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Review

A potential role of cockroaches in the transmission of pathogenic bacteria with antibiotic resistance: A scoping review

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Abstract

Introduction: The role of cockroaches in the cause of disease or human infections is not immediately obvious. The present study aimed to review the currently available research on the potential role of cockroaches in the transmission of pathogenic bacteria and bacteria with antibiotic resistance.

Methodology: A scoping review included the studies published for a period between January 2001 and December 2020. A search was performed through five databases, namely, PubMed, Sage, Springer, Sabinet, and Science Direct. A search strategy used was conducted according to the principles of Preferred Reporting Item for Systemic Reviews and Meta-Analyses (PRISMA). From 97 studies identified, 32 studies were included in the scoping review.

Results: The findings indicate that cockroaches may be a potential vector for a diverse range of pathogenic bacterial agents. Most bacterial agents isolated are antidrug-resistant and antibiotic-resistant which is considered the greatest threat to public health in the current period.

Conclusions: Cockroach infestation should be considered as a serious concern, given the possible role of cockroaches as reservoirs of antibiotic-resistant bacteria. Further research is needed which can provide a comprehensive understanding of the role of cockroaches in transmitting human infections.

Key words: Cockroaches vector; pathogenic; bacteria contamination; drug-resistant bacteria; antibiotic resistance.

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Introduction

Cockroaches are insects that are typically found in an environment where human beings exist. Such places include healthcare facilities, cafeterias, offices, homes, and markets, as well as urban and rural communities. In 2004, about 19,000 pest control service providers were reported to have reached a yearly income of US$ 6.1 billion of which 22.4% of that was due to rendering the service of cockroach management and in Malaysia, 20% of the income is from rendering the pest control services on cockroaches. Each year, the United States spends an estimated 1 billion USD to manage pests [1,2]. Cockroaches damage and stain clothes, books, furniture, and utensils and have reduced the aesthetic value of the human living environment. These are examples of economic losses attributed directly to cockroach infestation [1].

Despite these direct economic impacts and losses caused by the cockroach, the role of cockroaches in the spread of diseases or human infections is not immediately obvious and had always been questionable [3,4,5]. In addition, it has been a topic of discussion for many centuries [6]. Lately, there has been more research data that contributes significantly to the current knowledge and understanding of this topic. There is a scarcity of review papers explaining and discussing the research information on a sole platform to make available a comprehensive understanding of the role of cockroaches in human infections [7]. This review investigates the potential role of cockroaches in the transmission of pathogenic bacteria and bacteria with antibiotic resistance.

Methodology

Literature Search

Applicable scientific papers focused on the cockroach as a vector and bacterial carriage were collected from various scientific websites such as PubMed, Sage, Springer, Sabinet, and Science Direct for the period between January 2001 and December

2020. For the search, cockroaches and one or more keywords such as vector, bacterial contamination, pathogenic, drug-resistant bacteria, or antibiotic resistance were used. Furthermore, all searches were done in boolean/phrase mode and focused on papers published in the English language.

Data extraction

Papers were selected according to the established eligibility criteria (Table 1). A Preferred Reporting Item for Systemic Reviews and Meta-Analyses (PRISMA) flow chart was used to illustrate the inclusion of eligible papers (Figure 1). A total of 97 papers were screened and found to be eligible based on the title and the required standards of methodology such as sample size; cockroach population; isolation and susceptibility testing of bacteria. Papers that did not reflect the keywords in the title, sample size not indicated or the target population being a different population of interest were excluded from the study. Qualitative and qualitative studies in languages other than English were included in the review. Of the 97 identified papers, 32 papers were selected for the scoping review.

