Food Safety and Risk

REVIEW

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Staphylococcus aureus contamination of animal-derived foods in Nigeria: a systematic review, 2002—2022

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Abstract

Background *Staphylococcus aureus* (*S. aureus*) is a bacterium of public health importance. The zoonotic spread of this pathogen through animal-derived foods has been reported. This systematic literature review investigates the prevalence, distribution, antimicrobial resistance (AMR) profiles, and molecular characteristics of *S. aureus* in the food chain in Nigeria.

Methods A systematic search of online databases (Pub Med, Google Scholar, and Web of Science) for published articles from January 2002 to January 2022 was performed using the Prisma guideline.

Results Fifty articles were included from an initial 511 extracted documents. These papers included research carried out in 22 states across Nigeria. *S. aureus* detection in most studies was above the satisfactory level for foods ($\geq 10^4$ CFU/g). The prevalence of *S. aureus* ranged from 1.3% in raw cow meat to 72.5% in fresh poultry meat. Most *S. aureus* isolates demonstrated multiple drug resistance patterns, especially being resistant to beta-lactams. There is a lack of information on the molecular typing of the *S. aureus* isolates. The different *spa* types of *S. aureus* isolated were t091, t314, t1476, and t4690, categorized into Multi-Locus-Sequence Types ST8, ST121, ST152, and ST789. Virulence genes detected include *pvl, sea, see, spa, coa, edin, tsst,* and *hly.* Certain AMR-encoding genes were detected, such as *mec*A, *blaZ, fos, tet,* and *dfsr.*. Factors contributing to the presence of *S. aureus* were reported as poor processing, poor sanitary conditions of the food processing units, inadequate storage units, and poor handling.

Conclusion We showed that *S. aureus* is a major food contaminant in Nigeria despite the need for more information on the molecular typing of strains from animal-derived food sources. There is a need to control *S. aureus* by targeting specific entry points based on the findings on risk factors and drivers of food contamination.

Keywords *Staphylococcus aureus* contamination, Animal-derived foods, Antimicrobial resistance, Prevalence, Virulence, Nigeria

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Introduction

Staphylococcus aureus (*S. aureus*) is a symbiotic (commensal) and opportunistic pathogen that can cause many illnesses. It is a significant and ubiquitous bacterium because of its toxin-mediated pathogenicity, invasiveness, and antimicrobial resistance (AMR) (Oranusi et al. 2006; Yamada 2013). This organism has become a major cause of nosocomial and community-acquired illnesses (Taiwo et al. 2004; GBD 2019 Meningitis and Antimicrobial Resistance Collaborators 2023). Although *S. aureus* does not produce spores, it can contaminate food during preparation and processing, with subsequent staphylococcal enterotoxin (SE) production resulting in staphylococcal food poisoning (Kadariya et al. 2014). *S. aureus* thrives in potentially arid and harsh environments and on inanimate objects like clothing, surfaces, the human nose, and skin (Le Loir et al. 2003), favouring its growth in many food products (Cretenet et al. 2011). The environmental conditions experienced in tropical countries, including Nigeria, are suitable for the growth and dissemination of *S. aureus*.

S. aureus can multiply and produce toxins in food (Le Loir et al. 2003). The enterotoxins produced by this bacterium have been linked to staphylococcal food contamination resulting from poor hygiene by food handlers, packaging inadequacies, sterilizing errors, and contamination of surfaces, utensils, and equipment used in handling food for consumption (Kümmel et al. 2016; György et al. 2021; Gebremedhin et al. 2022).

S. aureus-related Foodborne illnesses (FBIs) can be contracted by consuming contaminated foods such as meat, fish, milk and its products, eggs, and other food products (Do Prado et al. 2021; Gebremedhin et al. 2022). This results in minor boil infections and other food poisoning conditions, characterized by nausea, sweating, dizziness, vomiting, hypothermia, stomach cramps, weakness, lethargy, and diarrhoea for 1–6 h after eating contaminated foods (Palupi et al. 2010). Unhygienic conditions and poor handling of animal-derived foods contaminated with pathogenic microbes like *S. aureus* impact the burden of Foodborne diseases (FBDs) (Abunna et al. 2016). *S. aureus* is categorized as a zoonotic pathogen of significant public health and veterinary importance, especially since the emergence of the methicillin-resistant *S. aureus* (MRSA) in food animals in Nigeria (Odetokun et al. 2018; 2022; Okorie-Kanu et al. 2020).

In 2019, *S. aureus* was regarded as one of the six leading pathogens responsible for mortality due to AMR, with the highest-burden noted in sub-Saharan Africa (Antimicrobial Resistance Collaborators 2022). Due to its public health significance, it is a priority to review the occurrence and distribution of *S. aureus* in food of animal origin in Nigeria, especially as *S. aureus* continues to contaminate animal-derived foods, causing FBIs. Therefore, this study aims to review and provide recent evidence on the contamination, prevalence, distribution, antibiotic resistance, and molecular characteristics of *S. aureus* in animal-derived foods in Nigeria.

Methods

Study design

A systematic review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Mourad et al. 2016; Page et al. 2021). This ensures a reduction of bias in the review process and guarantees that the reviewer do not influence relevant information regarding the review and its findings (Ghia et al. 2020).

Search strategy, selection criteria, and data extraction

The search terms developed for the articles' search were ("Foodborne" OR "Animal food" AND "*Staphylococcus aureus*" AND "Contamination" OR "Prevalence" AND "Nigeria"). The search was conducted in three databases: Pub Med, Google Scholar, and Web of Science. These databases were adopted because of their reliability, accessibility, and renowned indexed contents of research articles. The searched articles were limited to original papers written in English, reporting research conducted in Nigeria and published from January 2002 to January 2022. For Google scholar, the articles considered were within the first 10 online pages. Original research articles of various study designs and studies related to the prevalence, distribution, isolation, and molecular characterisation of *S. aureus* in foods of animal origin were considered. The timeline of 2002 to 2022 was chosen based on the increased consumption of food animals in Nigeria within these periods (Salman et al. 2021). All articles that did not meet the inclusion criteria were excluded.

Initially, a general search was carried out using the search terms described above, total results were recorded (Fig. 1), and duplicate articles from the three databases were removed. All the results were saved on the databases and in an Excel sheet (CSV files) and exported to Rayyan (a web/mobile-based intelligent research collaboration programme for systematic reviews) for further screening.

Four researchers performed the screening process. Studies not fulfilling the selection criteria were excluded based on titles and abstracts at primary screening. The articles included were assessed during a secondary screening process based on relevance to the research question by reviewing the articles' full texts. The entire screening process was pair-reviewed for efficiency and to reduce errors. All discrepancies were resolved by consensus between the reviewers before proceeding to the

