International Journal of Design & Nature and Ecodynamics
Vol. 21, No. 6, June, 2026, pp. 1757-1765
Journal homepage: http://iieta.org/journals/ijdne

Isolation and Microbiological Characterization of Bacterial Contaminants in Chicken Shawarma Samples from Mosul, Iraq

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https://doi.org/10.18280/ijdne.210620

Received: 16 April 2026
Revised: 11 June 2026
Accepted: 19 June 2026
Available online: 30 June 2026

Keywords:
chicken shawarma, microbiological contamination, foodborne pathogens, Escherichia coli, Staphylococcus aureus, Salmonella spp., Enterobacteriaceae, food safety risk

ABSTRACT

The goal of this study was to conduct a microbiological evaluation and characterization of bacterial pathogens in chicken shawarma collected from specific locations in the Iraqi city of Mosul. Forty samples in all were chosen at random from ten distinct locations; four samples were taken from each site, each representing a different restaurant. The analysis was conducted using standard microbiological methods. The results showed moderate to high levels of contamination for total count (TC), which ranged from 5.02 to 5.20 log CFU/g. *Escherichia coli* was detected in all samples (3.14 to 4.07 log CFU/g), indicating the presence of a large amount of fecal matter and very low hygiene quality with regard to these chicken products studied, and *Staphylococcus* species. Meanwhile, the results afterward revealed a major span of 0.00–4.04 log CFU/g that proved to have food handlers as the source of contamination. Although *Salmonella* spp. still identified at trace levels (0.00–2.58 log CFU/g) in a few places, but their existence poses an ongoing threat to health as they are still pathogenic for humans. Biochemical identification by the Analytical Profile Index (API) system demonstrated proof for multiple Enterobacteriaceae that included *E. coli*, *Klebsiella pneumoniae*, *Klebsiella oxytoca*, and *Shigella* spp., which can be caused by diverse sources of contamination such as raw materials (product ingredients), environment, or human handling. Besides, the identification of methicillin-resistant *Staphylococcus aureus* (MRSA) reinforces a potential role for ready-to-eat (RTE) food items in the dissemination of antibiotic resistance. It can be concluded that chicken shawarma in Mosul is prone to microbial infection due to poor hygiene, lack of careful handling, and the low level of temperature control during preparation or serving. To reduce the risk of infection and protect public health, ongoing microbiological monitoring is essential to identify isolates, followed by important food safety measures and hygiene improvements highlighted in this study.

1. INTRODUCTION

Ready-to-eat (RTE) foods, notably meat-based products such as chicken shawarma, have wide appeal because they are affordable, convenient, and palatable, and offer good value. Nevertheless, these meals are very susceptible to microbial contamination as a result of their improper handling, poor hygiene, and exposure in contaminated environments throughout preparation and serving [1, 2]. The emergence of the vast network of fast-food chains and peak reliance by consumers on street-vended foods has worsened challenges concerning food safety problems and public health [3].

Food spoilage and foodborne illness are therefore critical in global health, especially given that bacteria are the most important pathogens. Contaminated foods have been associated with many pathogenic bacteria, including *Escherichia coli* and *Salmonella* spp., *Staphylococcus aureus*, *Listeria monocytogenes,* and *Clostridium perfringens* [4-6]. Cross-contamination by food handlers, equipment, and environmental exposure may also cause contamination at different stages (processing/shipping/storage/serving) of foods with these microbes [7]. Moreover, also rising concern about resistance in foodborne pathogens carries a special focus on *E. coli* strains isolated from animal-origin foods [8, 9].

Foodborne diseases represent one of the most significant public health issues worldwide. Each year, many more individuals fall sick from consuming contaminated food — particularly in developing nations with possibly insufficiently enforced solutions to protect against potentially dangerous meals [10, 11]. Foodborne diseases occur mainly as a result of unsatisfactory conditions, poorly trained personnel on food safety-related issues, and poor sanitation [12].

The famous Arabic meat dish known as shawarma is made by layering thinly sliced lamb or beef on a vertical rotating

spit. When food is prepared, the exterior layers are heated enough, but the internal layers might not be, which could lead to the survival of harmful bacteria [13].

In addition, serving can lead to a high risk of infection from wearing gloves while constantly slicing and handling food or outdoor exposure [14]. The inefficient nature of heat allocation can also influence the load of microorganisms; thus, the configuration of grilling programs and cooking tools is another essential factor [15].

As such, several tests conducted in different markets have demonstrated high microbiological contamination of the shawarma products. For example, study [16] discovered foodborne pathogens in shawarma meat from Cameroon. Bacterial load on food shawarma sandwiches in Libya. Likewise, higher bacterial counts in Iraqi shawarma samples were reported by research [3], reflecting the unclean conditions of preparation and storage. Most recently, the highest prevalence of these pathogens was observed in shawarma sampled from different Iraqi cities, and also contained pathogenic bacteria such as *E. coli* or *Staphylococcus* spp. [17, 18]. In addition, *Salmonella* contamination of shawarma is particularly relevant given the emphasis on it as a foodborne danger [19].