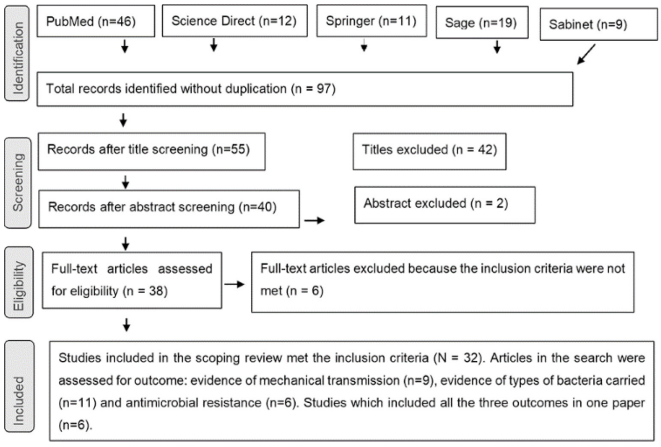
A Microsoft Excel spreadsheet was created to record all the papers that can help achieve the objective of this review. Details regarding the information of the selected paper, aims and objectives, as well as the outcomes were recorded in the spreadsheet. The last phase was to synthesize the results by establishing the main knowledge or gaps resulting from the reviewed papers were relevant to this review paper's objectives.

Results

Mechanical transmission of bacteria by cockroaches

The night-time habits and behavior of cockroaches may render them as a potential vector for a range of pathogenic microorganisms. Cockroaches can readily move from a contaminated environment and provide an opportunity for bacteria to contaminate the food, utensils, and food preparation areas [8]. Also, they forage readily on feces, sputum, skin scrapings, other human debris, and diverse foodstuffs. Consumed bacteria can thrive in the cockroach's digestive system, for at least a couple of months or even years. The bacteria can then be passed through its droppings

Figure 1. PRISMA flow chart.



[9,10]. Cockroaches depend on their wings, legs, and cuticles for grooming. This may increase the likelihood of direct contact with contaminated surfaces [11]. Potential pathogens can be easily spread by contact between the contaminated cockroaches and food, eating utensils as well as drinking vessels [12]. The spread of potentially pathogenic bacteria could occur by cockroach regurgitation or fecal pellet deposition into human foodstuffs [13]. Also, they expel portions of partially consumed food and drop feces at intervals. They also release a smelly discharge from their mouths and glands. In general, the literature illustrates that due to their mobility and frequent contact with humans they may be a vector of infections [11]. In essence, there is still a need to develop a better understanding of the relationships between cockroaches and bacterial agents.

Species of bacteria agents isolated from domestic cockroaches

Numerous studies have been carried out to study the prevalence of bacterial contamination by cockroaches. Table 2 and Table 3 highlight the most bacterial isolates associated with cockroaches. Data indicated that the bacteria agents on the external surfaces of cockroaches are potentially more harmful as compared to internal surfaces [14].

Ojiezeh [10] discovered about 32 types of bacteria associated with cockroaches. In a similar study, 78 bacterial species and 42 genera of bacteria were isolated from cockroaches [14]. In addition, a study on a rapid

Table 1. Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Study types	Systemic reviews, qualitative and quantitative studies	Editorials, and commentaries
Participants	Domestic cockroaches, German cockroach, American Cockroach or Oriental cockroach	Any insect or vector other than domestic cockroach
Settings	Households, health care, hospitality sector or any rural and urban environment	Setting outside household, hospitality or any human dwellings (not under rural and urban environment).

screening and characterization of bacteria associated with hospital cockroaches also isolated a total of 181 bacteria strains from 25 cockroach specimens. The results showed a high prevalence of bacterial pathogens harbored in the body and alimentary tract of German cockroaches (*Blattella germanica*). This indicates that German cockroaches can act as a source of bacterial pathogens and cause direct transmission of healthcare-associated infections [15]

Musa *et al.* [16] conducted a study to isolate and identify bacteria from the German cockroaches (*Blatella gerainica)* in Khartoum state (Khartoum, Khartoum North, and Omdurman). A biochemical test was used for microbial identification. The study found that 15 different bacterial species exist in the isolates from 3 cities. In another study, 14 bacterial species were isolated from 240 adult cockroaches collected from houses and hospitals in Lahore via bacterial screening for the external and internal surfaces of cockroaches. In this study, it was observed that there was no significant difference in bacterial load in each habitat [17].

Moges *et al.* [18] also carried out a study in 2014. The study was aimed at assessing the bacterial isolates and their antimicrobial profiles from cockroaches in Gondar town, Ethiopia. Similarly, in a study by Mehainaoui *et al.* [15], the authors identified 181 bacteria species. However, out of 181 bacteria species in this study, 110 (60.8%) and 71 (39.2%) were identified from the external and internal parts of cockroaches. *Klebsiella pneumoniae* was the most commonly found isolate, followed by *Escherichia coli* then *Citrobacter* species. Furthermore, *K. pneumoniae* was also the most common isolate from cockroaches in a hospital setting, whereas *E. coli* and *Citrobacter* species were mostly isolated from non-hospital cockroaches [15,18].

