-88. https://doi.org/10.1007/s12393-011-9038-4

33. Bintsis T, Litopoulou-Tzanetaki E, Robinson RK. Existing and potential applications of ultraviolet light in the food industry: a critical review. J Sci Food Agric. 2000;80(6):637-45. https://doi.org/10.1002/(SICI)-1097-0010(20000501)80:6<637::AID-JSFA603>3.0.CO;2-1
34. Lim W, Harrison A. Effectiveness of UV light as a means to reduce *Salmonella* contamination on tomatoes and food contact surfaces. Food Control. 2016;66:166-73. https://doi.org/10.1016/j.foodcont.2016.01.043
35. Fernández A, Thompson A. The inactivation of *Salmonella* by cold atmospheric plasma treatment. Food Res Int. 2012;45(2):678-84. https://doi.org/10.1016/j.foodres.2011.04.009
36. Oliveira M, Abadias M, Usall J, Torres R, Teixidó N, Viñas I. Application of modified atmosphere packaging as a safety approach to fresh-cut furits and vegetables: a review. Trends Food Sci Techol. 2015;46(1):13-26. https://doi.org/10.1016/j.tifs.2015.07.017
37. Bodbodak S, Rafiee Z. Recent trends in active packaging in fruits and vegetables. In: Bodbodak S, Rafiee Z, organizers. Eco-friendly technology for postharvest produce quality: recent trends in active packaging in fruits and vegetables. India: Academic Press; 2016., Chapter 3, Recent trends in active packaging in fruits and vegetables; p. 77-125. p. 77 -125, 2016.
38. Otoni CG, Espitia PJP, Avena-Bustillos RJ, McHugh TH. Review trends in antimicrobial food packaging systems: emitting sachets and absorbent pads. Food Res Int. 2016;83:60-73. https://doi.org/10.1016/j.foodres.2016.02.018
39. Restuccia D, Spizzirri UG, Parisi OI, Cirillo G, Curcio M, Iemma F et al. New EU regulation aspects and global market of active and intelligent packaging for food industry applications. Food Control. 2010;21(11):1425-35. https://doi.org/10.1016/j.foodcont.2010.04.028
40. Soares NF, Silva CAS, Santiago-Silva P, Espitia PJP, Gonçalves MPJC, Lopez MJG et al. Active and intelligent packaging for milk and milk products. In: Coimbra JSR, Teixeira JA, editors. Engineering aspects of milk and dairy products. Boca Raton: CRC Press; 2009. p. 175-99.
41. Sarantópoulos C, Cofcewiz LS. Embalagens ativas para produtos perecíveis. Bol Tecnol Desenvolv Embalagens. 2016;28(3):1-12.
42. Beuchat LR, Ryu JH. Produce handling and processing practices. Emerg Infect Dis. 1997;3(4):459-65. https://doi.org/10.3201/eid0304.970407
43. Vahidy R, Jahan F, Nasim R. Isolation of *Listeria monocytogenes* from fresh fruits and vegetables. HortScience. 1992;27(6):628.
44. Monge R, Arias ML, Antillón F, Utzinger D. [Microbiological quality of street sold fruits in San José, Costa Rica]. Arch Latinoam Nutr. 1995;45(2):117-21. Spanish.
45. Mukhopadhyay R, Mitra A, Roy R, Guha AK. An evaluation of street-vended sliced papaya (*Carica papaya*) for bacteria and indicator micro-organisms of public health significance. Food Microbiol. 2002;19(6):663-7. https://doi.org/10.1006/fmic.2002.0511
46. Bordini MEB, Ristori CA, Jakabi M, Gelli DS. Incidence, internalization and behavior of *Salmonella* in mangoes, var. Tommy Atkins. Food Control. 2007;18(8):1002-7. https://doi.org/10.1016/j.foodcont.2006.06.003
47. Pui CF, Wong CW, Chai LC, Nillian E, Ghazali FM, Cheah YK et al. Simultaneous detection of *Salmonella* spp., *Salmonella* Typhi and *Salmonella* Typhimurium in sliced fruits using multiplex PCR. Food Control. 2011;22(2) 337-42. https://doi.org/10.1016/j.foodcont.2010.05.021
48. Seow J, Agoston R, Phua L, Yuk HG. Microbiological quality of fresh vegetables and fruits sold in Singapore. Food Control. 2012;25(1):39-44. https://doi.org/10.1016/j.foodcont.2011.10.017
49. World Health Organization – WHO. WHO estimates of the global burden of foodborne diseases: foodborne disease burden epidemiology reference group 2007-2015. Geneva: World Health Organization; 2015.
50. Centers for Disease Control and Prevention – CDC. Surveillance for foodborne disease outbreaks United States, 2013: annual report. Atlanta: US Department of Health and Human Services; 2015.
51. Ministério da Saúde (BR). Secretaria de Vigilância em Saúde. Departamento de Vigilância das Doenças Transmissíveis. Surtos de doenças transmitidas por alimentos no Brasil. Brasília, DF: Ministério da Saúde; 2016[cited 2017 Feb 6]. Available from: http://portalsaude.saude.gov.br/images/pdf/2016/dezembro/09/Apresentacao-Surtos-DTA-2016.pdf
52. Ooi PL, Goh KT, Neo KS, Ngan CCL. A shipyard outbreak of salmonellosis traced to contaminated fruits and vegetables. Ann Acad Med Singapore. 1997;26(5):539-43.
53. *Salmonella* Oranineburg, Ontario.Canada Comm Dis Report. 1998;24-22: 177.
54. Sivapalasingam S, Barrett E, Kimura A, Van Duyne S, De Witt W, Ying M. A multistate outbreak of *Salmonella enterica* serotype Newport infection linked to mango consumption: impact of water-dip disinfection technology. Clin Infect Dis. 2003;37(12):1585-90. https://doi.org/10.1086/379710
55. Beatty ME, LaPorte TN, Phan Q, Van Duyne SV, Braden C. A multistate outbreak of *Salmonella enterica* serotype Saintpaul infections linked to mango consumption: a recurrent theme. Clin Infect Dis. 2004;38(9):1337-8. https://doi.org/10.1086/383156
56. Center for Disease Control and Prevention – CDC. 2003 Summary statistics: the total number of foodborne disease outbreaks by etiology. Atlanta: Center for Disease Control and Prevention; 2013[cited 2016 Feb 02]. Available from: http://www.cdc.gov/outbreaknet/pdf/surveillance/2003_linelist.pdf
57. Gibbs R, Pingault N, Mazzucchelli T, O'Reilly L, MacKenzie B, Green J et al. An outbreak of *Salmonella enterica* serotype Litchfield infection in Australia linked to consumption of contaminated papaya. J Food Prot. 2009;72(5):1094-8. https://doi.org/10.4315/0362-028X-72.5.1094
58. Center for Disease Control and Prevention – CDC. Multistate outbreak of human *Salmonella* agona infections linked to whole, fresh imported papayas (final update). Atlanta: Center for Disease Control and Prevention; 2011[cited 2016 Feb 02]. Available from: http://www.cdc.gov/salmonella/2011/papayas-8-29-2011.html

