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Survival of *Escherichia coli* in Banana Peels after Sanitation with Sodium Hypochlorite and during Simulated Export Transport Conditions

ABSTRACT

The efficacy of sodium hypochlorite for banana sanitation was assessed and the survival of *Escherichia coli* on bananas during simulated export transport from Costa Rica to the United States was evaluated. Bananas (*Musa* spp., AAA group, Cavendish sub-group) were surface inoculated with *E. coli* ATCC 25922 (7 log CFU/g) and then immersed for five minutes in sodium hypochlorite solutions (0, 50, 100, 150 and 200 ppm) adjusted to pH 7. The population of inoculated *E. coli* on banana surface was monitored during simulated export transport conditions (14 ± 1°C; 85–90% relative humidity; clusters packed in polyethylene bags and cardboard boxes). *E. coli* was enumerated at 0, 1, 5, 7, 12 and 14 days of storage using Tripticase Soy and MacConkey agars incubated at 35 ± 2°C for 24 h. Trials were performed in triplicate. A 100 ppm or higher concentration of sodium hypochlorite yielded at least a 3-log reduction of *E. coli*. No significant differences ($P \geq 0.05$) were found between 100 and 200 ppm of sanitizer. Storage time significantly influenced ($P \leq 0.05$) the *E. coli* population. Approximate 3-log reduction of *E. coli* was obtained the first day of storage, but afterwards the population remained constant (3–4 log CFU/g).

INTRODUCTION

Banana is is one of the most traded commodities and the world's most popular fruit. Worldwide, banana is grown in more than 150 countries of tropical and sub-tropical origin with an annual production of 164 million tons, contributing 18% of total fruit production *(14)*. Bananas undergo many processes and since the fruit is perishable, postharvest losses are relatively high and occurs mostly during transportation, handling, and storage *(30)*. Various technologies are being used like storage, artificial ripening, packaging, handling, and transportation for bananas within the supply chain *(1)*; however, a standardized sanitation procedure is not commonly applied and information is lacking regarding the presence and survival of human pathogens on this fruit and potential implications for consumer health.

As a climacteric fruit, bananas are harvested with zero degree of ripeness (green in color), but at physiological

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maturity to assure proper ripening at the final market. In the tropics, banana bunch age generally varies from 12 to 14 weeks. Banana harvesting consists of cutting banana bunches and transporting them to the packing house, usually using a cable system, and protecting the fruit from mechanical damage. For export purposes, the fruit must be free of superficial defects. After arrival at the packing house, bunches are weighed and the quality control protocol is undertaken. Then, a hand separation from the bunch takes places (de-handing), and the floral part is removed. Banana hands are dropped into a tank of water to remove the sap (latex) coming out from the cut, which could stain the surface and compromise the overall fruit quality. To avoid latex stain, 1% aluminum sulfate may be added in the water tanks or other chemicals such as a surfactant solution alone or combined with hydrogen peroxide. Banana hands are then removed from the water and cut into clusters. The fruit is selected and placed into trays. After packaging and during transportation, the storage temperature is reduced to diminish the fruit respiration rate and delay its ripeness, thus extending the fruit shelf life. Nevertheless, temperature has to be above 12°C to avoid chilling injury *(18)*.

The sap removing step, by immersing the clusters in an aqueous environment, is not currently intended for sanitation purposes but to avoid quality issues. Sanitation refers to the physical and/or chemical approach used to remove, inhibit and/or reduce microorganisms on the surface of products with the goal of eliminating potential human pathogenic microorganisms as well as spoilage microorganisms that may compromise the quality of the product and therefore its shelf life. Sanitizing agents used for fruits and vegetables include halogenated compounds, acids and active oxygen compounds. Among these, chlorinated compounds (chlorine gas, hypochlorite salts and chlorine dioxide) are the most widely used in the food industry due to their low cost and high effectiveness against bacteria and fungi, their effectiveness at room temperature and their tolerance to hard water *(15)*.