Another cross-sectional study was conducted in restaurants and cafeterias of Jimma town. The study aimed at determining the vector potential of cockroaches for medically important bacterial pathogens in restaurants and cafeterias. Ninety-one foodborne bacteria were isolated [19]. Also, eight bacteria species were reported after an investigation

Table 2. Common bacteria agents isolated from domestic cockroaches.

Author(s)/Date	Country	Number of cockroach samples	Common bacteria isolated
Mehainaoui *et al.* (2020) [15]	Algeria	25	*Citrobacter, Klebsiella, Kluyevera, Leclercia, Morganella, Serratia, Pseudomonas* sp.*, Staphylococcus* sp.*, Enterococcus* sp.*, S. marcescens, P. aeruginosa, K. oxytoca.*
Musa *et al.* (2018) [16]	Sudan	60	*Alcaligenes* spp.*, Bacillus* spp.*, Enterobacter* spp.*, Escherchia coli, Klebsiella* spp.*, Micrococcus* spp.*, Morganella* spp.*, Proteus* spp.*, Pseudomonas* spp.*, Salmonella paratyphi A, Salmonella* spp.*, Serattia* spp.*, Shigella* spp.*, Staphylococcus* spp.*, Streptococcus* spp.
Memona *et al.* (2017) [17]	Pakistan	240	*S. aureus, S. typhi, S. dysenteriae, E. Coli, P. aeruginosa, S. epidermidis, Proteus mirabilis, E. aerogenes, Streptococcus pneumoniae, Proteus vulgaris, Bacillus cereus, K. Pneumoniae, Enterococcus faecalis, Enterobacter cloacae.*
Moges *et al.* (2016) [18]	Ethiopia	60	*S. aureus, E. coli, Citrobacter* spp.*, Enterobacter* spp.*, K. pneumoniae, Klebsiella* spp.*, Shigella* spp.*, Providencia* spp.*, Serratia* spp.*, Proteus* spp.*, Salmonella, E. cloacae, E. aerogenes, Klebsiella ozaenae, Klebsiella rhinoscleromatis, Coagulase negative staphylococci.*
Solomon *et al.* (2016) [19]	Ethiopia	1140	*Salmonella* spp.*, E. coli, Shigella flexneri, S. aureus, B. cereus, Klebsiella* spp.*, Enterobacter* spp.*, K. pneumonia, P. mirabilis, P. vulgaris, Citrobacter freundii, S. marcescens, Edwardsiella tarda, Citrobacter diversus, P. aeruginosa, Bacillus* spp.*, Coagulase negative staphylococci, Bacillus subtilis.*
Sayyad *et al.* (2016) [20]	Iran	98	*Pseudomonas* spp.*, Proteus* spp.*, Klebsiella* spp.*, Staphylococcus* spp.*, Bacillus* spp.*, Serratia* spp.*, Entrobacter* spp.*, E. coli.*
Gonzalez-Astudillo *et al.* (2015) [21]	Colombia	59	*Leptospira* non *kirschneri (Leptospira interrogans, Leptospira borgpetersenii, Leptospira weillii, Leptospira noguchii, Leptospira santarosai, Leptospira meyeri), Leptospira kirschneri.*
Menasria *et al.* (2014) [11]	Algeria	39	*P. aeruginosa, Pseudomonas* spp.*, S. aureus,* Non-pathogenic *Staphylococcus, C. freundii, E. cloacae, E. aerogenes, Enterobacter* spp.*, K. pneumoniae, Pantoea* spp.*, S. marcescens, Serratia* spp.
Isaac *et al.* (2014) [22]	Nigeria	246	*Bacillus* spp.*, E. coli, P. mirabilis, P. aeruginosa, P. vulgaris, S. aureus, S. epidermidis, E. faecalis, C. freundi, Salmonella* spp.
Vazirianzadeh *et al.* (2013) [24]	Iran	39	*E. aerogenes, E. cloacae, Enterobacter agglomerans, K. pneumonia, K. oxytoca, C. freund, E. coli, Salmonella para-A, S. marcescens, P. mirabilis, P. vulgaris, Coagulase negative staphylococci, S. aureus, B. cereus, B. subtilis.*