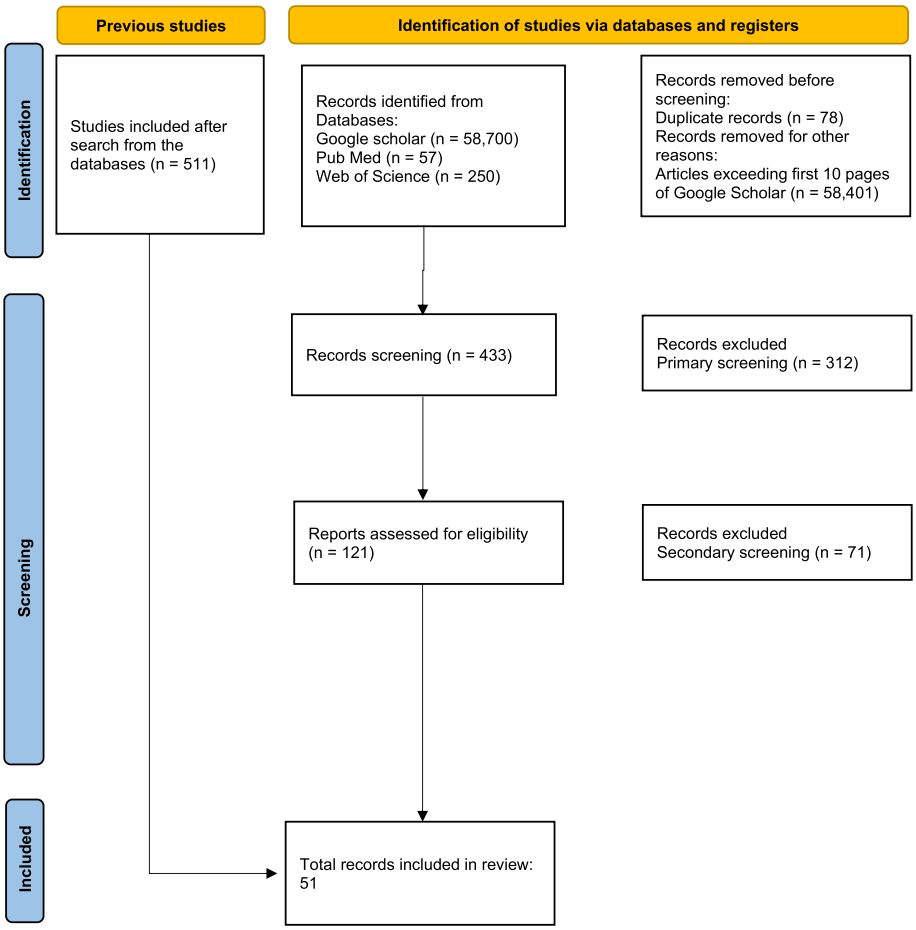

Fig. 1 Prisma chart showing articles identified, screened, and included in the review

next stage. All the screenings and the designated reasons for excluding articles were recorded. Finally, the selected articles adopted for the review focused on the search terms outlined earlier.

Assessment of risk of bias

To assess the within-study bias, we used the quality of the studies' designs and the reported microbiological methods for *S. aureus* isolation and characterisation from the animal-derived foods.

Results and discussion

This systematic review presents the findings of the staphylococcal contamination of foods of animal origin in Nigeria. We found high staphylococcal counts and prevalence in raw and processed foods from reported studies. Foodborne isolates of *S. aureus* demonstrated high resistance rates to commonly used antibiotics, especially penicillin and methicillin. Studies detailing the molecular characteristics of *S. aureus* from animal-derived foods in Nigeria are scarce. Several factors contributing to the staphylococcal contamination of foods were identified.

Distribution of articles included in the review

At the end of the search from the databases used, 511 records were extracted (Fig. 1). Duplicates of 78 articles were removed, leaving 433 articles available for further screening. The articles were subjected to primary screening by title and abstract, where 312 articles were excluded. At the secondary screening of the full text articles, 71 articles from 121 were excluded, leaving 50 for the systematic review. Finally, 50 papers were included in this study. These records were published from studies carried out in 22 states of Nigeria (Table 1). Kaduna, Ogun, and Oyo states have the highest records of studies (six records each). From the timeline of 2002 – 2022 considered in this study, most studies (seven each) were published in 2016 and 2020. Seventeen articles reported the microbial load of *S. aureus* in foods of animal origin/food animal products, forty-two described the prevalence, thirty-three stated results for antimicrobial resistance/

Table 1 Distribution of the articles used in the review

No	Study	State	Sample type	Outcomes recorded
1	Edema and Atayese (2006)	Ogun	Eggs (cracked eggs)	Prevalence
2	Oluwafemi and Simisaye (2006)	Edo and Ogun	Sausage	Prevalence
3	Oranusi et al. (2006)	Kaduna	Raw foods	Prevalence, toxicity test, and bacteriophage typing
4	Uzeh et al. (2006)	Lagos	Raw meat and roasted meat (tsire-suya)	Prevalence
5	Achi and Madubuike (2007)	Abia	Roasted beef, Fried fish, fried meat	Prevalence and antimicrobial susceptibility profile
6	Ehizibolo et al. (2007)	Plateau	Smoked fish	Prevalence
7	Edema et al. (2008)	South-west	Suya (beef)	Prevalence and critical control points in the processing
8	Okonko et al. (2008a)	Oyo and Lagos	Processed frozen seafood (shrimp, prawn, croaker, sole, and calamari)	Prevalence
9	Okonko et al. (2008b)	Lagos	Frozen shrimps	Prevalence
10	Abolagba and Igbinevbo (2010)	Edo	Fresh and smoked fish	Prevalence
11	Ologhobo et al. (2010)	Oyo	Chicken and beef suya	Prevalence
12	Salihu et al. (2010)	Sokoto	Local fried ground beef	Prevalence
13	Adesiji et al. (2011)	Osun	Retail raw chicken, pork, beef and goat meat	Prevalence and antimicrobial susceptibility profile
14	Iroha et al. (2011)	Ebonyi	Raw meat	Prevalence and antimicrobial susceptibility profile
15	Efuntoye et al. (2012)	Ogun	Catfish	Prevalence and antimicrobial susceptibility profile
16	Eze and Nwosu (2012)	Abia	Fresh goat meat (chevon)	Prevalence
17	Adegunloye (2013)	Ondo	Fresh cow meat (beef)	Prevalence and antimicrobial susceptibility profile
18	Bello et al. (2013)	Ogun	Fried fish and meat	Prevalence and antimicrobial susceptibility profile
19	Suleiman et al. (2013)	Plateau	Bovine milk	Prevalence, enterotoxigenic and antibiotic resistance profile
20	Umaru et al. (2014)	Kaduna	Milk (fresh and pasteurized) and milk products (yoghurt and *kindirmo*)	Prevalence and antimicrobial susceptibility profile
21	Dike-Ndudim et al. (2014)	Imo	Smoked fish	Prevalence
22	Ndahi et al. (2014)	Kaduna	Raw meat and meat products (*Suya, Balangu, Kilishi,* and *Dambun nama*)	Prevalence and antimicrobial susceptibility profile
23	Obadina et al. (2014)	Southwest*	Raw meat, sliced meat, staked meat, spiced meat, smoked/grilled meat (suya)	Prevalence and hazard analysis
24	Adeyeye et al. (2015)	Lagos	Smoked fish	Prevalence
25	Akagha (2015)	Anambra	Retail meats	Prevalence and antimicrobial susceptibility profile
26	Akinwumi and Adegbehingbe (2015)	Ondo	Dried smoked fish	Prevalence
27	Grema et al. (2015)	Borno	Fish	Phenotypic characterization of MRSA and antimicrobial susceptibility profile
28	Owuna et al. (2015)	Nasarawa	Fresh poultry meat	Prevalence and antimicrobial susceptibility profile
29	Igbinosa et al. (2016a)	Edo	Raw meat	Characterization of MRSA and antimicrobial susceptibility profile
30	Igbinosa et al. (2016b)	Edo	Raw milk	Genotypic characterization of MRSA and antimicrobial profile
31	Amaeze et al. (2016)	Abuja	Roasted beef (suya)	Prevalence, antibiotic resistance and heat resistance profile
32	Usman et al. (2016)	Kaduna	Yogurt and fermented milk (*Nono*)	Prevalence
33	Adeyeye (2017)	Oyo	Grilled/barbecued meat (beef Suya)	Prevalence
34	Alonge et al. (2017)	Abuja	Suya (beef)	Prevalence

Table 1 (continued)

No	Study	State	Sample type	Outcomes recorded
35	Okpo et al. (2017)	Kaduna	Fresh milk and milk product (*Nono*)	Prevalence and antimicrobial susceptibility profile
36	Abdulrahman et al. (2018)	Borno	Poultry	Phenotypic detection and antimicrobial susceptibility profile
37	Ribah and Manga (2018)	Kebbi	Meat products (*Tsire, Kilishi, Balangu*)	Prevalence
38	Orogu et al. (2018)	Delta	Barbecue fish	Prevalence
39	Bodunde et al. (2019)	Ondo	Muscle foods (beef, chicken, turkey, pork, chevon, mackerel, horse mackerel, herrings, blue whiting, and croaker	Prevalence and antimicrobial susceptibility profile
40	Yusuf et al. (2019a, b)	Kebbi	Fresh beef	Prevalence
41	Yakubu et al. (2020)	Nasarawa	Fresh milk and milk products (*Nono and Kindirmo*	Prevalence and antimicrobial susceptibility profile
42	Adesokan et al. (2020)	Oyo	Frozen meat	Prevalence and antimicrobial susceptibility profile
43	Ogundipe et al. (2020)	Ogun, Oyo, and Lagos	Chicken meat (freshly dressed and frozen/imported meat)	Prevalence, antimicrobial resistance, and virulence genes
44	Omoshaba et al. (2020)	Ogun	Milk and nasal swab samples from goats and sheep	Prevalence and antimicrobial susceptibility profile
45	Oyet et al. (2020)	Rivers	Roasted fish and meat (suya)	Prevalence
46	Egege et al. (2020)	Bayelsa	Shellfish	Prevalence and antimicrobial susceptibility profiling
47	Beshiru et al. (2021)	Delta	Shrimp	Prevalence, virulence genes/characteristics, and antimicrobial susceptibility profile
48	Esonu et al. (2021)	Kaduna	Milk (fresh and pasteurized) and milk products (*Ghee)*	Prevalence and antimicrobial susceptibility profile
49	Ogofure and Igbinosa (2021)	Edo	Frozen beef, fish, and chicken	Prevalence and antimicrobial susceptibility profile
50	Uzoigwe et al. (2021)	Imo	Beef	Prevalence

susceptibility pattern, fourteen showed molecular characteristics of *S. aureus* isolated from animal-derived foods/products, while eleven articles related the quality assessment of *S. aureus* in animal-derived foods/products in Nigeria.

