Journal of Food Protection, Vol. 78, No. 1, 2015, Pages 57–64
doi:10.4315/0362-028X.JFP-14-265

Contamination of Tomatoes with Coliforms and *Escherichia coli* on Farms and in Markets of Northwest Nigeria

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MS 14-265: Received 4 June 2014/Accepted 23 August 2014

ABSTRACT

Although recent reports indicated that produce contamination with foodborne pathogens is widespread in Nigeria, the sources and magnitude of microbial contamination of fruits and vegetables on farms and in markets have not been thoroughly identified. To ascertain possible pathways of contamination, the frequency and magnitude of coliform and *Escherichia coli* contamination of tomatoes produced in northwest Nigeria was assessed on farms and in markets. Eight hundred twenty-six tomato fruit samples and 36 irrigation water samples were collected and assessed for fecal indicator organisms. In addition, the awareness and use of food safety practices by tomato farmers and marketers were determined. Median concentration of coliforms on all field- and market-sourced tomato fruit samples, as well as in irrigation water sources, in Kaduna, Kano, and Katsina states exceeded 1,000 most probable number (MPN) per g. Median *E. coli* counts from 73 (17%) of 420 field samples and 231 (57%) of 406 market tomato fruit samples exceeded 100 MPN/g. Median *E. coli* concentrations on tomato fruits were higher ($P < 0.01$) in the rainy season (2.45 Log MPN/g), when irrigation was not practiced than in the dry (1.10 Log MPN/g) and early dry (0.92 Log MPN/g) seasons. Eighteen (50%) of 36 irrigation water samples had *E. coli* counts higher than 126 MPN/100 ml. Median *E. coli* contamination on market tomato fruit samples (2.66 Log MPN/g) were higher ($P < 0.001$) than those from tomatoes collected on farms (0.92 Log MPN/g). Farmers and marketers were generally unaware of the relationship between food safety practices and microbial contamination on fresh produce. Good agricultural practices pertaining to food safety on farms and in local markets were seldom used. Adoption of food safety practices on-farm, during transport, and during marketing could improve the microbial quality of tomatoes available to the public in this region of the world.

Several reports have shown that vegetable contamination with Shiga toxin–producing *Escherichia coli* and other microorganisms are a significant threat to public health *(8, 12, 34)*. Vegetable production and marketing practices such as use of raw animal manure, contamination, and cross-contamination by harvesting and packaging equipment, and worker health and hygiene are recognized as sources of produce contamination *(6, 35, 40)*. In addition, owing to frequent microbial contamination, irrigation water is speculated to be an important pathway in produce contamination *(1, 7, 38)*. Although adoption of food production standards is common in developed countries, standards are more difficult to implement in developing countries where clean water is frequently unavailable, and vegetable production is commonly undertaken by farmers with limited formal education, on small land holdings, and with limited resources. The deficiencies in food safety practices throughout the value chain can lead to high levels of vegetable contamination with human pathogens.

In Nigeria, illnesses associated with vegetables are an increasing public health problem *(2, 31, 36)*. Udo et al. *(37)* reported that 85 (56%) of 150 salad samples collected from retail food service outlets and private sources between 2006 and 2007 were contaminated with one or more pathogens including *Staphylococcus aureus, E. coli, Klebsiella aerogenes, Salmonella enterica* Typhimurium, and *Bacillus* species. In that same study, antimicrobial resistance among recovered isolates was common, with all the bacterial isolates, except *Salmonella* spp. showing multiple antibiotic resistance profiles of 25 to 72%. Another study in Kaduna state, Nigeria, demonstrated that fecal coliform (FC) contamination in irrigation water and on vegetables exceeded the World Health Organization *(44, 45)* and European Commission *(16)* standards of <1,000 FC/100 ml and 100 *E. coli* CFU/g *(38)*. Of 39 enteropathogenic *E. coli* isolated in a study by Okafo et al. *(31)*, 38% were toxigenic. These findings were similar to reports by Umoh et al. *(38)* and Chigor et al. *(9, 10)* that found high numbers of *Salmonella* present in irrigation water from Zaria and Kaduna in Kaduna state. Despite these reports, assessments of the tomato value chain in Nigeria to determine contamination pathways and provide information for implementing effective mitigation measures are still lacking. The purpose of this study was to investigate tomato fruit and irrigation water contamination

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with FCs and *E. coli* in northwest Nigeria and to evaluate food safety knowledge and practices among tomato farmers and retailers in the region with the aim of identifying critical control points and information gaps.

