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Research Paper

Microbial Contamination on Kitchen Surfaces in University Student Housing: Insights from Swab Analysis and Behavioral Surveys

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ABSTRACT

Shared kitchens are potential hotspots for microbial contamination due to frequent use and poor hygiene. In student residences, these risks are heightened by diverse hygiene behaviors and limited oversight. This study aimed to evaluate microbial contamination and hygiene-related behaviors in university student residences. Thirty student households in Botucatu, Brazil, were investigated through microbiological sampling of kitchen surfaces (refrigerator, sink, dish towels, and sponge). Samples were analyzed to assess the counts of mesophilic aerobic bacteria and *Enterobacteriaceae*, and the detection of *Salmonella* spp. and *L. monocytogenes*. In addition, a structured questionnaire was applied to gather data on hygiene routines and food handling practices. Feedback sessions were held to communicate the results to each household. No samples tested positive for *Salmonella* spp. or *L. monocytogenes*. Sponges exhibited the highest levels of microbial contamination, with median counts of 8.63 log CFU/cm^2 for mesophiles and 5.72 log CFU/cm^2 for *Enterobacteriaceae*, followed by dish towels (4.11 and 3.60 log CFU/cm^2), sinks (1.27 and 0.24 log CFU/cm^2), and refrigerators (-0.25 and -0.18 log CFU/cm^2). Some associations between hygiene behaviors and microbial load were observed, including differences linked to dishwashing habits and the number of residents using the refrigerator. The descriptive trends suggest that certain behaviors, such as the frequency of dish towel sanitization and refrigerator cleaning, may influence microbial risks. These findings emphasize the importance of consistent hygiene practices in shared kitchen environments and support the development of educational and preventive strategies aimed at improving food safety among young adults living in communal housing, such as promoting proper dish towel and sponge replacement, clear cleaning responsibilities, and separation of utensils for raw and cooked foods.

Foodborne illness represents a pervasive global public health challenge, with profound implications that extend far beyond acute gastrointestinal distress (World Health Organization, 2022). These illnesses, caused by the ingestion of pathogens such as *Salmonella*, *Campylobacter*, *L. monocytogenes*, and Shiga toxin-producing *Escherichia coli*, are linked to an estimated 600 million cases and 420,000 deaths annually worldwide (Adley & Ryan, 2025; World Health Organization, 2015). From 2013 to 2022, a total of 6,523 foodborne illness outbreaks were documented in Brazil, with households accounting for 35.1% of these occurrences (Brasil, 2024). Despite this, the true incidence is likely higher, given that many individuals experience only mild symptoms and therefore do not pursue medical evaluation. The

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broad and nonspecific clinical presentation of such illnesses further contributes to challenges in both their recognition and official reporting (Arendt et al., 2013; Pires et al., 2022). Beyond the immediate health consequences, ranging from mild discomfort to severe dehydration, organ failure, and mortality, foodborne illness exerts a cascading impact on economic stability, social well-being, and healthcare systems (Manipis et al., 2022; Zanetta et al., 2022). Vulnerable populations, including children, the elderly, pregnant people, and immunocompromised individuals, face disproportionate risks of complications (Njoagwuani et al., 2023).

The home kitchen, often perceived as a safer place for food consumption, paradoxically emerges as a critical epicenter for foodborne pathogen transmission (Carstens et al., 2022; Menini et al., 2022). Foodborne illnesses in the home can result from a variety of interconnected factors involving both individual behavior and structural conditions. Inadequate hand hygiene, improper storage of perishable items, undercooking, lack of food safety awareness, and the use of contaminated utensils or cleaning tools all contribute to the risk of contamination (Kirchner et al., 2022; Mihalache et al., 2021).

Shared living spaces, such as university student residences, present unique risks due to their confluence of high-density food preparation, variable hygiene practices, and limited oversight (Hassan & El-Bagoury, 2017; Kabir et al., 2021; Miko et al., 2012). Students, often navigating independent living for the first time, may lack the knowledge or motivation to implement safe food handling practices (Halwani, 2023; Serrem et al., 2021). Compounding this, communal kitchens in dormitories are frequently characterized by inadequate cleaning schedules, shared utensils, and prolonged moisture exposure, creating ideal conditions for biofilm formation and pathogen colonization (Chuang et al., 2021; Hassan & El-Bagoury, 2017). Yet, while multiple studies highlight gaps in student food safety knowledge and practices (Azanaw et al., 2021; Chuang et al., 2021; Keczeli et al., 2024; Madilo et al., 2023; Niţescu et al., 2025; Serrem et al., 2021), few studies have empirically mapped microbial contamination patterns in these environments or correlated them with self-reported behaviors (Akomah-Abadaike & Chumu, 2023; Dawson et al., 2024; Hassan & El-Bagoury, 2017; Osaili et al., 2020). This oversight is alarming given that young adults, particularly those in transitional living arrangements, represent a demographic at heightened risk for severe foodborne illness outcomes due to factors like dietary experimentation, high stress, and irregular immune responses (Collins et al., 2020; Lueke & Assar, 2022).

Current evidence suggests that microbial hotspots in residential kitchens, including sinks, fridges, and cleaning tools, harbor complex ecosystems of bacteria, including antibiotic−resistant strains (Rutala et al., 2023; Møretrø et al., 2022; Ferrero et al., 2022). These surfaces act as reservoirs for cross-contamination, transferring pathogens to hands, utensils, and food during routine meal preparation (Ferrero et al., 2022; Menini et al., 2022). The persistence of pathogens in these niches underscores the inadequacy of reliance on visual cleanliness as a proxy for hygiene (Møretrø et al., 2022; Evans & Redmond, 2019).

