Cockroaches and Food-borne Pathogens

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ABSTRACT: Food-borne disease is a widespread and escalating public health problem globally. About a quarter of the microorganisms isolated from cockroaches are food-borne pathogens including *Escherichia coli* O157:H7, *Staphylococcus aureus, Bacillus cereus, Shigella dysenteriae, Salmonella enterica* subsp. *enterica* serovar Typhi, *Rotavirus, Aspergillus fumigatus, and Cryptosporidium parvum*. Thus, cockroaches could be an important reservoir and mechanical vector of food-borne pathogens. Generally, the role of cockroaches in human infections is poorly understood and has been an issue of debate for several years. This article aims to elucidate the possible role of cockroaches in food-borne infections by reviewing the relevant research publications.

KEYWORDS: *Escherichia coli* O157:H7, food-borne pathogens, antibiotic resistance, cockroach

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Introduction

Food is an important vehicle for the transmission of infectious pathogens to humans. The high incidence of food-borne diseases coupled with the emergence and re-emergence of food-borne pathogens, have placed food safety high on the agenda of public health issues. Cockroaches appear to be suitable mechanical transmitters for a wide range of food-borne pathogenic microorganisms due to their filthy behaviour and occurrence in places where food is stored or handled.[1,2] Microorganisms may be carried externally on the cuticle of cockroaches,[3,4] or may be ingested and then later excreted or regurgitated.[3,4] In this way, cockroaches can easily contaminate food when they come into contact with it. Although there exist about 4000 species of cockroaches, only 30 are associated with human habitations.[2] The most common cockroach species found in human habitations or environments are *Periplaneta Americana, Blattella germanica, Blatta orientalis, Periplaneta australasiae*, and *Supella longipalpa*.[3] Generally, the role of cockroaches in human infections is poorly understood and has been an issue of debate for several years. In the last 2 decades, there has been an accumulation of adequate research data that contributes significantly to our understanding of this subject.[4] In this regard, the scientific community could benefit from a review of available research data that can provide a global understanding of the role of cockroaches in transmission of human infections. Therefore, in this review article, the author aims to elucidate the possible role of cockroaches in the transmission of food-borne pathogens by reviewing the relevant research publications.

Brief Overview of Food-borne Infections

The World Health Organization[5] estimates that food-borne diseases cause about 600 million illness episodes, 420 000 deaths and 33 million healthy life years lost (disability-adjusted life years, DALYs) annually. Food-borne disease is most prevalent in Africa and South-East Asia, where more than a third of all food-borne illness occurs.[5] Food-borne pathogens account for the vast majority of food-borne diseases, and diarrhoeal agents are responsible for more than half of the global burden of food-borne infections.[5,6] Although all human beings are at risk, the impact of food-borne infections is most severe in very young and elderly people, as well as immune-compromised individuals. Food-borne illness is associated with huge economic costs. For example, in the United States, food-borne illnesses cost the economy between US$10 and US$83 billion.[7] In Australia, the cost of food-borne illness has been estimated at US$1.289 billion per year,[8] whereas in New Zealand, it costs US$86 million.[9] The cost of food-borne illness in Sweden was estimated to be as high as US$171 million.[10] Generally, data on the financial costs of food-borne illness in the developing world are lacking, though the majority of food-borne cases occur in these countries.

The pathogens implicated in food-borne infections cover a wide spectrum of microbes including bacteria, parasites, viruses, and fungi.[11-15] Some of the common food-borne pathogens and types of food they affect are shown in Table 1. The incidence/prevalence of food-borne diseases caused by different pathogens has changed in the last few decades. For example, in the United Kingdom, in 2010, *Campylobacter* displaced *Salmonella* as the prime cause of food-borne disease while the incidence of *Listeria monocytogenes* rose between 2001 and 2009.[16] Viruses are implicated in an increasing number of food-borne cases in the United Kingdom currently, while toxin-producing *Escherichia coli* such as *E coli* 0157:H7 remain less common, but serious pathogens due to their clinical impact.[16] In the next decades of years, new food-borne pathogens are likely to emerge globally driven by factors such as microbial evolution and changes in food production processes.[17-19] In addition, food-borne infections due to existing pathogens can be expected to increase, especially in developing

Table 1. Potentially contaminated foods and the microbial pathogens implicated.