MATERIALS AND METHODS

Study location. The study was conducted in the states of Kaduna, Kano, and Katsina, Nigeria, which are in the northwest geopolitical zone and experience a Savannah climate with distinct, alternating wet (April through October) and dry (November through March) seasons *(5, 16)*. Minimum temperatures (during the dry season) range from 10 to 20°C, while maximum temperatures (during the rainy season) range from 40 to 45°C *(14, 30)*. The rainfall pattern in the region is unimodal and typically occurs between March and October *(21)*. The period between cessation of rains in October and the arrival of the dry, dusty West African trade wind (The Harmattan) in November or December is characterized by high daytime temperatures and high relative humidity. Tomato production at this time is dependent on overnight dew and residual soil moisture. This period (early dry season) was considered as a separate climatic period in the current study due to its climatic distinctiveness from the dry season.

Microbiological surveys. Tomatoes were collected from fields and local markets in the early dry season of 2010 and in the dry and rainy seasons of 2011. A stratified geopolitical sampling approach was used to sample around three villages in each of three local government areas of Kaduna, Kano, and Katsina. A minimum of 135 farms were sampled in each state on the basis of ongoing tomato production. A total of 412 tomato farms were sampled. Occasionally, additional tomato farms were sampled to maintain good farmer relations. Farmers were recruited by word-of-mouth, personal contact, and willingness to participate. In each region, tomatoes were collected from multiple fields, operated by different farmers using a common water source. In each field, one fruit was collected from each of three tomato plants. The three fruits from each field were pooled into one composite sample. A total of 45 composite samples were collected from each state in each of the three seasons, giving a total of 135 composite samples per state. Irrigation water samples (100 ml) from each common water source, were collected in sterile plastic bags for processing.

Retailers at local markets near sampled tomato fields were selected on the basis of their willingness to participate in the study. At each market, three tomato fruits were purchased from 15 retailers, with additional retailers sampled occasionally, again to maintain stakeholder involvement. A total of 409 tomato fruit samples were collected from 45 retailers at local markets in Kaduna, Kano, and Katsina. Three markets were sampled in each state in each of the three seasons.

Tomato farmer and retailer surveys. Field management and hygiene practices of tomato farmers in northwest Nigeria, and postharvest handling practices by retailers at local markets were determined by conducting individual interviews orally and by visual observation. Among the farms sampled for microbial testing, surveys were administered to 177 growers who were available and willing to participate. At the markets, 72 tomato retailers and 29 wholesalers were interviewed. Retailers and wholesalers were selected on the basis of availability and willingness to participate in the study. A similar number of subjects were interviewed in each state. Retailers were selected based on word-of-mouth, active participation in the tomato value chain at the time, and their willingness to be interviewed. The interviews were conducted in Hausa, the native language for most of the tomato growers in this region. All activities involving human subjects were reviewed and approved by appropriate human subjects review committees at The Ohio State University and Ahmadu Bello University.

Laboratory analyses. Tomato fruit and irrigation water samples were processed using the Colilert-18/Quanti-Tray method (IDEXX Laboratories, Inc., Westbrook, ME). The method is used for most-probable-number (MPN) enumeration of *E. coli* and other coliform bacteria from treated and untreated waters based on quantitative bacterial counts from 100 ml of samples using disuccinimidyl tartrate reagents. Tomato samples were washed with peptone-buffered saline reagents in a 1:1 (wt/vol) dilution. Plastic bags containing tomato fruits and peptone-buffered saline were shaken on an orbital shaker for 1 min per side to dislodge loosely attached bacteria. Total coliforms and *E. coli* most probable number in the rinsate were determined using 100 ml of a 10^{-1} dilution. The suspension was mixed with Colilert and added to the Quanti-Tray pouch, after which the pouch was sealed in a Quanti-Tray sealer and incubated at 35°C for 24 h. Total coliforms and *E. coli* most probable number for each sample were determined using the Most Probable Number Table. Total coliforms and *E. coli* counts were also determined from 100 ml of 1:1 and 1:100 dilutions of irrigation water samples using the Quanti-Tray 2000 method following the manufacturer's recommendations.