59. Center for Disease Control and Prevention - CDC. Multistate outbreak of *Salmonella* Braenderup infections associated with mangoes (final update). Atlanta: Center for Disease Control and Prevention; 2012[cited 2016 Feb 02]. Avaliable from: http://www.cdc.gov/salmonella/braenderup-08-12

60. Center for Disease Control and Prevention - CDC. Surveillance for foodborne disease outbreaks United States, 2013: annual report. Atlanta: Center for Disease Control and Prevention; 2013[cited 2016 Feb 02]. Availlable from http://www.cdc.gov/foodsafety/pdfs/foodborne-disease--outbreaks-annual-report-2013-508c.pdf

61. Center for Disease Control and Prevention - CDC. Foodborne outbreak online database (food tool). Atlanta: Centers for Disease Control and Prevention; 2016[cited 2016 Feb 24]. Availlable from: http://wwwn.cdc.gov/foodborneoutbreaks

62. Sivapalasingam S, Friedman CR, Cohen L, Tauxe RV. Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. J Food Prot. 2004;67(10):2342-53. https://doi.org/10.4315/0362-028X-67.10.2342

63. Escartin EF, Ayala AC, Lozano JS. Survival and growth of *Salmonella* and *Shigella* on sliced fresh fruit. J Food Prot. 1989;52(7):471-2. https://doi.org/10.4315/0362-028X-52.7.471

64. Castillo A, Escartin EF. Survival of *Campylobacter jejuni* on sliced watermelon and papaya. J Food Prot. 1994;57(2):166-8. https://doi.org/10.4315/0362-028X-57.2.166

65. Yigeremu B, Bogale M, Ashenafi M. Fate of *Salmonella* species and *E. coli* in fresh-prepared orange, avocado, papaya and pine apple juices. Ethiop. J. Health Sci. 2001;11(2):89-95.

