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Review

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A systematic review on the prevalence of multidrug-resistant *Staphylococcus aureus* from milk and milk products in Nigeria

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Abstract

The reports of increasing occurrence of multidrug-resistant (MDR) Staphylococcus aureus from milk and milk products across Nigeria constitute a significant public health threat. This study systematically reviewed the prevalence of MDR S. aureus in milk and milk products from all the geopolitical zones in Nigeria. Extensive literature search through African Journal Online, Google Scholar, Google, Semantic Scholar, PubMed, and Scopus was conducted. Articles published between August 8, 2007 and May 4, 2020 were included in the study and evaluated according to geopolitical zones where such studies were conducted. Of the 46 articles gathered, 28 were selected. The highest and lowest prevalence of MDR S. aureus recorded were 100% and 3.21% respectively. The phenotypic patterns of antibiotic resistance as evaluated from the studies examined consisted of different antibiotics combinations with multiple antibiotic resistance (MAR) indices ≥0.2. Furthermore, antibiotic resistance gene mecA was the dominant antibiotic resistance gene detected from S. aureus isolates exhibiting phenotypic resistance to the antibiotics tested. The high occurrence of MDR S. aureus in milk and milk products in Nigeria is worrisome, however, there was under-reporting or unavailable reports from some geopolitical zones. The MAR index > 2.0 recorded from the majority of the studies depicts the over use and/or misuse of antibiotics in Nigeria. The fight against MDR S. aureus should be holistic, involving the relevant authorities and stakeholders through the one health perspective which would ensure food safety and improve public health.

Introduction

Milk and milk products of different kinds are consumed in many homes and even for commercial purposes in Nigeria [1]. Milk products, especially those produced under neglected hygienic conditions, serve as vehicle for the transmission of different foodborne pathogens including *Staphylococcus aureus* [2,3]. *Staphylococcus aureus*, including livestock-associated methicillin-resistant *S. aureus* (LA-MRSA), have frequently been recovered from raw milk and milk products all over the world [4]. Despite the important roles that milk and milk products play in human nutrition, they serve as vehicles for the transmission of many bacterial pathogens, including multidrug resistant (MDR) *S. aureus* to man. For instance, in Europe, *S. aureus* have been reported to have accounted for 5% of foodborne disease outbreaks that resulted from the consumption of milk and other dairy products [5]. Presence of zoonotic pathogens and antimicrobial residues in milk pose a health risk to consumers. Pathogenic bacteria in milk can be derived from the milked cows, the human hand (during handling), and/or the environment [6,7].

The extensive use of antibiotics in both human medicine and livestock management, particularly for chemotherapy, prophylaxis, and growth promoters in animal production, is a major cause of the selection pressure and spread of antibiotic-resistant bacterial pathogens [8,9]. The extensive use of antibiotics is linked to the risk of inducing antibiotic resistance in bacterial pathogens and the transmission of these pathogens to humans via the food chain. Food contamination with antibiotic-resistant bacterial pathogens pose a serious public health threat as the determinants of antibiotic resistance can be transferred to other bacteria of clinical significance in the environment [9-11]. In recent years, the spread of antibiotic-resistant bacterial pathogens, particularly multidrug-resistant *S. aureus* has raised increasing public health concern, and it has been established that, the extensive use of antibiotics in livestock production is promoting the steady rise in the prevalence of multidrug-resistant pathogens [12-14]. Multidrug resistance in bacterial pathogens is defined as resistance to three or more classes of antibiotics [15].

The complete transmission cycle of multidrug-resistant *S. aureus* from foods of animal origin to man in Nigeria has been exemplified by the occurrence of methicillin-resistant *S. aureus*

(MRSA) in milk and milk products, which has the potential of causing epidemics [3,13,16,17]. Studies on the prevalence of MDR *S. aureus* from foods of animal origin have been reported from different parts of Nigeria. However, literature is scarce on the systematic review on the prevalence of multidrug-resistant *S. aureus* from milk and milk products in Nigeria. This study, therefore, provides a systematic review on the prevalence of MDR *S. aureus* from milk and milk products across the six (6) geopolitical zones in Nigeria.

Methods

This is a descriptive study that evaluated and reviewed different published studies on the occurrence and/or prevalence of multidrug-resistant *S. aureus* in milk and milk products reported across Nigeria. An internet-based search using the keywords: multidrug-resistant *S. aureus*, milk and milk products, states and capitals in Nigeria, major cities in states and geopolitical zones including north-central, northwest, northeast, southeast, southwest, and south-south respectively were used. This systematic review was conducted according to Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines [17]. A comprehensive search of publications on MDR *S. aureus* from milk and milk products in Nigeria was conducted. Electronic databases explored were those of African Journal Online (AJOL), Google Scholar, Google, Semantic Scholar, PubMed, and Scopus.