Contamination of food of animal origin by *S. aureus*

Studies in this category were conducted to detect the presence of *S. aureus* that would render food products unfit for consumption (Table 2). In this section, however, emphasis was placed on *S. aureus* detection above the satisfactory/acceptable level in foods ($\geq 10^4$ CFU/g). Nine studies were classified in this category from different states. In Sokoto State, Nigeria, local fried ground beef was tested for its bacterial quality (Salihu et al. 2010). The results obtained were generally higher than acceptable limits, and those of *S. aureus* were also high. Oyet et al. (2020) reported from Rivers State using selected street-vended foods as test samples and found a high total Staphylococcal count (TSC) (6.00 to 8.00 $\log_{10}$ CFU/g) in roasted fish in the rainy season. Similarly, the highest TSC was observed in roasted fish and plantain in the dry season; no growth was detected in the other food products (meat pie, doughnuts, and fried yam). Ologhobo et al. (2010) worked on barbecued beef and chicken in the Ibadan metropolis, comparing the leftover, unheated, spiced, and roasted "suya" (tender beef threaded on a skewer and then baked or grilled in a tantalizing spicy peanut sauce) between days. The results indicated *S. aureus* contaminating processed beef and chicken "suya" samples before and after heating on all days. After rinsing, Ogofure and Igbinosa (2021) compared bacterial load (including *S. aureus*) in frozen meat and fish sold for human consumption in Benin City, Nigeria. The results showed a significant reduction in the bacterial counts of the samples; from 11.53 ± 1.25 $\log_{10}$ CFU/g (beef), 11.16 ± 0.95 $\log_{10}$ CFU/g (fish), and 11.42 ± 1.58 $\log_{10}$ CFU/g (chicken) before rinsing, to total counts of 2.70 ± 0.45 $\log_{10}$ CFU/g (beef), 2.68 ± 0.25 $\log_{10}$ CFU/g (fish), and 2.79 ± 0.49 $\log_{10}$ CFU/g (chicken), respectively, after rinsing.

In Abeokuta, *S. aureus* was isolated from all the "suya" samples meant for consumption (Obadina et al. 2014). The study revealed that raw meat was a source

Table 2 Contamination of foods of animal origin in Nigeria by *S. aureus*

Study	Sample type	Results of contamination	*S. aureus* counts
Edema and Atayese (2006)	Eggs (Cracked eggs)	Steaming showed a competent method of reducing bacterial load than frying (which had no effect)	Fried eggs—1.9×10^7 CFU/ml, steamed (20 min)—2.4×10^7 CFU/ml, steamed (30 min)—2.0×10^7 CFU/ml, baked eggs—1.9×10^7 CFU/ml
Edema et al. (2008)	Suya (Beef)	Contamination at every point of the processing; Including washing raw meat, slicing, steaking, and smoking	Location one—1.80×10^5 CFU/g/ml), location two—1.53 (10^5 CFU/g/ml)
Salihu et al. (2010)	Fried ground beef (Danbum nama)	The presence of *S. aureus* in 69.9% (151/216) of the isolates exceeds the acceptable limits (Moroccan Department order, 2004)	10^5—10^7 CFU/g
Ologhobo et al. (2010)	Chicken and Beef suya	The presence of *S. aureus* isolates in sample pre-heating and post-heating is indicative of the need for critical control points in the processing methods	Chicken before heating—3.34×10^4 CFU/g Chicken after heating—3.67×10^3 CFU/g Beef before heating—3.33×10^1 CFU/g Beef after heating—3.33×10^1 CFU/g
Eze and Nwosu (2012)	Fresh goat meat	The presence of *S. aureus* isolates in samples was considered to be a result of contamination from handlers during processing and storage	Not indicated but 10.3% (9/54) occurrence was reported
Obadina et al. (2014)	Raw meat, sliced meat, staked meat, spiced meat, smoked/grilled meat (suya)	Raw meat is a significant entry point for contamination in the processing technique	Fresh meat—16.01×10^5 CFU/g, sliced meat—11.43×10^5 CFU/g, staked meat—16.46×10^5 CFU/g, spiced meat—15.72×10^5 CFU/g, smoked meat—3.26×10^5 CFU/g
Adeyeye et al. (2015)	Smoked fish	Reduced moisture content as a result of the processing technique was considered desirable	Fresh samples (CFU/g) Silver catfish—5.4×10^20, Spotted tilapia—4.7×10^2, Bonga shad—8.1×10^2, Tongue sole—7.1×10^2, Fresh barracuda—6.3×10^2; Smoked samples (CFU/g) Silver catfish—23.4×10^2, Spotted tilapia—57.3×10^2, Bonga shad—49.0×10^2, Tongue sole—48.0×10^2, Barracuda—21.1×10^2
Adeyeye (2017)	Grilled/barbecued meat (beef Suya)	Reduced moisture content as a result of the processing technique was considered desirable	Traditional smoked suya—2.71 ± 0.19 ($\log_{10}$ CFU/g), Electric grilling machine suya—1.49 ± 0.15 ($\log_{10}$ CFU/g), Hot air oven suya—1.28 ± 0.14 ($\log_{10}$ CFU/g)
Oyet et al. (2020)	Roasted fish and meat (suya)	Within acceptable limits; Need for improved quality control	6.00 to 8.00 log 10 CFU/g
Ogofure and Igbinosa (2021)	Frozen beef, fish, and chicken	Rinsing affected the bacterial concentration	Before rinsing (CFU/g) 11.53 ± 1.25 (beef) 11.16 ± 0.95 (fish) 11.42 ± 1.58 (chicken); After rinsing (CFU/g) 2.70 ± 0.45 (beef) 2.68 ± 0.25 (fish) 2.79 ± 0.49 (chicken)

of contamination and processing methods of the meat (slicing, spicing, steaking, washing, and smoking) due to the numerous contaminant sources involved in these processes. Similarly, Edema et al. (2008) reported the same results from two different locations (first location—1.80×10^5 CFU/g /ml), second location—1.53×10^5 CFU/g/ml) from "suya" spots in the southwestern region of Nigeria. Edema and Atayese (2006) showed that frying cracked eggs did not affect the bacterial concentration in the eggs. However, steaming (for 20–30 min and baking had a positive effect by ridding of the *S. aureus* (fried eggs—1.9×10^7 (CFU/ml), steamed (20 min)—2.4×10^7 (CFU/ml), steamed (30 min)—2.0×10^7 (CFU/ml), baked eggs—1.9×10^7 (CFU/ml).

In another study, fresh goat meat sold in Abia State showed that unhygienic and poor sanitary conditions contributed to the unwholesomeness of the meat for consumption (Eze and Nwosu 2012). Traditionally smoked fish in areas of Lagos State showed that smoking affected the quality and reduced the fish's water activity (moisture), which had a resultant effect on *S. aureus* levels. The study of fresh samples of different fish breeds showed varying levels of contamination (Silver catfish—5.4×10^2 CFU/g, Spotted tilapia—4.7×10^2 CFU/g, Bonga shad—8.1×10^2 CFU/g, Tongue sole—7.1×10^2 CFU/g, Fresh barracuda—6.3×10^2 CFU/g) while smoked samples contained from the same breeds showed the following contamination levels: Silver catfish—23.4×10^2 CFU/g, Spotted tilapia—57.3×10^2 CFU/g, Bonga shad—49.0×10^2 CFU/g, Tongue sole—48.0×10^2 CFU/g, and Barracuda—21.1×10^2 CFU/g, respectively (Adeyeye et al. 2015).