This study seeks to address gaps by integrating microbiological analysis with behavioral surveys across 30 student residences in Botucatu, Brazil. By quantifying microbial loads of mesophilic aerobes, *Enterobacteriaceae* and presence of *Salmonella* spp. and *L. monocytogenes* on high-touch surfaces, sinks, refrigerators, dish towels, and sponges, we aim to elucidate contamination in understudied residential settings. Concurrently, correlating these findings with self-reported hygiene practices will provide actionable insights to prevent cross-contamination.

Materials and methods

Study design and setting. This cross-sectional study was conducted in 30 university student shared residences located in Botucatu, São Paulo, Brazil. Data collection involved both a structured questionnaire and microbiological sampling of kitchen surfaces and cleaning utensils. The survey was pre-tested with colleagues residing in student houses affiliated with the research team to ensure clarity and comprehension of the questions. To prevent bias, the residences of team members were not included in the main study. This study was submitted for ethical review on the Plataforma Brasil of the Brazilian Ministry of Health (Conselho Nacional de Saúde, Ministério da Saúde, n.d.) and registered under CAAE 57892622.1.0000.5411, with a favorable ethical opinion No. 5.382.335.

Questionnaire application. Prior to the study, the lead professor trained all team members in surface sample collection. For data collection, members of the PET (Tutorial Education Program) group were divided into small teams, each responsible for visiting and surveying a subset of the selected residences. This division enabled all data to be collected on a single day (June 13th, 2024), minimizing the risk of communication between residences that could bias responses. During each visit, group members were assigned specific roles: while some administered the questionnaire orally and recorded responses, others simultaneously collected microbiological samples from kitchen surfaces and utensils. This approach ensured efficiency and minimized disruption for residents.

The questionnaire, developed in Google Forms, comprised questions divided into two main sections: (1) identification and characterization of the residence and its inhabitants, and (2) hygiene practices and potential health risks. Identification questions included the name and assigned number of the residence, classification by gender (male, female, or mixed), details about the physical environment (number of bedrooms, bathrooms, kitchens, living rooms, presence of outdoor areas), number and age range of residents, education level, and academic courses. Hygiene-related questions addressed the presence and frequency of professional cleaning staff, main cleaning products used, frequency and methods of kitchen and utensil sanitization, separation of utensils for raw and cooked foods, food handling and cleaning routines, use of dish towels and drying racks, replacement frequency of kitchen utensils, and the presence and habits of domestic animals (Supplementary Table 1).

Microbiological sampling. Microbiological samples were collected from four points in each residence: the refrigerator interior surface, kitchen sink, dish towels, and the sponge used for dishwashing. For the refrigerator and sink, sterile swabs and a 100 cm^2 template were used to standardize the sampled area. Three swabs were collected from each surface: one for enumeration of indicator microorganisms (mesophilic aerobes and *Enterobacteriaceae* plated in duplicate), one for *Salmonella* spp. detection (swab placed in buffered peptone water), and one for *L. monocytogenes* detection (swab placed in *Listeria* enrichment broth). Dish towels and sponges were also collected in sterile plastic bags. After collection, all samples were placed in an insulated box with reusable ice packs, transported to the laboratory, and stored at 4 °C until analysis, which was completed within 12 h of sampling.

Before the analysis, sponges were aseptically divided into three parts for analysis, with the total area recorded for calculation of microbial counts. Dish towels were cut into three sections of 100 cm^2 each.

Mesophilic aerobe counts. The enumeration of mesophilic aerobes was performed using ready-to-use Petrifilm™ Aerobic Count Plates (3 M™, St. Paul, MN, USA), following the manufacturer's instructions. Prior to analysis, swabs collected from the refrigerator and sink surfaces were vigorously agitated. Kitchen sponges and dish towels samples were individually diluted in 100 mL of sterile 0.85% saline solution, using sterile flasks. Each sample was homogenized in a stomacher for approximately one minute to ensure uniform suspension. From these initial solutions, serial tenfold dilutions were prepared using sterile saline as diluent, up to 10^{-8}. Aliquots of 1.0 mL from each dilution were aseptically inoculated in the center of Petrifilm™ AC plates. After inoculation, the top film of each plate was carefully repositioned, and the inoculum was evenly distributed using the plas-

tic spreader provided by the manufacturer. The plates were left to rest for about one minute to allow the culture medium to solidify. Plates were then incubated at 35 ± 1 °C for 48 h in a horizontal position with the transparent side facing up. After incubation, all red colonies, with or without gas production, were counted. Results were expressed as colony-forming units per square centimeter (CFU/cm2) of the sample solution.

***Enterobacteriaceae* count.** The quantification of *Enterobacteriaceae* was conducted using Petrifilm™ *Enterobacteriaceae* Count Plates (EB, 3 M™, St. Paul, MN, USA), also in accordance with the manufacturer's instructions. From the aforementioned dilutions, 1.0 mL aliquots of the appropriate dilutions were aseptically inoculated in the center of Petrifilm™ EB plates. Plates were incubated at 37 ± 1 °C for 24 h positioned horizontally with the transparent side facing up. After incubation, colonies with red to pink coloration, typically associated with gas bubbles and/or precipitate halos—characteristic of *Enterobacteriaceae* activity—were counted. Results were expressed as CFU/cm^2 of the sample solution.