FOOD	MAJOR ORGANISMS INVOLVED
Unpasteurized milk, cheese, and other dairy products	*Salmonella, Campylobacter, Escherichia coli* O157, *Listeria, Mycobacterium bovis, Brucella*
Unpasteurized fruit or vegetable juices	*E. coli* O157, *Salmonella, Clostridium botulinum*
Eggs	*Salmonella*
Raw or undercooked meat, poultry	*Salmonella, Campylobacter, E. coli* O157, *Yersinia, Listeria, Toxoplasma, Brucella, Trichinosis*
Raw fish and shellfish	Vibrios, norovirus, hepatitis A, many other pathogens, toxins and parasites
Fresh fruits and vegetables	*Cryptosporidium, Cyclospora*, calicivirus, norovirus, *Giardia*, Shigella, *E coli* O157, other *E coli* species, hepatitis A
Sprouts (alfalfa, mung bean)	*Salmonella, E coli* O157, hepatitis A
Honey	*C. botulinum*
Cream-filled pastry; potato, egg, or other salad with creamy dressing	*Staphylococcus aureus, Bacillus cereus*

Adapted from Centers for Disease Control and Prevention,[11] Redel,[15] and Lake et al.[13]

countries, partly because of environmental and demographic changes, as well as massive consumption of risky foods.[19,20]

The many food-borne pathogens can be classified into 3 main groups depending on their reservoirs. The first group are pathogens that are sustained in human reservoirs and contaminate food through the faeces of infected humans. This group contains pathogens such as *Norovirus*.[21,22] The second group are pathogens such as *Campylobacter* spp. and *Salmonella enteritidis*, which are sustained in animal reservoirs and contaminate animal source food of humans such as meat, milk, and eggs.[22,23] They could also occur in the faeces of infected animals and contaminate human food. The third group are pathogens that persist in the environment and can contaminate food usually through poor environmental hygiene. This group includes a wide range of pathogens such as *Clostridium perfringens* and *Bacillus cereus*.[24-27]

The diseases caused by food-borne pathogens can be classified into 2 forms: food-borne infection and food-borne intoxication.[27] In food-borne infection (eg, *L. monocytogenes* food poisoning), live cells of the food-borne pathogen are ingested, while in food-borne intoxication (eg, *Clostridium botulinum* food poisoning), toxins are ingested. Some food-borne diseases involve both ingestion of live cells and toxins (eg, *C. perfringens* food poisoning). For successful gastrointestinal infection, pathogens must gain access to the host in adequate numbers to initiate infection. Infective dose, which is the number of cells required to successfully infect a host, varies significantly among food-borne pathogens. For instance, the infective dose of *Yersinia enterocolitica* is about 10^6 cells while that of *Shigella flexneri* is 10^1 to 10^2 cells.[26] Once inside the host, the pathogens establish colonization, and this is facilitated by adhesion factors, invasion factors, chemotaxis, and sometime immune evasion. Most food-borne microorganisms such as *Staphylococcus aureus* cause localized infection but some such as *L. monocytogenes* spread to deeper tissues to induce systemic infection.