Two independent reviewers who were also co-investigators evaluated the titles of the works done and contents of abstracts for eligibility. Articles gathered for this study were evaluated based on preconceived criteria and disagreements that arose between the reviewers were resolved by consensus as described by Abrar *et al*. [18]. Only full-text articles published in the English Language on the prevalence or occurrence of MDR *S. aureus* in milk and milk products in Nigeria were considered. The studies were included based on the following criteria: 1) studies that reported the prevalence of MDR *S. aureus* in milk and milk products in Nigeria; and 2) point surveillance studies on the occurrence of MDR *S. aureus* from dairy products. The literature search included articles published between August 8, 2007 and May 4, 2020. A total of 41 articles were found. All titles related to the study questions were reviewed. The articles were further screened by reviewing their full details and at the third stage, selected articles were further evaluated as described by Abrar *et al*. [18]. After reading 34 articles, 8 were further r removed for reasons indicated in Figure 1.

Data extraction and analysis: data extracted from the articles gathered for this study included: 1) year of publication; 2) first author´s name; 3) sample size; 4) prevalence of MDR *S. aureus* recorded in the study; 5) number of antibiotics tested on the isolates; 6) antibiotic resistance patterns recorded. The geopolitical zone where the study was conducted was also extracted. Authors of articles with incomplete information were contacted through email and phone call for supplementary information.

Results

Distribution of articles describing the occurrence of MDR *S. aureus* in milk and milk products in Nigeria: this review was carried out in Nigeria. Nigeria is a country in the West African sub-continent characterized with diverse geography and climate, ranging from arid to humid conditions. The country is, however, most characterised by its diverse peoples and culture. Hundreds of languages are spoken in the country and this include: Hausa, Yoruba, Igbo, Fulfulde, Bini, Efik, Ibibio, Tiv, among others. However, English is the country´s official language. Nigeria is bordered in the north by Niger Republic, in the east by Chad Republic and Cameroon, in the west by the Republic of Benin, and in the south by the Gulf of Guinea of the Atlantic Ocean [19]. Electronic database searches yielded a total of 41 articles. A total of 28 articles were reviewed from

the six (6) geopolitical zones in the country. This included 7 (26.9%) from northwest, 10 (38.5%) from north-central, 3 (11.5%) from south-east, 6 (23.1%) from southwest, and 0 (0.0%) from south-south respectively. Many of the studies reviewed reportedly used the agar disc diffusion method for determining the antibiogram of the *S. aureus* isolates to a panel of antibiotics. However, only 2 (7.4%) of the studies used the minimum inhibitory concentration (MIC) method in determining the susceptibility/resistance of the isolates to antibiotics. For convenience, the results were divided based on the different geopolitical zones in Nigeria. The sample size, sample type, prevalence rates of MDR *S. aureus*, number of antibiotics tested on the isolates, antibiotic resistance patterns recorded are as presented in Table 1, Table 1 (suite), Table 2, Table 2 (suite), Table 2 (suite 1), Table 3, Table 4.

North-central Nigeria: a total number of 10 articles from north-central Nigeria were included in this study. The prevalence of MDR *S. aureus* from milk and milk products in this zone ranged from 5.0 - 100.0% (Figure 2). The sample size varied from 32 to 339, with studies conducted from Nasarawa, FCT, Plateau, Niger, and Benue States (Table 1 and Table 1 (suite)). However, no study was found from Kogi and Kwara States, which are parts of the north-central geopolitical zone. All studies used the agar disc diffusion method for the detection of phenotypic multidrug resistance in the isolates [20-29]. Furthermore, only two studies [20,27], reported the antibiotic resistance patterns of the MDR *S. aureus* isolated from milk and milk products. In all the studies reviewed from this zone, only 2 [21,28], went further to detect the presence of antibiotic resistance gene, *mec*A in the *S. aureus* isolates that demonstrated phenotypic resistance to methicillin.