Detection of *Salmonella* spp. The detection of *Salmonella* spp. was carried out according to the protocol described in the Bacteriological Analytical Manual (BAM), Chapter 5 – *Salmonella* by the Food and Drug Administration (Andrews et al., 2024). Swab samples placed in buffered peptone water (BPW, Oxoid^{TM}) were incubated at 35 ± 2 °C for 24 h. Dish towels and sponge samples were placed in sterile plastic bags with 100 mL of BPW and incubated under the same conditions. After the pre-enrichment step, 0.1 mL aliquots were transferred to 10 mL of Rappaport-Vassiliadis (RV, Oxoid^{TM}) broth and incubated at 42 ± 0.2 °C for 24 h. Simultaneously, 1 mL of the pre-enrichment broth was inoculated into 10 mL of tetrathionate (TT, Oxoid^{TM}) broth and also incubated at 42 ± 0.2 °C for 24 h. After 24 h of incubation in the selective broths, aliquots from each broth (RV and TT) were streaked onto selective Xylose Lysine Deoxycholate Agar (XLD, Oxoid^{TM}) and Bismuth Sulfite Agar (BSA, Oxoid^{TM}). These plates were incubated at 35 ± 2 °C for 24 h. After this period, suspected colonies were selected for biochemical confirmation using conventional tests such as TSI (Triple Sugar Iron Agar, Oxoid^{TM}), LIA (Lysine Iron Agar, Oxoid^{TM}), urease, motility, indole, and Simmons citrate. Serological confirmation was performed using agglutination tests with polyvalent O and H antisera specific to *Salmonella* spp. (Probac^{TM}). Results were expressed qualitatively, indicating the presence or absence of *Salmonella* spp. in the analyzed samples.

Detection of *L. monocytogenes*. The detection of *L. monocytogenes* followed the methodology described by Pagotto et al. (2001). Swabs enriched in *Listeria* Enrichment Broth (LEB, Oxoid^{TM}) were incubated at 30 °C for 48 h. Sponges and dish towels were placed in sterile plastic bags containing 100 mL of LEB and incubated under the same conditions. After this period, 0.1 mL aliquots from the LEB were transferred to tubes containing 10 mL of Fraser broth (Oxoid^{TM}), which were incubated at 35 °C for another 48 h. Following this step, cultures were streaked onto Palcam (Oxoid^{TM}) and Oxford Media (Oxoid^{TM}) agar plates, both incubated at 35 °C for 24–48 h. Characteristic colonies were subjected to catalase production tests, carbohydrate fermentation (xylose, rhamnose, and mannitol), β-hemolysis production, and motility assays. Results were expressed qualitatively, indicating the presence or absence of *L. monocytogenes* in the analyzed samples.

Statistical analysis and data handling. All statistical analyses were conducted to evaluate potential associations between microbiological contamination levels (log CFU/cm^2) on household kitchen surfaces and various categorical variables related to resident behavior and household characteristics. Although some bacterial count distributions met the assumptions of normality, others did not; therefore, nonparametric statistical methods were applied consistently across all comparisons to ensure methodological robustness. For comparisons involving two independent groups (e.g., gender of the household, presence of pets, frequency of cleaning), the Wilcoxon rank-sum test was employed. In cases where the independent variable included more than two categories (e.g., number of animals or residents), the Kruskal–Wallis test was used to determine overall group differences. Pairwise group differences were assessed using the Dwass, Steel, Critchlow-Fligner (DSCF) multiple comparison test after Kruskal-Wallis. A significance level of $p < 0.05$ was adopted throughout. All microbiological data were log-transformed prior to analysis to facilitate interpretation and comparability. Additionally, associations between categorical variables from the questionnaire, such as gender of the residence, number of residents, and presence of animals, and reported hygiene behaviors were assessed using Chi-square or Fisher's exact tests, depending on expected cell counts.

Feedback sessions. Following the sample collection and analysis, a comprehensive feedback session was held with representatives from each participating student republic. The specific findings regarding microbiological contamination in refrigerators, dish towels, sponges, and kitchen surfaces were presented and thoroughly discussed. To facilitate the implementation of corrective measures, an informational pamphlet detailing best practices for hygiene and sanitation was also provided (Supplementary Document 1).

Results

A structured questionnaire was applied across 30 student residences to assess food handling routines and hygiene-related behaviors. The full distribution of responses is provided in Supplementary Table 2. Households were classified as female only in 17 (56.7%) residences and male only in 13 (43.3%) residences, with no mixed gender residences included. In 29 (96.7%) residences, at least one resident was aged 21–24 years, and in 24 (80%) residences, at least one resident was aged 17–20 years. All residences (100%) included at least one undergraduate student, and 7 (23.3%) had at least one resident who had already completed a higher education degree.

Regarding academic background, 28 (93.3%) of residences included students enrolled in agronomy, forestry, or biotechnology-related programs, and 26 (86.7%) included students in veterinary medicine or animal science. Residences also included students from medicine, nursing (26.7%), and health-related programs such as biology, nutrition, or biomedical sciences (90%).

In terms of food handling practices, all households reported daily preparation of vegetables, and 28 (93.3%) reported daily handling of raw meat. Regarding vegetable sanitization, only 6 (20%) of the residences stated that any resident used sodium hypochlorite, while 21 (70%) reported no such practice and the remaining 3 (10%) reported using vinegar. A total of 24 (80%) of households stated that no resident washed raw meat before preparation.

Regarding surface and utensil usage, 29 (96.7%) of residences reported using the same cutting board for both meat and vegetables, and only 3 (10%) reported any form of utensil separation for raw and cooked foods. In 14 (46.7%) of the households, at least one resident reported washing the cutting board between uses, while 13 (43.3%) reported not washing it, and 2 (6.7%) simply flipped it to the other side.

