Archives of Agriculture and Environmental Science 10(3): 408-413 (2025)
https://doi.org/10.26832/24566632.2025.100303

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes

ORIGINAL RESEARCH ARTICLE

Comparative analysis of microbial contamination in vegetables sourced from farms, markets and street vendors in cape coast, Ghana

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ARTICLE HISTORY

Received: 12 May 2025
Revised received: 06 July 2025
Accepted: 12 July 2025

Keywords

Food borne disease
Microbial contamination
Vegetables

ABSTRACT

Safety of fresh vegetables has become a critical public health concern, especially in urban centers where contamination can occur at multiple points along the food supply chain. This study enumerated the microbial load of some selected vegetables (lettuce, cabbage, green pepper, and carrot) collected from farms, markets, and street food vendors within the Cape Coast metropolis. A total of 24 fresh vegetables were conveniently sampled from 3 locations and analyzed for certain microbial contaminants such as *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes* and *Salmonella species*. Standard microbial techniques were used for the culture and identification of the selected microbes. Results showed *E. coli* counts ranged from 4.53 $\log_{10}$ CFUg^{-1} (UCCSM-L) to 2.23 $\log_{10}$ CFUg^{-1} (UCCBV-L) while *S. aureu* ranged from 3.68 $\log_{10}$ CFUg^{-1} (UCCBV-L) to 0 $\log_{10}$ CFUg^{-1} with six of the samples recording the least count. Aerobic Mesophilic counts ranged from 3.23 to 6.72 $\log_{10}$ CFUg^{-1}. *Salmonella species* were present in 16.67% samples, while *L. monocytogenes* was absent in all samples. The cabbage, carrot and lettuce samples collected from the Cape Coast Metropolis had high microbial loads followed by green pepper samples. Therefore, the detection of pathogenic microorganisms such as *E. coli*, *S. aureus*, and *Salmonella spp.* underscores a serious public health concern. The presence of these pathogens suggests poor hygienic practices during transport and vending of these vegetables.

Citation of this article: Appiah, H., Darkwa, A. A., & Darkwa, S. (2025). Comparative analysis of microbial contamination in vegetables sourced from farms, markets and street vendors in Cape Coast, Ghana. *Archives of Agriculture and Environmental Science*, *10*(3), 408-413, https://dx.doi.org/10.26832/24566632.2025.100303

INTRODUCTION

Vegetable consumption has increased due to their importance as a dietary source of vitamins, fiber, and other nutrients. These also play vital roles in human health and well-being, particularly because they provide vitamins including vitamin C and vitamin A. Vegetables have also been shown to lower the risk of several diseases, including cancer and chronic degenerative diseases like cardiovascular disease (Alissa & Ferns, 2017). Owing to these health advantages, customers try to maintain a balanced diet and take advantage of these items all year-round. The global production of vegetables grew by 65% between 2000 and 2020, with significant increases in production across regions, including Africa, where Ghana contributes to vegetable farming. Vegetables play a crucial role in addressing chronic diseases due to their high nutritional value, especially traditional vegetables like okra and garden eggs which provide higher amounts of vitamin A, vitamin C, and important minerals compared to intensively grown vegetables (Dias, 2012; Chhem-Kieth *et al*., 2022). Despite the benefits of vegetable consumption, the growing concern over microbial contamination of vegetables during cultivation, harvesting, distribution, and consumption poses a significant health risk. In Ghana, vegetables pass through various distribution channels, including farmers, wholesalers, markets, and food vendors, with the introduction of microorganisms at each stage potentially introducing contamination (Chhem-Kieth *et al.*, 2022). Studies have reported high incidences of foodborne disease outbreaks linked to contaminated vegetables across the world, including Ghana, where 31% of outbreaks are attributed to vegetable contamination (de Oliveira Elias *et al.*, 2018). Despite the growing global demand for fresh fruits and vegetables, there is an increasing concern about microbial contamination, which threatens food safety (Snyder & Worobo, 2018). Contaminants such as pathogenic bacteria, pesticides, and untreated organic manure are frequently found in vegetables, leading to foodborne diseases (Yoon & Lee, 2017; Oh *et al.*, 2021; Mazzoni *et al.*, 2021).

