Review

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Presence of Major Bacterial Foodborne Pathogens in the Domestic Environment and Hygienic Status of Food Cleaning Utensils: A Comprehensive Review

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Presence of Major Bacterial Foodborne Pathogens in the Domestic Environment and Hygienic Status of Food Cleaning Utensils: A Comprehensive Review

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Abstract

Maintaining an appropriate level of food hygiene is crucial in assuring food safety and preventing foodborne illnesses, although the importance of food hygiene is often neglected in the household kitchen setting. Adherence to good hygienic practices (GMPs) in the domestic environment is equally important as the implementation of GMPs to any other food preparation environment, like the one encountered in the food industry. The current review encompasses research data on prevalence and isolation of major foodborne pathogenic bacteria (*Salmonella*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli* pathotypes, *Campylobacter*) from household kitchen equipment, with a special emphasis on the comparative hygienic status of food cleaning utensils used in home kitchens, such as sponges, brushes, kitchen dishcloths and hand towels. The bacterial pathogen most commonly found in the domestic environment is *S. aureus*, which can be transmitted through hand-to-mouth route via direct contact with the contaminated kitchen surface and/or cleaning utensils or indirectly through the consumption of contaminated food due to cross-contamination incidences during preparation of food (e.g., portioning of ready-to-eat meat in the same cutting board surface and with same knife used previously for cutting fresh leafy salad vegetables). Moreover, research findings on the hygiene of food cleaning utensils clearly demonstrate that (i) sponges present the highest microbial load compared to all other cleaning utensils, (ii) kitchen dishcloths and hand towels are frequently used multiple times for more than one uses (e.g., hand drying and cleaning/removing excess humidity from the dishes at the same time), contributing in that way to cross-contamination, (ii) brushes are more hygienic than sponges and safer for cleaning kitchen cutlery and utensils.

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1. Introduction

Foodborne diseases represent a major global public health challenge, contributing to substantial morbidity, mortality and socioeconomic losses worldwide [1,2]. According to the World Health Organization (WHO), an estimated 600 million people suffer from foodborne illnesses annually, leading to approximately 420,000 deaths, with children under five years of age disproportionately affected [3] (p. 72). The most recent assessment by the WHO Foodborne Disease Burden Epidemiology Reference Group (FERG), further highlights that foodborne diseases remain pervasive globally, accounting for millions of disability-adjusted life years (DALYs) and continuing to pose a considerable strain on public health systems [4]. In the United States, the Centers for Disease Control and Prevention (CDC) have recently updated their 2011 estimates [5], reporting that six major pathogens (Norovirus, *Campylobacter* spp., *Salmonella* spp., *Clostridium perfringens*, Shiga toxinproducing *Escherichia coli*; STEC, *Listeria monocytogenes*) were responsible for millions of illnesses annually, including hospitalizations and deaths, stressing the persistent burden of foodborne disease even in settings with advanced surveillance capacity and food safety infrastructures [6]. International organizations including the Food and Agriculture Organization (FAO) and WHO of the United Nations (UN), state that foodborne disease is not confined to acute gastrointestinal illness but also has long-term consequences, such as malnutrition, developmental impairments and increased vulnerability to other infections [7]. To this end, the Codex Alimentarius Commission (CAC) has long emphasized towards the necessity of fostering a proactive character in hygiene practices followed from primary production through to final consumption, thus preventing cross-contamination at any stage during food manufacturing/production or food preparation. In its basic texts for food hygiene, CAC has adopted this approach by highlighting among others the importance of interventions at the consumer-level to minimize the risks for consumers of contracting foodborne diseases [8].

While much attention has been directed toward improving safety standards in food processing and retail, the domestic kitchen remains an overwhelmingly critical but often overlooked environment in the food chain [9–12]. Pathogens of global concern include *Salmonella* spp., *Campylobacter* spp., *E. coli* O157:H7, *L. monocytogenes*, and *Staphylococcus aureus*, all of which are commonly detected in domestic settings [3,13–15]. Studies increasingly recognize the home as a high-risk environment, where unsafe consumer behaviors and contaminated equipment contribute to the persistence and spread of foodborne pathogens [13,16]. Cross-contamination within kitchens, involving both food-contact and non-food-contact surfaces, has been identified as one of the most important routes of pathogen transmission to ready-to-eat (RTE) foods [17,18].

The microbial ecology of domestic kitchens is characterized by diversity, persistence and adaptability of microorganisms. High-throughput sequencing techniques have revealed a complex bacterial community inhabiting kitchen surface, utensils and cleaning tools, reflecting frequent interactions between humans, food and the surrounding environment [19,20]. Importantly, pathogenic bacteria like *Salmonella* spp., *L. monocytogenes* and *S. aureus* have been shown to persist in these environments due to their ability to survive desiccation, attach to surfaces and form biofilms [21–23]. These adaptive mechanisms reduce the efficacy of routine household cleaning and disinfection, enabling pathogens to persist in abiotic surfaces (e.g., cutting boards, sink drains, dish sponges) [24,25].