Survival of pathogenic microorganisms in fruits depends on many factors such as the physicochemical characteristics of the fruit, the postharvest processes applied, and product handling by the consumer *(3, 7, 18, 32)*. Studies have shown dissimilarities in the results depending on food tested *(8, 9, 12, 21, 22, 27)* and the pathogenic microorganisms involved. A study carried out in 2018 reported the presence and growth of *E. coli* 25922 in the peel and edible part of bananas during postharvest and storage at controlled temperatures. In the study, five boxes of bananas were randomly collected from the packing line and an initial sampling was conducted at 26°C. The boxes were then stored in a cold room at 17–18°C and samples were taken again after 4 and 18 days of storage. A negative result for the presence of *E. coli* was obtained in all of the samples analyzed. However, due to the apparent absence of *E. coli* at the beginning of the experiment, no growth of the indicator microorganism was observed, although storage conditions were favorable for its development *(17)*.

To the authors' knowledge, no foodborne outbreaks associated with contaminated fresh bananas have been documented. However, pathogen survival on fresh fruits is a potential safety issue of public health concern. This study aimed to 1) evaluate the efficacy of sodium hypochlorite for sanitizing the banana surface and 2) determine the survival of *Escherichia coli* on banana peels during storage under conditions simulating export transport from Costa Rica to the United States. The research provides relevant information to the global food industry regarding one of the most highly consumed fruits worldwide that is of great economic and social importance for Costa Rica and other developing countries.

MATERIALS AND METHODS

Fruit samples

Fresh Costa Rican bananas (Cavendish variety) with a zero degree of ripeness, 12 weeks of harvest age, and no signs of surface damage were used. Bananas were provided by CORBANA (National Banana Corporation, Costa Rica).

Inoculum preparation and inoculation of bananas

One isolated colony of *E. coli* ATCC 25922 was transferred to 9 mL of Trypticase Soy Broth (TSB) (Difco Laboratories, Sparks, MD) and incubated at 35 ± 2°C for 5 ± 1 h. The entire inoculum was then transferred to an Erlenmeyer flask containing 400 mL of TSB and incubated at 35 ± 2°C for 18 ± 2 h, until the stationary phase was reached, using a Lab Companion SI-600 shaking incubator at a constant agitation of 200 rpm (Jeio Tech, Daejeon, Korea) *(31)*. Banana clusters (4 bananas per cluster) were independently dip inoculated with *E. coli* ATCC 25922 for 20 min, simulating the immersion time during the sap removal step currently applied in Costa Rican banana industry, to achieve an initial population of 7 log CFU/g *(20)*. The inoculum significantly surpassed the initial microbiota level naturally present in bananas. Thus, the targeted bacteria inoculated mostly represent the microbial population reported as the initial *E. coli* population in the fruit.

Clusters were completely submerged throughout the inoculation step and gently agitated to ensure contact of the entire surface of each fruit with the inoculum. Bananas were then removed from the suspension, placed on sterilized aluminum foil, left to drain for 20 min (the period currently used in Costa Rica after immersion for sap removal), and assigned to the corresponding sanitation treatments.

Banana sanitation

The efficacy of commercial sodium hypochlorite treatments to eliminate *E. coli* on the banana surface was assessed at 0, 50, 100, 150 and 200 ppm (Clorox Co.,