The increasing concerns about the safety of vegetables in Ghana highlight the need to research into microbial contamination in these vegetables collected along the food chain. In Cape Coast, Ghana, where about 8,000 to 10,000 farmers engage in commercial vegetable farming, and more than 200,000 people consume these vegetables daily (Amo-Adjei & Kumi-Kyereme, 2014), there have been reported cases of foodborne diseases, particularly diarrhoea, linked to vegetable consumption (Adjei *et al.*, 2020). While studies in Ghana have focused on vegetable distribution, consumption patterns, and nutritional values (Seidu *et al.*, 2021; Dias, 2012), limited research has been conducted on the microbial contamination of locally grown vegetables in Cape Coast. Previous studies, such as Yafetto *et al.* (2019), have only explored contamination in vegetables sold in specific markets, without considering those cultivated locally. A key strength of this study lies in its comprehensive and comparative approach to evaluating microbial contamination in vegetables sourced from three major points within the distribution chain: farms, markets, and street vendors. By collecting and analyzing samples from diverse locations within the Cape Coast metropolis, the study offers a holistic view of the microbial risks associated with vegetables at various stages of their journey to consumers. Furthermore, the use of standardized laboratory procedures and analysis through a certified microbiological research facility (CSIR) enhances the credibility and reliability of the findings. This study aimed to fill this gap by assessing the microbial contamination of vegetables grown, sold, and consumed in Cape Coast, Ghana.

MATERIALS AND METHODS

Experimental design and treatment factors

The experimental research design was employed to enumerate and identify microbial loads in vegetables collected along the food chain (from farm gate through market sellers, food vendors to consumers) in the Cape Coast metropolis, Ghana. The experiment identified various microorganisms associated with contamination of cabbage, lettuce, green pepper and carrot obtained from the farm, sellers in the market and food vendors. These vegetables were selected for the study because these are often eaten raw. These vegetables after washing are cut into pieces and served as an accompaniment with rice, "waakye" and "jollof" by food vendors. Since these vegetables are served raw, their risk of causing illness if contaminated is high.

Population and subjects

The population for the study comprised vegetable farmers, vegetable sellers and food vendors in the Cape Coast metropolis. These groups were targeted since they are the key agents in vegetable distribution. One hundred and twenty (120) respondents (40 each of vegetable farmers, market women and food vendors who sell their food with cut vegetables) were sampled. This sample size was obtained using the formula for calculating sample for unknown populations. Convenience sampling procedure was used to select the respondents for the study. Convenience sampling is suitable for populations without sample frames, and it is quick, cheap, and time efficient (Hulley *et al.*, 2013).

Data collection procedures

Samples of the selected vegetables were picked from the three points, placed in sterile zip-lock plastic bags, which were placed in an ice chest, immediately covered with ice, and kept at 6°C - 10 °C. The cold temperature maintained in the ice chest was to help suppress the growth of microorganisms. Afterwards, the samples were transported to the Council for Scientific and Industrial Research's (CSIR) food microbiology laboratory in Accra for microbiological analysis. The CSIR laboratory was chosen because it is a reputable laboratory that serves the west African region. Twenty-four samples in total were randomly. collected from two different farms (University of Cape Coast (UCC) Farm and Krowfofordo), two different markets (UCC Science market and Abura market) and two different vendors (at Abura and UCC) within the Cape Coast Metropolis. The samples include cabbage (*Brassica oleracea var. capitata L.*), a bunch of loose-leaf lettuce (*Lactuca sativa*), carrot and green pepper. International Standardization Organisation (ISO) and the Nordic Committee on Food Analysis (NMKL) standards guided the analyses. Ten grams of sample was homogenized for 30 seconds using a blender (Lab Blender, Model4001, Seward Medical, London, England) in 90ml sterile diluent (0.1% peptone, 0.8% NaCl, pH 7.2). The pour plate on Plate Count Agar (PCA 15ml) was used to enumerate aerobic mesophiles incubated for 72hours at 30 °C. For *Escherichia coli*, Tryptone Soy Agar pH 7.3 overlaid with Violet Red Bile Agar pH 7.4 was used and incubated at 44 degrees Celsius for 24h. Further test was performed to confirm colonies formed.