Cleaning routines also varied. While 27 (90%) of residences had a hired cleaner, only 20 (66.7%) reported this service being present five times per week. Dishwashing was done immediately after use in 12 (40%) of households, while 15 (50%) allowed dishes to accumulate during the day. Most households reported drying dishes with dish towels (76.7%), but only 8 (26.7%) replaced those towels weekly or more frequently. In 16 (53.3%) of the households, the dish rack was reportedly never washed, and in 8 (26.7%), the refrigerator was only cleaned when visibly dirty.

Figure 1 presents the median counts of mesophilic aerobic bacteria and *Enterobacteriaceae* (log CFU/cm^2) recovered from four kitchen surfaces across the 30 student residences. Individual counts are provided in Supplementary Table 3.

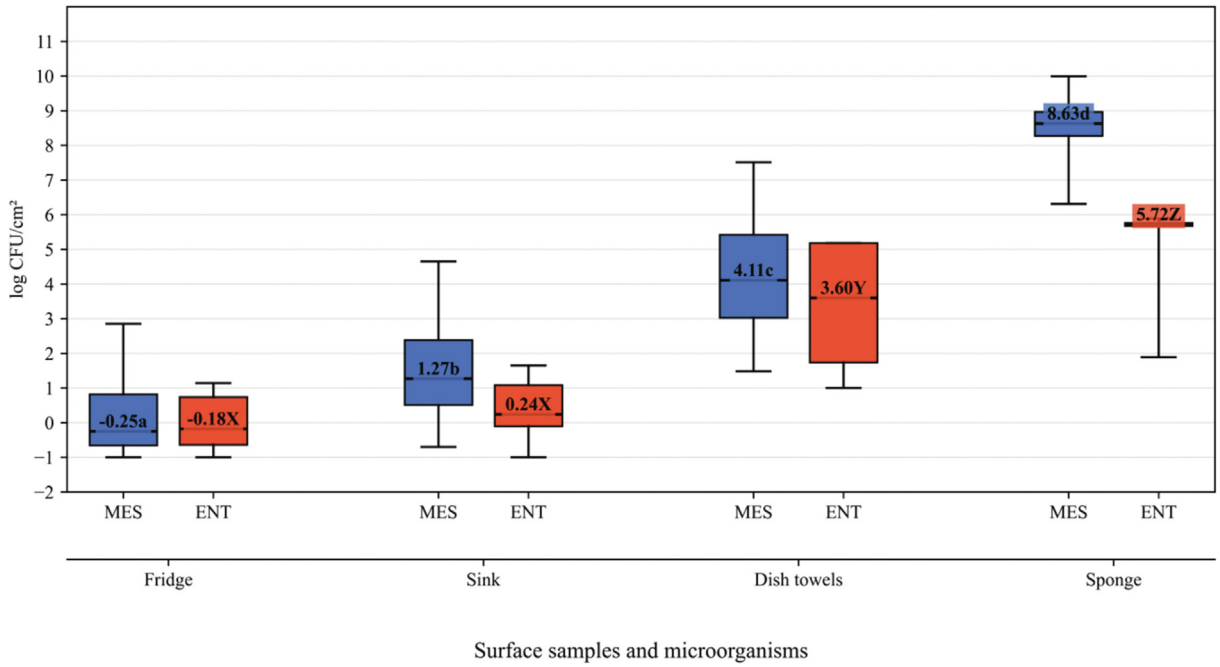

Figure 1. Box plot showing median counts of mesophilic aerobes and *Enterobacteriaceae* on kitchen surfaces in student residences (log CFU/cm^2). Negative log values indicate microbial counts below 1 CFU/cm^2 after normalization. Different lowercase letters (a, b, c, d) indicate statistically significant differences between locations (refrigerator, sink, dish towels, sponge) for MES = mesophilic aerobe counts ($p \leq 0.05$). Different uppercase letters (X, Y, Z) indicate statistically significant differences between locations for ENT = *Enterobacteriaceae* counts ($p \leq 0.05$).

Sponges exhibited the highest levels of contamination, with median values of 8.63 log CFU/cm^2 for mesophilic bacteria and 5.72 log CFU/cm^2 for *Enterobacteriaceae*. Dish towels followed, with median counts of 4.11 and 3.6 log CFU/cm^2 for mesophiles and *Enterobacteriaceae*, respectively. Lower contamination levels were observed in sinks (1.27 log CFU/cm^2 for mesophiles, 0.24 log CFU/cm^2 for *Enterobacteriaceae*) and refrigerators (-0.25 log CFU/cm^2 for mesophiles, -0.18 log CFU/cm^2 for *Enterobacteriaceae*). None of the samples tested positive for *Salmonella* spp. or *L. monocytogenes* across any of the four kitchen surfaces analyzed.

Table 1 summarizes the median bacterial counts on each surface, stratified by household characteristics. Most comparisons showed no statistically significant differences between groups. Two exceptions were observed: mesophilic aerobe counts on refrigerators were significantly lower in residences where dishes were washed immediately after use compared to those where dishwashing occurred only after accumulation ($p = 0.0028$). Additionally, a statistically significant difference in *Enterobacteriaceae* counts on sinks was detected among groups with varying numbers of refrigerator users ($p = 0.04$). However, subsequent posthoc analysis (Dwass-Steel-Critchlow-Fligner test) did not identify which specific group comparisons contributed to this result.