The persistence of foodborne pathogens in domestic environments also highlights the problem of risk perception among consumers; while many individuals express awareness of foodborne risks, there is often a disconnect between knowledge and observed behavior [26]. Observational and survey-based studies reveal that poor hygiene practices are widespread, including inadequate handwashing, improper separation of raw and RTE foods, and reliance on visual cleanliness as a proxy for hygiene [27–29]. For example, sponges and dishcloths are frequently reused across multiple cleaning tasks, inadvertently spreading bacteria between food-contact surfaces and utensils [30–32]. Similarly, improper storage practices in domestic refrigerators, such as overloading of shelves with food products, infrequent cleaning and operation at non-recommended temperatures, have been strongly linked to the persistence of *L. monocytogenes* and other psychrotrophic and psychrophilic pathogens [33–35].

Furthermore, the domestic kitchen has been increasingly recognized as a potential reservoir for antimicrobial resistance (AMR). Several studies have detected antibiotic-resistant bacteria and resistance genes in household refrigerators, sponges and surfaces, raising concerns about the contribution of domestic environments to the dissemination of AMR [36–38]. This emerging dimension adds complexity to foodborne risk management, linking household hygiene practices to broader antimicrobial stewardship initiatives [39].

Taken together, the domestic kitchen is not merely a passive setting for food preparation but rather an active “arena” in the transmission of foodborne pathogens. The persistence of bacteria in household equipment, coupled with unsafe consumer practices, creates a conducive environment prone to contamination and cross-infections [40,41]. While substantial progress has been made in improving food safety across production and retail sectors, the home preparation environment remains the final and often weakest link in the food chain [9,42], where the need for consumer-level interventions into broader food safety strategies, behavioral change, household hygiene, and innovations in kitchen equipment and design is always present [43,44].

This review, therefore, examines bacterial foodborne pathogens prevalent in the domestic environment, the household kitchen equipment that harbors them, and the implications of these findings for public health by synthesizing evidence from microbiology, epidemiology, and consumer behavior.

2. Bacterial Foodborne Pathogens Prevalent in the Domestic Environment

Domestic kitchens comprise the reservoirs for not only well-known foodborne pathogenic bacteria, but also of emerging and opportunistic bacteria [18,19], as shown in Table 1. Bacterial persistence and resistance profiles suggest that household environments may contribute to the spread of AMR, further complicating food safety management at the consumer level [37,38].

Table 1. Major bacterial foodborne pathogens in domestic kitchens: sources, reservoirs, and consumer-related risk factors for pathogen transmission.

Pathogen	Domestic reservoirs	Transmission routes	Main consumer behaviors	References
Campylobacter spp.	Raw poultry and meat products	Cutting boards, countertops, sinks, knives, cooking salt	Washing poultry in sinks, cross-use of utensils, poor hand hygiene	[14,15,45–47]
E. coli pathotypes	Raw meat, fresh produce, salads irrigated with sewage water	Sponges, dishcloths, cutting boards, countertops	Inadequate washing of vegetables, reuse of sponges/dishcloths, poor surface sanitation	[13,25,31,48]
L. monocytogenes	Ready-to-eat foods, dairy, raw vegetables	Refrigerators, cutting boards, countertops, sinks	Improper refrigeration temperatures, prolonged food storage, poor refrigerator cleaning	[33,49–52]
Salmonella spp.	Poultry, eggs, raw meat	Cutting boards, dishcloths, sponges, refrigerators	Insufficient cooking, poor disinfection of utensils, inadequate refrigerator cleaning, cross-contamination between raw and ready-to-eat foods	[13,17,34,53,54]
S. aureus	Human carriers,	Sponges, dishcloths,	Direct contamination from handlers, reuse	[30,41,55–57]

	contaminated foods	refrigerators, countertops	of cloths, poor refrigerator hygiene	
Other bacteria (*Cronobacter* spp., *Arcobacter* spp., *Acinetobacter* spp.)	Powdered infant formula, poultry, food/water	Kitchen surfaces, utensils, refrigerators	Contamination from emerging pathogens, antimicrobial resistance spread, improper cleaning	[37,58–60]

2.1. *Campylobacter spp.*

Campylobacter spp. is among the leading causes of bacterial foodborne illness and have been frequently implicated in contamination events in domestic environments. Surveys have shown that raw poultry is a primary reservoir and cross-contamination during handling and preparation in household kitchens plays a crucial role in the pathogenic species transmission [15,45]. The bacteria are capable of transferring from raw chicken to hands, utensils, cutting boards and other surfaces, or even cooking salt used for seasoning, thereby contaminating RTE foods prepared in the same environment [14,47]. Contraindicated consumer practices, such as washing raw poultry meat in the kitchen sink or using the same utensils for raw and cooked RTE food without proper sanitation (i.e., cleaning and disinfection) of the latter, have been identified as significant contributors to cross-contamination incidences [46,61].