was carried out in Ghods hospital and five dwelling localities of Paveh city [20]. Fifty-nine cockroaches were trapped from seven sites in Colombia to determine specifically if pathogenic *Leptospira* is harbored by *Periplaneta* spp. The study found that *Leptospira* was more likely to be isolated from body surfaces than from the digestive tract ($p < 0.001$). Thus, also demonstrated an association between *Periplaneta* spp and *Leptospira* [21]. Menasria *et al.* [11] carried out a study to isolate and identify the bacterial flora from German cockroaches collected from 2 public hospital environments in Tebessa city. The external surfaces and alimentary tract of 39 cockroaches were screened for microbial load using standard bacterial protocols. A total of 174 bacterial species were isolated from cockroach specimens [11].

In a comparative analysis study of pathogenic organisms in Nigeria, 240 cockroach specimens were examined. It was reported that many microbes and parasites were from the alimentary canal than the body surface of cockroaches [22]. In another study, 250 cockroaches were collected from hospitals in southwest Iran. The samples were examined specifically for the presence of *K. pneumoniae* by plating onto a combination of culture media. Hundred and seventy-nine samples (71.60%) were found positive for *K. pneumoniae* [23]. Also, 39 brown-banded cockroaches were collected in another study from the kitchen area of houses in Ahvaz, southwestern Iran. About 179 bacterial species were isolated, 92 from alimentary ducts and 87 from the external body surfaces [24]. Other cockroaches were captured from the indoor and outdoor

Table 3. Common bacteria agents isolated from hospital cockroaches.

Author(s)/Date	Country	No.of cockroach samples	Common bacteria isolated
Tatfeng *et al*. (2005) [5]	Nigeria	234	*E. coli, K. pneumoniae, P. vulgaris, P. mirabilis, C. freundii, E. cloacae, Salmonella* spp*, P. aeruginosa, Serretia marcescens, S. aureus, Staphylococcus feacalis, S. epidermidis, Aeromonas s*pp.
Pai (2013) [25]	Taiwan	558	*S. marcescens, Hafnia alvei, Enterobacter gergoviae, K. pneumoniae, Morganella morganii ss Siboni, Aerom. veronii biov. Veronii, E. aerogenes, E. cloacae, Moraxella nonliguefaciens, Providencia rettgeii, Aeromonas jondaei, Citrobacter amalonaticus, C. freundii, Citrobacter wermanii, Citrobacter youngae, Enteric group, Escherichia blattae, Ewingella americans, K. oxytoca, K. ozaenae, K. rhinoscleromatis, Moraxella oslensis, S. marcescens, Vibrio damsela, Vibrio vulnificus, Aeromonas caviae, Aeromonas hydrophilia, Enteric* spp, *Enterobacter taylorae, Leclercia adecarboxylata, Morganella morganii ss morganii, Myroides odoratum, Plesiomonas shigelloides, P. vulgaris, Serratia fonticola, Vibrio parahaemolyticus, Vibrio alginolyticus, Vibrio mimicus, Stenotrophomonas maltophilia, P. aeruginosa, Burkholderia cepacian, Pseudomonas fluorecens/putida, Flavobacterium thalpophilum, Alcaligengs faecalis, Comamonas acidovorans, Pseudomonas* spp., *Alcaligenes, Acinetobacter lwoffii, Alcaligenes xylosoxidans, Eikenella corrodens, Shewanella putrefaciens, Shingomonas paucimobilis, Acinetobacter calcoacticus, Acinetobacter johnsonii, Ochrobactruno anthropic, Oligella urethralis, Pseudomonas stutzeri, Xanthomonas maltophilia, Bacillus* spp., *Enterococcus* spp., *Staphylococcus saprophyticus, Streptococcus* spp., *Micrococcus* spp., *S. aureus.*
Tetteh-Quarcoo *et al.* (2013) [26]	Ghana	60	*K. pneumoniae, E. coli, P. vulgaris, Citrobacter ferundii, E. cloacae, E. faecalis, P. aeruginosa, K. oxytoca.*
Wannigama *et al.* (2013) [27]	India	203	*K. pneumoniae, E. coli, E. aerogenes, E. cloacae Salmonella* spp*., C. freundii, P. mirabilis, P. aeruginosa*.
Tilahun *et al*. (2012) [28]	Ethiopia	400	*K. oxytoca, K. pneumoniae, Citrobacter* spp., *E. cloacae, C. diversus, P. aeruginosa, Providencia rettgeri, K. ozaenae, Enterobacter aeruginosa, Salmonella, S. aureus, E. coli, Acinetobacter spp., Shigella flexneri.*
Bouamama *et al.* (2010) [30]	Morocco	60	*Acinetobacter lwoffi, Citrobacter* spp*., Enterobacter* spp., *E. coli, Klebsiella* spp*., Pasteurella* spp*., Proteus* spp., *Providencia* spp., *Salmonella* spp., *Serratia* spp., *Shigella dysenteriae, Yersinia enterocolitica, S. aureus, Staphylococcus coagulase-negative, Enterococcus* spp*.*
Salehzadeh *et al.* (2007) [32]	Iran	178	*Enterobacter* spp., *Klebsiella* spp*., Enterococcus* spp*., Staphylococcus* spp*., E. coli, Streptococcus* spp*., Pseudomonas* spp. *Shigella* spp, *Haemophilus,* group A beta-hemolytic *Streptococcus* spp*.*
Gliniewicz *et al*. (2003) [35]	Poland	60	*Streptococcus oestibularis, Streptococcus salivarius, Enterococcus avium, Enterococcus durans, Staphylococcus hominis, Staphylococcus equorum, S. epidermidis, Micrococcus luteus, C. freundii, E. cloacae, K. oxytoca, S. marcescens, Pseudomonas putida, P. aeruginosa,* Bacilli.