Recently, contamination with food handlers and environmental pollution has been fully documented as predominant factors of infections in RTE foods [20]. Toxin-producing bacteria, such as *Staphylococcus aureus,* during handling can contaminate food and pose significant health risks via their heat-stable enterotoxins [21]. In addition to meat products, microbial contamination has also been reported in a wide range of food commodities used for processed foods and agricultural purposes [19]. This highlights fundamental shortcomings of the food quality and safety systems [22, 23].

Microbial infections not only show widespread distribution in food-related contamination, but they also have been found in clinical and environmental samples, where their potential effects on human health were investigated [10, 24, 25]. Our results emphasize the importance of full food safety procedures to lower contamination risks along the food chain.

The microbiological hazards associated with shawarma meat consumption have been highlighted as an emerging public health concern in rapidly growing populations. Therefore, the aim of this study is to evaluate some microbiological contamination in chicken shawarma samples collected from different areas of Mosul/Iraq. Classification and isolation of some important pathogenic bacteria were the focus point in this study to evaluate whether commonly ingested food is safe or needs sound evidence to support higher hygiene standards, laws related to food safety, and public health efforts.

2. METHODOLOGY

2.1 Microbiological analysis

All microbiological studies were performed aseptically using conventional protocols with specific adjustments. To create a 10^{-1} dilution for each sample, 25 g of chicken shawarma were aseptically weighed and homogenized with 225 mL of sterile buffered peptone water (BPW). Then, sterile diluent was used to prepare serial decimal dilutions up to the necessary amount.

Sterile diluent was then used to serially dilute the homogenized contents ten times (decimal). To create countable colonies for accurate counting, the dilution series was prepared up to 10^{-3} depending on the expected microbial load.

Microbiological analysis was conducted using the pour plate method. 1.0 mL of the appropriate dilution was aseptically added to sterile Petri dishes. After cooling to 45°C, 15–20 mL of molten Plate Count Agar (PCA) was added to each plate. The plates were gently rotated to ensure even sample distribution before solidification. After all infected plates were incubated at 37 ℃ for 24 to 48 hours, colony counts were measured and reported as colony-forming units per gram (CFU/g).

PCA was used in the pour plate method to calculate the total aerobic plate count (APC). Results were reported as colony-forming units per gram (CFU/g) after inoculated plates were incubated for 24–48 hours at 37 ℃. MacConkey agar was used to count *Escherichia coli*. Standard biochemical tests were used to count and confirm typical colonies after plates were incubated at 37 ℃ for a full day. Mannitol Salt Agar (MSA) was used to count *Staphylococcus aureus*. After 24 to 48 hours of incubation at 37 ℃, yellow colonies on the plates were indicative of mannitol fermentation. Fermentation was verified and counted. The detection of *Salmonella* spp. was carried out using conventional techniques. In short, samples were selectively enriched in Rappaport–Vassiliadis broth at 42 ℃ for 24 hours after being pre-enriched in BPW at 37 ℃ for 24 hours. After streaking the cultures onto Xylose Lysine Deoxycholate (XLD) agar, they were incubated for 24 hours at 37 ℃. Biochemical studies were used to confirm the presence of presumed colonies [26, 27].

All assays were carried out in triplicate, and the detection limits were established using conventional microbiological methods. This study was carried out in various areas of Mosul, Iraq, to evaluate bacterial contamination in shawarma served in restaurants. Four eateries from each of the ten places that were chosen to represent various regions were included in the sampling procedure. There were four samples of chicken shawarma from each site, for a total of forty samples. In order to provide a representative evaluation of the microbiological quality of several Mosul restaurants, this sampling technique was employed.

To evaluate the microbiological quality and safety of shawarma sold in the various research sites, all samples underwent the necessary microbiological investigations, such as total viable count (TVC), detection of *Escherichia coli*, *Staphylococcus* spp., and *Salmonella* spp.

The detection limits were determined using the initial sample preparation, serial dilution technique, and the lowest detectable colony count on the selected growth media under standard laboratory conditions. Since 25 g of each sample was homogenized with 225 mL of sterile BPW to obtain a 10^{-1} dilution, and subsequent ten-fold serial dilutions were prepared, the theoretical detection limit for all enumerated bacteria (TVC, *Escherichia coli*, and *Staphylococcus* spp.) was 10 CFU/g. This is equivalent to the pour plate method's lowest countable dilution on the agar plates (1.0 mL inoculum). The detection limit for *Salmonella* spp. was qualitative rather than quantitative due to the enrichment-based detection method. The process involved pre-enrichment in BPW, selective enrichment in Rappaport-Vassiliadis broth, and plating on selective media (XLD agar). Consequently, the detection limit for *Salmonella* spp. was established as presence/absence in 25 g of sample under the applied

enrichment conditions in accordance with standard microbiological techniques. The minimal recoverable colony-forming units detectable under the incubation and plating conditions used in this experiment, along with standard food microbiology procedures, were used to establish these detection limits [26-28].