Temperature management is another important factor that must be given consideration in control of campylobacters. Even if refrigeration significantly retards bacterial growth, nevertheless it does not eliminate *Campylobacter* spp. which can persist in cold storage and contribute to the risk of infection when cross-contamination occurs [43,62]. Furthermore, research indicates that consumer knowledge of proper handling is often insufficient to prevent contamination events [32,63].

2.2. *Escherichia coli Pathotypes*

E. coli is a diverse bacterial species with several pathogenic phenotypes implicated in foodborne diseases. The most prominent are STECs, with enterohemorrhagic *E. coli* serotype O157:H7 being well-recognized for causing a serious blood disorder (hemolytic uremic syndrome), leading to kidney failure. Other syndromes manifested by *E. coli* pathotypes include urinary tract infections, different forms of diarrhea (e.g., bloody, watery, traveler's diarrhea), and systemic infections (e.g., sepsis, meningitis), depending on the *E. coli* strain and location of the infection [64]. Cross-contamination in domestic kitchens has been identified as a major transmission pathway for these bacterial strains [48,65,66].

Research demonstrates that pathogenic *E. coli* O157:H7 can be transferred from contaminated vegetables and raw meats to kitchen surfaces, sponges, and cloths, where it can persist for extended periods [25,31]. Practices such as reusing kitchen sponges and dishcloths for multiple tasks, contribute additionally to the persistence of *E. coli* in home kitchens [30,67]. The presence of antibiotic-resistant *E. coli* in frozen foods further complicates the issue, raising public health concerns regarding resistant strains in household environments [36]. The risks pose by *E. coli* presence in the domestic environment further enlarge the importance of safe handling, adequate cleaning and disinfection of utensils and surfaces, and consumer awareness for cross-contamination pathways in food preparation at home [11,13].

2.3. *Salmonella spp.*

Salmonella spp. represents one of the most significant bacterial pathogens associated with foodborne outbreaks and have been repeatedly isolated from domestic environments [13,15]. Poultry, eggs, and raw meat products are common reservoirs of salmonellae and handling these products in kitchens introduces substantial risks [68,69]. Studies have documented the persistence of *Salmonella* on cutting boards, dishcloths, and sponges, with evidence of recurrent cross-contamination events from raw to RTE food products [17,57].

Poor consumer practices, for instance improper sanitation of utensils and inadequate cooking, exacerbate risk of salmonellosis in home [70,71]. Besides, as it is already known refrigeration does not eliminate *Salmonella*, resulting to domestic refrigerators contaminated with the pathogen [54,72]. Field surveys also demonstrate that *Salmonella* biofilms can form on surfaces, enhancing persistence and complicating any control efforts in the domestic setting [22,73].

2.4. Staphylococcus aureus

S. aureus represents part of the natural microbiota encountered in the human skin and body cavities of people. Hence, *S. aureus* is the most prevalent bacterial species in domestic environments [34,74], due to the usual direct hand contact of food surfaces, equipment and utensils occurring in homes, whereas it is a major pathogen of concern because of its ability to produce enterotoxins responsible for food poisoning incidents [55,75]. Different studies have shown that coagulase positive staphylococci and *S. aureus* can persist on surfaces, dishcloths, sponges, and within refrigerators, with isolates often carrying genes associated with toxin production [23,56,57].

Cross-contamination occurs both directly, through contact with contaminated surfaces, and indirectly, via human carriers who frequently transfer *S. aureus* through hand contact during food preparation [41,76]. The ability of the pathogen to form biofilms further increases its persistence and survivability on domestic surfaces and utensils [77,78]. In addition, studies indicate that poor household cleaning practices are insufficient to eliminate *S. aureus*, particularly when sponges and dishcloths are reused without prior disinfection [30,32].

2.5. Listeria monocytogenes

L. monocytogenes is a psychrotrophic pathogen capable of surviving and multiplying at refrigeration temperatures. The organism is rather prevalent in domestic kitchens. In that context, several studies have documented for many years the presence of *Listeria* spp. and *L. monocytogenes* in domestic refrigerators, demonstrating widespread contamination in consumer households [49,50,52]. Temperature fluctuations and inadequate cleaning of refrigerators contribute significantly to pathogen's persistence [33,51].