Costa Rica). Seven banana clusters were used per replicate; including one cluster for each of the sodium hypochlorite concentrations, an inoculated untreated cluster as a positive control and used to calculate the log reductions resulting from the treatments, and a non-inoculated untreated negative control to determine the natural population of generic *E. coli* present on the fruit before the experiment. The experiment was performed in triplicate, corresponding to three independent biological replicates. After inoculation, banana clusters were treated with the corresponding sanitizer concentration in independent dump tanks with a maximum capacity of 7 L. Solutions were adjusted to pH 7 with HCl (1 M) and banana clusters were immersed for 5 min. Both bananas and sanitizer solutions were tempered at room temperature (25°C). Banana clusters were gently agitated to ensure an even distribution of the solution over the surface of the fruits. Banana clusters were then placed into sterile stomacher bags and weighed, then 0.1% sterile peptone water was added to reach a proportion of 1:10 (banana:peptone water) and the fruit surface was gently hand-massaged for 1 min *(12, 18)*. The resulting suspension was used to prepare decimal dilutions for *E. coli* counts. *E. coli* was enumerated, in duplicate, using the pour-plate technique with Tripticase Soy Agar (TSA) (Difco Laboratories, Sparks, MD) and MacConkey agar (Difco Laboratories, Sparks, MD), both incubated at 35 ± 2°C for 24 h *(8)*. For the negative control, the most probable number (MPN) technique was used for enumeration given that a low concentration or absence of generic *E. coli* was expected in the non-inoculated untreated bananas *(13)*. The non-selective media TSA was used considering that *E. coli* may suffer sublethal damage due to chlorine exposure and therefore, it may not grow as expected in the selective agar (MacConkey agar) representing an underestimation and, in consequence, a potential safety concern. Thus, since injured bacteria are not normally detected in selective media, but they resuscitate and subsequently multiply in a suitable environment such as non-selective media, both medias were used *(28)*.

E. coli survival during banana simulated transportation

Survival kinetics of *E. coli* on the banana surface were assessed under conditions simulating transport from Costa Rica to the United States. Banana clusters were inoculated as described. Inoculated samples were sprayed with a fungicide solution with 25% of azoxystrobin (Bankit® 25 SC, Syngenta, Costa Rica) and 1% m/v aluminum and potassium sulfate (Banalum, Agrotico, Costa Rica) to mimic the postharvest treatment currently applied in the banana industry in Costa Rica. For this trial, eight banana clusters were used: one for each of the six sampling times (0, 1, 5, 7, 12 and 14 days after inoculation), and one for each positive and negative control. The positive control was used as a reference to calculate *E. coli* population changes over time. The clusters were packed into polyethylene plastic bags and placed into cardboard boxes. Packaging materials were provided by the National Banana Corporation (Costa Rica). Samples were stored at 14 ± 1°C and 85 to 90% relative humidity for up to 14 days to simulate export transportation conditions from Costa Rica to the United States. At each sampling point, one banana cluster was microbiologically analyzed following the procedure described in the sanitation experiment.

Statistical analysis

All experimental trials were performed in triplicate. For the sanitation trial, a unifactorial unrestricted random type experimental design was followed using *E. coli* log reduction as the response variable. For the survival trial, the same experimental design was followed using *E. coli* log count as the response variable. Analysis of variance (ANOVA) followed by Tukey's test was performed to determine significant differences among log reductions after sanitation treatments in the efficacy trial and among sampling times in the transportation experiment. The significance level was set at 5%. JMP®9 (SAS Institute, Cary, NC) was used for statistical analyses.

RESULTS AND DISCUSSION

Banana sanitation

A critical factor for the antibacterial efficacy of sodium hypochlorite is pH *(22, 25)*. The average pH values for each treatment solution, measured before performing the sanitation trials, are summarized in *Table 1*. This factor did not differ significantly ($P>0.05$) among treatments; thus, pH was not an influencing variable on the *E. coli* reductions obtained. Analysis of the negative controls (non-inoculated, untreated banana clusters) using the MPN technique for *E. coli* enumeration showed a < 1.8 MPN/g population in all samples analyzed, which is the lower limit of detection of the most probable number method used for quantification. This result indicates a low population of generic *E. coli* in the non-inoculated samples. Thus, this variable had no influence on the results reported. To confirm the absence of the microbial indicator in the fruit collected from banana farms or detect lower levels of contamination before conducting the sanitation experiments, an increased number of samples or an alternative approach such as sponge sampling of all the bananas in a cluster would be required.