North-west Nigeria: the prevalence of MDR *S. aureus* ranged from 3.21 - 97.90% in this geopolitical zone (Figure 2). A total number of seven (7) articles were included in this study from northwest Nigeria. Of the seven (7) states in this geopolitical zone, studies on the occurrence of MDR *S. aureus* in milk and milk products from four (4) states (Kebbi, Zamfara, Katsina, and Jigawa) were not found. All the studies reviewed were either from milk and milk products or raw milk only (Table 2, Table 2 (suite), Table 2 (suite 1)). The studies reviewed [13,16,30-33] used the agar disc diffusion method for the determination of multidrug resistance among the isolates. Three studies [13,16,34] used polymerase chain reaction (PCR) to examine the presence of antibiotic resistance gene (*mec*A) that code for resistance to methicillin. In the study conducted by Umaru *et al*. [13], only 4 out of the 18 methicillin-resistant *S. aureus* (MRSA) isolates were found to have harboured the gene. While in the studies conducted by [16,34], none of the 9 and 13 MRSA isolates examined, respectively, was found to have harboured the *mec*A gene. Furthermore, from the seven (7) articles reviewed, four (4) contained information on the antibiotic resistance patterns of the isolates showing the different combinations of antibiotics to which the isolates exhibited phenotypic resistance [16,30-32,34] (Table 2, Table 2 (suite), Table 2 (suite 1)).

North-east Nigeria: studies on the prevalence of MDR *S. aureus* from milk and milk products from northeast Nigeria could not be accessed. However, two reports on the occurrence of MDR *S. aureus* from soup and fish in Taraba and Borno states respectively were found [35,36]. The prevalence of MDR *S. aureus* reported in the studies were 42.0% and 6.6% respectively [35,36]. Both studies used the agar disc diffusion technique in determining MDR in the isolates. Neither of the studies used PCR to detect the presence of antibiotic resistance genes in the isolates. More so, antibiotic resistance patterns showing various combinations of antibiotics to which the isolates exhibited phenotypic resistance to antibiotics were not reported.

South-west Nigeria: from the 6 states (Lagos, Oyo, Osun, Ekiti, Ogun, and Ondo) consisting the southwest geopolitical zone, articles reporting studies on the prevalence of MDR *S. aureus* from

milk and milk products could only be obtained from Lagos, Oyo, and Ogun states respectively [37-42] (Table 3). The prevalence of MDR *S. aureus* reported from this zone varied between 13.9% - 26.0%. Also, MDR *S. aureus* isolates were mainly obtained from raw milk, evaporated milk, ice-cream, and white cheese. All the studies reviewed used the agar disc diffusion technique to determine MDR with none proceeding with the detection of antibiotic resistance genes from the isolates showing phenotypic resistance. More so, the articles reviewed did not carry information on the antibiotic resistance patterns the MDR isolates exhibited (Table 3).

South-east Nigeria: three (3) articles that reported the occurrence of MDR *S. aureus* in foods of animal origin from this zone were found and evaluated for this study. Two articles [43,44] reported the occurrence of MDR *S. aureus* in milk, while one [45] reported the occurrence of MDR *S. aureus* in roasted meat (Table 4). The prevalence of MDR *S. aureus* reported from this zone ranged from 9.4% - 58.0%, while the sample size ranged from 4 to 225. The three (3) studies reviewed used the agar disc diffusion technique in determining the resistance of the isolates to the antibiotics tested. Furthermore, only one (1) [45] out of the three (3) studies reported the antibiotic resistance patterns showing different combinations of antibiotics to which the isolates exhibited phenotypic resistance (Table 4).

South-south: no article reported the occurrence of MDR *S. aureus* in milk and milk products from the states in the south-south geopolitical zone was accessed. However, articles reporting the occurrence of MDR *S. aureus* in clinical and environmental samples were assessed and further excluded because they did not satisfy the inclusion criteria set for this study.

Discussion

This review indicates that there is a widespread and significant occurrence of MDR *S. aureus* in milk and milk products, and other products of animal origin in Nigeria. The prevalence ranged from as low as 3.21% to as high as 100.00%. Yet relevant authorities and even the populace are either unaware or underestimating the threat this poses to public health. This review could not fully access articles that discussed the prevalence of MDR *S. aureus* from milk and milk products in the northeast, southeast, and south-south geopolitical zones as only studies on the prevalence of MDR *S. aureus* from other products of animal origin from the zones were accessible, and hence reviewed. Although the prevalence of MDR *S. aureus* from milk and milk products varies across the geopolitical zones, there was however no major difference in the trend *S. aureus* resistance to antibiotics evaluated. As reported in many studies both within and outside Nigeria, the prevalence of MDR *S. aureus* in milk and milk products varies from one location to another, or from one setting to another, or in even in a specified place over time [46-54]. The prevalence rate in the north is higher especially in the northwest and north-central Nigeria, and then followed closely by the southwest region. Based on the inclusion criteria for this study and the availability of studies conducted in the northeast region, a definite conclusion could not be drawn because only few studies were accessed from that zone. From the findings of this study, more research on the occurrence of MDR *S. aureus* in milk and milk products were conducted from the northern parts of Nigeria when compared to the south. This may probably be due to the fact that a larger percentage of the cattle population in Nigeria are resident in the north where raw milk and fermented milk products are produced (often traditionally) and consumed as supplements to normal meals in homes and even traded as major source of livelihood. Nomadic cattle herders and their women mostly control the processing and marketing of milk up north Nigeria. Kindirmo and

Nono are locally fermented milk products mostly consumed by Hausa and Fulani speaking people as well as the entire populace in northern Nigeria [22].