The microorganism's ability to form biofilms allows for pathogenic *Listeria* spp. to colonize refrigerator surfaces, cutting boards, and countertops, where they can persist despite any cleaning attempts [21,80,81]. *L. monocytogenes* presence in RTE products further amplifies the risks in domestic environments [81,82]. Vulnerable populations such as the elderly and immunocompromised are especially at risk, as improper domestic practices may result in listeriosis outbreaks [83,84].

2.6. Other Bacterial Pathogens

In addition to the major pathogens, several other bacterial genera have been identified in domestic environments. Although more commonly associated with powdered infant formula, Arslan & Ertürk [58] have recovered *Cronobacter* spp. from a variety of RTE foods. Thence, the possibility of detecting strains of the pathogen in the home kitchen setting should not be disregarded. *Arcobacter* spp. are considered emerging pathogens and have been linked to poultry products and thus they may contaminate household environments during preparation of poultry meat [60,85]. Finally, *Acinetobacter* spp. are opportunistic bacteria with antimicrobial resistant potential that have been isolated from food and water [59], further promoting the microbial diversity capacity encountered in home kitchens.

3. Household Kitchen Equipment that Harbors Foodborne Pathogenic Bacteria

The major bacterial foodborne pathogens in descending order of prevalence, most commonly isolated from household kitchens, are *S. aureus*, *Salmonella* spp., and STECs. Other notable pathogens detected in the domestic environment include *Campylobacter* spp. and *L. monocytogenes*. These bacteria can contaminate various kitchen surfaces, including sinks, countertops, and cutting boards, posing a risk for cross-contamination and foodborne illness (Table 2).

Table 2. Household kitchen equipment harboring microbial foodborne pathogens and the associated consumer-related risk factors for pathogen transmission.

Kitchen equipment	Associated pathogens	Reservoir characteristics	Main consumer behaviors	References
Countertops & kitchen surfaces	*Salmonella* spp., *L. monocytogenes*, *S. aureus*	Support biofilm formation, resistant to desiccation	Wiped with contaminated cloths/sponges, reliance on visual cleanliness instead of microbial hygiene	[15,22,45,46]
Cutting boards	*Campylobacter* spp., *Salmonella* spp., *E. coli* pathotypes, *L. monocytogenes*	Cracks and knife scars, porous materials allow bacterial attachment and persistence	Inadequate cleaning between raw and ready-to-eat foods, cross-use of same board for meat and vegetables	[15,17,31,86]
Dishcloths & hand towels	*S. aureus*, *E. coli* pathotypes, *Salmonella* spp.	High bacterial load from repeated use, slow drying promotes survival	Used for drying hands, wiping surfaces, and cleaning utensils without adequate laundering	[30,32,87–89]
Knives & small utensils	*Campylobacter* spp., *Salmonella* spp., *E. coli* pathotypes	Direct contact with raw meat and produce	Inadequate cleaning between uses, sharing knives for raw and ready-to-eat foods	[63,89]
Refrigerators	*L. monocytogenes*, *Salmonella* spp., *S. aureus*	Poor temperature control, long-term storage, biofilm formation on shelves	Operating above recommended temperatures, infrequent cleaning, raw–ready-to-eat food contact	[33,35,41,49,50]

Sponges	*E. coli* pathotypes, *Salmonella* spp., *S. aureus*, diverse microbiota	Moist, porous structure supports microbial growth and biofilm formation	Frequent reuse, lack of disinfection, multiple-task usage (dishes, counters, hands)	[24,25,90,91]
Sinks & faucets	*Campylobacter* spp., *Salmonella* spp., *L. monocytogenes*	Drain areas and faucets harbor biofilms; splash dispersal spreads contamination	Washing raw poultry in sink, poor faucet hygiene, infrequent disinfection	[33,35,41,49,50]

Past and current research has demonstrated that a plethora of environmental conditions (e.g., microorganism species, surface moisture, contact surface type, surface material composition) influence bacterial survival and inactivation on kitchen equipment. Wooden surfaces may absorb and retain pathogens, resulting generally in less recoveries compared to surfaces made of plastic or stainless steel [92,93]. However, pathogens may remain viable on dry stainless-steel surfaces and comprise a contamination hazard for considerable period of time, dependent on the contamination levels and microorganism species [31,94]. Novel surface modifications are being investigated nowadays for their potential to reduce microbial contamination [95–99].