Data analysis

Microsoft Excel and the Statistical Package for Social Sciences (SPSS) version 25 were used to analyze the collected data. To examine common microbial contaminants in the selected vegetables collected from each distribution point, means and standard deviations were used. Difference in microbial contaminants at each stage of distribution was statistically tested using Analysis of Variance (ANOVA) at $p \geq 0.05$.

RESULTS AND DISCUSSION

The bacteria count obtained from the collected vegetables (carrot, lettuce, cabbage and green pepper) from the University of Cape Coast farm, Science Market, and Science Market food vendor are presented in Table 1. Aerobic mesophilic bacteria count in the vegetable samples were in the range of 3.23 to 5.71 log10 $CFUg^{-1}$. However, there were statistically significant differences in the Aerobic mesophilic counts from some of the collection points ($p \le 0.05$). The highest count for Aerobic mesophilic bacteria was enumerated from UCCSM-L (5.71 log10 $CFUg^{-1}$) while the least was from UCCBV-L (3.23 log10 $CFUg^{-1}$). The population of *E. coli* found in the vegetables sampled varied significantly ($P \le 0.05$) among the collection points. The highest population of 4.53 log10 $CFUg^{-1}$ was recorded from UCCSM-L while the least population of 2.23.log10 $CFUg^{-1}$ was from UCCBV-L. *S. aureus* was present in six (6) out of the twelve (12) vegetables sampled from the three collection points. UCCBV-L had the highest population of 3.68 log10 $CFUg^{-1}$ with six of the samples recording the least of 0.0 log10 $CFUg^{-1}$. *Salmonella spp.* was present in the vegetable samples collected from two (2) out of the three (3) collection points investigated. These were from UCCF-L and UCCSM-CA samples. *L. monocytogenes* was absent in all the vegetable samples collected from the three collection points along the food chain.

The second objective sought to compare the microbial contaminants in vegetables collected at each stage of vegetable distribution in the Cape Coast metropolis. The bacteria count obtained from the vegetables (carrot, lettuce, cabbage and green pepper) from the Krowfofordo Farm, Abura Market and Abura Market food vendor are presented in Table 2. Vegetables from all three points or locations had aerobic mesophilic counts ranging from 3.25 to 6.72 log10 $CFUg^{-1}$. Aerobic mesophilic bacteria were found in AML samples at the highest count (6.72 log $CFUg^{-1}$) and in AMGP samples at the lowest count (3.25 log10 $CFUg^{-1}$). Nevertheless, there were significant variations ($p \le 0.05$) in the counts from few of the locations. *E. coli* found in the vegetables sampled varied significantly ($p \le 0.05$) from one location to the other. The highest microbial load of 5.42 log10 $CFUg^{-1}$ was recorded from the KFC sample while the lowest microbial load of 0.0 log10 $CFUg^{-1}$ was obtained from AMWVGP samples. *S. aureus* was positive for seven (7) out of the twelve (12) vegetable sampled from the three points or locations along the food chain. The highest microbial load of 4.0 2 log10 $CFUg^{-1}$ was recorded from the KFC sample while the lowest microbial load of 0.0 log10 $CFUg^{-1}$ was from KFL, KFGP, AMGP, AMWVC and AMWVCA samples. *Salmonella spp.* was present in the vegetable samples collected from only two (2) out of the twelve (12) vegetables investigated. These vegetables were AMCA and AMWVCA samples. *L. monocytogenes* was not detected in any of the vegetable samples collected from any of the twelve locations.