The reported loads of *S. aureus* from the studies were higher than the satisfactory level of $<10^4$ CFU/g recommended in foods (Ologhobo et al. 2010). Satisfactory TSC load was reported in chicken meat in Kathmandu Valley, Nepal (Maharjan et al. 2019). Other studies have reported higher counts of *S. aureus* in chicken meat at unsatisfactory levels (Joshi and Joshi 2010; Sengupta et al. 2012; Kuncara et al. 2022). Comparably in the formal and informal meat sectors of South Africa, TSC on raw meat (after washing) from cattle, sheep, and pigs ranged from 2.8 ± 1.8 to 3.8 ± 2.4, 2.9 ± 1.7 to 4.0 ± 2.5, and 2.7 ± 1.5 to 3.2 ± 1.7 log CFU/cm^2, respectively (Jaja et al. 2018). Food contamination with *S. aureus* reflects poor sanitary operations during food handling and processing.

Prevalence of *S. aureus* in foods of animal origin

The prevalence levels of *S. aureus* in various food samples, including meat, fish and seafood, milk, and milk products, are presented in Table 3. Seven studies reported the prevalence of *S. aureus* in cow milk and its products. The lowest prevalence of MRSA in milk samples was reported in Nasarawa State in a study conducted by Yakubu et al. (2020), which revealed a prevalence of 5% (9/180). In a study by Omoshaba et al. (2020) in Abeokuta, the detection rate of MRSA in raw milk was 18.5% (37/200).

Other four studies were conducted in Kaduna and its environs (Umaru et al. 2014; Usman et al. 2016; Okpo et al. 2017; Esonu et al. 2021). Usman et al. (2016) found an overall prevalence of 3.1% from yoghurt and "nono" samples. Nine MRSA isolates (one yoghurt and eight nono isolates) were confirmed from the 24 isolates, and the occurrence of *S. aureus* was higher in nono (24) than in yoghurt (10). Another study reported a prevalence of 8.7% from similar samples (Okpo et al. 2017). Umaru et al. (2014) reported the highest prevalence from milk samples, with 47 (12.4%) *S. aureus* isolates observed from 372 milk (raw milk, bulk milk, "kindirmo", pasteurized milk, and yoghurt) samples. A recent study reported a prevalence of 3.1% with 28 isolates out of 90 samples of pasteurized milk, "ghee", and fresh milk samples in Zaria and its environs (Esonu et al. 2021).

Thirteen studies on prevalence in meat samples revealed a consistent presence of *S. aureus* in meat and meat products. From 300 samples analysed in one study, 138 *S. aureus* isolates were recovered, giving a prevalence of 31.1% (Adesiji et al. 2011). Another survey on ready-to-eat foods reported about 32.1% prevalence of the *S. aureus* isolates detected from the meat/meat-related samples (Achi and Madubuike 2007). Analysis of barbequed meat from selected locations in Abuja revealed that "suya" contained isolates of *S. aureus*. Four samples of raw and barbequed meat were sampled from each location, and *S. aureus* was confirmed in at least one of the samples (Alonge et al. 2017).

Other studies reported different prevalence of *S. aureus,* including 71.6% in raw meat sampled in Awka, Anambra State (Akagha et al. 2015), 39.7% of MRSA in Benin City with 50 *S. aureus* isolates from 126 meat samples, 26 from pork, 14 from beef, and 10 chicken samples (Igbinosa et al. 2016a). In northern Nigeria, Ndahi et al. (2014) reported results on raw meat and meat products in areas of Zaria with a prevalence of 33.7% (101 from 300 samples). In Keffi, out of 40 poultry meat samples, 29 *S. aureus* isolates were isolated, as reported by Owuna et al. (2015), showing high frequency.

The prevalence pattern for *S. aureus* in this review ranged from relatively low (5.0%) (Yakubu et al. 2020) to high (72.5%) (Owuna et al. (2015). Other studies conducted in Africa reported a high prevalence of *S. aureus*. For instance, in South Africa, Ateba et al. (2010) reported a prevalence of 100% in milk from different farm settings in Mafikeng, South Africa, while

Table 3 Prevalence of *S. aureus*/MRSA in food/food products of animal origin in Nigeria

Study	Sample type	Prevalence
Achi and Madubuike (2007)	Roasted beef, fried fish, fried meat	Roasted beef—17.2%, Fried fish—8.3%, Fried meat—6.6%
Ehizibolo et al. (2007)	Smoked fish	44.6%
Okonko et al. (2008a)	Processed frozen seafood (shrimp, prawn, croaker, sole, and calamari)	5.9%
Okonko et al. (2008b)	Frozen shrimps	4.2%
Salihu et al. (2010)	Local fried ground beef	69.9%
Adesiji et al. (2011)	Retail raw chicken, pork, beef and goat meat	48.0%
Iroha et al. (2011)	Raw meat	1.3%
Eze and Nwosu (2012)	Fresh goat meat (chevon)	10.3%
Adegunloye (2013)	Fresh cow meat (beef)	28.5%
Bello et al. (2013)	Fried fish and meat	20.0%
Umaru et al. (2014)	Milk (fresh and pasteurized) and milk products (Yoghurt and *Kindirmo*)	12.4%
Ndahi et al. (2014)	Raw meat and meat products (*Suya, Balangu, Kilishi,* and *Dambun nama*)	33.7%
Akagha et al. (2015)	Retail meats	71.6%
Grema et al. (2015)	Fish	21.1%
Owuna et al. (2015)	Fresh poultry meat	72.5%
Igbinosa et al. (2016a)	Raw meat	MRSA—39.7%
Igbinosa et al. (2016b)	Raw milk	60.0%
Amaeze et al. (2016)	Roasted beef (suya)	54.0%
Usman et al. (2016)	Yogurt and fermented milk (*Nono*)	3.2%
Okpo et al. (2017)	Fresh milk and milk product (*Nono*)	8.8%
Abdulrahman et al. (2018)	Poultry	22.5%
Orogu et al. (2018)	Barbecue fish	20.0%
Bodunde et al. (2019)	Muscle foods (beef, chicken, turkey, pork, chevon, mackerel, horse mackerel, herrings, blue whiting, and croaker)	20.3%
Yusuf et al. (2019a, b)	Fresh beef	16.3%
Yakubu et al. (2020)	Fresh milk and milk products (*Nono and Kindirmo)*	MRSA—5.0%
Adesokan et al. (2020)	Frozen meat	42.2%
Ogundipe et al. (2020)	Chicken meat (freshly dressed and frozen/imported meat)	*S. aureus*—9.6%, MRSA – 91.8%
Omoshaba et al. (2020)	Raw milk	18.5%
Beshiru et al. (2021)	Shrimp	31.0%
Esonu et al. (2021)	Milk (fresh and pasteurized) and milk products (*Ghee)*	31.1%
Ogofure and Igbinosa (2021)	Frozen beef, fish, and chicken	*S. aureus* – 40.0%, MRSA – 10.0%
Uzoigwe et al. (2021)	Beef	18.6%

Abebe et al. (2016) reported a 74.7% prevalence from cows sampled in Ethiopia. *S. aureus* contaminates raw cow milk more than milk from other animals (Deddefo et al. 2022). In other climes, a study in Bangladesh reported a prevalence of 74.0% from milk samples (Hoque et al. 2018), and 72.5% and 28.3% were reported in Poland and Turkey, respectively (Kirkan et al. 2005). The high prevalence was thought to result from poor handlers' hygiene, poor storage conditions, contamination during the processing, distribution/retail points, and inadequate sanitary conditions during processing (Akagha et al. 2015; Akinwumi and Adegbehingbe 2015; Bodunde et al. 2019). Other factors causing the observed prevalence were the state of an animal before slaughter (Abebe et al. 2016) and during milk collection (Hoque et al. 2018).