2.2 Study area and sample collection

In Figure 1, the study was conducted in Mosul, Iraq. Restaurants were selected at random from different regions of the city to ensure an unbiased and representative sample. The period of sample collection was May 1–June 10, 2025. From the ten Mosul locations that comprised the survey, four restaurants were selected. For a total of forty samples, four samples of chicken shawarma were collected from each location. The sampling includes numerous restaurants per site, and the selected venues were geographically proximate within each neighborhood to better reflect the diversity of commercial food outlets around the city.

A straightforward random sampling method was used to choose the restaurants. To prevent selection bias, eateries were first chosen at random using random number assignment from a list of registered and often functioning shawarma outlets within each designated location. Every restaurant has an equal chance of being included in the study because to this process. No exclusions based on perceived sanitation status, cleanliness grade, or hygiene level were established in order to guarantee representativeness. Rather, in order to reflect the actual diversity of food service enterprises in Mosul, the sampling purposefully included restaurants with different operational conditions and cleanliness practices. In order to ensure that the study caught a realistic spectrum of microbiological contamination hazards among the city's shawarma sellers, the inclusion of various hygiene conditions was implicitly confirmed through the selection of geographically and operationally diverse outlets rather than pre-classification.

All samples were collected under aseptic conditions and immediately transported to the microbiology laboratory in insulated refrigerated boxes maintained at 0–4 °C. Sample processing was carried out within two hours of collection to ensure microbiological integrity. All laboratory materials, culture media, and preparation procedures were carried out according to research [28].

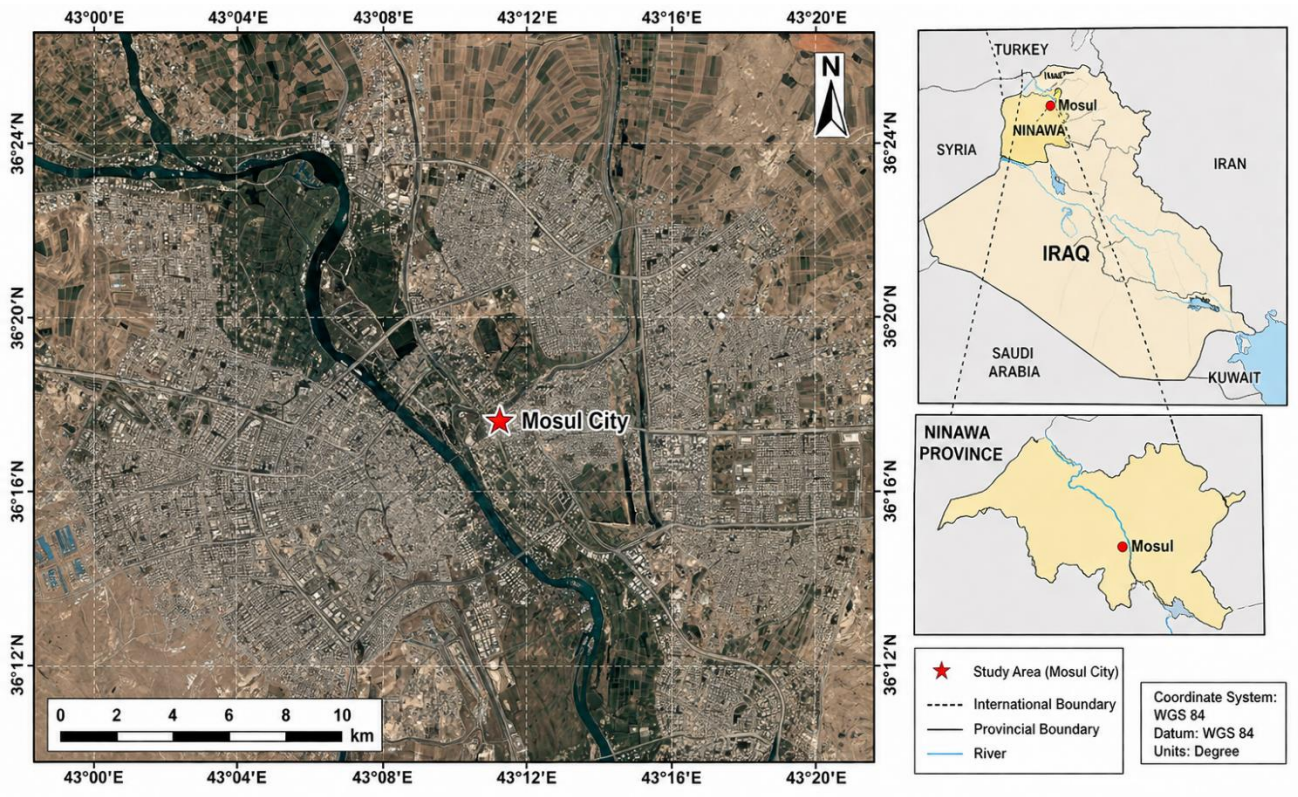

Figure 1. (a) Google Maps view of Mosul, (b) Spatial distribution map illustrating the position of the study area within Nineveh Governorate, Iraq