Table 1. Microbial population in CFU/g of leafy vegetables obtained from UCC farm, Science market and Science food vendors.

Samples	*Aerobic mesophiles*	*Escherichia coli*	*Staphylococcus aureus*	*Salmonella spp.*	*Listeria monocytogenes*
UCCF-C	5.33 ± 0.07^{a}	4.28 ± 0.00^{a}	3.59 ± 0.66^{a}	nd	nd
UCCF-L	5.60 ± 0.00^{a}	4.51 ± 0.07^{a}	0	detected	nd
UCCF-CA	5.65 ± 0.14^{a}	4.48 ± 0.14^{a}	0	nd	nd
UCCF-GP	5.39 ± 0.07^{bc}	2.38 ± 0.28^{c}	2.43 ± 0.02^{a}	nd	nd
UCCSM-C	5.39 ± 0.14^{a}	3.37 ± 0.14^{b}	2.43 ± 0.02^{a}	nd	nd
UCCSM-L	5.71 ± 0.07^{a}	4.53 ± 0.07^{a}	0	nd	nd
UCCSM-CA	5.48 ± 0.00^{a}	4.46 ± 0.15^{a}	2.26 ± 0.18^{a}	detected	nd
UCCSM-GP	4.28 ± 0.00^{b}	3.27 ± 0.14^{b}	0	nd	nd
UCCBV-C	3.29 ± 0.09^{c}	2.35 ± 0.14^{c}	0	nd	nd
UCCBV-L	3.23 ± 0.07^{c}	2.23 ± 0.00^{c}	3.68 ± 0.00^{a}	nd	nd
UCCBV-CA	3.27 ± 0.00^{c}	2.24 ± 0.15^{c}	0	nd	nd
UCCBV-GP	3.26 ± 0.14^{c}	2.24 ± 0.00^{c}	3.54 ± 0.08^{a}	nd	nd

Key: nd= not detected; Each value represents the mean and standard deviation of the count in $CFUg^{-1}$. Means in the column that do not share a superscript are significantly different (p< 0.05) within farm, market and vendor. UCCF-C= University of Cape Coast Farm Carrot, UCCF-L= University of Cape Coast Farm Lettuce, UCCF-CA= University of Cape Coast Farm Cabbage, UCCF-GP= University of Cape Coast Farm Green Pepper, UCCSM-C= University of Cape Coast Science Market Carrot, UCCSM-L= University of Cape Coast Science Market Lettuce, UCCSM-CA= University of Cape Coast Science Market Cabbage, UCCSM-GP= University of Cape Coast Science Market Green Pepper, UCCBV-C= University of Cape Coast Food Vendor Carrot, UCCBV-L= University of Cape Coast Food Vendor Lettuce, UCCBV-CA= University of Cape Coast Food Vendor Cabbage, UCCBV-GP= University of Cape Coast Food Vendor Green Pepper.

Table 2. Microbial Population in CFU/g of Leafy Vegetables Obtained from Krowfofordo Farm, Abura Market and Abura Food Vendors.

Samples	*Aerobic mesophiles*	*Escherichia coli*	*Staphylococcus aureus*	*Salmonella spp*	*Listeria monocytogenes*
KFC	6.41 ± 0.07^{a}	5.42 ± 0.00^{a}	4.02 ± 0.93^{a}	nd	nd
KFL	6.56 ± 0.14^{a}	5.35 ± 0.14^{a}	0	nd	nd
KFCA	6.37 ± 0.14^{a}	4.47 ± 0.07^{b}	3.32 ± 0.93^{a}	nd	nd
KFGP	4.41 ± 0.14^{b}	3.22 ± 0.14^{c}	0	nd	nd
AMC	6.72 ± 0.07^{a}	3.35 ± 0.00^{c}	3.35 ± 0.00^{a}	nd	nd
AML	6.72 ± 0.14^{a}	3.49 ± 0.00^{b}	1.73 ± 0.42^{a}	nd	nd
AMCA	6.65 ± 0.14^{a}	4.70 ± 0.07^{b}	1.85 ± 0.62^{a}	detected	nd
AMGP	4.43 ± 0.21^{b}	1.38 ± 0.35^{d}	0	nd	nd
AMWVC	4.51 ± 0.14^{b}	1.26 ± 0.07^{d}	0	nd	nd
AMWVL	3.25 ± 0.14^{b}	1.40 ± 0.00^{d}	3.30 ± 0.14^{a}	nd	nd
AMWVCA	4.51 ± 0.14^{b}	3.49 ± 0.36^{c}	0	detected	nd
AMWVGP	3.25 ± 0.00^{c}	0	1.62 ± 0.29^{a}	nd	nd