3.1. Cutting Boards

Cutting boards are one of the most frequently reported kitchen items involved in bacterial cross-contamination incidents. Studies have consistently revealed that raw poultry, fresh or frozen meat and fresh-cut produce prepared on cutting board surfaces can introduce, on the board and then in food, pathogenic bacteria like *Salmonella* spp., *Campylobacter* spp., and *E. coli* pathotypes [15,31,100–103]. The porous nature of wooden board and the presence of extensive cracks and knife scars on plastic cutting boards, relevant to the use status of the board, provide space for bacterial attachment and biofilm formation, reducing in that way the efficacy of routine cleaning and disinfection procedures [86,104]. The suitability of wood against plastic, recommended as the appropriate material for crafting cutting boards for food preparation, has long been debated, primarily due to hygienic concerns related to the porous structure and hygroscopic nature of wood. Research suggests that wooden cutting boards from certain hardwoods (white ash, black cherry, red oak, sugar maple wood) possess bactericidal properties leading to reduced microbial loads compared to plastic cutting boards [105,106]. Besides, research findings indicate that inadequate sanitation between uses can allow persistence of microbial pathogens onto cutting boards and subsequent transfer to RTE foods, highlighting the latter as major contamination sources in household kitchens [13,17].

3.2. Kitchen Countertops and Other Surfaces

Countertops and surrounding surfaces play a central role in domestic food preparation and are frequently contaminated by raw food residues and cleaning tools as well. Bacterial survival on these surfaces is enhanced by biofilm formation and resistance to desiccation [21,22]. Research has shown that *Salmonella* spp., *L. monocytogenes*, and *S. aureus* can survive for extended periods on kitchen surfaces, posing risks when these areas are used for preparing RTE foods [10,12,15]. Visual cleanliness has been assessed as a poor indicator of microbial contamination [29], whereas the frequent use of

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dishcloths and sponges to wipe countertops increases contamination levels, often redistributing bacteria rather than mechanically removing them [25,30].

3.3. Kitchen Sink and Faucet

The sink and faucet in the kitchen are high-risk areas due to their frequent contact with raw food products, dishwashing water, contaminated hands and utensils. In several studies, sinks have been identified as reservoirs for *Salmonella* spp., *Campylobacter* spp., and *L. monocytogenes*, particularly when raw poultry meat is washed prior to cooking [15,45]. Studies have also revealed that washing raw poultry directly in the sink results in extensive contamination of surrounding surfaces because of the splash dispersal of microbial droplets [46]. Faucets and drainage areas harbor biofilms that protect microbial pathogens against common cleaning and disinfection practices, contributing to their persistence and recontamination capacity [22,104].

3.4. Domestic Refrigerators

Given its psychrotrophic character, the bacterial pathogen reportedly found in domestic refrigerators is *L. monocytogenes*. The manifestation of the disease caused by this microorganism (listeriosis) confers serious complications (e.g., meningitis, sepsis) to human health or even death at a later stage. Other pathogens like *S. aureus* and various coliforms are also frequently isolated from domestic refrigerators.

Although the scope of domestic refrigerators is food preservation by controlling microbial growth and preventing food spoilage, numerous studies have reported microbial harborage of pathogens in the refrigerators due to inadequate refrigeration temperatures, poor hygienic status of the refrigerators itself and cross-contamination between raw and RTE stored foods [49,50,52]. Investigations in Europe and elsewhere have revealed that a significant proportion of household refrigerators operates above the recommended temperatures, allowing for an increased microbial growth rate, especially for psychrotrophic pathogens like *L. monocytogenes* [23,33–35]. Contamination by *Salmonella* spp. and *S. aureus* has also been documented, often associated with poor cleaning of the refrigerator and direct contact of raw with RTE food inside the refrigerator [41,54,74].

As foods are often stored for prolonged periods and domestic refrigerators are rarely cleaned thoroughly or frequently, this further highlights the hygiene and safety issues that exist with the latter [107,108]. Additionally, resistant bacteria and antibiotic resistance genes have been isolated and detected in domestic refrigerators, highlighting their role as overlooked reservoirs with broader public health implications [37,38].

3.5. Food Cleaning Utensils

Food cleaning utensils include sponges, dishcloths, hand towels, and brushes, all of which have consistently been identified as the most contaminated items in household kitchens. Sponges in particular harbor dense and diverse microbial communities, among others *E. coli*, *S. aureus*, and *Salmonella* spp. [90,91]. Their porous structure, constant exposure to moisture and storage under increased humidity, as well as nutrient residues absorbed on them, create an ideal environment for bacterial growth and persistence [24,25]. Sponges are more unhygienic than brushes due to the faster drying and reduced bacterial survival in brushes [32]. When it comes to the hygiene of sponges though, the use of polyurethane compared to cellulose sponges seems to have a better effect on reducing exposure to enterobacteria in the kitchen [109].