environments of 69 long-term care facilities and nursing homes in Kaohsiung City. Thirty-eight Gram-negative bacteria, 20 glucose non-fermenter bacilli, and 6 Gram-positive bacteria species were isolated [25].

Eight nosocomial bacteria were also isolated from the cockroaches. The most prevalent was *K. pneumoniae*, which occurred internally in 29.5% of the cockroaches and externally in 26.2% of the cockroaches [26]. Wannigama *et al.* [27] carried out a study on 203 adult cockroaches collected from 44 households and 52 food-handling establishments. The study found that there was no significant difference between the overall bacteria load on the external surface in *Periplaneta americana* (64.04%) and *Blattella germanica* (35.96%). Bacteriological examination of external surfaces of *Periplaneta americana* and *Blattella germanica* were carried out in another study using a standard method. Four hundred *Blatella germanica* roaches were trapped from a neonatal intensive care unit in Ethiopia. At least 231 isolates belonging to 12 species of pathogenic bacteria were discovered in the gut and external homogenates of these cockroaches [28].

Twenty-five different species of medically important bacteria were also isolated and identified at 4 buildings in central Tehran, Iran. The genus of enteric bacteria commonly isolated from the cockroach species was *Klebsiella.* In addition, the study found that the cockroaches from hospitals were much more likely to be found contaminated with medically important bacteria than those from the house [29]. A total of 126 bacteria were found among 60 specimens of *Periplaneta americana* trapped in the residential areas of 6 districts in Tangier, Morocco. The results showed no difference between the species of bacterial strains from cockroaches and houseflies [30].

In a survey on species and prevalence rate of bacterial agents isolated from cockroaches in 3 hospitals in Tehran. Three hundred and five cockroaches were trapped, and 19 species of bacteria were identified from them. The most frequent species of bacteria isolated from cockroaches were *E. coli, Streptococcus* Group D, *Bacillus* spp., *K. pneumoniae*, and *P. vulgaris* [31]. Salehzadeh *et al.* [32] trapped 178 cockroaches in hospitals and residential areas of Hamadan. This study's statistics highlighted cockroaches' significance as potential vectors of medically important microorganisms.