Key: nd= not detected; Each value represents the mean and standard deviation of the count in $CFUg^{-1}$. Means in the column that do not share a superscript are significantly different (p< 0.05) within farm, market and vendor. KFC= Krowfofordo Farm Carrot, KFL= Krowforfordo Farm Lettuce, KFCA= Krowfofordo Farm Cabbage, KFGP= Krowfofordo Farm Green Pepper, AMC= Abura Market Carrot, AML= Abura Market Lettuce, AMCA= Abura Market Cabbage, AMGP= Abura Market Green Pepper, AMWVC= Abura Market Waakye Vendor Carrot, AMWVL= Abura Market Waakye Vendor Lettuce, AMWVCA= Abura Market Waakye Vendor Cabbage, AMWVGP= Abura Market Waakye Vendor Green Pepper.

Nevertheless, vegetables typically contain epiphytic microbiota that is non-pathogenic. Produce may become contaminated with bacteria during agricultural production and product handling at every stage, from harvest at the farm gate to the point of sale or consumption. These microorganisms may include pathogenic species. These microorganisms are found everywhere, in the soil, water and air. Handling of these vegetables during growth and harvest, as well as the possibility of dust exposure during storage and processing could increase the risk of contamination. Different degrees of microbial contamination are shown by the current evaluation of vegetable samples that were examined for microbiological quality. The carrots (*Daucus carota*), lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*) and green pepper (*Capsicum annum*) collected from the farms, markets, and food vendors within the Cape Coast metropolis, showed the following microbial loads in all the vegetables. The mean Aerobic mesophilic count, *E. coli* and *S. aureus* in all sampled vegetables ranged from 3.23 to 6.72 log_{10} $CFUg^{-1}$, 1.26 to 5.42 log10 $CFUg^{-1}$, 1.62 to 4.02 log10 $CFUg^{-1}$, respectively.

Salmonella spp. was present in 4 out of 24 samples analyzed. Aerobic mesophilic microorganisms found in the vegetable samples collected from the various locations in this study indicate their level of contamination and probable shelf life or stability. The presence of aerobic microorganisms in these vegetables implies the existence of favorable conditions that promote the growth of microorganisms. Dugassa *et al.* (2014) also reported this observation in a similar study. They reported that 16.7% of the lettuce samples they collected from Jimma City was contaminated with *Salmonella spp.* Ameme *et al.* (2016) also found *Salmonella spp.* in 32% of the pepper sauce samples they collected in southern Ghana. Kim *et al.* (2016) discovered that vegetables typically included *Salmonella spp.* and suggested that stagnant water used for sprinkling and washing vegetables might be the most important source of *Salmonella* contamination. *Salmonella spp.* is linked to human gastrointestinal problems such as fever, abdominal pains, vomiting, and diarrhoea caused by food poisoning (Erhirhie *et al.*, 2020). GSA (2018) stated that when *Salmonella spp.* is not discovered in 25g of food, it is classified as satisfactory, whereas *Salmonella spp.* detected in 25g of food are unsatisfactory.