Dishcloths and hand towels also contribute significantly to cross-contamination, as their repeated use for drying hands, wiping surfaces and cleaning dishes, allows pathogens to spread widely across the kitchen [30,67,87]. Studies demonstrate that bacterial levels on dishcloths and towels increase significantly with prolonged use and inadequate laundering [88,89,91]. Although disinfection methods such as microwaving or chemical cleaning can reduce microbial loads, inconsistent consumer adoption of these practices limits their effectiveness [111,112].

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3.6. Other Kitchen Appliances and Utensils

Communal kitchen environments have shown high levels of microbial contamination on shared appliances, pointing out risks in multi-user settings [113,114]. Additionally, knives, forks, blenders, bowls and other utensils that come into direct contact with raw food have also been identified as potential vectors of cross-contamination when not adequately cleaned [63,90].

4. Discussion

Food hygiene is the cornerstone of food safety. Maintaining an appropriate level of food hygiene in terms of controlling cross-contamination in the food preparation environment is of paramount importance in assuring food safety. The present review demonstrates how the domestic kitchen environment can contribute to the development of persistence and the transmission of bacterial foodborne pathogens, with implication that extend far beyond individual households and signify broader public health outcomes. In scientific literature *Salmonella* spp., *Campylobacter* spp., coliform strains (e.g., *E. coli* O57:H7), *L. monocytogenes*, and *S. aureus* are repeatedly reported and consistently emerge as the most prevalent bacterial pathogens detected in domestic kitchens [13–15]. Their ability to withstand and survive adverse environmental conditions under variable household practices (e.g., refrigeration of foods, mild or no disinfection of surfaces), underlines the importance of recognizing the domestic setting as an integral part of the food safety chain [11,12].

One of the most consistent themes across studies is the role of consumer behavior in shaping microbiological risks. Practices such as washing raw poultry under running water in kitchen sinks, reusing sponges and dishcloths for multiple purposes, create favorable conditions for cross-contamination to occur [30,46,63]. Even when consumers express awareness of hygiene risks, observed behavior in domestic kitchen often contradicts stated knowledge, pointing to a gap between food safety awareness and its practical application [26,28]. Interventions that target consumer practices, including educational campaigns and behavior-focused strategies, have shown potential for minimizing identified hygiene risks, however the adoption of such interventions remains limited [115,116].

Another key issue highlighted herein is the persistence of pathogens in household equipment and kitchen appliances. Food cleaning utensils repeatedly appear as the most contaminated items, harboring diverse microbial populations; bacterial pathogens and food spoilage organisms among others [44,91,92]. The structural properties of those cleaning utensils and their frequent humid storage and use, as well as their organic load from food residue, allow bacteria to thrive, with sponges showing particularly high microbial loads when compared to brushes or towels [32,110]. Similarly, refrigerators have been identified as hotspots for contamination due to inadequate temperature control and poor cleaning frequency [34,49,108]. Studies indicate that refrigerators frequently operate above recommended storage temperatures, enabling the survival and even growth of psychrotrophic microbial pathogens [33,51,117–120].

The capacity of foodborne pathogens to persist in the home kitchen environment is closely related to their adaptive mechanisms, which include biofilm formation and resistance to sanitizers, among others. Biofilm-associated persistence has been documented for *L. monocytogenes, Salmonella* spp. and *S. aureus*, making it difficult to eradicate these pathogens from household surfaces and utensils [21,78,80]. The frequent detection of microbial pathogens in cleaning tools, despite regular consumer washing of these tools, supports the importance of biofilm-mediated persistence [24,25]. Chmielewski & Frank [21] described how microbial pathogens attach to a variety of food-contact surfaces, form complex biofilm structures and thereby gain protection from chemical and physical removal, which explains why biofilm-associated cells often persist at the expense of the more easily inactivated planktonic cells. In the case of *L. monocytogenes*, Norwood & Gilmour [121] observed robust biofilm formation on food contact surfaces, while Pan et al. [122] demonstrated that food-derived listerial strains readily establish biofilms that enhanced their resistance to cleaning and disinfection procedures. Rodríguez et al. [123] confirmed that *Listeria* biofilms displayed significant