66. Penteado AL, Leitão MFF. Growth of *Salmonella* Enteritidis in melon, watermelon and papaya pulp stored at diferent times and temperatures. Food Control. 2004;15(5):369-73. https://doi.org/10.1016/S0956-7135(03)00099-9

67. Penteado AL, Leitão MFF. Growth of *Listeria monocytogenes* in melon, watermelon and papaya pulps. Int J Food Microbiol. 2004;92(1):89-94. https://doi.org/10.1016/j.ijfoodmicro.2003.08.020

68. Mutaku I, Erku W, Ashenafi M. Growth and survival of *Escherichia coli* O 157:H7 in fresh tropical fruit juices at ambient and cold temperatures. Int J Food Sci Nutr. 2005;56(2):133-9. https://doi.org/10.1080/09637480500082439

69. Strawn LK, Danyluk MD. Fate of *Escherichia coli* O 157:H7 and *Salmonella* spp. on fresh and frozen cut mangoes and papayas. Int J Food Microbiol. 2010;138(1-2):78-84. https://doi.org/10.1016/j.ijfoodmicro.2009.12.002

70. Barbosa AAT, Araújo HGS, Matos PN, Carnelossi MAG, Castro AA. Effects of nisin-incorporated films on the microbiological and physicochemical quality of minimally processed mangoes. Int J Food Microbiol. 2013;164:135-40. https://doi.org/10.1016/j.ijfoodmicro.2013.04.004

71. Penteado AL, Castro MFPM, Rezende ACB. *Salmonella enterica* serovar Enteritidis and *Listeria monocytogenes* in mango (*Mangifera indica* L.) pulp: growth, survival and cross-contamination. J Sci Food Agriv. 2014;94(13):2746-51. https://doi.org/10.1002/jsfa.6619

72. Ma C, Li J, Zhang Q. Behavior of *Salmonella* spp. on fresh-cut tropical fruits. Food Microbiol. 2016;54:133-41. https://doi.org/10.1016/j.fm.2015.10.006

73. De Roever C. Microbiological safety evaluations and recommendations on fresh produce. Food Control. 1998;9(6):321-47. https://doi.org/10.1016/S0956-7135(98)00022-X

74. Bassett J, McClure P. A risk assessment approach for fresh fruits. J Appl Microbiol. 2008;104(4):925-43. https://doi.org/10.1111/j.1365-2672.2007.03697.x

75. Feng K, Hu W, Jiang A, Xu Y, Sarengaowa, Li X, Bai X. Growth potential of *Listeria monocytogenes* and *Staphylococcus aures* on fresh-cut tropical fruits. J Food Sci. 2015;80(11):M2548-54. https://doi.org/10.1111/1750-3841.13089

76. Cardello HMAB, Cardello L. Teor de vitamina C, atividade de ascorbato oxidase e perfil sensorial de manga (*Mangifera indica* L.) var. Haden, durante o amadurecimento. Ciênc Tecnol Aliment. 1998;18(2):211-7.

77. Food Safety & Health. pH values of common foods and ingredients. [place unknown: publisher unknown]. 2016[cited 2016 Feb 02]. Available from: http://foodsafety.wisc.edu/business_food/files/approximate_ph.pdf

78. Tandon DK, Kalra, SK. Pectin changes during the development of mango fruit cv Dashehari. J Hortic Sci. 1984;59(2):283-6. https://doi.org/10.1080/00221589.1984.11515198

79. Lima LM, Morais PLD, Medeiros EV, Mendonça V, Xavier IF, Leite GA. [Postharvest quality of 'Tainung 01' papaya formosa traded in different types of establishments]. Rev Bras Frutic. 2009;31(3):902-6. Portuguese. https://doi.org/10.1590/S0100-29452009000300038

80. Benevides SD, Ramos AM, Stringheta PC, Castro VC. [Quality of the fruits and pulp of Ubá mango]. Ciênc Tecnol Aliment. 2008;28(3):571-8. Portuguese. https://doi.org/10.1590/S0101-20612008000300011

81. Branco IG, Gasparetto CA. Response surface methodology applied to the study of temperature effect on the rheological behavior of ternaries mixtures with mango pulp and orange and carrot juices. Ciênc Tecnol Aliment. 2003;23 suppl:166-71. https://doi.org/10.1590/S0101-20612003000400031

82. Correa SF, Souza MS, Pereira T, Alves GVL, Oliveira JG, Silva MG, Vargas H. Determination of thermal diffusivity in papaya pulp as a function of maturation stage. Rev Bras Frutic Jaboticabal. 2008;30(3):611-5. https://doi.org/10.1590/S0100-29452008000300008

83. pH values of food products. Food Eng. 1962;98-99.