Cockroaches and Food-borne Pathogens

In the 1950s, Tarshis[28] provided a compelling evidence incriminating cockroaches as possible vectors of human infections, through a study that reported a correlation between the incidence of hepatitis A and the lack of cockroach control. From 1956 to 1959, the Carmelitos Housing Project had 20% to 39% of the hepatitis A cases in Los Angeles. However, through a concentrated pest control programme, there was a sharp decline in the incidence of endemic infectious hepatitis: in 1960, the hepatitis A incidence at the housing project reduced to 6.6%, then further to 3.6% in 1961, and to 0.0% in 1962. Meanwhile, around the same period, every other place in Los Angeles County that was not receiving the pest control service experienced increasing incidence of the infection. It was observed that the decline in hepatitis A incidence occurred simultaneously with a significant reduction (about 70%) in cockroach infestation due to the pest control programme. The hepatitis A virus occurs in the faeces of infected persons and is usually transmitted through consumption of contaminated water or food. The association of cockroaches with faeces and food makes their transmission of hepatitis A virus highly plausible. Although the study of Tarshis[28] was not supported with experimental data, it provides evidence supporting the theory that cockroaches play a role in the transmission of food-borne pathogens. Experimental evidence supporting the possible role of cockroaches in the transmission of food-borne pathogens has been provided by several investigators. A study done by Ash and Greenberg[29] in 1980 reported that exposure of cockroaches to *Salmonella enterica* subsp. *enterica* serovar Typhimurium resulted in occurrence of the pathogen in the excreta of the cockroaches in a dose-related fashion with outputs of 8×10^1 to 2×10^7 cells/defecation over a range of 3 to 20 days. The investigators observed that *S.* Typhimurium was recoverable about 10 days longer in the cockroach gut compared with the faeces, and persistence of the organism occurred primarily in the hindgut. In another experiment by Kopanic et al[30] in 1993, it was shown that cockroaches could be infected with a naladixic acid-resistant strain of *S.* Typhimurium from a contaminated food source. The investigators also showed that the infected cockroaches could transmit the naladixic acid-resistant strain of *S.* Typhimurium to uninfected cockroaches, food (eggs), and water. A study by Zurek and Schal[31] in 2004 investigated the vectorial potential of German cockroaches for verotoxigenic *E. coli* F18, an important porcine bacterial pathogen. Forty adult cockroaches were divided into 2 groups of 20 each; 1 group of cockroaches was exposed to *E. coli* F18 (5.0×10^5 CFUs mL) in 10 mL of phosphate buffer solution (PBS), while the second group (control) received 10 mL of sterile PBS. After 5 hours, the PBS was replaced with sterile tap water, and sterile piglet feed ration (collected from the swine farm) was supplied to both cockroach groups. Viable and virulent *E. coli* F18 cells were detectable in cockroach faeces for up to 8 days after the initial exposure, and the number of bacterial cells decreased over time. In the control group, no *E. coli* F18 organisms were detected in cockroach faeces. The average number of faecal coliforms in cockroach faeces was high (4.4×10^5 g^{-1}) and not significantly different from that found in piglet faeces ($1.9 \pm 0.8 \times 10^6$ g^{-1}). Using non-food-borne pathogens such as *Helicobacter pylori*[32] and *Mycobacterium avium* subsp. *paratuberculosis*,[33] other investigators have also demonstrated the vectorial potential of cockroaches through controlled laboratory studies.

Several observational studies on microbial carriage of cockroaches have been carried out in many parts of the world.[34-45] As shown in Table 2, these studies report many different microorganisms including bacteria, parasites, fungi, and viruses. This is not surprising given the broad habitat range of cockroaches and the ubiquitous nature of microorganisms. Approximately, a quarter of the microorganisms reported in Table 2 are food-borne pathogens and will be discussed in detail.

Food-borne bacterial pathogens isolated from cockroaches include *Shigella boydii, Shigella dysenteriae, Shigella flexneri, Salmonella enterica* subsp. *enterica* serovar Typhi, *Salmonella* Typhimurium, *Escherichia coli* O157:H7, *Staphylococcus aureus, and Bacillus cereus*. It is important to note the several species of *Shigella* and *Salmonella* that have been isolated from cockroaches, which probably indicates that cockroaches are an important reservoir for these bacteria.[34-36,39] As *Shigella* spp. and *S.* Typhi are mainly sustained in humans,[46-49] their occurrence in food is thought to be associated with food handlers. However, these organisms could be disseminated by cockroaches in food environments. *Shigella* spp. have a very low infective dose (10^1-10^2 cells) and cause bacillary dysentery (shigellosis), a highly invasive intestinal infection characterized by fever, violent abdominal cramps, rectal urgencies, and complications such as intestinal perforations, septicaemia, and toxic megacolon.[46,47] In particular, a strain of *S. dysenteriae* (one of the *Shigella* spp. isolated from cockroaches) is implicated in severe epidemics of bacillary dysentery through the production of shiga toxins[46,47]. *S.* Typhi causes typhoid fever, which is a serious disease as it could lead to complications such as liver damage, inflammation of the heart, holes in the gut, and internal bleeding.[48,49] The association of cockroaches with *S.* Typhi should be viewed with seriousness in developing countries where typhoid fever is most prevalent and lack of food hygiene is also of serious concern. *S.* Typhimurium causes a mild gastroenteritis and is often transmitted from animals through consumption of raw or undercooked animal source food such as meat.[50,51] Compared with *Shigella, Salmonella* has a relatively high infective dose of 10^5 to 10^6 cells. The isolation of *E. coli* O157:H7 from cockroaches is interesting, as this organism emerged as a food-borne pathogen only in the 1990s.[52] The organism resides in the intestinal tract of live animals and is shed in their faeces, which may contaminate food, water, and the environment.[52-55] It has unusual persistence features in the environment and survives at low temperatures and under acidic conditions.[52,55] The infective dose of *E. coli* O157:H7 is very small (10-100 cells) and is implicated in severe clinical conditions including, haemorrhagic colitis leading to bloody diarrhoea, haemolytic uremic syndrome and kidney damage.[52-55] *S. aureus* and *B. cereus*, also isolated from cockroaches, are among the predominant food-borne pathogens globally. Both pathogens have an infective dose of 10^5 to 10^6 cells and produce toxins, which mediate the food-borne disease; *S. aureus* produces enteroxins, which cause diarrhoea,[56] while *B. cereus* produces an emetic and enterotoxin responsible for vomiting and diarrhoea, respectively.[57,58] *B. cereus* is a spore-forming bacteria and can therefore survive for a very long period in the environment, which enhances its chances of contaminating cockroaches.[59,60]