The population of *E. coli* on banana peels after inoculation and prior to sanitation was 7.4 ± 0.2 ($n = 3$), using the positive control samples as a reference. *Figure 1* shows *E. coli* log reductions obtained after samples were exposed to the different sanitation treatments. When nutritive culture media (TSA) was used for *E. coli* enumeration *(Fig. 1a)*, no significant differences ($P = 1.000$) were observed between the results obtained with water (control treatment, 0 ppm of sodium hypochlorite) and 50 ppm of the sanitizer. This range of sodium hypochlorite concentrations is currently used in the Costa Rican banana industry in water in dump

TABLE 1. Average pH values of sodium hypochlorite solutions at different concentrations used to sanitize the banana surface (mean ± standard deviation, *n* = 3)

Sodium hypochlorite theoretical concentration (ppm)	pH
50	6.93 ± 0.05
100	6.96 ± 0.10
150	7.01 ± 0.04
200	7.03 ± 0.01

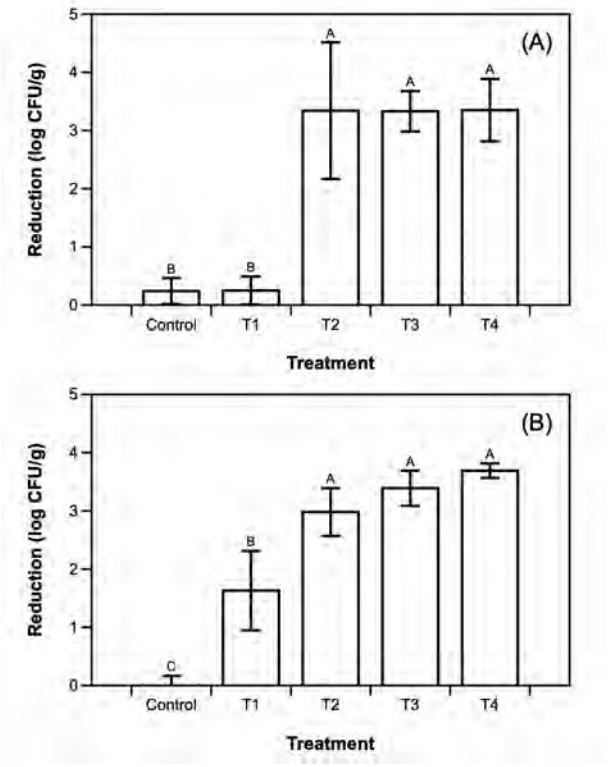

FIGURE 1. *E. coli* ATCC 25922 reductions in (A) TSA and (B) MacConkey agar after sanitation treatment with sodium hypochlorite (T1: 50 ppm; T2: 100 ppm; T3: 150 ppm and T4: 200 ppm). Error bars depict the standard deviation, *n* = 3. Different letters in the bars indicate significant differences according to Tukey's test (*P*<0.05).

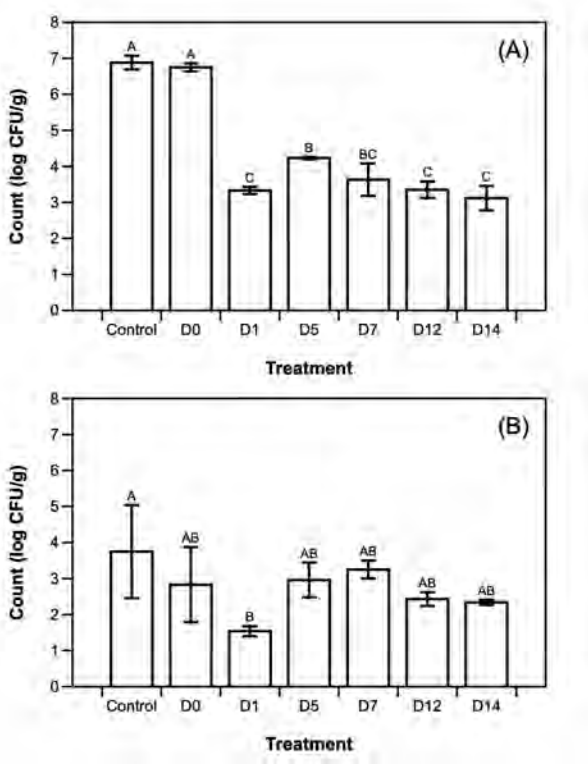

FIGURE 2. *E. coli* ATCC 25922 population in (A) TSA and (B) MacConkey agar during storage (D0: 0 days; D1: day 1; D5: day 5; D7: day 7; D12: day 12; and D14: day 14). Error bars depict the standard deviation, *n* = 3. Different letters in the bars indicate significant differences according to Tukey's test (*P*<0.05).