The higher loads of aerobic mesophilic microorganisms observed may be attributed to possible poor hygienic practices that persist during harvesting of these vegetables. Contaminated soil particles or workers' dirty hands, during harvesting, transportation, unsuitable marketplaces and the use of unclean water. This observation was earlier made by Mathur *et al.* (2014) who reported aerobic mesophilic count ranging from 4.24 to 5.21 log_{10} $CFUg^{-1}$ in vegetables they collected from the Madina market in Accra, Ghana. The presence of these pathogens in vegetable samples may suggest lapses in sanitary practices during harvesting, handling, transportation, and marketing, particularly among farms, open markets, and street vendors. Also, Worku & Hailu (2018) in a similar work reported aerobic mesophilic counts greater than 3 log $CFUg^{-1}$ in vegetables obtained from South Ethiopian markets. Gomez-Govea *et al.* (2012) also reported Aerobic mesophilic counts of 6.6 log $CFUg^{-1}$ from freshly cut fruit and vegetable samples obtained from some Nigerian markets. However, Adebayo-Tayo *et al.* (2012) in a similar study reported a lower Aerobic mesophilic count of 2.05 $CFUg^{-1}$ in Nigeria as compared to this study. According to the Ghana Standards Authority (2018) guidelines for fresh vegetables, microbial counts of 10^2 in vegetables is unsatisfactory. Per these guidelines, all the 24 vegetable samples collected from the various locations were unsatisfactory. Furthermore, a substantial variation occurred in the mean counts of *E. coli* in the vegetable samples collected across all the locations, suggesting that *E. coli* contamination may be linked to the location or region in which samples were collected (Tables 1 and 2).

The presence of *E. coli* in the vegetable samples may be an indication of faecal contamination and poor hygienic procedures by farmers, market sellers and food vendors (Bakobie *et al.*, 2017). Akter *et al.* (2016) believe that some strains of *E. coli* contained in food might induce gastroenteritis and diarrhoea in people when consumed. According to the Ghana Standards Authority (2018) guidelines, *E. coli* counts of 10^2 are considered unsatisfactory (Table 3). As per this guideline, 15 vegetable samples representing 62.50% that were detected as positive for *E. coli* contamination were categorized as unsatisfactory and unsafe for consumption, and 5 samples representing 20.83 % were on the borderline. whilst the remaining 4 samples that recorded negative (16.67%) occurrence were considered satisfactory.

Table 3. Guidelines on the interpretation of results for vegetable bacterium in ready-to-eat vegetables in general (CFU)/ml.

Criterion	Satisfactory	Borderline	Unsatisfactory: unfit for human consumption
Aerobic mesophiles	$0 < 10^2$	$= 10^2$	$>10^2$
Escherichia coli	$0 < 10^2$	$= 10^2$	$>10^2$
Staphylococcus aureus	$0 < 10^2$	$= 10^2$	$>10^2$
Salmonella spp	Not detected in 25g	N/A	Detected in 25g
Listeria monocytogenes	Not detected in 25g	N/A	Detected in 25g

Key: N/A = not applicable; Source: Ghana Standards Authority (2018). GS 956. Microbiological criteria (3rd ed.). Ghana Standards Authority. ICS 67.061.

The mean load/count of *S. aureus* in this study may be due to poor hygienic practices such as coughing or sneezing and improper handling of vegetables with contaminated hands during harvesting, transportation and processing. These results are similar to those of Gitahi *et al.* (2012) who recorded *S. aureus* load/counts of 3.13 to 4.69 log CFUg^{-1} in freshly cut fruits and vegetables in India. However, Guchi & Ashenafi (2010) reported *S. aureus* counts that ranged from 4.0 and 6.0 log CFUg^{-1}. *S. aureus* might be present on the surface of the vegetables due to contact with unclean hands while selecting vegetables to buy (Iyoha & Agoreyo, 2015). According to Schelin *et al.* (2011), enterotoxin production begins when *S. aureus* levels exceed 6 log CFUg^{-1}. Out of the 24 vegetables collected from the sampling points or locations, 58.33 % were satisfactory category, 29.17% were unsatisfactory whereas 12.50 % were on the borderline.

