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Impact of E. Coli Contamination On Food Security And Public Health

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ABSTRACT

Contamination of food with Escherichia coli continues to pose a significant public health risk and threaten food security. We determined the prevalence, pathotype distribution, and antimicrobial susceptibility of E. coli in foods commonly consumed by humans, along with the associated public health and food security issues. A 12-month cross-sectional surveillance design was used, with microbiological analysis of 360 food samples (90 per category: raw milk, raw meat, fresh vegetables, and ready-to-eat foods) and clinical and exposure data from 180 individuals reporting foodborne disease. In total, E. coli was isolated from 100 (27.8%) food samples, with raw meat (37.8%) and raw milk (31.1%) being the most frequent. The average bacterial load varied from $2.6 \pm 0.9 \times 10^3$ CFU/g (in ready-to-eat food) to $5.9 \pm 1.6 \times 10^3$ CFU/g (in raw meat). Enterotoxigenic (29%), enteropathogenic (24%), and Shiga toxin-producing (18%) E. coli were identified as the predominant pathotypes, respectively, based on the analysis. The proportion of resistance profiles was high for ampicillin (71%) and tetracycline (65%), and 46% of isolates were multidrug-resistant. Of the 180 people exposed, 67 (37.2%) had lab-confirmed E. coli infections. There were also six cases of dehydration, including one hemolytic uremic syndrome (HUS) case, nine hospitalized, and three deaths. The food security assessment showed significantly higher proportions of rejected foods, greater household food waste, lower food availability scores, and consumers' lower confidence in high contamination ($P < 0.001$). These results provide a quantitative estimate of the interrelated effects of E. coli contamination on food safety, public health, antimicrobial resistance, and food security, highlighting the importance of holistic food system interventions.

INTRODUCTION:

Food safety is an essential element of public health and a significant factor in determining food security, particularly in low- and middle-income countries where the food supply chain is frequently exposed to microbes. Escherichia coli is a key foodborne pathogen by virtue of its wide distribution, multiple pathogenic forms, and apparent association with both individual cases and epidemic-sized outbreaks of foodborne disease [1, 2]. Although most E. coli strains are commensals, many of those belonging to the diarrheagenic pathotypes can cause severe gastrointestinal disease and systemic sequelae, leading to death in humans. Microbial contamination and inactivation are the main concerns throughout the food supply chain, from production through processing and distribution to the preparation stage, which renders E. coli a recurring issue for food safety management [3, 4]. Global demand for food is growing, and food chains are becoming more complex, and the risks associated with microbial contamination are increasing and pose a direct threat to the accessibility, safety, and acceptability of food [5].

The public health importance of the consequences of E. coli infections is substantial and recognized. Foodborne E. coli is responsible for millions of cases of diarrheal disease annually, mainly in susceptible populations such as children, the elderly and immuno-compromised patients [6]. Some pathotypes such as Shiga toxin-producing E. coli are associated with severe diseases like hemolytic-uremic syndrome (HUS) and acute renal failure. In addition to morbidity and mortality, E. coli infection is also costly in economic terms; the costs of medical care, productivity loss and control of outbreaks are expensive [7]. Further complicating the issue is the increasing problem of antimicrobial-resistant E. coli strains which has become a worldwide public health concern. Antimicrobial use and misuse in food-producing animals have been identified as key drivers for resistance, promoting dissemination of resistant bacteria through the food chain and compromising treatment options for antimicrobials that are used most frequently [8].

Aside from the immediate health effects of the E. coli contamination, there are also wider implications for food security, which is broadly defined as availability and access to safe and nutritious food that is sufficient, appropriate and stable. Thus, food safety risk often results in refuse of food that disrupts waste and decrease consumer trust and undermines the effectiveness of food supply and access [9]. In places with already limited provisions of food, these losses could exacerbate malnutrition and poverty. The links between food safety and food security are now better understood, although the two concepts continue to be considered as separate in policy and research contexts. There is also absence of synthesis evidence that included summary measures for microbial contamination, public health impact and food security indicators [9]. Therefore, the objective of this study was to quantify Escherichia coli contamination in commonly consumed foods and estimate disease burden due to E. coli infection through this analysis, contributing to a fuller understanding of food safety and food security.