tanks used for sap removal. This is currently the only aqueous environment in the postharvest procedure; thus, a higher concentration of sanitizer would be required to adapt the water immersion step for sanitation purposes. Further studies would also be required to analyze mechanisms to control the sanitizer concentration over time, given the presence of organic matter in the tanks. The greatest reduction, around 3 log CFU/g, was obtained with a sanitizer concentration of 100 ppm or higher; there were no significant differences (*P*>0.05) in *E. coli* inactivation rates among treatments from 100 to 200 ppm. Similar results were obtained using MacConkey agar, a selective and differential media for Gram negative bacteria *(Fig. 1b)*, thus confirming the effect of the sanitizer on the inoculum. On this last media, *E. coli* was isolated from other microorganisms naturally present in the fruit that were able to grow in TSA but not in the selective media. In addition, sublethally damaged *E. coli* cells that were not able to grow in the selective media may have caused the

differences in counts observed when using the TSA as a non-selective enumeration agar.

The *E. coli* reductions obtained in this investigation were slightly higher than values previously reported in similar studies. Behrsing et al. *(4)* reported 2.3 and 2.4 log CFU/g reductions of *E. coli* (TGI) in broccoli and lettuce, respectively, treated with sodium hypochlorite at 100 ppm for 5 min. Lindsey et al. *(20)* obtained a log reduction of 1.58 log CFU/g of *E. coli* O157:H7 (7 SEA13B88) in lettuce exposed to sodium hypochlorite at 200 ppm for 2 min. Similarly, Beuchat et al. *(7)* obtained 0.70, 2.02 and 2.43 log CFU/g reductions of *E. coli* O157:H7 on apples, tomatoes and lettuce, respectively, exposed to a 200 ppm hypochlorite solution for 5 min. Differences in these results may be due to multiple factors, including natural differences in the surfaces of the fruits and vegetables and differences in exposure times and inoculated strains. The efficacy of a sanitation procedure may be reduced as the time between inoculation and sanitation is extended. In the present study, bananas were sanitized immediately after inoculation *(16, 22)*, which may have facilitated microbial elimination.

Anvarian et al., *(2)* evaluated the effect of sodium hypochlorite solutions against *E. coli* K-12 SCC1. As in our research, there was no significant effect on the inactivation of *E. coli* at concentrations of 0 ppm and 50 ppm when using non-selective agar but a significant difference in the results obtained with those concentrations was found when the selected media was used instead. Chung et al., *(10)* found that increasing the concentration of sodium hypochlorite from 50 to 200 ppm increased the inactivation of *E. coli* in different fruits and vegetables, and when water was used as a control treatment (0 ppm sanitizer) the population of the added inoculum remained constant.

The non-significant effect of increasing concentrations from 100 to 200 ppm in our study was expected. Previously, Mani et al. *(22)* found that increasing the sodium hypochlorite concentration used to sanitize peppers from 100 to 10000 ppm and exposure times from 5 and 120 min did not affect inactivation rates of aerobic mesophilic bacteria. The authors attributed the effect to the hydrophobic nature of pepper skins, which may repel the aqueous solution used for sanitation purposes. Lindsey et al., *(20)* also found no significant differences in the results when 100 and 200 ppm sodium hypochlorite solutions were used to sanitize lettuce inoculated with *E. coli* O157:H7 SEA13B88. Similarly, Beuchat et al., *(7)* found no significant differences in the log reductions of a cocktail of *E. coli* O157:H7 strains (CA1, E0019, E09, 932, and F500) on tomatoes and apples sanitized for 5 min with sodium hypochlorite solutions at concentrations ranging from 200 to 2000 ppm.