Statistical analysis. Total coliform and *E. coli* counts were log transformed and categorized into six groups. For tomato samples, group 1 contained less than 1.0 Log MPN/g (detection threshold), group 2 contained between 1.0 Log to less than 2.0 MPN/g, group 3 contained 2.0 Log to less than 3.0 MPN/g, group 4 contained between 3.0 Log to less than 4.0 MPN/g, group 5 contained 4.0 Log to less than 5.0 MPN/g, and group 6 had microbial concentrations above 5.0 Log MPN/g. Microbial concentrations in irrigation water samples were grouped in six similar categories with counts expressed as MPN/100 ml. Initial assessments of normality were performed by Anderson-Darling test, and nonnormally distributed data were analyzed by appropriate nonparametric tests. Significances in the differences between seasonal and spatial median concentrations of total coliforms and *E. coli* were determined using the Kruskal-Wallis test, while differences in total coliform and *E. coli* counts between field and market samples were determined using the Mann-Whitney Z test. Sociodemographic data were descriptively summarized using Excel (Microsoft Corp., Redmond, WA) and SPSS version 20 (IBM Corp., Armonk, NY), and Minitab version 16.1.1.0 (Minitab Inc., State College, PA).

RESULTS

Spatial variability in tomato fruit contamination levels. There was significant variability ($P < 0.001$) in the spatial distribution of total coliform and *E. coli* contamination on field-sourced tomatoes (Fig. 1). Total median concentration of total coliforms on field-sourced tomatoes from Kaduna (5.4 Log MPN/g) and Kano (5.4 Log MPN/g) did not differ from each other, but were higher ($P < 0.05$) than those from Katsina (5.2 Log MPN/g). Median concentration of total coliforms on market-sourced tomatoes and field-sourced tomatoes in the three states were similar