Compared with bacteria, the other types of food-borne microbes tend to be carried by cockroaches to a lesser extent. Four main food-borne parasites are reported to be carried by cockroaches: *Cryptosporidium parvum, Cyclospora cayetanensis, Entamoeba histolytica,* and *Giardia duodenalis* (Table 2). These pathogens are transmitted faecal-orally from ingestion of their oocyst/cysts, which can persist and survive for long periods in the environment, water, and on foods.[61-64] Animals are known to be a reservoir of human infection for *C. parvum* and *G. duodenalis,* but not *C. cayetanensis* and *E. histolytica*.[63,64] Among food-borne viruses, rotavirus and hepatitis A virus have been reported to be associated with cockroaches.[28,43] Rotavirus is the leading cause of severe diarrhoea in young children globally, and is responsible for about 50% of paediatric diarrheal disease hospitalizations in developing countries.[65-69] In this regard, the presence of cockroaches in homes could have serious implications for paediatric health. Hepatitis A is the most common form of acute viral hepatitis worldwide and therefore its

Table 2. Microbial carriage of cockroaches.

STUDY	COUNTRY	N	ORGANISMS ISOLATED
Fotedar et al[34]	India	96	*Pseudomonas aeruginosa, Staphylococcus aureus, Streptococcus faecalis, Micrococcus* spp.
Tachbele et al[35]	Ethiopia	600	*Salmonella* spp.*, Shigella flexneri, Escherichia coli O157, Staphylococcus aureus*, and *Bacillus cereus.*
Oothuman et al[36]	Malaysia	104	*Shigella boydii, Shigella dysenteriae, Salmonella* Typhimurium*, Klebsiella oxytoca, Klebsiella ozaenae, Serratia marcescens.*
Le Guyader et al[37]	France	532	*Citrobacter freundii, Enterobacter cloacae, Klebsiella oxytoca, Klebsiella pneumoniae, Enterobacter agglomerans, Escherichia adecarboxylata, Serratia marcescens, Serratia liquefaciens, Acinetobacter* spp.*, Pseudomonas fluorescens, Pseudomonas putida, Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus.*
Fotedar et al[38]	India	279	Bacteria: *Klebsiella* spp.*, Escherichia coli, Enterobacter* spp.*, Pseudomonas aeruginosa, Proteus* spp.*, Staphylococcus aureus, Streptococcus epidermidis, Streptococcus faecalis, Streptococcus viridans, Micrococcus, Bacillus* spp. Parasites: *Endolimax nana, Entamoeba coli, Entamoeba histolytica.* Fungi: *Candida* spp.*, Rhizopus* spp. *Mucor* spp.*, Alternaria* spp. *Aspergillus niger, Aspergillus flavus, Aspergillus* spp.
Moges et al[39]	Ethiopia	60	*Klebsiella pneumoniae, Escherichia coli, Citrobacter* spp.*, Salmonella* spp.*, Enterobacter* spp. *Shigella* spp.*, Providencia* spp.*, Serratia* spp.*, Proteus* spp.*, Staphylococcus aureus*, *Escherichia coli.*
Salehzadeh et al[40]	Iran	133	Bacteria: *Enterobacter* spp.*, Klebsiella* spp.*, Enterococcus* spp.*, Staphylococcus* spp.*, Escherichia coli, Streptococcus* spp.*, Pseudomonas* spp. *Shigella* spp*, Haemophilus* and group A beta-haemolytic *Streptococcus* spp. Fungi: *Candida* spp.*, Mucor* spp.*, Rhizopus* spp.*, Penicillium* spp.*, Aspergillus fumigans. Aspergillus niger.*
Naher et al[41]	Bangladesh		*Escherichia coli, P aeruginosa, Salmonella* spp.*, Shigella* spp.*, Klebsiella* spp.*, Proteus* spp.*, Staphylococcus aureus.*
Mensaria et al[42]	Algeria		*Citrobacter freundii, Enterobacter cloacae, S marcescens, Klebsiella pneumoniae, Pantoea* spp.*, Enterobacter aerogenes, Enterobacter* spp.