Across all samples and surfaces analyzed, mesophilic aerobe counts ranged from -1.0 log CFU/cm^2 to 9.99 log CFU/cm^2, while *Enterobacteriaceae* ranged from -1.0 log CFU/cm^2 to 5.89 log CFU/cm^2 (Supplementary Table 3 - **Individual counts**). Although most comparisons did not reach statistical significance, several household characteristics were associated with notable differences in median bacterial contamination. Dish towels from households with more than one animal showed higher *Enterobacteriaceae* counts (4.81 log CFU/cm^2) compared to those with one or no animals (3.1 log CFU/cm^2), a difference of 1.71 log. Similarly, households with fewer than ten residents had higher *Enterobacteriaceae* counts on dish towels (4.89 log CFU/cm^2) than those with ten or more residents (3.0 log CFU/cm^2).

Sanitization habits also appeared to influence results. Residences where dish towels were sanitized less than twice per week had higher *Enterobacteriaceae* contamination on dish towels (4.67 vs. 3.2 log CFU/cm^2) compared to those with more frequent sanitization. Additionally, households that reported cleaning the refrigerator only when visibly dirty had higher *Enterobacteriaceae* levels on that surface (1.14 log CFU/cm^2) compared to those that cleaned it monthly or more often (-0.4 log CFU/cm^2), a difference of over 1.5 log CFU/cm^2.

Another notable observation was that households without utensil separation for raw and cooked foods had lower mesophilic aerobe counts on refrigerators (-0.4 log CFU/cm^2) compared to those that did separate utensils (1.39 log CFU/cm^2), though the sample size for the latter group was small ($n = 3$).

A series of comparisons were conducted to explore associations between key household characteristics and reported hygiene behaviors. Of all the tests performed, only one reached statistical significance: households with two or more animals were significantly less likely to report frequent dish towel sanitization (Chi-square test, $p = 0.0253$). No other statistically significant associations were observed across variables such as gender of the residence, number of residents, or dishwashing behavior (all $p > 0.05$).

Discussion

Among the various behavioral and structural characteristics assessed, only two demonstrated statistically significant associations with microbial counts. First, mesophilic aerobe contamination on refrigerator surfaces was significantly lower in residences where dishes were washed immediately after use compared to those where dishwashing occurred only after accumulation ($p = 0.0028$). This finding may reflect broader hygiene behavior patterns in these households, as more frequent dishwashing could correlate with cleaner overall kitchen environments, including surfaces less directly involved in food preparation. These results underscore the importance of consis-

Table 1
Median counts (log CFU/cm^2) of mesophilic aerobes and *Enterobacteriaceae* on four household surfaces, stratified by household characteristics

Household Characteristics	Group	Fridge		Sink		Dish towel		Sponge	
		MES	ENT	MES	ENT	MES	ENT	MES	ENT
Residence gender	Male (N = 13)	−0.25	−0.18	1.48	0.40	4.11	4.52	8.73	5.7
	Female (N = 17)	−0.25	0.31	1.02	0.1	4.11	3.4	8.61	5.75
	p value	*0.96*	*0.77*	*0.85*	*0.72*	*0.4*	*0.85*	*0.74*	*0.13*
Number of residents	>=10 (N = 16)	−0.25	0.37	1.27	0.11	3.86	3.0	8.56	5.71
	<10 (N = 14)	−0.25	−0.24	1.13	0.52	4.3	4.89	8.75	5.72
	p value	*0.78*	*0.56*	*0.81*	*0.4*	*0.59*	*0.39*	*0.25*	*0.41*
Number of animals	>1 (N = 12)	−0.1	−0.18	1.48	0.52	5.11	4.81	8.63	5.7
	<=1 (N = 18)	−0.4	0.31	0.67	0.04	4.09	3.1	8.69	5.73
	p value	*0.75*	*0.77*	*0.14*	*0.28*	*0.23*	*0.51*	*0.34*	*0.25*
Animals with access to both indoors and outdoors	Yes (N = 16)	−0.1	−0.18	1.18	0.32	4.06	4.67	8.78	5.7
	No (N = 14)	−0.52	0.31	2.2	0.24	4.11	3.20	8.54	5.73
	p value	*0.1*	*0.87*	*0.55*	*0.98*	*0.45*	*0.8*	*0.1*	*0.69*
Weekly frequence of cleaning professional	>=5 (N = 20)	−0.25	−0.18	1.27	0.32	3.89	2.2	8.71	5.72
	<5 (N = 10)	−0.55	0.31	1.04	0.24	4.27	4.06	8.44	5.72
	p value	0.43	0.87	1.0	0.65	0.88	0.58	0.42	0.9
Dishwashing behavior	Dishes cleaned immediately after usage (N = 11)	−0.52	−0.4	1.61	0.2	3.67	4.09	8.61	5.73
	Dishes cleaned only after accumulation (N = 19)	0.59	0.04	1.09	0.28	4.2	3.60	8.65	5.72
	p value	*0.0028*[a]	*1.0*	*0.87*	*0.92*	*0.53*	*0.67*	*0.61*	*0.53*
Who cooks in the residence	Hired professional only (N = 15)	−0.4	−0.18	1.45	0.63	4.06	4.52	8.77	5.72
	Only students or both students and professionals (N = 15)	−0.1	0.31	0.95	0.02	4.11	3.4	8.57	5.73
	p value	*0.72*	*0.87*	*0.57*	*0.19*	*0.48*	*1.0*	*0.3*	*0.47*
Dish towel sanitization weekly frequency	>=2 (N = 15)	−0.52	−0.76	2.08	0.52	4.11	3.20	8.78	5.74
	<2 (N = 15)	−0.1	0.33	1.09	0.08	4.04	4.67	8.57	5.7
	p value	*0.31*	*0.19*	*0.38*	*0.32*	*0.9*	*0.98*	*0.18*	*0.26*
Number of fridge users	One to five (N = 6)	−0.7	−1.0	0.91	0.12	5.11	4.67	8.44	5.71
	Six to ten (N = 11)	−0.1	−0.4	1.48	1.18	4.4	4.97	8.9	5.74
	More than ten (N = 13)	−0.25	1.14	1.18	0.06	3.67	2.2	8.59	5.72
	p value	*0.54*	*0.09*	*0.63*	*0.04*[a]	*0.08*	*0.38*	*0.25*	*0.4*
Frequency of fridge cleaning	Monthly or more frequently (N = 16)	−0.4	−0.4	1.72	0.64	4.09	2.93	8.69	5.73
	Less than once a month (N = 7)	0.34	0.31	0.62	0.18	4.34	4.28	8.57	5.72
	Only when visibly dirty (N = 7)	−0.76	1.14	0.6	−0.03	4.04	4.52	8.73	5.69
	p value	*0.45*	*0.25*	*0.32*	*0.09*	*0.5*	*0.95*	*0.95*	*0.64*
Separation of utensils for raw and cooked foods	Yes (N = 3)	1.39	0.88	1.37	0.04	4.04	2.0	9.06	5.72
	No (N = 27)	−0.4	−0.46	1.11	0.28	4.11	4.06	8.59	5.72
	p value	*0.35*	*0.13*	*0.5*	*1.0*	*1.0*	*0.27*	*0.19*	*0.73*