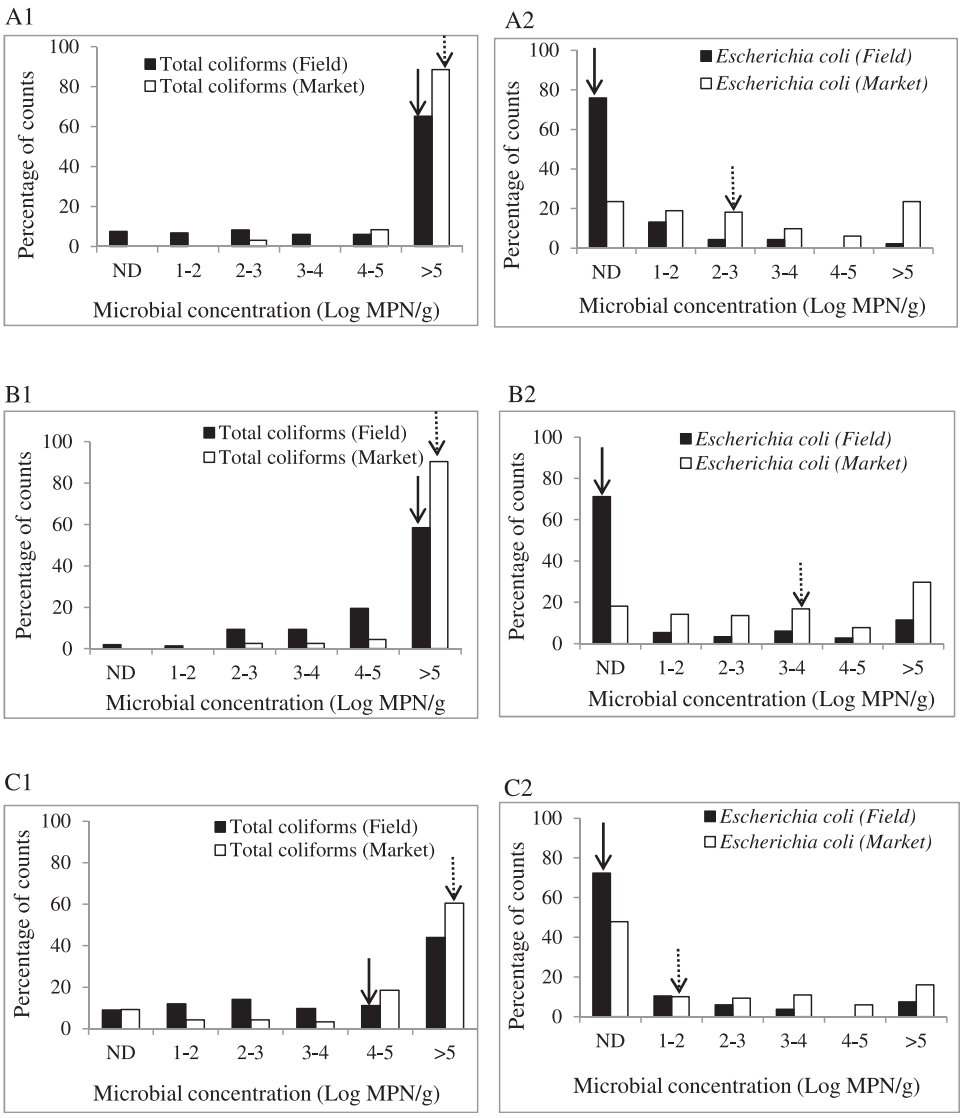

FIGURE 1. *Spatial variability in distribution of total coliforms and* E. coli *on tomato fruits in northwest Nigeria. Bacterial counts were determined as most probable number per gram using the Idexx Quanti-tray method. (A1), (B1), and (C1) show total coliform distribution in the states of Kaduna, Kano, and Katsina, respectively, while (A2), (B2), and (C2) show* E. coli *distribution in the states of Kaduna, Kano, and Katsina, respectively. Solid arrows on panels indicate median positions of total coliform and* E. coli *distribution from field-sourced tomato samples, while broken arrows indicate total coliform and* E. coli *distribution from market-sourced tomato samples. Median coliform counts were 5.4 Log MPN/g for all seasons. The median concentration of total coliforms on field-sourced tomatoes in Kaduna was 5.4 Log MPN/g, while those from field-sourced samples from Kano and Katsina were 5.4 and 5.2 Log MPN/g, respectively. Market-sourced tomato samples in Kaduna, Kano, and Katsina had similar total coliform counts. Median* E. coli *counts from field-sourced tomatoes in Kaduna, Kano, and Katsina were 0.9 Log MPN/g (=7.94 MPN/g), 1.2 Log MPN/g (=15.84 MPN/g), and 0.7 Log MPN/g (=5.01 MPN/g), respectively.* E. coli *counts from market-sourced tomato samples were 0.9 Log MPN/g, 1.2 Log MPN/g, and 0.7 MPN/g for the states of Kaduna, Kano, and Katsina, respectively.*

(5.4 Log MPN/g), except in Katsina state where total coliform concentration on market-sourced tomatoes were higher ($P < 0.05$) than those from field-sourced tomatoes by a magnitude of 1 log. The median concentration of *E. coli* on field-sourced tomatoes in Kano state (1.2 Log MPN/g = 15.84 MPN/g) was higher ($P < 0.05$) that those from Kaduna (0.9 Log MPN/g = 7.94 MPN/g) and Katsina (0.7 Log MPN/g) states. There was a two- to threefold increase in the median concentration of *E. coli* on market-sourced tomatoes, compared with those on field-sourced samples, with fruits from Kano carrying higher ($P < 0.05$) *E. coli* counts (3.2 Log MPN/g) than those from Kaduna (2.7 Log MPN/g = 501.19 MPN/g) and Katsina (2.0 Log MPN/g = 100 MPN/g) states.

Seasonal variability in tomato fruit contamination levels. The median concentration of total coliforms on field-sourced tomatoes was higher ($P < 0.05$) in the rainy season (4.8 Log MPN/g) than in the early dry (3.7 Log MPN/g) and dry (3.4 Log MPN/g) seasons (Fig. 2). However, total coliform concentrations on market-sourced tomatoes was significantly higher (Mann-Whitney $Z = -8.103$, $P < 0.001$) than those from field-sourced fruits across the seasons. Coliform concentration on market-sourced tomato