2.3 Microbiological analysis procedure

TVC was determined using nutrient agar and standard plate count techniques as described by research [29]. This method was used to estimate the overall bacterial load in each food sample. In addition, enumeration and detection of total coliforms, *Staphylococcus* spp., and *Salmonella* spp. were performed using standard microbiological procedures outlined by research [29], employing selective and differential culture media. Detection of *Salmonella* spp. was carried out using selective enrichment in Rappaport–Vassiliadis broth followed by plating on XLD agar and triple sugar iron (TSI) agar for presumptive identification.

2.4 Bacterial identification and time series culture processing

All cultured plates were examined for colony growth, pigmentation, morphology, and biochemical characteristics. Suspicious colonies were sub-cultured for purification and

further identification. Plates showing no visible growth were re-incubated for extended periods, while those showing no growth after 48 hours were recorded as negative and discarded following standard laboratory procedures [28].

Pure bacterial isolates were further identified using the VITEK 2 automated identification system (BioMérieux, France). Bacterial suspensions were standardized to 0.5 McFarland turbidity in sterile saline before being loaded into VITEK GN and GP identification cards. The system analyzed metabolic and biochemical reactions using a colorimetric detection method, and the results were interpreted through an integrated database software. For confirmation of coliform bacteria, the Analytical Profile Index (API) 20E identification system (BioMérieux) was used according to the manufacturer's instructions.

2.5 Quality control and data validation

Quality control measures were applied throughout all laboratory procedures to ensure accuracy and reproducibility of results. All media were prepared and sterilized according to standard microbiological protocols [28]. Sterility checks were performed to avoid contamination.

Duplicate analyses were conducted for selected samples to ensure consistency of results. Incubation times and temperatures were strictly controlled according to standard protocols. All biochemical and identification tests were validated using manufacturer guidelines for both VITEK 2 and API 20E systems to ensure the reliability of bacterial identification outcomes.

2.6 Statistical analysis

Analysis of variance (ANOVA) was used for analyzing the data; the means among locations were determined by using Duncan's multiple range test at a probability level of 5% using the SAS program version 9.1 [30].

3. RESULTS AND DISCUSSION

3.1 Microbiological quality and total bacterial count in chicken shawarma samples

The distant different mean values colonization (Table 1) results display a log CFU/g were completely measured microbiological quality of chicken shawarma World Health Organization (WHO) from various Mosul locations. These differences reflect the diversity seen in the manner and ways of possible foods, including the cleanliness maintained, and variations in their environments. Overall, total count (TC), *E. coli*, *Staphylococcus* species, and *Salmonella* species are vital indicators of food safety as well as spoilage sources. The overall bacterial load (TC) ranged from 5.02 to 5.20 log CFU/g. The lowest mean counts were recorded at locations 7 and 10, whereas location 9 showed the highest mean TC. Duncan's multiple range test indicated limited variation among locations (most sites shared the same grouping, "ab"). Nevertheless, the generally high TC values suggest moderate to severe microbial contamination. The findings are consistent with other research, which demonstrated that improper storage conditions and longer time stocks of shawarma in ambient temperatures resulted in similar values of TVC [1, 3]. Poor thermal control through food prep and service, cross-contamination, or sanitation issues are mostly associated with high TC levels [2, 20]. Also, germs would find a way of escaping if the heat does not penetrate properly during cooking in deeper areas, such as within the meat layers [15].

Table 1. The microbial total count's log (CFU/g) contamination of Shawarma samples in various restaurants of Mosul city

Location	TC	*E. coli*	*Staphylococcus aureus*	*Salmonella* spp.
1	5.18 ± 0.01 ab	4.07 ± 0.04 a	3.97 ± 0.04 ab	0.00 ± 0 a
2	5.03 ± 0.01 ab	3.48 ± 0.07 a	4.04 ± 0.04 a	1.70 ± 0.01 a
3	5.04 ± 0.01 ab	3.14 ± 0.07 a	3.70 ± 0.06 ab	0.00 ± 0 a
4	5.06 ± 0.01 ab	3.95 ± 0.04 a	3.94 ± 0.04 ab	0.00 ± 0 a
5	5.11 ± 0.01 ab	4.01 ± 0.04 a	3.00 ± 0.07 c	2.11 ± 0.02 a
6	5.08 ± 0.01 ab	3.80 ± 0.05 a	3.63 ± 0.06 abc	2.58 ± 0.04 a
7	5.02 ± 0.01 ab	3.80 ± 0.05 a	3.40 ± 0.07 bc	0.00 ± 0 a
8	5.06 ± 0.01 ab	4.05 ± 0.04 a	2.70 ± 0.05 c	0.00 ± 0 a
9	5.20 ± 0.01 a	3.97 ± 0.04 a	3.62 ± 0.06 abc	0.00 ± 0 a
10	5.02 ± 0.01 b	3.78 ± 0.05 a	0.00 ± 0 a	0.00 ± 0 a

Notes: The means followed by the same letter for each trait are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. TC: Total count.