E. coli survival during banana transportation

E. coli populations in negative control samples (non-inoculated, untreated banana clusters) were <1.8 MPN/g in all cases. Thus, the initial *E. coli* population present in the samples represents only the added inoculum. Comparison of the *E. coli* population at Day 0 with the inoculated untreated control showed no significant effect (P=1.000) of the fungicide mixture applied before the storage period *(Fig. 2)*.

An analysis of variance was performed to compare the *E. coli* population at the different sampling points during storage; there were no significant differences (P=1.0000) among results obtained on days 1, 7, 12 and 14. Likewise, there were no significant differences between *E. coli* populations at days 5 and 7 (P=1.0000). As depicted in *Figure 2a*, the greatest reduction of *E. coli* occurred on the first day of storage. The population of the indicator then remained constant from day 1 until the end of the study (day 14), with a slight increase at day 5. This trend agrees with findings previously published by Delbeke et al. *(11)*.

One explanation for the population drop observed on the first day of storage is that when the inoculated microorganism was placed in a different environment, the population decreased in response to the sudden changes in environmental conditions, including stress factors such as nutrient limitation, temperature variation, desiccation, and competition with surface microbiota *(27)*. The population increase on day 5 of storage may be attributed to adaptation of the bacteria to the new environment and/or alterations in their cellular physiology that allowed the development of resistance to the different environmental stress factors *(27)*.

A similar trend was seen in the results with MacConkey agar. Slightly lower counts were expected and were consistently obtained because the selective and differential media selected the microorganism of interest from the background microbiota present in banana peels *(28, 29)*. When MacConkey agar was used for enumeration *(Fig. 2b)*, in all treatments, with the exception of day 1 of storage, no significant differences were found (P=1.0000) with respect to the control and a non significant effect of time on the *E. coli* population in the fruit was detected (P=1.0000).

The survival of *E. coli* shown in *Figure 2* is similar to that reported in a study by Delbeke et al. *(11)*. These authors studied the survival of *E. coli* O157:H7 LFMFP846 in strawberries and basil during storage at three temperatures: 7, 15 and 22°C. Strawberries were inoculated with 5–6 log CFU/g of *E. coli* and basil with 4–5 log CFU/g. *E. coli* survived for one week on basil at all temperatures mentioned. At 7°C, the population of the inoculated microorganism decreased during storage, and there was no increase afterwards. However, at 15°C, the population of *E. coli* O157:H7 decreased in the first days of storage, then increased at day 4 and remained constant until the end of the study (day 7). Although the strain, food matrix and conditions differed from those used in the present investigation, a similar storage temperature was used and the results followed the same trend. Singh et al., *(26)* studied survival of the population of a cocktail of *E. coli*

(ATCC 23716, 25922 and 11775) inoculated to the surface of watermelons in the field prior to harvest. The *E. coli* population suffered the greatest reduction in the first 24 hours of storage and then remained constant until the end of the study (120 h). It is important to note that in our study and all of the mentioned studies, *E. coli* survived until the end of the storage time. The ability of this microorganism to survive in a challenging environment should prompt the establishment of adequate control measures to prevent consumers from receiving contaminated fresh fruits and vegetables. In banana, for example, the establishment of a post-harvest sanitation process may help to avoid the presence of unwanted microorganisms such as *E. coli* on the surface of exported fruit.

CONCLUSIONS

Our findings regarding *E. coli* ATCC 25922 survival on banana peels during transportation underscore the relevance of good agricultural practices to prevent contamination of fresh fruit and the importance of implementing a postharvest sanitation treatment for banana safety assurance. Immersion of banana fruit in a sodium hypochlorite solution of at least 100 ppm for 5 min coupled with one day of storage at 14°C could achieve up to 6 log reduction of *E. coli* under the simulated transportation conditions described in this study. Further research, with a larger sample size, is needed to confirm these results with different pathogenic strains of concern and to determine the impact of sodium hypochlorite on the sensory profile of the fruit.