Antimicrobial resistance of *S. aureus* isolated from food of animal origin

Twenty-seven (27) studies reported antimicrobial resistance profiles for sixteen (16) antibiotics. The average resistance rate is presented in Fig. 2. The lowest average resistance was for ciprofloxacin, with 23%, while the highest was 100% for penicillin and methicillin, demonstrating that all studies reported resistance to these two latter antibiotics. There was an average of 77% resistance to cefoxitin and 66%, 64%, and 61% to ampicillin, oxacillin, and augmenting, respectively. The average resistance

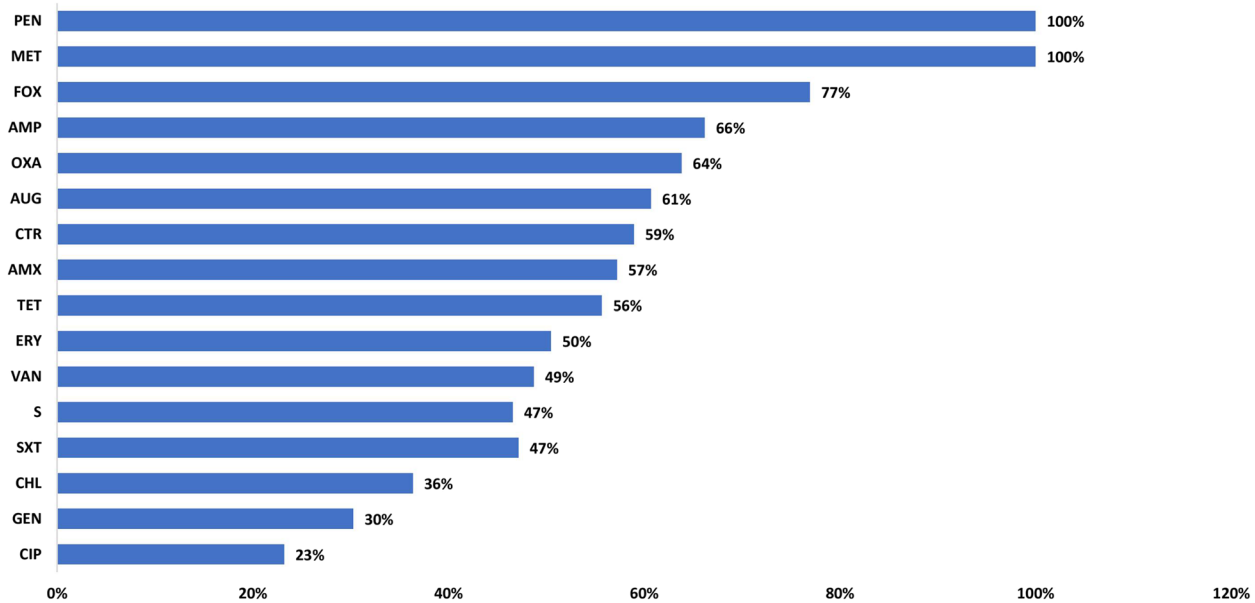

Fig. 2 Average resistance rate of reported antibiotics from all studies. CIP (Ciprofloxacin); ERY (Erythromycin); AMX (Amoxicillin); MET (Methicillin); OXA (Oxacillin); GEN (Gentamicin); CHL (Chloramphenicol); SXT (Sulphamethoxazole); TET (Tetracycline); AMP (Ampicillin); PEN (Penicillin); S (Streptomycin); VAN (Vancomycin); AUG (Augmentin); FOX (Cefoxitin); CTR (Ceftriaxone)

of 59%, 57%, 56%, and 50% was stated for ceftriaxone, amoxicillin, tetracycline, and erythromycin, respectively. Six antibiotics had averaged resistance below 50% (vancomycin: 49%, streptomycin: 47%, sulphamethoxazole: 47%, chloramphenicol: 36%, and gentamycin: 30%), while the lowest average resistance by *S. aureus* isolates is 23% for ciprofloxacin. The resistance rate to antimicrobials by *S. aureus* isolates of food of animal origin in Nigeria is presented in Table 4. Thirty-two studies reported antimicrobial resistance profiles in this review.

For antibiotic susceptibility, the profiles showed a large percentage of resistance to beta-lactams—penicillin, oxacillin, methicillin, ampicillin, and amoxicillin (Umaru et al. 2014; Ndahi et al. 2014; Ogundipe et al. 2020; Omoshaba et al. 2020; Beshiru et al. 2021) similar to the findings in slaughtered food animals in Nigeria (Suleiman et al. 2012; Odetokun et al. 2022). This is also consistent with the findings of Ateba et al. (2010), who reported a multi-drug resistance profile of *S. aureus* isolates in South Africa with high resistance to methicillin, ampicillin, penicillin, sulphamethoxazole, oxytetracycline, erythromycin, nitrofurantoin, and streptomycin. The observed resistance rates of isolates to commonly used antibiotics in this study were linked to several factors like indiscriminate use of drugs in live animals (Akagha et al. 2015; Igbinosa et al. 2016a) and the presence of genes responsible for antibiotic resistance from *S. aureus* isolates from animals (Okorie-Kanu et al. 2020; Odetokun et al. 2022). These findings also corroborate studies in other world regions that reported the advent of resistant strains due to frequent/over-use of antimicrobials over a long period (Kumar et al. 2010; Rall et al. 2014).

Penicillin and methicillin had the highest average resistance from the review. A study in China by Zhang et al. (2012) also reported the highest resistance by *S. aureus* isolates to penicillin (90.0%) from pig and chicken carcasses. Other studies in this review (Bello et al. 2013; Grema et al. 2015; Okpo et al. 2017; Abdulrahman et al. 2018; Yusuf et al. 2019a, b) also reported high resistance to tetracycline, gentamicin, second-generation and third-generation cephalosporins (ceftriaxone, cefuroxime, cefotaxime). Havaei et al. (2014) recorded resistance for tetracycline 36%, gentamicin 22%, cefoxitin 18%, clindamycin 12%, ciprofloxacin 12%, levofloxacin 6%, rifampicin 6%, and 0% for vancomycin. However, some studies showed susceptibility of *S. aureus* to antibiotics, including trimethoprim/sulphamethoxazole (Suleiman et al. 2013) and gentamicin (Owuna et al. 2015), and is similar to earlier findings where all the strains were susceptible to vancomycin and trimethoprim-sulfamethoxazole (Zhang et al. 2012). For most *S. aureus* strains tested (Hoque et al. 2018), there was a resistance to oxytetracycline, oxacillin, ciprofloxacin, amoxicillin, trimethoprim/sulfamethoxazole, while gentamicin, penicillin, and erythromycin were less resistant.

Table 4 Percentage resistance demonstrated by *S. aureus* isolates to selected antibiotics