[a] Represent *p value* with statistical significance ($p < 0.05$). Negative log values indicate microbial counts below 1 CFU/cm^2 after normalization. MES = mesophilic aerobic bacteria; ENT = *Enterobacteriaceae*.

tent hygiene routines in maintaining a cleaner and safer kitchen environment as a whole (Didier et al., 2021).

Second, *Enterobacteriaceae* counts on sinks differed significantly depending on the number of refrigerator users ($p = 0.04$). Although the posthoc comparison did not reveal which specific group drove this difference, descriptive data suggest that households with six to ten refrigerator users had higher sink contamination than those with fewer or more users. While a previous study showed that the number of people living in the household was not related to the bacterial contamination found on kitchen surfaces (Chen et al., 2011), to our knowledge, no studies report that mid-sized groups perform worse than larger ones. Our finding that moderate quantity of refrigerator users (6–10 users) exhibited the highest levels of *Enterobacteriaceae* on sink surfaces suggests a nonlinear relationship between group size and hygiene. This may reflect a threshold effect where responsibility becomes most diffused at mid-level occupancy, while larger groups develop more formal or organized cleaning routines.

In addition to these statistically significant associations, other trends emerged that, while not meeting the threshold for significance, may hold practical relevance. Notably, a meaningful trend was observed in households that reported cleaning the refrigerator only when visibly dirty, which had more than 1.5 log CFU/cm^2 higher *Enterobacteriaceae* levels on refrigerator surfaces compared to those cleaned monthly or more frequently (1.14 log CFU/cm^2 vs. −0.4 log CFU/cm^2). This suggests that reactive, visual-only cleaning strategies are insufficient to prevent microbial buildup. Since *Enterobacteriaceae* are often indicators of fecal or environmental contamination (Moen et al., 2023), their presence, even on infrequently touched surfaces like the interior of refrigerators, may signal inadequate sanitation and improper food storage practices (Kilonzo-Nthenge et al., 2008).

One of the most striking nonsignificant trends was observed in relation to the presence of animals in the household. Dish towels from residences with more than one animal showed markedly higher *Enterobacteriaceae* counts (4.81 log CFU/cm^2 vs. 3.1 log CFU/cm^2). While pets may not directly interact with dish towels, their movement through kitchen areas, shedding of hair, and potential contact with food preparation zones likely increase overall environmental microbial load (Hickman et al., 2022; Menini et al., 2022).

Similarly, the frequency of dish towel sanitization appeared to impact bacterial loads. Residences where dish towels were sanitized less than twice per week had notably higher *Enterobacteriaceae* counts (4.67 log CFU/cm^2 vs. 3.2 log log CFU/cm^2). While this difference did not reach statistical significance, a 1.5 log CFU/cm^2 difference represents an approximately 30-fold increase in bacterial burden per square centimeter, an amount that may be relevant in the context of cross-contamination, especially when dish towels are reused to clean multiple surfaces or used to dry dishes that come into direct contact with food (Kusumaningrum, 2003; Hara-Kudo & Takatori, 2011).

Among the surfaces analyzed, the refrigerator exhibited the lowest levels of microbial contamination, with median values of −0.25 log CFU/cm^2 for mesophilic aerobic bacteria and −0.18 log CFU/cm^2 for *Enterobacteriaceae*. Catellani et al. (2014) reported an average total

viable count of 1.2 log CFU/cm^2 across refrigerator surfaces in domestic settings. Similarly, Andritsos et al. (2021) found a mean count of 1.2 log CFU/cm^2 in refrigerator samples. Although our study reports slightly lower values, the overall findings are consistent in identifying refrigerators as among the least contaminated areas in household kitchens.

Contamination of the sink surface was moderate, with median counts of 1.27 log CFU/cm^2 for mesophilic bacteria and 0.24 log CFU/cm^2 for *Enterobacteriaceae*. These levels are a lot lower than those reported by Chen et al. (2011), who found average counts of 5.9 log CFU/sample for mesophilic aerobes and 4.1 log CFU/sample for *Enterobacteriaceae* on domestic sink bottoms. Although different units were used, the discrepancy still suggests comparatively lower microbial loads in the student residences examined in the present study.