MATERIALS AND METHODS

STUDY DESIGN AND STUDY AREA

Cross-sectional surveillance study was carried out at Bahaudin Zakariya University, Multan to investigate the impact of Escherichia coli infection on food security and public health. Data for this study was collected over a 12-month period to cover seasonal fluctuations in food contamination and cases of foodborne disease. To broadly cover the commonly consumed food products, samples were collected and data were recorded at several food production, distribution, and retail sites within the study area.

SAMPLE SIZE AND SAMPLING STRATEGY

A total of 360 food samples were collected and analyzed during the study period. 4 food commodities (raw milk, raw meat, fresh vegetables and ready-to-eat foods) were sampled and 90 samples per type were divided. Data on 180 individuals presenting to the study of vomiting and diarrhea who were apparently infected and symptomatic with a foodborne-like illness was also included to assess the public health significance of exposure to E. coli. Food samples were collected by stratified random samplings from farms and slaughter points, markets and food outlets, respectively while human cases were recruited using a facility-based surveillance.

FOOD SAMPLE COLLECTION AND PROCESSING

Food samples were aseptically removed, put into sterile containers and transported on ice within the appropriate time of incubation in order to prevent bacterial overgrowth. Raw milk was obtained directly from bulk tanks and traders, raw meat samples from retail outlets and slaughter slabs, fresh vegetables from open markets, and ready-to-eat foods at food vending sites and restaurants. All samples were homogenized and prepared for analysis according to standard microbiological procedures.

ISOLATION AND IDENTIFICATION OF ESCHERICHIA COLI

E. coli was isolated by standard cultural methods. Enriched samples were plated on selective and differential media. All colonies presumed to be E. coli were detected based on colony morphology, Gram staining, and a series of biochemical tests. Positive isolations were also stored for further analysis.

ENUMERATION OF E. COLI

The number of E. coli contamination was quantitatively determined by the standard plate count method. The results were reported as CFU/g or CFU/mL in liquid samples. Average bacterial counts were determined for positive samples across all food categories.

PATHOTYPE CHARACTERIZATION

Confirmed E. coli isolates were characterized as belonging to one of the major diarrheagenic pathotypes using conventional and molecular phenotypic methods. Isolates pathotype were determined by the presence of virulence markers: enterotoxigenic, enteropathogenic, Shiga-toxin-producing, enteroaggregative, and enteroinvasive.

ANTIMICROBIAL SUSCEPTIBILITY TESTING

The disk diffusion method, according to the standard international protocol, was used to determine the antimicrobial susceptibility of E. coli isolates. The isolates were screened against commonly used antibiotics from various antimicrobial classes. Multidrug resistance was defined as resistance to three or more antimicrobial classes.

HUMAN CASE DATA COLLECTION

Clinical and exposure information were obtained from 180 patients presenting with gastrointestinal symptoms consistent with foodborne illness. A standard questionnaire was used to collect data on recent food intake, symptoms, and hospitalization status. Confirmation of E. coli infection in the laboratory was achieved through stool culture, using methods used for food isolation identification.

ASSESSMENT OF FOOD SECURITY INDICATORS

Food security was measured using established household-level indicators. Rates of food rejection, availability of household food stores, monthly food waste, and consumer confidence in food safety were recorded using structured questionnaires in communities with varying levels of E. coli contamination. Scores and quantitative indices were derived using validated instruments.

Statistical Analysis

Data were analyzed using SPSS version-26. Prevalence, microbial load, antimicrobial resistance and clinical outcome was determined by descriptive statistics. Association between food groups and E. coli contamination was tested using chi-square tests. Analysis of variation was used to compare the microorganism load and food security indicators. $p < 0.05$ were regarded as statistically significant.

RESULTS

PREVALENCE OF ESCHERICHIA COLI CONTAMINATION IN FOOD SAMPLES

Of the 360 food samples tested, E. coli was isolated from 100, for an overall contamination rate of 27.8%. It was more in the raw meat sample than in the raw milk, fresh vegetables, and ready-to-eat items, as presented in Table 1. There were statistically significant differences in the proportions of contaminated foods across food categories, indicating that E. coli was not evenly distributed throughout the food supply chain.