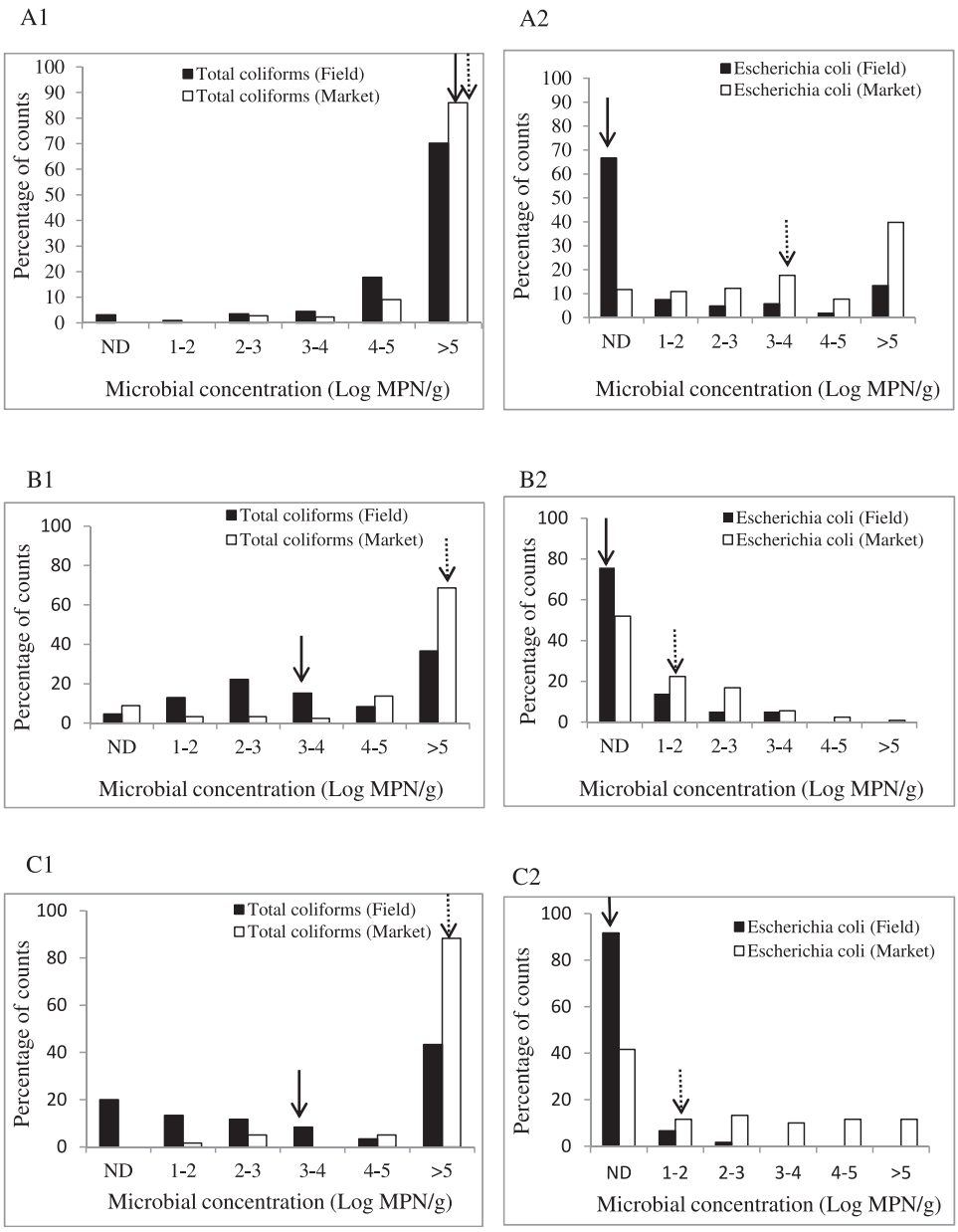

FIGURE 2. *Seasonal variability in distribution of total coliforms and* E. coli *on tomato fruits in northwest Nigeria. Bacterial counts were determined as most probable number per gram using the Idexx Quanti-tray method. (A1), (B1), and (C1) show total coliform distribution in the rainy season (April through October), early dry season (October through March), and dry season (March to June), respectively. (A2), (B2), and (C2) show* E. coli *distribution in the same seasons. Solid arrows on panels indicate median positions of total coliform and* E. coli *distribution from field-sourced tomato samples, while broken arrows indicate total coliform and* E. coli *distribution from market-sourced tomato samples. Median coliform count from field-sourced tomatoes in the rainy season was 4.8 Log MPN/g, while counts for the early dry and dry seasons were 3.7 and 3.4 Log MPN/g, respectively. From the market samples, median total coliform concentration in the rainy, early dry, and dry seasons was 5.2 Log MPN/g, while those for the early dry and dry seasons were 4.6 and 5.2 Log MPN/g, respectively. Median of* E. coli *counts from field-sourced tomatoes in the rainy season was 1.3 Log MPN/g, while those from early dry and dry seasons were 0.6 and 0.2 Log MPN/g. From the market samples, median* E. coli *concentrations in the rainy, early dry, and dry seasons were 3.6, 1.3, and 2.0 Log MPN/g, respectively.*