Study (n)	Method	CIP	ERY	AMX	MET	OXA	GEN	CHL	SXT	TET	AMP	PEN	VAN	AUG	S	FOX	CTR
Abdulrahman et al. 2018 (135)	KBD	100%	60.7%	-	-	-	86.7%	77.8%	52.0%	68.1%	-	-	-	-	-	-	-
Achi and Madubuike 2007 (120)	KBD	5.8%	0.8%	2.9%	-	-	49.2%	-	-	59.2%	-	-	-	-	60.0%	-	-
Yakubu et al. 2020 (9)	KBD	0.0%	55.6%	-	-	-	0.0%	22.2%	33.3%	66.7%	0.0%	-	11.1%	0.0%	-	0.0%	-
Beshiru et al. 2021 (53)	NS	-	79.2%	-	-	-	-	-	79.2%	83.0%	-	100.0%	-	-	-	-	-
Bodunde et al. 2019 (26)	KBD	73.1%	69.2%	38.5%	-	-	69.2%	-	42.3%	-	57.7%	-	-	-	61.5%	-	-
Efuntoye et al. 2012 (11)	KBD	0.0%	66.7%	66.7%	-	-	40.0%	53.3%	20.0%	40.0%	73.3%	-	-	-	46.7%	-	-
Esonu et al. 2021 (28)	KBD	-	-	-	-	100.0%	14.3%	21.4%	-	64.3%	-	-	57.1%	-	-	-	39.3%
Umaru et al. 2014 (20)	KBD	0.0%	50.0%%	65.0%%	40.0%%	40.0%	40.0%	0.0%	10.0%	50.0%	-	100.0%	100.0%	-	-	-	-
Grema et al. 2015 (38)	KBD	94.7%	23.7%	-	NS	76.3%	89.5%	7.9%	7.9%	68.4%	-	-	-	-	-	100.0%	-
Adesokan et al. 2020 (76)	KBD	10.5%	93.4%	-	-	-	26.3%	92.1%	-	65.8%	100.0%	-	-	31.6%	82.9%	-	Yes
Igbinosa et al. 2016b (30)	KBD	-	90.0%	100.0%	100.0%	-	0.0%	100.0%	100.0%	-	-	100.0%	13.3%	-	-	-	-
Amaeze et al. 2016 (27)	KBD	-	25.9%	22.2%	-	-	0.0%	7.4%	-	18.5%	-	-	29.6%	-	0.0%	-	-
Ogofure and Igbinosa 2021	KBD	6.0%	94.0%	-	-	-	62.5%	-	81.0%	-	-	-	-	87.5%	-	-	44.0%
Ogundipe et al. 2020 (56)	MIC	33.9%	28.6%	-	-	-	32.1%	-	10.7%	60.7%	-	-	0.0	-	-	-	-
Okpo et al. 2017 (14)	KBD	7.14%	64.3%	-	-	-	0	7.1%	35.7%	85.7%	-	-	50.0%	64.3%	-	64.3%	-
Bello et al. 2013 (24)	KBD	16.7%	4.2%	37.5%	-	-	45.8%	12.5%	-	29.2%	-	-	-	-	29.2%	-	-
Omoshaba et al. 2020 (52)	KBD	23.1%	65.4%	-	-	-	17.3%	-	100.0%	-	100.0%	-	-	80.8%	38.5%	-	75%
Owuna et al. 2015 (29)	KBD	17.3%	58.6%	-	-	-	17.2%	-	-	-	-	-	-	-	20.7%	-	96.5%
Egege et al. 2020 (35)	KBD	17.1%	2.9%	100.0%	NS	100%	8.6%	-	17.3%	-	-	-	-	100.0%	82.9%	100.0%	40.0%

KBD Kirby-bauer disk diffusion method, *MIC* Minimum inhibitory concentration method, *NS* Percentage resistance—Not specified, *n* Number of isolates, *CIP* Ciprofloxacin, *ERY* Erythromycin, *AMX* Amoxicillin, *MET* Methicillin, *OXA* Oxacillin, *GEN* Gentamicin, *CHL* Chloramphenicol, *SXT* Sulphamethoxazole, *TET* Tetracycline, *AMP* Ampicillin, *PEN* Penicillin, *S* Streptomycin, *VAN* Vancomycin, *AUG* Augmentin, *FOX* Cefoxitin, *CTR* Ceftriaxone;—The antibiotic agent was not included in the antibiotic susceptibility profile of the study

Molecular types and virulence characteristics of *S. aureus* isolated from foods of animal origin

A summary of the common molecular characteristics of *S. aureus* detected in various studies is presented in Table 5. Molecular typing of *S. aureus* from food of animal origin in Nigeria is limited. In Nigeria, the *mec*A gene was detected in raw meat and meat products (Ndahi et al. 2014), fermented milk and yoghurt (Usman et al. 2016), fresh milk and milk products (Yakubu et al. 2020), and ready-to-eat shellfish (Egege et al. 2020). Other reported genes used to type *S. aureus* include *balZ*, *nuc*, and *coa*. Whole genome sequencing of chicken revealed four *spa* types (t091, t314, t1476, and t4690), four Direct Repeat Unit (*dru*) types (dt9aw, dt10dr, dt11a, and dt11dw), three Staphylococcal Cassette Chromosome *mec* (SCC*mec*) types (SCC*mec* IVa, SCC*mec* V, and SCC*mec* Vc), and four sequence types (ST8, ST121, ST152, and ST789) which differ mainly based on the different sample locations (Ogundipe et al. 2020). *S. aureus* isolates from ready-to-eat seafood revealed several virulence and antimicrobial resistance genes (ARGs) such as *coa, hla, ica*A, *ica*B, and *spa* (Beshiru et al. 2021). Other virulence determinants detected include *sea, seo, sek, see, seb, pvl, tsst, sep, ser, sel, sed, sei, ser,* and *seu.* The ARGs detected were *mec*A, tetK, blaZ, *aac(6')-Ie-aph(2")-Ia, ant(4')-Ia, aph(3')-IIIa,* dfrD, ermA, *erm*B, *erm*C, *dfr*K, *dfr*G, *cat::pC194, cat:: p*C221, *sul*III, *sul*II, *and sul*I (Beshiru et al. 2021).

The ARG and resistance-mediating mutations detected were: *mec*A (methicillin resistance gene), trimethoprim resistance gene *dfr*G, and the tetracycline resistance gene *tet*K. Other resistance genes detected were *bla*Z, *fos*B, tetK, *aac*A-*aph*D, *aph*A3, *msr*(A), *mph*(C), *dfr*S1, and *sat*4. The virulence genes reported were: *fnb*A, *ica*A, *ica*B, *ica*C, *ica*D, *and ica*R associated with adhesion and biofilm production, those associated with cell lysis and tissue invasion (*aur, clp*P, *coa, esa*A, *esa*B, *geh, lip, ssp*A, *ssp*B, *ssp*C, *vWbp*), associated with blood cell lysis (*hla, hlb, hld, hlg*B, *hlg*C, *hly*), the genes associated with immune evasion (*cap, chp, spa, sbi, scn*) and iron uptake (*str*B, *isd*A, *isd*B, *isd*C, *isd*D, *isd*E, *isd*F, *isd*G) (Beshiru et al. 2021). Finally, Ogofure and Igbinosa (2021) and Igbinosa et al. (2016a) also worked on food-producing animals. They detected the presence of *mec*A, 16S rRNA, and *pvl* genes using PCR in all the *S. aureus* strains isolated.

Only a few studies carried out the molecular characterization of virulence genes of *S. aureus* isolated from food of animal origin in Nigeria. Virulence genes, including *coa, tsst, edin*B, *pvl, sea, sec, see, cap, chp, ica*A, *ica*B, *hly, hlg, Luk*, and *dru* have also been identified from animals and the food processing environment, such as the abattoir in Nigeria (Suleiman et al. 2013; Ogundipe et al. 2020; Beshiru et al. 2021; Ogofure and Igbinosa 2021; Odetokun et al. 2022). These genes confer the abilities for cell invasion, tissue invasion, cell adhesion, toxin production, and immune evasion on the isolates. AMR genes including *mec*A, *bla*Z, *mph, sat, erm, sul, dfsr, fos, tet*, and SCC*mec* (Ndahi et al. 2014; Usman et al. 2016; Egege et al. 2020; Odetokun et al. 2022). Hoque et al. (2018) in Bangladesh also detected a combination of six genes (*pvl, see, seb, sea, sec,* and *sed*). Also, 67.8% of isolates cultured in a study in Turkey had genes encoding for enterotoxins (Turutoglu et al. 2006). The only *spa* types (t091, t314, t1476, and t4690) documented from food of animal origin were from chicken. This is comparable to other known circulating types isolated from human and animal samples. Several different *spa* types (t346, t4690, t304, t355, t786, t1931, t448, t18346, t2216, t279, t18345, t085, t2393, t5562, t934, t14223 and t491) clustered into six CCs (CC1, CC8, CC5, CC152, CC15, and CC88) were detected from pigs and chicken (Okorie-Kanu et al. 2020). Also, 19 different *spa* types (including t091) from humans and animals (cattle, goat, and pig) from abattoirs were previously confirmed (Odetokun et al. 2018). Though no study on the food of animal origin has reported circulating CCs of *S. aureus*, the SCC*mec* types IVa and V and CC1, CC88, and CC152 appear to be widely circulated in Nigeria's food processing environment (Okorie-Kanu et al. 2020; Odetokun et al. 2022). The CC88 is denoted as the African Clone (Lozano et al. 2016).