Table 1: Prevalence of E. Coli Contamination in Different Food Categories

Food Category	Samples Tested (n)	Positive Samples (n)	Prevalence (%)	Mean CFU/g ($\times 10^3$) ± SD
Raw milk	90	28	31.1	4.6 ± 1.2
Raw meat	90	34	37.8	5.9 ± 1.6
Fresh vegetables	90	22	24.4	3.8 ± 1.1
Ready-to-eat foods	90	16	17.8	2.6 ± 0.9
Total/Average	**360**	**100**	**27.8**	—

DISTRIBUTION OF E. COLI PATHOTYPES

All E. coli isolates were additionally subtyped into the major diarrheagenic pathotypes. Enterotoxigenic E. coli was the most frequently detected pathotype, followed by enteropathogenic and Shiga-toxin-producing strains, as shown in Table 2. The distribution of pathotypes indicates the potential severity of the health consequences associated with contaminated food.

Table 2: Distribution of E. Coli Pathotypes Isolated from Food Samples

Pathotype	Number of Isolates (n)	Percentage (%)
Enterotoxigenic (ETEC)	29	29.0
Enteropathogenic (EPEC)	24	24.0
Shiga toxin-producing (STEC)	18	18.0
Enteroaggregative (EAEC)	16	16.0
Enteroinvasive (EIEC)	13	13.0
Total	**100**	**100**

ANTIMICROBIAL RESISTANCE PROFILE OF E. COLI ISOLATES

Antibiotic susceptibility testing showed resistance to multiple antibiotics. The resistance rates were highest to tetracycline and ampicillin, while the lowest resistance was recorded against gentamicin and ceftriaxone, as shown in Table 3. Almost 50% of the isolates tested were multidrug-resistant.

Table 3: Antimicrobial Resistance Pattern of E. Coli Isolates

Antibiotics	Resistant Isolates (n)	Resistance (%)
Ampicillin	71	71.0
Tetracycline	65	65.0
Trimethoprim–sulfamethoxazole	58	58.0
Ciprofloxacin	29	29.0
Gentamicin	21	21.0
Ceftriaxone	18	18.0
Multidrug resistant	**46**	**46.0**

ASSOCIATION BETWEEN E. COLI CONTAMINATION AND FOODBORNE ILLNESS

Of the 180 people with symptoms of foodborne disease, 67 cases of E. coli infection were laboratory-confirmed, yielding an average attack rate of 37.2% (Table 4). Raw meat had the highest attack rate, followed by raw milk, fresh vegetables, and ready-to-eat foods.

Table 4: Association Between Exposure to Contaminated Foods and Confirmed E. Coli Infection

Exposure Source	Individuals Exposed (n)	Confirmed Cases (n)	Attack Rate (%)
Raw milk	48	19	39.6
Raw meat	56	26	46.4
Fresh vegetables	42	14	33.3
Ready-to-eat foods	34	8	23.5
Total	**180**	**67**	**37.2**

CLINICAL OUTCOMES OF E. COLI INFECTION

Acute diarrhea was the presenting symptom in all diagnosed cases. Over half the cases developed dehydration, and nearly one-third required hospital admission, as shown in Table 5. There was also a small number of deaths and severe complications, such as hemolytic uremic syndrome.

Table 5: Clinical Outcomes Among Confirmed E. Coli Cases

Clinical Outcome	Number of Patients (n)	Percentage (%)
Acute diarrhea	67	100
Dehydration	39	58.2
Hospitalization	21	31.3
Hemolytic uremic syndrome	6	9.0
Mortality	3	4.5

IMPACT OF E. COLI CONTAMINATION ON FOOD SECURITY INDICATORS

Food security indicators were substantially different between low- and high E. coli-contaminated food areas. Regions with high contamination also rejected more food, generated more food waste, had lower household food availability scores, and reported a decrease in consumer trust in food safety, as reported in Table 6.

Table 6: Food Security Indicators in Areas with Low and High E. Coli Contamination

Indicator	Low Contamination Areas	High Contamination Areas	P-value
Food rejection rate (%)	8.4 ± 2.1	21.7 ± 4.6	<0.001
Household food availability score	7.8 ± 1.2	5.3 ± 1.4	<0.001
Monthly food waste (kg/household)	3.2 ± 0.9	7.6 ± 1.8	<0.001
Consumer confidence index	82.5 ± 6.4	61.9 ± 7.2	<0.001

DISCUSSION

The current results reveal high levels of Escherichia coli contamination in multiple food items, including raw meat and raw milk. These findings are consistent with previous studies indicating that animal-derived foods are a significant source of E. coli transmission to humans [10, 11]. The lower observed prevalence in ready-to-eat foods also indicates the successful implementation of post-processing and handling interventions. However, the presence of E. coli, even in these products, reflects continuing deficiencies in hygiene throughout retail and food service establishments. Analogous epidemiological contamination patterns are reported for fresh produce, where environmental exposure and the quality of irrigation water play crucial roles [12]. Variation in prevalence between food categories may be due to differences in slaughter hygiene, cold chain integrity, and consumer handling history, as reported by Chepkemei [11].