Our findings on microbial contamination in domestic kitchens align with previous studies reporting that home kitchens can harbor multiple foodborne pathogens. Evans & Redmond (2019) demonstrated that older adults' kitchens showed high contamination on in-use cleaning equipment (dish brushes, sponges, and dishcloths) and hand towels, with significant correlations between contamination levels and cleaning frequency or usage duration of cleaning tools. Similarly, Borrusso & Quinlan (2017) found that 45% of domestic kitchens tested positive for at least one foodborne pathogen, including *Escherichia coli*, *Staphylococcus aureus*, *Salmonella*, *Campylobacter*, and *Listeria* spp., with contamination often associated with unsanitary conditions and inadequate cleaning materials.

In our study, although we also detected multiple foodborne bacteria on food contact surfaces, *L. monocytogenes* was not isolated from any sink samples, contrasting with the findings of Evans & Redmond and Borrusso & Quinlan. This divergence may be explained by differences in detection protocols, sample types, or population characteristics. Nonetheless, consistent with these prior studies, our results emphasize that improper hygiene and inadequate cleaning of kitchen tools and surfaces remain critical risk factors for microbial contamination in domestic kitchens.

Dish towels exhibited higher contamination than refrigerators and sinks, with median counts of 4.11 log CFU/cm^2 for mesophiles and 3.6 log CFU/cm^2 for *Enterobacteriaceae*. There was also no detection of *Salmonella* spp. and *L. monocytogenes* in our samples. These values align with findings from Hong & Lim (2015), who analyzed dish towels from 50 domestic kitchens and also reported the absence of *Salmonella* spp. and *L. monocytogenes*, consistent with our results. Similarly, Chavatte et al. (2014) also reported a high bacterial load on dish towels, with a mean total aerobic count of 7.47 log CFU/cm^2. In our study, the variation in dish towel contamination was associated with factors such as number of residents and presence of companion animals, although these differences did not reach statistical significance.

Sponges were the most heavily contaminated surfaces, with median mesophilic and *Enterobacteriaceae* counts of 8.63 log CFU/cm^2 and 5.72 log CFU/cm^2, respectively. These findings are comparable to those reported in studies conducted in both student residences and general household environments. Osaili et al. (2020), in a study of university student residences, reported mean values of 7.9 log CFU/cm^3 for mesophilic bacteria and 7.3 log CFU/cm^3 for *Enterobacteriaceae* in sponges. Similarly, Marotta et al. (2019) observed a mean value of 8.25 log CFU/g for mesophilic aerobes and 5.89 log CFU/g for *Enterobacteriaceae* in household sponges. Despite methodological differences in quantification units, all three studies consistently identify kitchen sponges as major microbial reservoirs. Additionally, *L. monocytogenes* was detected in one sponge sample in Marotta et al. (2019), whereas neither *Listeria* nor *Salmonella* spp. were found in our samples. Dawson et al. (2024), also studying student residences, reported total aerobic counts of 6.9 log CFU/25 cm^2 in sponges, lower than those observed in our study, though again unit differences and methodological factors may limit direct comparability.

It is not unexpected that the sponge was the most contaminated surface in our study, as this finding is consistent with several previous investigations (Hassan & El-Bagoury, 2017; Donofrio et al., 2012; Dawson et al., 2024; Evans & Redmond, 2019; Borrusso & Quinlan, 2017; Chen et al., 2011). This is primarily due to the frequent accumulation of food residues and organic matter during dishwashing and surface cleaning, combined with the sponge's ability to retain moisture, conditions that together promote bacterial proliferation following initial contamination (Osaili et al., 2020). Furthermore, because the sponge routinely comes into contact with various utensils and surfaces, it acts as a central agent for microbial spread within the kitchen environment (Marotta et al., 2019).

In our study, only 10% of student residences reported separating utensils used for raw and cooked food preparation, a practice that, when neglected, increases the risk of cross-contamination with major foodborne pathogens such as *Campylobacter* spp. and *Salmonella* spp. (Dang-Xuan et al., 2018; Bai et al., 2020; Cardoso et al., 2020).

A statistically significant association was found between the number of animals in the household and the reported frequency of dish towel sanitization, with residences that housed two or more animals reporting less frequent cleaning ($p = 0.0253$). While this finding may reflect lower overall hygiene awareness or cleaning capacity in more animal-intensive households, the biological plausibility of this association remains unclear. It is also possible that this result reflects residual confounding or chance, given the number of comparisons performed.

The fact that households with a hired professional did not present lower microbial counts may be related to the multifaceted role of these workers. In most cases, they are not exclusively cooks, but rather carry out a range of household tasks, including cleaning and food preparation, often without formal training in food safety. Consequently, their practices may not differ substantially from those of the students. Additionally, in households where both students and professionals share responsibilities, the effectiveness of cleaning and sanitization may depend on the combined practices of all residents rather than on the presence of a professional alone. These findings highlight the importance of food safety education and training for all individuals involved in food handling, regardless of their role.