In Table 1, *E. coli* counts ranged from 3.14 to 4.07 log CFU/g with no difference between sites. The unchanged distribution not only indicates a hygiene failure but also systemic issues of fecal contamination. The maximum was observed at location 1 value (4.07 log CFU/g) and the minimum deduction in location 3 (3.14 log CFU/g). The universal presence of viable *E. coli* in all samples suggests contamination arising from food handlers and from raw materials or water, indicating poor personal hygiene and inadequate sanitation practices. Similar findings were reported by research [17], which observed that *E. coli* was the predominant contaminant in shawarma samples, and by research [16], which linked its occurrence to lax hygiene during food preparation. Moreover, *E. coli* recognized as an indicator organism of both hygienic quality and fecal contamination in the food chain [5, 9].

In contrast, the species of *Staphylococcus* were significantly different according to location (0.00–4.04 log CFU/g—letters a, b, c). However, although site 2 showed a high concentration (4.04 log CFU/g) of contaminations tested in accordance with site 10 tests results as well. *Staphylococcus aureus* is frequently correlated with skin, fingertips and nostrils of food handlers [31] so this variation appears to represent a change connected to human contamination. Research studies indicate that improper personal hygiene, inappropriate manipulation and using gloves are considerable reasons for *Staphylococcus* infection [21]. Also, production of heat-stable enterotoxins by *Staphylococcus aureus* can lead to huge health risks at low levels [14]. The diversity of this study speaks to the fact that hygiene practices —particularly in terms of serving and

handling— differ greatly between sites.

The microbiological patterns observed are due to many factors. Environmental contamination from surfaces, utensils, and air contact has been indicated as a major factor responsible for the spread of microbes [20]. Moreover, multiple cycles of heating and long-term storage at temperatures conducive to such bacterial development are also worsened by this factor [2]. In addition, variations between locations may also reflect differences in personnel training or adherence to hygienic procedures and quality control measures. Until recently, regional studies have reported the same results, demonstrating that restaurant environment and staff members can significantly act as a source of contamination [18]. More broadly, these findings align with global reports focused on the health risks of RTE foods. Despite the numerous advances in medicine and technology, foodborne diseases remain a globally important public health challenge, particularly in fast foods [32] and street vendors, where hygiene management is often inadequate [6, 11, 33]. Different types of bacterial indicators used in this study demonstrate that chicken shawarma can act as a carrier for foodborne diseases if proper safety measures are not taken.

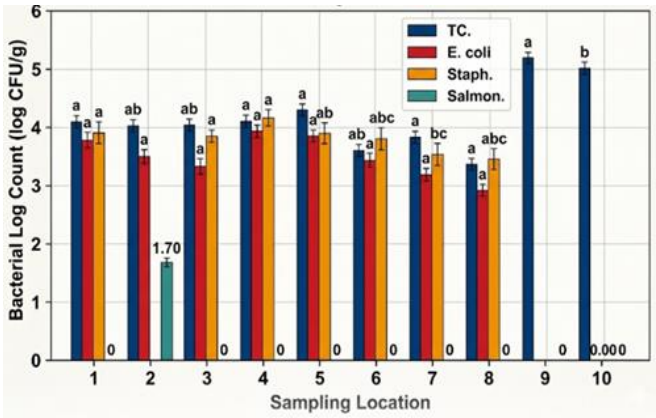

Figure 2. Mean bacterial log counts (log CFU/g) of various contaminants in shawarma samples across different locations in Mosul city

In summary, the table literally illustrates that despite similar levels of total bacteria and *E. coli* contamination between sites, *Staphylococcus* spp. exhibit significant variation from pure cultures, and *Salmonella* spp. present infrequently. Then, these trends illustrate that human and procedural, as well as environmental variables, all contribute to food contamination. This indicates the need for ensuring hygiene and control of temperature, along with constant monitoring of shawarma microbiological safety, as is required in the case of RTE foods.

3.2 Phenotypic and biochemical identification of *E. coli* isolates from ready-to-eat chicken shawarma using API system

This study is an integrated microbiological and biochemical identification of some bacterial contaminations isolated from chicken shawarma samples in the city of Mosul, Iraq. Integration of API biochemical characterization and antimicrobial susceptibility testing provides a detailed overview of the diversity, contamination sources, and public health risks associated with RTE beef products. Our data reveal the diverse nature of microbial contaminations present in street food and contribute to an increasingly global concern around food-borne pathogens [34] and antibiotic resistance.