fruits was higher ($P < 0.05$) in the rainy season (5.2 Log MPN/g) than in the early dry (4.6 Log MPN/g) and dry (5.2 Log MPN/g) seasons. Similarly, the distribution of *E. coli* on tomatoes across the seasons also varied considerably (Mann-Whitney $Z = -13.14$, $P < 0.001$). *E. coli* concentration on field-sourced tomatoes was higher ($P < 0.01$) in the rainy season (1.3 Log MPN/g = 19.95 MPN/g) than in the early dry season (0.6 Log MPN/g = 3.98 MPN/g) and dry season (0.2 Log MPN/g = 1.58 MPN/g). However, market-sourced tomatoes in the same locations had significantly higher ($P < 0.05$) *E. coli* concentrations than field-sourced fruits. Tomato fruit contamination at the market was higher ($P < 0.01$) in the rainy season (3.6 Log MPN/g) than in the early dry (1.3 Log MPN/g = 19.95 MPN/g) and dry (2.0 Log MPN/g = 100 MPN/g) seasons.

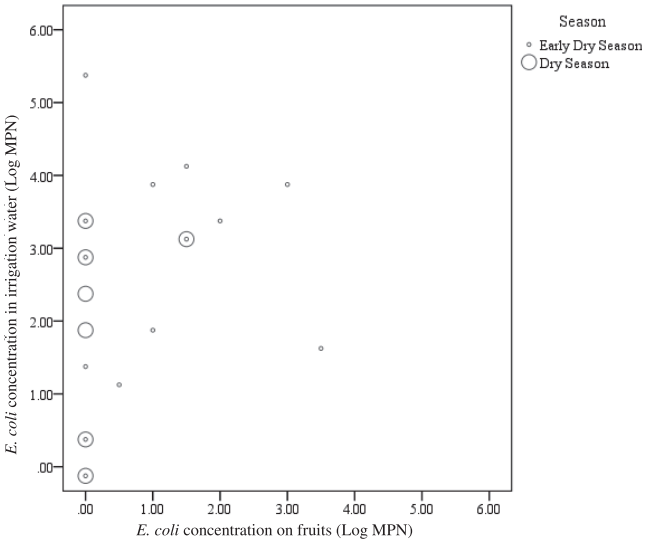

FIGURE 3. *Association between total coliforms and* E. coli *concentrations in irrigation water and on tomato fruits in northwest Nigeria. Small circles represent the early dry season, while large circles represent the dry season. The figure compares microbial concentration on tomato fruits with that in irrigation water, therefore, the rainy season is not represented on the figure, because the crop was not irrigated in that season. Higher microbial counts (log MPN) in irrigation water for both the early dry and dry seasons (*y *axis) did not correlate with higher microbial counts on fruits (*x *axis).*

Irrigation water contamination with total coliforms and *E. coli*. During dry season production, water from open wells, streams, and ponds was pumped, using irrigation pumps, into a network of channels running through the tomato fields. Only 3 (8%) of 36 water samples were collected in the rainy season (from Katsina state). The Katsina samples had a total coliform concentration of 5.40 Log MPN/100 ml. These counts did not differ from early dry season (4.9 Log MPN/100 ml) and dry season (5.4 Log MPN/100 ml) counts from the same state. Early dry and dry season concentrations of total coliforms in Kaduna (5.2 Log MPN/100 ml; 3.8 Log MPN/100 ml) and Kano (5.4 Log MPN/100 ml; 5.4 Log MPN/100 ml) states were similarly high and did not differ from those of Katsina, nor from each other. The median concentration of *E. coli* in irrigation water in Katsina state in the rainy season (5.4 Log MPN/100 ml) was higher ($P < 0.05$) than those in the early dry (1.7 Log MPN/100 ml = 50.12 MPN/100 ml) and dry (1.9 Log MPN/100 ml = 79.43 MPN/100 ml) seasons. Median *E. coli* concentration in irrigation water in Kano, in the early dry season, was 3.1 Log MPN/100 ml. This was higher ($P < 0.05$) than *E. coli* counts from Kaduna (1.8 Log MPN/100 ml = 63.10 MPN/100 ml) and Katsina (1.7 Log MPN/100 ml = 50.12 MPN/100 ml) states in the same season. Median dry season counts of *E. coli* in irrigation water in Kaduna (1.2 Log MPN/100 ml = 15.85 MPN/100 ml) and Katsina (1.9 Log MPN/100 ml = 79.43 MPN/100 ml) did not differ significantly. There was no significant correlation between irrigation water contamination and *E. coli* contamination on tomato fruits (Fig. 3).