84. Raybaudi-Massilia R, Calderón-Gabaldón MI, Mosqueda-Melgar J, Tapia MS. Inactivation of *Salmonella enterica* ser: poona and *Listeria monocytogenes* on fresh-cut "Maradol" red papaya (Carica papaya L) treated with UV-C light and malic acid. J Verbr Lebensm. 2013;8(1):37-44. https://doi.org/10.1007/s00003-013-0808-1

85. Souza BS, Durigan JF, Donadon JR, Teixeira GHA. [Preservation of fresh cut 'Formosa' papaya stored under refrigeration]. Rev Bras Frut Jaboticabal. 2005;27(2):272-6. Portuguese. https://doi.org/10.1590/S0100-29452005000200021

86. Himathongkham S, Riemann H. Destruction of *Salmonella typhimurium*, *Escherichia coli* O157:H7 and *Listeria monocytogenes* in chicken manure by drying and/or gassing with ammonia. FEMS Microbiol Lett. 1999;171(2):179-82. https://doi.org/10.1111/j.1574-6968.1999.tb13430.x

87. Suslow TV. Ozone applications for postharvest disinfection of edible horticultural crops. Oakland: University of California; 2004[cited 2017 Feb 6]. Available from: http://anrcatalog.ucanr.edu/pdf/8133.pdf

88. Zhou B, Luo Y, Millner P, Feng H. Sanitation and design of lettuce coring knives for minimizing *Escherichia coli* O157:H7 contamination. J Food Prot. 2012;75(3):563-6. https://doi.org/10.4315/0362-028X.JFP-11-218

89. Park S, Navratil S, Gregory A, Bauer A, Srinath I, Jun M et al. Generic *Escherichia coli* contamination of spinach at the preharvest stage: effects of farm management and environmental factors. Appl Environ Microbiol. 2013;79(14):4347-58. https://doi.org/10.1128/AEM.00474-13

90. Rodrigues RQ, Loiko MR, Paula CMD, Hessel CT, Jacxsens L, Uyttendaele M et al. Microbiological contamination linked to implementation of good agricultural practices in the production of organic lettuce in Southern Brazil. Food Control. 2014;42:152-64. https://doi.org/10.1016/j.foodcont.2014.01.043

91. Monaghan JM, Hutchison ML. Ineffective hand washing and the contamination of carrots after using a field latrine. Lett Appl Microbiol. 2016;62(4):299-303. https://doi.org/10.1111/lam.12549

92. Ceuppens S, Hessel CT, Rodrigues RQ, Bartz S, Tondo EC, Uyttendaele M. Microbiological quality and safety assessment of lettuce production in Brazil. Int J Food Microbiol. 2014;181:67-76. https://doi.org/10.1016/j.ijfoodmicro.2014.04.025

93. Brackett RE. Shelf stability and safety of fresh produce as influenced by sanitation and disinfection. J Food Prot. 1992;55(10):808-14. https://doi.org/10.4315/0362-028X-55.10.808

94. Gil MI, Selma MV. Overview of hazards in fresh-cut produce production: Control and Management of food safety hazards. In: James J, editor. Microbial hazard identification in fresh fruit and vegetables. New York: John Wiley & Sons; 2006. p. 156-219.

95. Leifert C, Ball K, Volakakis N, Cooper JM. Control of enteric pathogens in ready-to-eat vegetable crops in organic and 'low input' production systems: a HACCP-based approach. J Appl Microbiol. 2008;105(4):931-50. https://doi.org/10.1111/j.1365-2672.2008.03794.x

96. Hurst WC. Microbiology of fruits and vegetables. In: Sapers GM, Gorny JR, Yousef AE. HACCP: a process control approach for fruit and vegetables safety. Boca Raton: CRC Taylor & Francis; 2006. p. 339-64.

Conflict of Interest

Authors have no potential conflict of interest to declare, related to this study's political or financial peers and institutions.