This study has several limitations that should be acknowledged when interpreting the findings. First, although microbial sampling was standardized across residences, we did not collect information on when surfaces and utensils were last cleaned or replaced. For example, the time since the refrigerator or sink was last sanitized, or how long dish towels and sponges had been in use prior to sampling, was not assessed. These variables are likely to significantly influence microbial load and may have introduced uncontrolled variability across samples. It is also worth noting that the sterile saline solution used when preparing samples does not inactivate residual cleaning agents or surface sanitizers, meaning that microbial counts may have been underestimated where such chemicals remained present. Second, cross-study comparisons were constrained by methodological differences in literature. Many studies report bacterial counts in nonstandardized units such as log CFU/g, log CFU/mL, or log CFU/25 cm^2, whereas our data were expressed in log CFU/cm^2. These variations hinder direct quantitative comparison and may obscure true similarities or differences in contamination levels. Additionally, the microbial indicators used vary across studies, and some report total viable counts, others focus on mesophilic aerobes, coliforms, or specific pathogens, which further complicates comparative interpretation. It is important to acknowledge that this was a cross-sectional study, providing only a snapshot of hygiene practices and microbial contamination at a single point in time. Seasonal variation and academic schedules may influence behaviors, as student residences are typically occupied during the school year and cleaning habits could fluctuate depending on the period. For instance, practices might deteriorate during exam weeks when time pressures are greater or improve at the

beginning of terms when routines are being reestablished. Future longitudinal studies would be valuable to clarify how these temporal factors shape hygiene patterns in shared student housing. Lastly, while our study included 30 kitchens, other studies have analyzed up to 100 kitchens, providing more robust and statistically significant results.

Despite its limitations, this study possesses several strengths that enhance the validity and relevance of the findings. Microbiological sampling was conducted in a standardized manner across all residences, enhancing internal consistency and reliability of the collected microbiological data. The study targeted university student residences, a high-risk, high-density setting that is often overlooked in hygiene research. This fills an important gap in understanding microbial contamination of communal living spaces. The research clearly identified sponges and dish towels as the most contaminated kitchen items, providing actionable insights for hygiene interventions in shared residential environments. Although no major pathogens (*Salmonella* spp. or *L. monocytogenes*) were found, the study successfully detected high levels of mesophilic aerobic bacteria and *Enterobacteriaceae*, indicating potential hygiene risks and the presence of fecal-origin bacteria. The findings support the conclusion that basic hygiene practices may reduce microbial contamination, underscoring the value of targeted hygiene education and structured sanitation protocols for communal living environments. The study highlights methodological challenges in cross-study comparisons, drawing attention to the need for standardized reporting units and microbial indicators in microbiological research. This reflexive analysis contributes to improving research practices in the field. The sample size was adequate to detect some statistically significant and biologically meaningful trends, even if subtle associations may have been missed. This demonstrates careful analysis and interpretation within the study's scope.

Future research should aim to further investigate the relationship between specific behaviors and microbial outcomes through longitudinal designs and direct observational methods, which could help disentangle the effects of self-reported practices from actual routines. Intervention-based studies are also warranted to evaluate the effectiveness of targeted educational programs, routine cleaning protocols, and behavior-change strategies tailored to communal living environments. Additionally, exploring microbial survival and transfer dynamics on frequently used kitchen tools, such as sponges and dish towels, under real-use conditions could enhance understanding of their role in cross-contamination. The data generated by this research can support the development of evidence-based public health guidelines and hygiene education campaigns directed at student populations, who may carry these practices into future domestic or professional food handling contexts. By identifying key behavioral risk factors and patterns of contamination, this study lays the groundwork for preventive strategies that promote safer shared kitchen environments and reduce the risk of foodborne illness in this underrepresented population.

Future research with larger cohorts, more granular behavioral data, and repeated sampling over time would allow for a more robust assessment of hygiene practices and microbial risk in shared residential environments.

Conclusion

This study identified sponges and dish towels as the most contaminated kitchen items in university student residences, environments where hygiene routines are often shared and inconsistently applied. The results demonstrate that basic hygiene behaviors can be associated with reductions in microbial contamination, even when differences do not always reach statistical significance. The unique characteristics of student residences, including high-density living, communal kitchens, and ambiguous cleaning responsibility, may contribute to the microbial patterns observed. These findings highlight the need for targeted hygiene education and structured sanitation protocols in such environments. Based on our findings, we recommend incorporating practical, hands-on training modules and repeated reinforcement of safe food handling practices into the curriculum to effectively improve students' knowledge and behaviors around food safety. Future research in student residences should adopt longitudinal approaches, standardized methodologies, and include behavioral interventions to better mitigate microbial risks in these increasingly common housing arrangements.

CRediT authorship contribution statement

Gustavo Guimarães Fernandes Viana: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation. **Ana Julia Pereira Mello:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Beatriz da Apresentação:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Danilo dos Santos Gonçalves:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Eduarda Yamauti Gerolamo:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Giulya Monteiro de Castro:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Guilherme Cardoso da Silva:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Henrique de Rezende Corá:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Izabella Regina da Silva Marcelino:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Kaedra Piva Busch:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Luana Kleinubing Aguiar:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Luiza Mattos Mendonça:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Max Sândalo Ferreira da Silva:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Mayara de Sousa Canute:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Miguel Sionti de Medeiros Paulino:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Pedro Barasnevicius da Silva:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Pedro Caldeira de Araújo:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Talita Duran Semedo:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Victoria Ribeiro Silvestre:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Vinicius Guilherme de Araújo:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Yasmim Rodrigues da Silva Santos :** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Rafael Alves Santomauro:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Fábio Sossai Possebon:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Carlo Spanu:** Writing – review & editing, Writing – original draft. **Juliano Gonçalves Pereira:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Juliano Goncalves Pereira reports administrative support was provided by São Paulo State University Faculty of Veterinary Medicine and Animal Science. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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