Food safety and hygiene practices. The use of food safety and hygienic practices among tomato farmers was compared on the basis of gender and summarized in Table 1. The majority of tomato farmers (53%) applied bovine manure as a fertilizer and soil amendment. Manure application was done in the first 1 to 2 weeks after transplanting tomatoes. Sixty-seven percent of tomato farmers had daily contact with chickens, 28% with goats and sheep, and 58% with cattle. A majority (80%) claimed to wash their hands after using the bathroom or cleaning children. However, most farmers acknowledged that they did not wash their hands before harvesting tomatoes. A significant number of tomato farmers admitted that livestock and wild animals had regular access to tomato fields and irrigation water sources. Although women responded less affirmatively regarding use of food safety practices, the differences were not significant.

At retail points in local markets, baskets displaying tomato fruits for sale were frequently placed directly on the ground. Fifty-three percent of retailers reused baskets for storing tomatoes, but only 14% of them claimed to wash the baskets before reusing them, and only 4% of them claimed to use a disinfectant to sanitize the baskets. Most of the retailers washed the tomato fruits using water from open wells and boreholes, before displaying them; however, the wash water was seldom changed between washes. Most (83%) of the retailers were not aware that tomato fruit contamination with human pathogens could be a cause of foodborne illness, and almost one-half of retailers were unaware of anyone who had become sick with a foodborne illness.

DISCUSSION

This study represented a systematic approach to examine the tomato value chain in Nigeria for the magnitude and frequency of tomato fruit and irrigation water contamination with total coliforms and *E. coli*. This study demonstrated that tomato fruit contamination with total coliforms and *E. coli* is endemic in northwest Nigeria, with a dramatic increase in contamination as fruits progressed from farm to market. Irrigation water sources were subject to contamination, but the absence of association between irrigation water contamination and microbial concentration on tomato fruits indicated that factors, other than irrigation water, may be more important sources of contamination. Awareness and use of food safety practices at local markets were low, and tomato growers and retailers lacked knowledge of the association between food-safety practices, tomato fruit contamination with foodborne pathogens, and human illness.

The exact cause of the higher *E. coli* concentrations on tomatoes from Kano state was undetermined, but low water quality, cross-contamination, and unknown factors could be contributing factors. Tomato-producing areas in Kano are generally more urbanized and have higher population density than those in Kaduna and Katsina states. The lack of sanitary and sewage management facilities in these areas *(4),* coupled with close interactions between people,

TABLE 1. *Hygiene and food safety practices among male and female tomato farmers in northwest Nigeria*

Question on hygiene and food safety practices	Percentage of farmers who responded in the affirmative		
	Men	Women	Total
Do you apply raw poultry droppings?	15.3	3.5	18.8
Do you apply raw cow dung?	47.1	5.9	52.9
Do you apply raw night soil?	15.3	1.2	16.5
Do animals have access to irrigation water	8.2	0.0	8.2
Do you wash tomatoes after they are harvested?	1.2	0.0	1.2
Do you clean basket before re-using them?	2.4	0.0	2.4
Do you use disinfectants to clean your baskets?	0.0	3.5	3.5
Do you have daily contact with chickens?	58.8	8.2	67.1
Do you have daily contact with goats or sheep?	15.3	12.9	28.2
Do you have daily contact with cattle?	49.4	8.2	57.6
Do you have daily contact with dogs?	15.3	4.7	20.0
Do birds or wildlife enter your tomato farm?	4.7	3.5	8.2
Do you wash your hands after toilet use?	83.5	12.9	96.5
Do you wash your hands before eating?	81.2	14.1	95.3
Do you wash your hands before harvesting tomatoes?	15.3	4.7	20.0
Do you wash your hands after touching animals?	65.9	10.6	76.5
Are you aware of anyone getting diarrhea from eating raw tomatoes?	8.2	3.5	11.8

livestock, water sources, and fresh produce, could result in high concentrations of total coliforms and *E. coli* in the environment and increase the risk of produce cross-contamination.