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tolerance to disinfectants that are routinely applied in industrial sanitation protocols, regardless of surface roughness and stainless steel finish, whereas Ferreira et al. [80] further demonstrated that persistent isolates frequently possessed enhanced biofilm-forming abilities, allowing them to survive through repeated sanitation cycles and contribute to recurring contamination events. Most importantly, in alignment with previous data regarding interstrain variation in adherence [121], Borucki et al. [124] emphasized to the fact that the biofilm-forming ability in *L. monocytogenes* varied by genetic lineage, indicating that *Listeria* lineage II possess markedly greater adhesion capacity for surface colonization than other lineages, a genetic trait linked directly to the long-term persistence of *L. monocytogenes* strains of serotypes 1/2a and 1/2c (PCR-serogroups IIa and IIc) in food processing facilities. The biofilm-forming ability of *S. aureus* also represents an important persistence mechanism for the microorganism. Miao et al. et al. [78] examined the stages of *S. aureus* biofilm development and described how biofilm-embedded cells displayed increased resistance to disinfectants and environmental stressors compared to their planktonic counterparts, hindering eradication efforts and facilitating survival on food-contact materials and domestic utensils. Smyth et al. [56] provided further evidence by identifying *S. aureus* isolates from Irish domestic refrigerators that not only carried novel enterotoxin genes but also exhibited clonal biofilm-forming capacity, linking virulence with persistence in household environments. For *Salmonella* spp., Lianou & Koutsoumanis [125] demonstrated strain variability on the biofilm-forming ability of *Salmonella* which was affected by three environmental parameters tested (pH, cell concentration, temperature), while Shi & Zhu [126] reported that *Salmonella* and *E. coli* biofilms formed on biotic and abiotic surfaces were more resistant to antimicrobials and environmental stressors than planktonic cells, underpinning the protective effect of biofilm matrices on pathogen survivability. Mattick et al. [25] showed that during dishwashing practices taking place, pathogens transferred to sponges and kitchen surfaces were able to persist irrespective of the repeated character of cleaning, with biofilm formation likely enabling survival under conditions where non-adherent cells would otherwise be eliminated. Likewise, Kusumaningrum et al. [24] found that foodborne pathogens inoculated into domestic sponges survived exposure to antibacterial dishwashing liquid and co-existed with competitive microbiota, suggesting that biofilm structures facilitated in the maintenance of diverse microbial populations under antimicrobial pressure. The aforementioned findings echo the conclusions of Ferreira et al. [80] that once biofilms are established in the food-associated environment, conventional cleaning measures applied fail to achieve full eradication. These findings are mirrored in studies on chlorine-based treatments. Singh et al. [127] evaluated peracetic acid, a chlorine-derived agent, on fresh produce surfaces and proved that while effective in reducing microbial loads, pathogens such as *Salmonella* and *L. monocytogenes* could persist under certain conditions, hence limiting the reliability of chlorine disinfection. Recently, Cuggino et al. [128] tested chlorine and peroxyacetic acid washes on *Salmonella* cells inoculated in fresh-cut lettuce and found out that although initial reductions were achieved, surviving cells of the pathogen were capable of regrowth, demonstrating the adaptive capacity of foodborne pathogens to recover even after exposure to widely used commercial disinfectants.

An emerging concern is the role of domestic kitchen in AMR dissemination. Studies have identified antibiotic-resistant bacteria apart from foods, also in sponges, refrigerators and kitchen surfaces, indicating the potential for household environments to act as reservoirs for resistance genes [36–38]. Baek et al. [36] reported that *L. monocytogenes*, *Salmonella* and *S. aureus* isolates from frozen foods displayed significant resistance traits, with *Salmonella* exhibiting resistance to tetracycline and ampicillin, while certain *L. monocytogenes* strains were resistant to erythromycin. Extending this scope, Arslan & Ertürk [58] demonstrated that *Cronobacter* spp. from RTE foods were resistant to ampicillin, tetracycline, and cefotaxime, with β-lactamase genes detected as a genetic base for the noted resistance. Márquez et al. [69] further reported AMR to tetracycline, ampicillin, and streptomycin, for *Salmonella* strains isolated from hen eggshells, with notable correlations among the different AMRs, suggesting the existence of cross-resistance mechanisms. In the domestic environment, Smyth et al. [56] identified *S. aureus* strains isolated from refrigerators in Ireland, that were resistant to penicillin and erythromycin, while at the same time notably carried novel enterotoxin genes. Scott et al. [75] provided one of the most characteristic examples of resistance to penicillins for staphylococci, by isolating methicillin-resistant *S. aureus* (MRSA) from domestic kitchens, noticeably pointing that while some households showed no detectable contamination, others exhibited persistence MRSA strains across multiple surfaces. More recently, Soltanzadeh et al. [129] examined bacterial isolates from hospital refrigerators in Tehran, Iran, reporting resistance of *E. coli* strains to ciprofloxacin and ceftazidime, as well as resistance of *Klebsiella pneumoniae* to imipenem and cefotaxime. What is more, extended-spectrum β-lactamase (ESBL) genes were detected, confirming that these opportunistic pathogens not only resisted treatment with antibiotics, but also carried transferable resistance determinants.