Pathotype investigation identified a broad distribution of diarrheagenic E. coli, mainly enterotoxigenic, followed by enteropathogenic, and a large proportion of Shiga toxin-producing E. coli. This distribution is consistent with that reported by Kaper, Nataro [13] for pathogenic E. coli, who stressed the importance of public health of more than one pathotype of organisms other than STEC. Detection of STEC is especially alarming given its association with severe sequelae such as HUS, a finding also reflected in the clinical information collected in the current study. Similar studies have identified variance in dominant pathotypes by geography and food matrices [14], indicating that local ecology and production factors are drivers of differences in pathotype circulation. Conversely, some outbreak-centered studies have reported higher STEC fractions [15], suggesting that routine surveillance may capture a broader and milder range of E. coli infections.

The antimicrobial resistance patterns identified in the current investigation are worrisome for public health. High levels of resistance to ampicillin, tetracycline, and trimethoprim–sulfamethoxazole are consistent with results from previous studies that implicate the use of antimicrobial agents in food animals as a source of resistance in zoonoses [16, 17]. The high percentage of MDR was consistent with recent calls for concern by the World Health Organization about the food chain as a significant route of dissemination of antimicrobial resistance [18]. Although the resistance to crucial antimicrobials such as ceftriaxone and gentamicin was relatively low, its occurrence represents an increasing threat. Some studies in developed countries have observed relatively lower multidrug resistance due to stringent regulations on antimicrobial use [19], suggesting that policy and stewardship variations could account for regional discrepancies.

From a public health perspective, the described attack rates and clinical severity illustrate that foodborne E. coli infections have remained an important cause of diseases. The proportions hospitalized and those who died are similar to the published ones reported by Scallan, Hoekstra [19] and Majowicz, Scallan [14], but the rate of severe complications is slightly higher in this study. This heterogeneity may be due to differences in healthcare access, late diagnosis, or the circulation of more virulent strains [15]. Foodborne infection is food poisoning cause, and this research supports the importance of integrated surveillance systems for food safety that can link contaminated foods to clinical information.

In addition to health impacts, the study has potentially dire implications for food security. Higher levels of contamination were correlated with more food rejection, household food wastage, lower food supply and consumer confidence. These results are in line with the theoretical and empirical literature explaining how breaches of food safety relate to problems of access to safe food, and economic losses [20]. A reduction in consumer confidence in food safety, could lead to changes in purchasing behavior and potential for nutritional risk [21]. While some regulatory scales focus on food safety without overt recognition of the implication with respect to food security [22], the findings suggest better alignment with Organization's definition [23], which suggests that it is more appropriate to take a holistic approach, in an integrated manner where food safety interventions are recognized as part of sustainable strategies for ensuring food security.

CONCLUSION

This study revealed that E. coli contamination continues to be a concern for public health and food safety in all types of samples, especially raw meat and raw milk with the greatest contamination (the highest prevalence of bacteria) and bacterial load. Different diarrheagenic E. coli pathotypes, including Shiga toxin-producing strains raised the issue on the significant risks for public health and emphasized not to underestimate microbiological monitoring in food production. The high degree of antimicrobial resistance, especially to multidrug strains, raises further public health concern as it curtails treatment options and facilitates the transfer of resistant isolates from food to human. Other than health effects, food contamination has wider socio-economic impacts such as rise in rejected foods (wastage), increase in household food waste and inadequate supply of safe/quality diets along with loss/gain of consumer trust. Combined, these impacts threaten food security, particularly in settings where access to safe and affordable food is already hindered. These results underscore the interconnectedness of food safety, resistance, public health and food security, and provide evidence for the value of collaborative, multisectoral frameworks in which efforts to positively influence hygienic practices and antimicrobial use are complemented by activities to promote adequate regulatory oversight and enforcement. The solution is to build stronger food safety systems "from farm to fork," as well as robust public health surveillance, to reduce the dual risks of foodborne disease and food insecurity. The control of E. coli contamination is not only a question related to public health, but it is also an integral part of the long-term food security and resiliency of the food systems.

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