3.3 Phenotypic and biochemical identification of *E. coli* isolates from ready-to-eat chicken shawarma using API system

In Figure 2, identification of species using the API system was verified for some Enterobacteriaceae, including *Escherichia coli*, *Klebsiella pneumoniae*, *Klebsiella oxytoca,* and *Shigella* spp. The biochemical reactions (especially urease activity, lysine and ornithine decarboxylation, and carbohydrate fermentation patterns such as sorbitol and maltose) showed a significant heterogeneity, suggesting high metabolic diversity among the isolates. Such variability is indicative of both multiple sources of contamination as well as factors related to the environment that are determining factors in bacterial adaptation. The detection of β-galactosidase (ONPG-positive responses) and glucose fermentation across *E. coli* isolates was in concordance with known diagnostic markers used for food microbiology and clinical laboratories [35]. Besides, able to distinguish *Klebsiella* spp. The identification of Enterobacteriaceae as *S. enterica*, *C. sakazakii*, and *E. coli* urease-positive and citrate-negative supports the value of API systems for identifying foodborne Enterobacteriaceae in resource-poor laboratories [36].

Importantly, those species are very low in biochemical activity and do not ferment lactose; thus, the isolation of Shigella species is a strong indication of direct fecal contamination. Its presence suggests serious breaches of hygienic practices in the preparation and handling of food, as it is a disease that can only be associated with humans [37]. This is concerning, given that Shigella has a low infectious dosage, which increases the threat of epidemics even in environments with mild contamination. This biochemical diversity suggests that contamination is likely from multiple sources, including raw poultry itself (one study), cross-contamination during processing (two studies), contact with environmental surfaces and equipment, or workers who had poor hygiene practices in the food handling process. New work has recently shown that RTE meat products are also contaminated with differing species of Enterobacteriaceae that have such varying biochemical and metabolic properties [38-40].

3.4 Public health significance of enterobacteriaceae contamination

In Figure 3, the high number of *E. coli* in the samples suggests that hygiene conditions are poor and faecal contamination has indeed occurred. *E. coli* is commonly used as an important indicator organism to assess the safety of food and sanitation. Detection in RTE foods connotes contamination post-cooking predominantly through infected utensils or improper handling [41].

Recent international reports have indicated pathogenic and antimicrobial-resistant *E. coli* strains in food systems with potential serious threats to public health [32, 42]. Those strains could have some resistance factors and virulence genes to increase their persistence or become more pathogenic.

Next, the *K. pneumoniae* are defined within this framework, since their increasing relevance as foodborne pathogens is addressed in detail. *K. pneumoniae* is a pathogen linked with clinical morbidities but has progressively been identified in food products [43]. It is an established MRDO with

demonstrated biofilm-producing ability and persistence in food processing environments [36]. *Klebsiella oxytoca* environmental contaminations detected from soil, water, and improperly sterilized surfaces are another evidence for the contamination. The recovery of *M. avium* suggests that cleaning and hygiene status are insufficient in food processing fields [39].

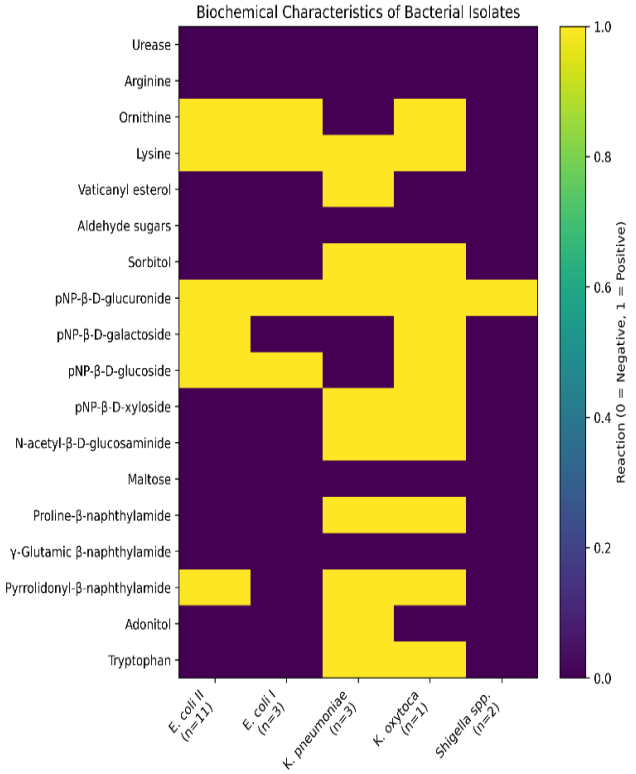

Figure 3. Analytical Profile Index (API) test for *E. coli* bacteria to detect its types (intestinal)

3.5 *Staphylococcus aureus* and antimicrobial resistance patterns

Figure 4 displays the antimicrobial susceptibility profile of *Staphylococcus aureus* isolates found in chicken shawarma samples. The findings showed a distinct pattern of resistance, especially to β-lactam antibiotics. Methicillin-resistant *Staphylococcus aureus* (MRSA) strains were confirmed by the significant percentage of isolates that demonstrated resistance to cefoxitin (47.5%) and oxacillin (45.0%). This result is in line with earlier reports showing the introduction of MRSA in RTE meats and food products derived from animals [44, 45].