This study identified several possible preharvest tomato fruit contamination sources. Several reports have linked the use of raw manure in vegetable production to produce contamination with *E. coli (19, 25, 27).* Although this study found that manure application was done prior to transplanting, or within the first 3 weeks of transplanting, the period between application and fruit ripening (80 to 100 days after transplanting) fell far short of the recommended minimum time frame (120 days *(39)* or 9 months *(40)*) deemed necessary for pathogens to die off *(18, 29, 33, 40).* Therefore, the manure could still harbor *E. coli* inoculums that could contaminate tomato fruits throughout the growing season *(20, 40, 42).* In addition, ruminant animals, such as cattle and sheep, are recognized as reservoirs of *E. coli,* shedding it in their feces *(25–27).* Their intrusion into tomato fields, which was viewed as a sign of good luck by some farmers, poses a risk of *E. coli* contamination *(13, 15, 28).*

In this study, water sources in northwest Nigeria did not meet minimum World Health Organization standards (<1,000 FC/100 ml) for water used for irrigating fresh produce like tomatoes *(44, 45).* This finding was in agreement with previous reports *(9, 10, 31)* and conformed with those of Abakpa et al *(1),* who reported that FC concentrations in irrigation water sources and on vegetables in the rainy season in Kano were higher than in the dry season. However, the findings of this study differed from reports by Agbogu et al. *(3)* and Chigor et al. *(9, 10),* who reported higher FC concentrations in irrigation water sources and on vegetables in the dry season. Chigor et al. *(9, 10)* and Okafo et al. *(31)* attributed higher dry season microbial counts in the irrigation water sources they sampled to frequent discharge of raw domestic sewage from residential houses and sewage treatment plants into the water sources, leading to higher microbial concentrations when the water volume significantly reduced during that season. High concentrations of FCs in irrigation water sources in the rainy season, reported in this study, may be attributed to surface runoff from surrounding areas *(31, 38),* which are frequently contaminated by livestock and human wastes *(31).* The contribution of precipitation events and surface runoff to FC concentrations in water sources has been reported *(17, 24).*

The finding in this study that preharvest tomato fruit contamination was highest in the rainy season, when supplemental irrigation was not practiced, indicated sources of tomato fruit contamination other than irrigation water. Other sources of contamination during tomato production and harvesting, which could have contributed to tomato fruit contamination in the rainy season included raw manure, which was applied directly to tomato plants during the growing season, rain splash, and other hydrologic processes affecting microbial dissemination and cross-contamination within fields *(8, 9, 33).* Large amounts of precipitation in the rainy season, the torrential nature of rainfalls, and accompanying high relative humidity and air temperatures *(5, 14, 30)* provide enhanced conditions for bacterial growth and survival.

High concentrations of total coliforms and *E. coli* recovered from market-sourced tomatoes in northwest Nigeria may have resulted from two sources: first, preharvest microbial contamination in the field may have persisted on tomato fruits and proliferated rapidly on harvested fruits during postharvest processing and marketing. *E. coli* has been shown to persist in the field for several months, when nutrient availability and abiotic conditions are optimal *(32, 41, 43).* Microbial proliferation on fresh produce can readily occur after harvest *(11, 22, 23)* if storage conditions are suboptimal. Second, apart from preharvest contamination, market-sourced tomatoes could have been contaminated through inadequate food safety practices at local markets, such as dirty baskets and contact of food containers on bare ground,

infrequent changes and minimal use of disinfectants in the wash water, contamination transmittal by flies, and human handling in the absence of personnel hygiene.

Although Nigeria has a regulatory framework for food hygiene and safety, the implementation of its provisions are difficult under the current tomato production and retail structure. The bulk of tomato production in Nigeria is on small land holdings scattered throughout the production areas, making effective monitoring by regulatory officials difficult, if not impossible. The tomato producers themselves lacked knowledge on the link between food safety practices and foodborne illnesses. Thus, they did not have a strong motivation to implement safe production practices. Under these circumstances, the existing food safety challenges may be better addressed through farmer and marketer education programs that are based on an effective, needs-driven, good agricultural practices package.

Given the tomato production and food safety practices identified in this study, there are many opportunities for intervention to enhance produce safety. Farmer and retailer education programs that lead to increased awareness and a change in food safety practices by tomato value chain players in Nigeria may be an effective way of reducing the magnitude and frequency of tomato contamination with FCs. Basic food safety practices at the farm level, such as reduced or time-sensitive application of raw manure to tomatoes, protection of irrigation water sources from animal intrusion, and tomato-workers hygiene (especially hand washing), are critical points for improving the safety of Nigerian tomatoes. A tomato-retailer component of such a program would also cover such aspects as tomato wash water quality, retailer hygiene, proper cleaning of baskets with disinfectants, and the imperative of adding suitable and locally available sanitizing agents in the wash water.

ACKNOWLEDGMENTS

The authors thank the USAID Horticulture Collaborative Research Support Program (Horticulture CRSP), The Ohio State University, USA, and Ahmadu Bello University, Zaria, Nigeria, for providing the funds and other support that made the research possible.

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