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REFERENCES

1. Al-Dairi, M., P. B. Pathare, R. Al-Yahyai, H Jayasuriya, and Z Al-Attabi. 2023. Postharvest quality, technologies, and strategies to reduce losses along the supply chain of banana: A review. *Trends Food Sci.* 134:177–191.
2. Anvarian, A., M. Smith, and T. Overton. 2018. Flow cytometry and growth-based analysis of the effects of fruit sanitation on the physiology of *Escherichia coli* in orange juice. *Food Sci. Nutr.* 7(3):1072–1083.
3. Bartz, J., and R. Showalter. 1981. Infiltration of tomatoes by aqueous bacterial suspensions. *Phytopathology.* 71:515–518.
4. Behrsing, J., S. Winkler, P. Franz, and R. Premier. 2000. Efficacy of chlorine for inactivation of *Escherichia coli* on vegetables. *Postharvest Biol. and Technol.* 19:187–192.
5. Beier, R., S. D. Pillai, T. D. Phillips, and R. L. Ziprin. 2004. *Preharvest and Postharvest Food Safety.* Blackwell Publishing, United States.
6. Beuchat, L. R. 1996. Pathogenic microorganisms associated with fresh produce. *J. Food Prot.* 59(2):204–216.
7. Beuchat, L., B. Adler, and M. Clavero. 1998. Efficacy of spray application of chlorinated water in killing pathogenic bacteria on raw apples, tomatoes, and lettuce. *J. Food Prot.* 61(10):1305–1311.
8. Buchanan, R. L., S. G Edelson, R. L Miller, and G. M. Sapers. 1999. Contamination of intact apples after immersion in an aqueous environment containing *Escherichia coli* O157:H7. *J. Food Prot.* 62(5):444–450.
9. Chen, Y., P. Evans, T. S. Hammack, E. W. Brown, and D. Macarisin. 2016. Internalization of *Listeria monocytogenes* in whole avocado. *J. Food Prot.* 79(8):1440–1445.
10. Chung, C. C., T. C. Huang, C. H. Yu, F. Y. Shen, and H. H. Chen. 2011. Bactericidal effects of fresh-cut vegetables and fruits after subsequent washing with chlorine dioxide. *International Conference on Food Engineering and Biotechnology* 9(21):54–59.
11. Delbeke, S., S. Ceuppens, L. Jacxsens, and M. Uyttendaele. 2015. Survival of *Salmonella* and *Escherichia coli* O157:H7 on strawberries, basil, and other leafy greens during storage. *J. Food Prot.* 78(4):652–660.
12. Eblen B. S., M. O. Walderhaug, S. Edelson-Mammel, S. J. Chirtel, A. De Jesus, R. I. Merker., R. L. Buchanan, and A. J. Miller. 2004. Potential for internalization, growth, and survival of *Salmonella* and *Escherichia coli* O157:H7 in oranges. *J. Food Prot.* 67(8): 1578–1584.
13. Feng, P., S. D. Weafent, M. A. Grant, and W. Burkhardt. 2002. Bacteriological Analytical Manual (BAM). Chapter 4: Enumeration of *Escherichia coli* and the Coliform Bacteria. Available at: https://www.fda.gov/food/laboratory-methods-food/bam-chapter-4-enumeration-escherichia-coli-and-coliform-bacteria. Accessed February 27, 2023.
14. Food and Agriculture Organization (FAO). 2022. Bananas–crops and livestock products. Available at: https://www.fao.org/faostat/en/#search/banana. Accessed June 8 2023.
15. Frisón, L. N., C. A. Chiericatti, E. E. Aríngoli, J. C. Basílico, and M. Z. Basílico. 2015. Effect of different sanitizers against *Zygosaccharomyces rouxii. J. Food Sci. Technol.* 52(7):4619–4624.
16. Gil, M. I., M. V. Selma, F. López-Gálvez, and A. Allende. 2009. Fresh-cut product sanitation and wash water disinfection: Problems and solutions. *Int. J. Food Microbiol.* 134:37–45.
17. Girón Revolorio, B., F. Cano Granados, L. Monney Castillo, A. Espinoza García, H. Espinoza García. 2019. Determinación de la presencia de *Escherichia coli* en la cáscara y parte comestible del banano y evaluación de su crecimiento durante el proceso de postcosecha y almacenamiento a temperatura controlada. *Revista Científica Guatemala.* 28(2):26–36.
18. Ibarra, L. S., S. Alvarado-Casillas, M. O. Rodríguez-García, N. E. Martínez-Gonzáles, and A. Castillo. 2004. Internalization of bacterial pathogens in tomatoes and their control by selected chemicals. *J. Food Prot.* 67(7):1353–1358.
19. Lobo, M. G. and M. Montero-Calderón. 2020. Harvesting and postharvest technology of banana. *In* M. Siddiq, J. Ahmed, and M. G. Lobo (eds). *Handbook* of Banana Production, Postharvest Science, *Processing Technology, and Nutrition*. John Wiley & Sons Ltd. Hoboken, NJ.
20. Lindsey, A., A. Burke and A. Bassam. 2009. Efficacy of chlorine, acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate *Escherichia coli* O157:H7 from lettuce leaves. *Int. J. Food Microbiol.*132:134–140.
21. Macarisin, D., A. Wooten, A. De Jesus, M. Hur, S. Bae, J. Patel, P. Evans, E. Brown, T. Hammack, and Y. Chen. 2017. Internalization of *Listeria monocytogenes* in cantaloupes during dump tank washing and hydrocooling. *J. Food Microbiol.* 257:165–175.
22. Mani, E., E. Palau, and A. Lopez. 2016. Effect of different sanitizers on the microbial load and selected quality parameters of "chile de arbol" pepper (*Capsicum frutescens* L.) fruit. *Postharvest Biol. Technol.* 119:94–100.