Elgderi *et al.* [33] also isolated at least 27 species of potential pathogens from the 403 cockroaches captured from hospital and household settings in Tripoli. It was found that *Klebsiella, Enterobacter, Serratia,* and *Streptococcus* were predominant in the cockroach specimens. In another study, cockroaches were collected from 40 households in Taiwan. Twenty-five species of bacteria were isolated from *Periplaneta americana* and only 21 from *Blattella germanica* [34].

Two hundred and thirty-four cockroaches were collected from different sites (toilets, parlors, kitchens, and bedrooms) in houses with pit latrines and water system in Ekpoma, Nigeria. The study found that the microorganisms isolated were alike irrespective of the site screened [5]. Twenty strains of different taxons were isolated from 60 German cockroaches collected in 2 hospitals in Poland. After examinations, they were all found to be potentially pathogenic to humans [35]. Further investigations are required to determine cockroach carriage of the variety of other bacterial agents that have not been documented in the past.

Isolation of bacteria with antidrug resistance from domestic cockroaches

In several studies, cockroaches have been reported to harbor highly antibiotic-resistant bacteria. Hence, it is imperative to highlight and discuss these studies. A study in Ethiopia revealed that 64.1% of bacteria isolated from cockroaches were multidrug-resistant to 3 or more classes of antibiotics. *Salmonella* spp. were the most predominant multidrug-resistant isolates (100%), *Enterobacter* (90.5%), and *Shigella* spp. (76.9%) [6,18]. The bacteria isolated from cockroaches in the hospital environment also seem to have a higher prevalence of multidrug resistance (67%) as compared to those from the community (61.3%).

Among the isolated bacteria from the Brown-Banded cockroach, Vazirianzadeh *et al.* [24]. observed the pattern of resistant rates for Gram-negative bacilli and Gram-positive cocci regarding 18 antibiotics. The resistance rate of Gram-negative bacilli from the kitchen area of houses was above 52.4% for ampicillin, cephalothin, ceftazidime, nitrofurantoin, nalidixic acid, trimethoprim-sulfamethoxazole, cefalexin, and tetracycline. All the isolates from the kitchen area showed the highest susceptibility to cefotaxime. In addition, Gram-positive cocci, from the kitchen area of houses showed resistance to ampicillin, amikacin penicillin, ceftazidime, nitrofurantoin, nalidixic acid, trimethoprim-sulfamethoxazole, cefalexin, cefotaxime, and tetracycline, whereby resistance rates were above 53.8%. More susceptibility was observed to be on ciproflexoxacin among all the isolates from the kitchen area.

Pai [25] found resistance to 12 antibiotics from the bacteria isolated from the examined cockroaches. Most

of the Gram-negative bacteria isolated were observed to have resistance to ampicillin (10 g) and cephalothin (30 g). *Pseudomonas aeruginosa* was the second frequently isolated Glucose non-fermenter bacilli and found to have resistance to imipenem, ceftazidime, and cefepime. However, *Acinetobacter* spp. was not found frequently and only had resistance on imipenem. Moreover, Gram-positive bacteria were observed to have 100% resistance to oxacillin (1 g) and pipemidic acid (20 g). The results of the antibiotic sensitivity tests showed that, among the 6 Gram-negative pathogenic bacteria species studied, resistance to 8 of 12 antibiotics (66.66%) was observed. *P. aeruginosa* and *P. mirabilis,* had resistance to 7 of 12 antibiotics tested. *Klebsiella pneumoniae* and *Enterobacter aerogenes* were resistant to 4 antibiotics and extended-spectrum beta-lactamase (ESBL). *E. coli* was resistant to 7 and *C. freundii* to six antibiotics. However, *K. pneumoniae* and *P. aeruginosa* were the most predominant with 100% resistance to sulfamethoxazole/trimethoprim and ampicillin. *E. coli, C. freundii*, *E. aerogenes,* and *P. mirabilis* were observed to be multi-resistance to 4 antibiotics tested. Overall sensitivity to imipenem, cefoperazone, ciprofloxacin, and ofloxacin was also found [27].