Factors influencing *S. aureus* contamination of food of animal origin

This outcome represents studies that provided information on the various reasons or conditions contributing to the concentration of *S. aureus* in animal-derived foods/products (Table 6). One study on fresh and smoked fish (*Clarias gariepinus*) attributed the higher levels of microorganisms (*S. aureus* inclusive) in fresh fish to poor handling, delayed processing, and preservation (Abolagba and Igbinevbo 2010). The microbial load observed in smoked fish was associated with poor sanitary practices in the markets, poor packaging, and inefficiency of the smoking process. Another study on smoked fish (Catfish, Herring, and Tilapia) observed a higher load in the catfish and attributed the results to the specific environment where the fish were harvested in contaminated waters, not particularly to the species (Akinwumi and Adegbehingbe 2015). There were also sanitary implications as smoked fish were reported to be displayed in dirty and unkempt areas on the market floor, which could hasten the contamination of the fish. The quality of smoked products was said to depend on several factors, including the condition of the fish at the time of smoking, the method of preparing the raw material to be used, the type

Table 5 Detection of selected virulent determinants in *S. aureus* isolates from foods of animal origin

Study	Yakubu et al. (2020)	Beshiru et al. (2021)	Igbinosa et al. (2016a)	Igbinosa et al. (2016b)	Ndahi et al. (2014)	Ogundipe et al. (2020)	Egege et al. (2020)	Usman et al (2016)
Method	PCR	PCR	PCR	PCR	PCR	MLST	PCR	PCR
Typing								
23S RNA	+	-	-	-	-	-	-	-
16S RNA	-	-	+	+	-	-	+	-
*mec*A gene	+	+	+	+	+	+	+	+
blaZ	-	+	-	-	-	+	-	-
nuc	-	+	+	-	-	-	-	-
coa	-	+	-	-	-	+	-	-
sat	-	-	-	-	-	+	-	-
spa	-	-	-	-	-	t314, t4690, t1476, t091	-	-
dru	-	-	-	-	-	dt11a, dt9aw, dt10dr, dt11dw,	-	-
SCC*mec*	-	-	-	-	-	SCC*mec* IVa, SCC*mec* V, SCC*mec* Vc	-	-
CC	-	-	-	-	-	-	-	-
ST	-	-	-	-	=	ST8, ST121, ST152, and ST789	-	-
Leukocidins								
PVL	-	+	+	+	-	+	-	-
*luk*S	-	-	+	+	-	+	-	-
*luk*F	-	-	+	-	-	+	-	-
*luk*D	-	-	-	-	-	-	-	-
*luk*E	-	-	-	-	-	-	-	-
*luk*R	-	-	-	-	-	-	-	-
*luk*X	-	-	-	-	-	-	-	-
*luk*Y	-	-	-	-	-	-	-	-
Heamolysins								
hla	-	+	-	-	-	+	-	-
hlb	-	+	-	-	-	+	-	-
hly	-	-	-	-	-	+	-	-
hld	-	-	-	-	-	+	-	-
*hlg*A	-	-	-	-	-	-	-	-
*hlg*C	-	-	-	-	-	+	-	-
*hlg*B	-	-	-	-	-	+	-	-
Proteases								
*edin*B	-	-	-	-	-	-	-	-
tsst-1	-	+	-	-	-	+	-	-
*ica*D	-	+	-	-	-	+	-	-
*ica*C	-	+	-	-	-	+	-	-
*ica*B	-	+	-	-	-	+	-	-
*ica*A	-	+	-	-	-	+	-	-
icaR	-	-	-	-	-	+	-	-
Antimicrobial resistance genes								
*tet*K	-	+	-	-	-	+	-	-
*tet*L	-	+	-	-	-	-	-	-
*tet*M	-	+	-	-	-	-	-	-
*tet*O	-	+	-	-	-	-	-	-
aac(6')-Ie-aph(2")-Ia	-	+	-	-	-	-	-	-
ant(4')-Ia	-	+	-	-	-	-	-	-
aph(3')-IIIa	-	+	-	-	-	+	-	-
*dfr*S1	-	-	-	-	-	+	-	-

Table 5 (continued)

Study	Yakubu et al. (2020)	Beshiru et al. (2021)	Igbinosa et al. (2016a)	Igbinosa et al. (2016b)	Ndahi et al. (2014)	Ogundipe et al. (2020)	Egege et al. (2020)	Usman et al (2016)
*Dfr*D	-	+	-	-	-	-	-	-
*Dfr*K	-	+	-	-	-	-	-	-
*Dfr*G	-	+	-	-	-	-	-	-

Table 6 Factors contributing to the occurrence and distribution of *S. aureus* in foods of animal origin in Nigeria

Study	Sample type	Factors contributing to results observed
Oluwafemi and Simisaye (2006)	Sausage	● Poor power supply during storage ● An inadequate sanitary condition during processing and distribution
Uzeh et al. (2006)	Raw meat and roasted meat (tsire-suya)	● The concentration of bacteria in the raw meat was found to be higher than those of grilled meat due to the heat process
Okonko et al. (2008a)	Frozen shrimps	● Inadequate hygiene and sanitary practices in the processing plants and retail stores
Abolagba and Igbinevbo (2010)	Fresh and Smoked fish	● Inadequate sanitary conditions and packaging of the products ● Increased rate of contamination at markets due to exposure
Iroha et al. (2011)	Raw meat	● Sub-therapeutic antibiotic dosages in live animals and poor processing methods
Adegunloye (2013)	Fresh cow meat (beef)	● Poor animal handling during slaughter, dressing, and evisceration in the abattoir
Dike-Ndudim et al. (2014)	Smoked fish	● Poor handling or cross-contamination of the fish
Akinwumi and Adegbehingbe (2015)	Dried smoked fish	● Processing and storage under poor sanitary and packaging conditions
Amaeze et al. (2016)	Roasted beef (suya)	● Poor handling and sanitary condition
Orogu et al. (2018)	Barbecue fish	● Contamination during the processing, storage, and handling period
Yusuf et al. (2019a, b)	Fresh beef	● Poor quality control and hygiene measures during meat handling
Bodunde et al. (2019)	Muscle foods (beef, chicken, turkey, pork, chevon, mackerel, horse mackerel, herrings, blue whiting, and croaker	● Poor hygiene of retail sellers and the handlers
Adesokan et al. (2020)	Frozen meat	● Indiscriminate use of antibiotics in animals ● Poor preservation
Uzoigwe et al. (2021)	Beef	● Sub-optimal conditions of the abattoir (hygiene and sanitary conditions)

of wood, and the smoking procedure employed. Dike-Ndudim et al. (2014) compared the microbial status of factory-smoked, market-smoked, and hawked-smoked. The Hawked-smoked fish showed the highest microbial loads attributed to increased contamination potential while moving the fish from one location to another under poor hygiene and sanitary practice. The microbial loads in factory-smoked fish were associated with errors in the pre/post handling/smoking procedures (inadequate dehydration). This report also revealed that smoking procedures do not eliminate the microbial load of fresh fish proven to be naturally high due to the nature of their habitat. Bacterial examination results of barbeque fish sold in Delta State were majorly attributed to poor fish handling by processors and traders (exposure of fish to unsanitary conditions) and post-processing contamination (Orogu et al. 2018). Okonko et al. (2008a) studied frozen shrimps in Ibadan and Lagos, showing high concentrations in unprocessed shrimps, which were attributed to poor handling and hygiene.

Bodunde et al. (2019) compared the microbial level of *S. aureus* in meat (muscle food). This was compared to

pork, turkey, beef, chicken, chevon, and fish, with the highest level recorded in pork and the lowest in chevon. *S. aureus* was the second most predominant (20.3%) bacteria cultured in the foods. These results were associated with sanitary conditions. The low levels observed in meat and fish sampled from cold rooms were linked to storage under cold temperatures that inhibit bacterial growth. Adesokan et al. (2020) reported results for meat stored in different cold rooms in a study in Ibadan, with 42.2% of the bacteria reported as *S. aureus*. The results observed from this study were suggestive of substandard operational quality of the cold room operators, including poor temperature maintenance, frequent thawing, and freezing cycles, all indicative of poor preservation. Poultry meat is easily contaminated along the processing lines, and critical control points must be applied to limit bacterial contamination (Adetunji and Odetokun 2013). Bacterial contamination of raw meat in Abakiliki, Ebonyi State (Iroha et al. 2011) was compared among beef, chevon, and chicken. *S. aureus,* the least isolated (1.3%) from these samples, was thought to result from the method of slaughter at the abattoir, promoting contamination by other faecal coliforms. However, the microbial profile of roasted beef in Abuja showed 54% of *S. aureus* (Amaeze et al. 2016). These results showed that the meat was unfit for consumption and indicated poor sanitary and processing/handling practices as is typically observed in most Nigerian slaughterhouses and retail environments (Adetunji and Odetokun 2011; Odetokun et al. 2020, 2021a, 2021b).