The cross-contamination pathways within kitchens represent a unifying mechanism that explains much of the persistence and distribution of bacterial pathogens in the domestic environment. Cross-contamination occurs when the pathogen's microbial cells are being transferred from raw food to RTE products, surfaces or utensils, either directly or indirectly through hand contact, cloths or sponges [17,130]. Evidence suggests that the majority of contamination incidents in kitchens are preventable, provided that consumers adopt simple but consistent hygiene measures; for instance, separating raw and RTE foods, cleaning utensils between uses, maintaining adequate refrigeration [11,109].

Scientific literature also points to variability across households, with differences in contamination levels and consumer practices influenced by cultural, demographic, and socioeconomic factors. The persistence of unsafe practices across different cultural and socioeconomic contexts suggests that barriers to behavior change extend beyond knowledge deficits and may involve convenience, habit or misperceptions of risk [27,131]. Older adults, for example, have been shown to engage in riskier storage and handling practices, increasing their vulnerability to listeriosis [83,84]. Similarly, households with children or multiple family members may face greater challenges in maintaining consistent hygiene due to frequent food preparation and shared appliance use [132].

Most importantly, the domestic environment has been recognized as an overlooked but critical component of the food safety chain. While significant efforts have been invested in developing and implementing hazard analysis and critical control point (HACCP) system in the food industry, the home kitchen lacks structured monitoring mechanisms [9,42]. As a result, household-level food safety depends largely on individual consumer practices, which are often inconsistent and difficult to regulate [28,40].

The findings from this review also suggest opportunities for intervention through consumer-oriented hygiene measures. Studies demonstrate that targeted cleaning and disinfection programs, improved refrigeration temperature control and safer utensil design, can substantially reduce contamination risks in household kitchens [104,119,133]. Disinfecting sponges through microwaving, frequent replacement or replacing them with brushes, using antibacterial dishwashing liquids, and improving consumer awareness of high-risk behaviors, are all alternate promising practices contributing in the reduction of microbial loads in the kitchen environment [24,111,112]. Furthermore, ergonomic considerations including kitchen layout, equipment accessibility and surface design, may indirectly influence consumer practices and enhance food safety outcomes [100,132,134]. These interventions suggest that household kitchens can be modified to reduce microbial risks through a combination of consumer behavior change and improved equipment design.

5. Conclusions

The existing literature reviewed herein underscores the importance of the domestic kitchen as a key, nonetheless underestimated, environment in the epidemiology of foodborne diseases. Despite significant technological advances in food production and processing, the persistence of microbial pathogens in households continues to compromise food safety at the consumer level [10,12]. Thence, pathogens like *Salmonella* spp., *Campylobacter* spp., pathogenic *E. coli*, *S. aureus*, and *L. monocytogenes* are constantly being isolated from the domestic environment, with their survival supported by the biofilm-forming ability of the bacteria and the poor consumer hygiene practices and/or the application of inadequate food hygiene measures [13–15].

Household equipment and cleaning utensils, namely sponges, dishcloths, cutting boards, countertops, sinks, and refrigerators, represent prominent reservoirs of bacterial prevalence and cross-contamination hotspots [24,30,34]. Especially the aforementioned utensils are repeatedly identified as the most contaminated items in kitchens, harboring dense microbial populations, many times hosting bacterial pathogens such as the ones previously reported, thus serving as vectors for bacterial spread [91,92]. Specifically, sponges present the highest microbial load compared to all other cleaning utensils, while brushes are more hygienic than sponges and safer for cleaning kitchen cutlery and utensils [32]. It is also noteworthy that kitchen dishcloths and hand towels are frequently used multiple times for more than one uses (e.g., hand drying and cleaning/removing excess humidity from the dishes at the same time). Moreover, inadequate hygiene conditions and poor temperature control in domestic refrigerators have been strongly associated with the presence of *L. monocytogenes* and other bacterial pathogens in consumer households [35,49,51,135].

The repeatedly observed unsafe consumer practices of washing raw poultry in the kitchen sink, using sponges for whipping spills on the kitchen countertop, placing raw foods above RTE products in the refrigerator and storing foods at improper temperatures [23,26,28,32,104,118,135]. Besides that, the detection of antibiotic-resistant bacteria in household environments adds urgency to efforts aimed at improving food hygiene at the consumer level, as domestic kitchens may contribute to the dissemination and the horizontal transfer of resistance genes in bacteria [36–38].

Conclusively, as it was evidenced from all the above, domestic kitchens represent a major front line in the prevention of foodborne diseases. The presence of bacterial pathogens on kitchen surfaces, utensils, and equipment in addition to risky behaviors by the food consumers, indicates the need for consumer awareness and adoption of safe practices, including targeted hygiene interventions, consumer education, and improved household equipment design [116,131,132,134].

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