Tetteh-Quarcoo *et al.* [26] examined bacterial agent vulnerability patterns for numerous antibiotics. The antibiotics examined included amikacin, gentamicin, chloramphenicol, tetracycline, cotrimoxazole, ceftizoxime, ampicillin, piperacillin, cefotaxime, ciprofloxacin, ofloxacin as well as levofloxacin. It was also found that resistance to multidrug was in *K. pneumoniae*, *Citrobacter ferundii*, *P. vulgaris*, *E. cloacae,* and *E. coli*. Another drug sensitivity was done against 12 antibiotics for all the isolates obtained from cockroach specimens in Tikur Anbessa specialized hospital, Addis Ababa, Ethiopia. A Multidrug resistant pattern was observed in almost all the isolates. Resistance to ampicillin, augmentin, and amoxicillin were found to be high in the bacteria agents. In addition, resistance to Gentamicin and Trimethoprim-sulfamethoxazole was found among gut isolates as compared to external isolates (p value = 0.018 and 0.021 respectively). There was also no statistically significant difference in the proportion of resistance between body parts for the other antimicrobials. Overall, resistance to the fluoroquinolones (Norfloxacin and Ciprofloxacin) was observed to be lower. It was lower for Norfloxacin than Ciprofloxacin. Cefotaxime and Ceftriaxone resistance was high for all the isolates. However, it was lower for penicillin. The most frequent pattern of resistance was to all the 12 tested antimicrobials [28].

Carbapenems and aminoglycosides were found to be active against 100% of the Gram-negative bacilli isolated from *Periplaneta americana* and *Musca domestica* in Tangier, Morocco. *Staphylococcus* spp. strains were vulnerable to linezolid, vancomycin, daptomycin, levofloxacin, and cotrimoxazole but no antibiotic resistance was found in *Enterococcus* spp [30]. In a different study, multiple resistance to 6 different antibiotics was commonly observed among the enteric bacteria isolated from the hospital cockroaches than among those from the household. Overall, more than 30% of the isolates of *Enterobacteria* recovered were each resistant to 4 antimicrobial agents. Moreover, 95% of the *Pseudomonas* isolates were each resistant to at least 8 antimicrobial agents [33]. Antibiotic resistance was also reported for *Staphylococcus aureus, Enterococcus spp., P. aeruginosa, K. pneumoniae, E. coli, S. marcescens,* and *Proteus* spp. isolated from cockroaches [34].

Some strains were resistant to antibacterial drugs broadly used for the treatment of patients. Gram-negative rods were resistant to amoxicillin/clavulanic acid. *Pseudomonas* spp. additionally resistant to co-trimoxasole. Strains of *S. equorum* and *Staphylococcus hominis* were methicillin-resistant. *Staphylococcus epidermidis* showed macrolide, licosamide, and streptogamin B (MLSB) mechanisms of resistance [35]. The results of this review reflect a high likelihood that cockroaches can act as an important carrier for a variety of disease-causing bacteria which are resistant to a wide range of drugs.

Conclusions

The significance of cockroaches is much greater than generally comprehended as they have been reported to harbor diverse bacterial agents which may be pathogenic. For instance, *Aeromonas* spp. causes wound, diarrhea, and other infections; *Alcaligenes faecalis* causes of gastroenteritis, and urinary tract infections; *Bacillus cerreus* causes food poisoning, *B. subtilis* causes conjunctivitis; *Campylobacter jejuni* causes enteritis; *Clostridium perfringens* causes food poisoning and gas gangrene. *Enterobacter* spp. causes bacteremia*; Enterococcus* spp. causes urinary tract and wound infections; *E. coli* causes diarrhea; *Klebsiella* spp. causes pneumonia and urinary tract infections; *Mycobacterium leprae* causes leprosy and *Morganella morganii* would cause wound infections [36]. Whereas most are found to be anti-drug resistant, antibiotic resistance is considered the greatest threat to public health in the current period. Therefore, cockroach

infestation should be considered a serious concern, given the possible role of cockroaches as reservoirs of antibiotic-resistant bacteria. The researchers and general community could benefit from a review of existing research information which can provide a comprehensive understanding of the role of cockroaches in the transmission of human infections.

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Authors' Contributions

All authors have significantly contributed to the work reported in the article. MLM was responsible for collecting data, and writing the initial and final manuscript. TGB and NN assisted with technical aspects, reviewing, and editing the final article.

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