23. Parish, M., L. R. Beuchat, T. Suslow, L. J. Harris, E. H. Garret, J. Farber, and F. F. Busta. 2006. Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. *Compr. Rev. Food Sci. Food Saf.* 2(1):161–173.

24. Penteado, A. L., B. S. Eblen and A. J. Miller. 2004. Evidence of *Salmonella* internalization into fresh mangos during simulated postharvest insect disinfestation procedures. *J. Food Prot.* 67(1):181–184.

25. Schneider, K., and M. Fatica. 2009. The use of chlorination and alternative sanitizers in the produce industry. *CAB Rev.: Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* 4(52).

26. Singh, V., K. Fontenot, R. Strahan, V. Yemmireddy, C. Cason, K. Kharel, and A. Adhikari. 2019. Attachment strength and on-farm die-off rate of *Escherichia coli* on watermelon surfaces. *Plos One.* 14(1): e0210115.

27. Solomon, E., S. Yaron, and K. Matthews. 2002. Transmission of *Escherichia coli* O157:H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. *Appl. Environ. Microbiol.* 68(1):397–400.

28. Walsh, S. M., and Bissonnette. G. K. 1983. Chlorine-induced damage to surface adhesions during sublethal injury of enterotoxigenic *Escherichia coli*. *Appl. Environ Microbiol.* 45(3):1060–5.

29. Wanger, A., V. Chavez, R. Huang, A. Washed, A. Dasgupta, and J. Actor. 2017. Microbiology and molecular diagnosis in pathology. Chapter 4: Media for the Clinical Microbiology Laboratory. United States: Elsevier, 51–60.

30. Wasala, C. B., C. Dissanayake, D. Dharmasena, C. Gunawardane, and T. Dissanayake Postharvest losses, current issues and demand for postharvest technologies for loss management in the main banana supply chains in Sri Lanka. *J. Postharvest Technol.* 2(1):80–87.

31. Usaga, J., J. J. Churey, O. I. Padilla-Zakour, and R. W. Worobo. 2014. Determination of the validation frequency for commercial UV juice processing units. *J. Food Prot.* 77(12):2076–2080.

32. Zhuang, R. Y., L. R. Beuchat, and F. J. Angulo. 1995. Fate of *Salmonella* Montevideo on and in raw tomatoes as affected by temperature and treatment with chlorine. *Appl. Environ. Microbiol.* 61(6):2127–2131.