Vancomycin, on the other hand, continued to be a successful treatment for resistant *S. aureus* strains because all isolates (100%) were still completely sensitive to it. Other widely used antibiotics, such as erythromycin (50.0% resistance), clindamycin (35.0% resistance), gentamicin (25.0% resistance), and tetracycline (37.5% resistance), showed varying resistance. Different selective pressures and potential exposure to antibiotics in both clinical and environmental settings are suggested by this variation in resistance profiles [42, 46].

Since *S. aureus* is frequently linked to human skin, nasal passages, and poor hygiene practices among food handlers, the presence of MRSA in RTE chicken shawarma strongly suggests contamination during food handling rather than raw meat alone [21]. Additionally, the identification of isolates that are resistant to multiple drugs highlights the possible contribution of foods sold on the street to the spread of antibiotic resistance in the population [47].

The growing number of reports of MRSA in food products worldwide lends credence to these conclusions, suggesting that the food chain may serve as a reservoir for bacteria resistant to antibiotics.

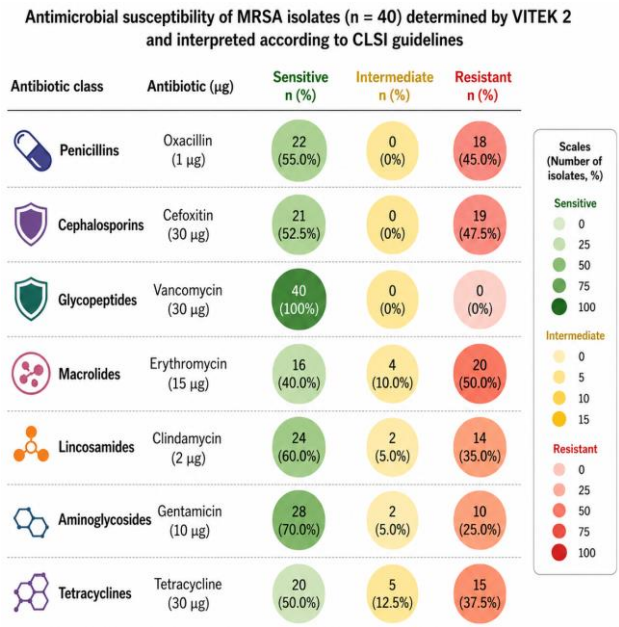

Figure 4. Antimicrobial susceptibility of *Staphylococcus aureus*, data are presented as number (n) and percentage (%)

3.6 Biochemical enzyme activity and bacterial survival

By the API system, the enzymatic activity included β-galactosidase (Allium), β-glucosidases, and β-xylosidases, as well as amino acid decarboxylase; also detected lysine and ornithine. Such enzymes are essential for bacterial survival, virulence, and appropriate adaptation. Decarboxylase enzymes are a major means by which certain bacteria can be adapted to acidic environments like those found in the human stomach, increasing the potential for pathogenicity. On the other hand, glycosidase enzymes break down polysaccharides and are able to provide nutrients from food matrices for bacteria [38]. In addition, this metabolic plasticity also allows for the potential of transmission to consumers and complicates their removal from food systems. This is even more critical in RTE meals, where bacteria might survive the cooking step but grow during storage.

3.7 Association with hygiene and food safety practices

In Figure 5, the clustering of different Enterobacteriaceae, MRSA, and exclusive human diseases, such as *Shigella*, can only be explained by failed systemic hygiene management rather than by single-point contamination events. Some of the other major contributing factors include poor hand hygiene, cross-contamination between raw and cooked meat, inadequate cooking temperature, particularly for chicken dishes consumed by children over 5 years (these easily harbour *Campylobacter*); improper storage conditions, and use of contaminated water and utensils. Such observations are in agreement with global food safety assessments wherein

shawarma and similar RTE foods have been prioritized as a high-risk due to extensive manual handling, combined exposure of products to ambient temperatures [48]. Moreover, the uneven heat generated by the conventional vertical rotisserie used for shawarma preparation may allow bacteria to survive within the inner tissue of meat layers, especially if slicing takes place before full cooking [37].