Tetteh-Quarcoo et al[43]	Ghana	61	Bacteria: *Klebsiella pneumoniae, Escherichia coli, Proteus vulgaris, Citrobacter ferundii, Enterobacter cloacae, Enterococcus faecalis, Pseudomonas aeruginosa*, *Klebsiella oxytoca.* *Parasites: Ancylostoma duodenale, Hymenolepis nana, Taenia* spp. *Viruses:* Rotavirus.
Tilahun et al[44]	Ethiopia	400	*Klebsiella oxytoca, Klebsiella pneumoniae, Klebsiella ozaenae, Citrobacter spp., Citrobacter diversus, Enterobacter cloacae, Pseudomonas aeruginosa, Enterobacter aeruginosa, Providencia rettgeri, Salmonella* spp.*, Streptococcus* spp. *Staphylococcus aureus, Escherichia coli, Acinetobacter* spp. and *Shigella flexneri*
Oyeyemi et al[45]	Nigeria	130	*Ascaris lumbricoides, Enterobius vermicularis*, hookworm, *Trichuris trichiura, Entamoeba histolytica, Taenia* spp.

N is the number of cockroach samples.

association with cockroaches is a cause for concern, especially in the developing world where the infection is mostly prevalent.[70] Several fungi implicated in food-borne infections have been isolated from cockroaches and include *Aspergillus* spp., *Candida* spp., *Mucor* spp., and *Alternaria* spp. (Table 2). Among these fungal pathogens, *Aspergillus* spp. poses the biggest threat to humans through the production of aflatoxins, which are extremely potent liver carcinogens.[71,72] The most pathogenic species of *Aspergillus* is *A. fumigatus*, followed by *A. flavus*, both of which have been isolated from cockroaches.[73-75]

Conclusions and Further Research

Cockroaches could harbour and disseminate many food-borne microbial pathogens including bacteria, fungi, viruses, and parasites. These food-borne pathogens vary widely in their biological characteristics, host associations, virulence determinants, and transmissions. This implies that cockroaches could play a very broad role in food-borne infections. Given the association between cockroaches and food-borne pathogens, it is important to consider them in food-borne outbreak investigations, which has not been the case hitherto.

Further studies are needed to describe cockroach carriage of the several other food-borne pathogens that have not been reported previously. These include important food-borne pathogens such as *C. perfringens*, *C. botulinum*, *Campylobacter* spp., norovirus, and hepatitis A. In addition, there is the need for a better understanding regarding host–microbe relationships that occur between cockroaches and food-borne microbial pathogens. Microbiome studies could provide invaluable insights in this regard.

Considering the food-borne risks associated with cockroaches, their presence should not be tolerated in the food industry. Similarly, cockroaches should not be tolerated in the hospital setting as they might spread nosocomial pathogens such as *S. aureus* and *E. coli*. Efforts to control cockroaches should involve good hygiene and sanitation of facilities and also the application of proper insecticides to cockroach hiding spots.[4,76,77] It is also important to remove hiding places of cockroaches such as cardboard, as this will prevent future infestations.

Author Contributions

ESD conceived the idea for this paper, undertook literature review and wrote the manuscript.

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