This was reaffirmed when compared to the guidelines provided by the (GSA, 2018), which states that *S. aureus* counts of 10^2 are unsatisfactory for human consumption. It was observed that the retailers and food vendors did not wear gloves nor wash their hands after handling money during the sale of these vegetables. *Salmonella spp.* are linked to majority of food-borne disorders because, according to microbiological and epidemiological studies, even a tiny number of these bacteria in foods can cause sickness (Amissah & Owusu, 2012). The current study reports *Salmonella spp.* in 4 vegetable samples out of 24 collected, representing 16.67%. This was supported with observations that demonstrated that the farmers, retailers, and vendors employed organic matter (human and animal origin), water (irrigation, cleaning), inappropriate handling of products with contaminated hands, and harvesting, and processing equipment. Also, the marketplaces and vending premises were not kept tidy.

According to these recommendations, 16.67% of vegetable samples tested positive for *Salmonella spp.* contamination was deemed unfit for human consumption (Table 3). Also, according to GSA (2018), *L. monocytogenes* when absent in 25g of food makes the food satisfactory, whereas positive results of *L. monocytogenes* in 25g of food makes it unsatisfactory. *L. monocytogenes* was absent in the vegetables collected from all the points or locations for the sampling of vegetables (Tables 1 and 2). Contrary to this study, Adeleke *et al.* (2012) detected *L. monocytogenes* in apples and carrots from Nigeria. Per these guidelines, all the vegetable samples analyzed were acceptable for consumption. Most of the vegetables (carrots, lettuce, cabbages and green pepper) samples assessed in this study, therefore, did not meet the Ghana Standards Authority guidelines due to the high level of aerobic mesophilic, *E. coli*, *S. aureus* and *Salmonella spp.* The norms are often enforced in the professional food industry, whereas farmers, stores, and street food selling are considered informal operations.

Conclusion and recommendations

In conclusion, cabbage, carrot, and lettuce samples collected from the selected points along the food chain in the Cape Coast Metropolis exhibited significantly high microbial loads, with green pepper samples showing comparatively lower but notable contamination. The detection of pathogenic microorganisms such as *E. coli*, *S. aureus*, and *Salmonella spp.* underscores a serious public health concern. These microbes are commonly associated with foodborne illnesses including bloody diarrhoea, haemolytic uremic syndrome, gastroenteritis, and salmonellosis, all of which pose risks to the health and nutritional status of consumers. Seasonal variations, hygiene practices of individual handlers, and environmental conditions were not extensively controlled or monitored, which could influence microbial load outcomes. These findings highlight the urgent need for the enforcement of hygiene standards and food safety protocols along the vegetable supply chain. Public health authorities such as the Ghana Food Authority, Agricultural Extension officers, and food vendors must collaborate to implement effective measures that minimize contamination risks. Also, the findings are indicative of potential health risks, broader and more longitudinal studies are needed for more robust conclusions. Furthermore, consumer education on proper washing and handling of raw vegetables is essential to reduce the incidence of foodborne infections.

DECLARATIONS

Author contribution statement: Conceptualization: A.A.D., S.D. and H.A.; Methodology: A.A.D., S.D. and H.A.; Software and validation: A.A.D and H.A.; Formal analysis and investigation: A.A.D. and H.A.; Resources: A.A.D., S.D. and H.A.; Data curation: A.D.; Writing—original draft preparation: A.A.D., S.D. and H.A.; Writing—review and editing: A.A.D.; Visualization: A.A.D. and S.D.; Supervision: S.D.; Project administration: X.X.; Funding acquisition: A.A.D., S.D. and H.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study obtained ethical clearance from the University of Cape Cpoast Institutional Review Board with ID: UCCIRB/CES/2023/88.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for the paper.

Funding statement: No external funding is available for this study.

Additional information: No additional information is available for this paper.

Publisher's Note: Agro Environ Media (AESA) remains neutral with regard to jurisdictional claims in published maps, figures and institutional affiliations.

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