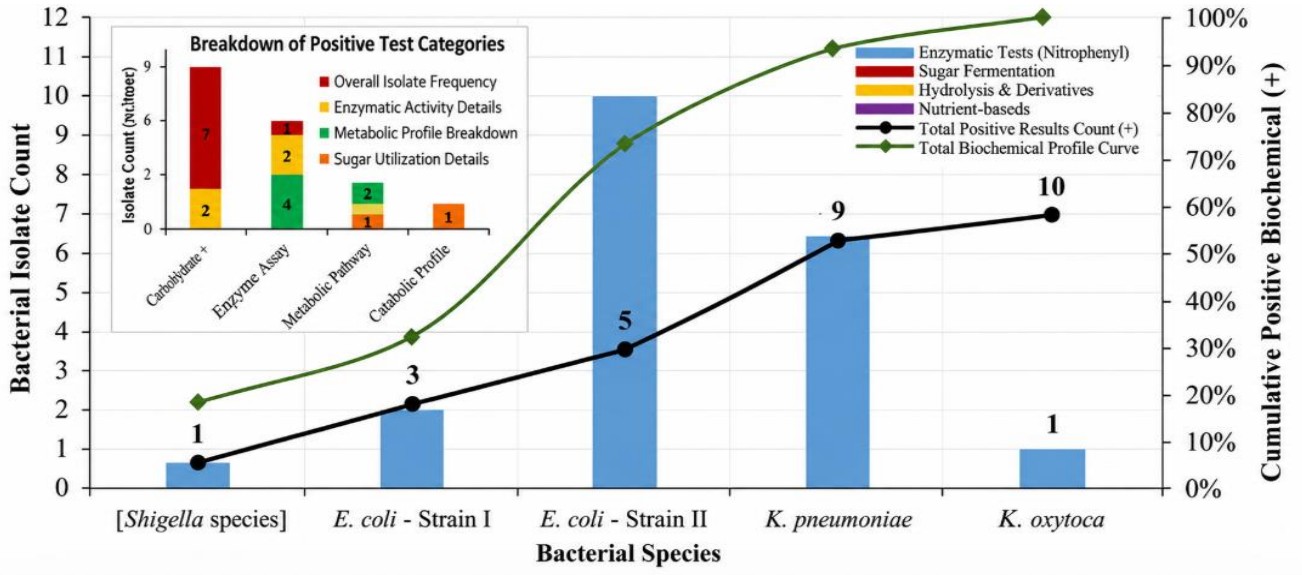

Figure 5. Comprehensive analysis of biochemical phenotypes and isolate distribution among five bacterial species

3.8 Public health implications

The presence of multidrug-resistant *Staphylococcus aureus*, especially MRSA strains, in chicken shawarma samples poses a significant risk to public health. The coexistence of β-lactam antibiotic resistance and vancomycin susceptibility indicates that overuse or misuse of commonly prescribed antibiotics in both human medicine and animal production systems has led to the evolution of selected resistance [45, 48].

Foods that are ready to eat, like chicken shawarma, could act as reservoirs for bacteria that are resistant to antibiotics, making it easier for them to spread to customers. This is especially important in areas where hygienic standards and food safety laws are not adequately implemented [49-51]. The detection of MRSA in food samples indicates that cross-contamination, improper handling techniques, and poor sanitation during the preparation and serving processes are probably the causes of contamination [20, 21].

Treatment options for foodborne infections are further complicated by the existence of resistant *S. aureus* strains in food chains, which raises worries about the possible transmission of resistance genes to other harmful bacteria. Therefore, to lower the public health risk associated with RTE foods in Mosul and similar contexts, stringent adherence to hygiene procedures and food safety regulations is crucial, as is ongoing monitoring of antibiotic resistance in foodborne bacteria.

The growing number of reports of MRSA in food products worldwide lends credence to these conclusions, suggesting that the food chain may serve as a reservoir for bacteria resistant to antibiotics.

4. CONCLUSIONS

The present study confirms that chicken shawarma sold in various places of Mosul vary significantly in the level of microbial contamination, potentially affected by food handling practices and environmental conditions. The consistently high total bacterial counts suggest poor hygiene practice and a possible lack of temperature control during cooking and storage. The widespread presence of *Escherichia coli* in each sample suggests high-level fecal contamination, inadequate personal hygiene, and cross-contamination during food preparation. Although *Salmonella* spp., even in low amounts, poses a severe public health risk due to its pathogenic status, the difference between *Staphylococcus* spp. levels emphasise the significant contribution of food handlers to infecting RTE foods. The identification of a multitude of *Enterobacteriaceae* species, including *Klebsiella* and *Shigella*, lends support to the idea that multiple routes for cross-contamination exist, such as environmental exposure along with contaminated equipment or water sources. Sounding the alarm that detection of MRSA has been reported, pathways for other antibiotic-resistant pathogens are arguably revealing a high-order threat; this increase has since become evident due to growing incidence rates emerging as foodborne transmission opportunities. This is an important food safety issue as it indicates that shawarma could be a significant public health risk, not only from the perspective of foodborne illness but also with respect to resistance-associated ramifications. In summary, chicken shawarma can be a potential source of the transmission of zoonotic infections if food safety and hygiene regulations are not adequately followed. Therefore, systematic microbiological surveillance implemented regularly, along with strict hygiene practice by food handlers ensuring proper cooking and storage conditions, as well as a tour de force on the strength of information architectures through inspections, is highly desirable. It is about the recipes to avoid contamination, for greater quality in food, and the health protection of consumers.

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