Fresh and frozen chicken samples from traditional markets and processing units were tested for microbial load (Olukemi et al. 2015). *S. aureus* had the highest concentration in both locations, 84% in the market and 52% from processing units. The result was linked to numerous points of contamination at the markets by rodents, insects, sewage waste, and the low concentration at the processing units due to a more controlled environment with freezing and other sanitary condition for processing the carcasses for sale. The results could also be a pointer to the level of handlers' hygiene. In the study of sausage samples sold in Abeokuta (Oluwafemi and Simisaye 2006), the total viable counts were within acceptable limits, while those from Benin City differed. This was associated with improper cleaning and sanitizing of equipment used, poor hygiene of handlers within the storage unit, and erratic power supply. The analysis of bacterial counts of raw meat and roasted meat "tsire-suya" samples (Uzeh et al. 2006) indicated the presence of contaminants during meat processing. In Owerri, bacterial assessment of beef processed at the slaughterhouses revealed total bacteria levels, albeit not exclusive to *S. aureus*, were higher than acceptable limits, indicative of poor sanitary conditions and poor handlers' hygiene (Uzoigwe et al. 2021). The occurrence of *S. aureus* in Birnin-Kebbi central market beef samples resulted from cross-contamination of meat with human body discharges, poor hygiene, handling, and processing (Yusuf et al. 2019a, b).

Although several reports identified isolated *S. aureus* to be unsatisfactory levels, the findings in this study present an array of issues contributing to its occurrence and distribution. Raw meat was said to be a primary source of contamination in the processing of a local meat delicacy called "Tsire/suya" (Uzeh et al. 2006). Power supply presents a significant factor contributing to the entry of *S. aureus* into the meat due to thawing (Adesokan et al. 2020). Also, street-vended foods recorded a high prevalence (Achi and Madubuike 2007), and this was linked to ease of contamination (Alonge et al. 2017) during the processing, e.g. use of contaminated water (Okonko et al. 2008b), distribution by hawking with poor packaging (Bello et al. 2013) and poor hygiene of handlers (Gulani et al. 2016; Odetokun et al. 2018), and poor sanitation at the markets/retail points (Akagha et al. 2015).

Live animals sampled with high prevalence were associated with poor hygiene of farm hands, inadequate sanitary conditions at the farms (Yakubu et al. 2020), and poor management practices with indiscriminate use of antimicrobials in animals (Adesiji et al. 2011; Suleiman et al. 2012; Abdulrahman et al. 2018). Other risk factors reported to influence the prevalence of *S. aureus* were milking materials, e.g. knives, slaughter slabs, etc. (Obadina et al. 2014; Ghali-Mohammed et al. 2022) that serve as easy entry points for *S. aureus* into the food chain. Processing plants, traditional milking, and milk cuddling methods (Esonu et al. 2021) were also highly incriminated, albeit some of the processing techniques were shown to reduce contamination of the food, among which are heating/Smoking of meat (Adeyeye et al. 2015; Amaeze et al. 2016) and fish (Orogu et al 2018) that showed low prevalence linked to the inability of *S. aureus* to survive under high temperatures. Spices used to flavour grilled meat and fish were also reported to reduce the occurrence of bacterial isolates (Adeyeye 2017). Proper storage and packaging (Ogofure and Igbinosa (2021) were also seen to reduce the occurrence of isolates in samples. Weather (rainy season) was also shown to have a resultant effect on the cultured isolates (Oyet et al. 2020). Furthermore, safe handling of food alongside appropriate food processing practices, ensuring a cold chain, proper cleaning, disinfecting equipment, limiting cross-contamination, and minimizing food contamination in all food chain aspects are necessary preventive measures (Kadariya et al. 2014).

However, it is crucial to note that the sampling procedures, antimicrobial susceptibility testing (AST) method,

and molecular techniques used in most studies may have influenced their findings. The sampling methods designed for each of the studies differed from swabs samples from carcasses (Omoshaba et al. 2020) and surfaces (Oranusi et al. 2006) to portions of the meat or fish sampled (Olukemi et al. 2015). For AST, the most commonly used method employed was the Kirby-Bauer disk diffusion method which only gives the results of resistance/susceptibility phenotypically. This method does not give room for detecting the minimum concentration at which the agent can inhibit bacterial growth. Molecular characterization results were also influenced by the method used. The most commonly employed method was the simple PCR, which did not allow elaborate detection of genes present in the isolates, as seen in the results. Only studies that employed more extensive methods like whole genome sequencing (Ogundipe et al. 2020) yielded in-depth results. Most studies in this review did not include molecular detection of ARGs. This resulted in limited studies reporting the characterization of *S. aureus* in this review (Dike-Ndudim et al. 2014; Owuna et al. 2015; Ribah and Manga 2018). Also, studies that sought to detect the presence of MRSA did not require molecular characterization and relied on phenotypic results from the screening media used (Umaru et al. 2014; Grema et al. 2015). Future studies in Nigeria should focus more on the molecular detection and typing of *S. aureus* contamination of food of animal origin while detailing the origin and source of the staphylococcal contamination to control FBIs.

Implications and limitations

Our study emphasized the need to control *S. aureus* in animal-derived foods in Nigeria. This information is useful to policymakers for necessary intervention in protecting the public from *S. aureus* contamination of food along the animal-derived food chain in Nigeria. A major limitation of this systematic review is the availability of a few reports on the detailed molecular characterization of *S. aureus* in various foods from animal sources. Furthermore, only one study reported the use of the MIC in determining the antibiotic susceptibility of *S. aureus*.

Conclusion

There is a variation in the occurrence and distribution of *S. aureus* in food of animal origin in Nigeria. Contamination levels were unsatisfactory compared to the standard. *S. aureus* isolates show high resistance to most commonly used antibiotics (beta-lactams antibiotics, tetracycline, first and second-generation cephalosporins, trimethoprim, ciprofloxacin) and carry genes capable of evading host immune systems and cause serious clinical conditions. These findings have been linked to various factors, including poor sanitation, processing, indiscriminate use of antimicrobials, improper processing methods, storage, packaging, and distribution. Our findings established a need to address the various entry points of *S. aureus* into the food chain in Nigeria. Special care is required to maintain hygiene, proper processing techniques, and food storage and to reduce the indiscriminate use of antimicrobials in food animals to avoid staphylococcal contamination. There is a need for a detailed molecular characterization of *S. aureus* in various foods from animal sources. There is a need to improve the condition of processing and storage plants to improve the quality of food of animal origin available for human consumption. In addition, awareness of the need for proper hygiene and sanitation during food handling, adequate packaging to decrease contamination, and the appropriate use of antimicrobials in food animals. Quality control points for processing various food animal products need to be designed and implemented.

Supplementary Information

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Additional file 1. PRISMA 2020 checklist for Staphylococcus aureus contamination of animal-derived foods in Nigeria: a systematic review, 2002—2022.

Authors' contributions

IAO: Conceptualization, Investigation, Methodology, Data curation, Writing – original draft, Writing – review editing. MAA: Investigation, Methodology, Data curation, Writing – original draft, Writing – review editing. ROA: Investigation, Methodology, Writing – review editing. AOA: Investigation, Methodology, Writing – review editing. ANA: Investigation, Methodology, Data curation, Writing – review editing. IG-M: Conceptualization, Writing – original draft, Writing – review editing. AIA: Methodology, Writing – original draft, Writing – review editing. AF: Methodology, Writing – original draft, Supervision, Writing – review editing.

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Availability of data and materials

All data generated during this study are included in this article and its additional files.

Declarations

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Competing interests

The authors declare no competing interests.

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