In all the studies reviewed, the agar disc diffusion technique was the predominant method used in determining the antibiotic susceptibility profiles of the *S. aureus* isolates obtained. Most of the articles reviewed did not molecularly characterize the multidrug resistance in the *S. aureus* isolates examined. Some of the challenges that might have limited the use of molecular characterization in the majority of the studies across Nigeria include the unreadily available laboratories fitted with contemporary equipment for such characterization. Also, the paucity of research grants and funds hinder researcher from exploring molecular studies after the preliminary phenotypic evaluations. In Nigeria, fortunes are expended for any meaningful microbiological study involving molecular analysis. Of all the articles reviewed, only three [13,21,28] used PCR in detecting the presence of an antibiotic resistance gene (mecA) in the MDR *S. aureus* that exhibited phenotypic resistance to methicillin. The inability of most studies to proceed with the determination of the presence of antibiotic resistance determinants from the *S. aureus* isolated from milk and milk products is however worrisome, and may not clearly reveal the true epidemiological dynamics of the environmental as well as zoonotic implications of the transfer of these determinants to other pathogens or naïve microbial strains which may later emerged with greater risks.

In the articles reviewed, different antibiotic resistance patterns with varied combinations of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 antibiotics tested. Only two resistance patterns were reported consisting of lone antibiotic [34,38]. Different antibiotic resistance patterns recorded in the studies could reflect different levels of use and misuse of antibiotics in the different areas where such studies were conducted across Nigeria. A Hundred percent (100.00%) of the *S. aureus* isolates obtained in all the articles reviewed in this study had a multiple antibiotic resistance (MAR) index of 0.2 and above. Multiple antibiotic resistance index is calculated as the ratio of the number of antibiotics to which an organism is resistant, to the total number of antibiotics to which an organism is exposed [55]. Multiple antibiotic resistance index gives an indirect suggestion of the probable source of an organism. A microbial strain with a MAR index greater than 0.2 indicates that such a strain originates from an environment where there are no strict regulations regarding the use of antibiotics [55]. While there are a substantial number of studies on the occurrence of MDR *S. aureus* in milk and milk products in Nigeria, however, there are geopolitical zones with either under-reported or none reported occurrence of MDR *S. aureus* in milk and milk products, and so the prevalence seems unrealistic and vague. This could be attributed to the fact that most research in Nigeria including those of public health relevance are often not funded or grossly underfunded by the subregional, regional and the central governments. Similarly, only limited non-governmental organizations, industries and few well-meaning individuals seldom support research in Nigeria.

From the present study, it is clear that the most prevalent antibiotic resistance gene detected in the MDR *S. aureus* from the various studies examined and reviewed is mecA, which code for resistance to methicillin. Therefore, a thorough and continuous monitoring of MDR *S. aureus* in milk and milk products, and other products of animal origin would undoubtedly unravel the importance of MDR *S. aureus* in food safety issues and also provide measures for mitigating the public health threat associated with this MDR pathogen. Also, other bacterial pathogens of clinical significance can acquire such determinants of antibiotic resistance from pathogens harbouring antibiotic resistant gene(s). Future research should be conducted in areas where there are scanty studies, involving a variety of food of animal origin. Finally, the fight against MDR *S. aureus*

should be holistic such that, relevant authorities, researchers, scientists, livestock managers, producers of milk and milk products, and consumers should all make contributions toward addressing the problem. This, therefore, underscores the need to address the problem from the ''one health perspective.''

Conclusion

This study provides baseline data on the prevalence of multidrug-resistant *Staphylococcus aureus* from milk and milk products in Nigeria. The most prevalent antibiotic resistance gene detected in the MDR *S. aureus* from the various studies examined and reviewed is *mec*A, which code for resistance to methicillin. A thorough and continuous monitoring of MDR *S. aureus* in milk and milk products, and other products of animal origin would in no doubt unravel the importance of MDR *S. aureus* in food safety issues and also provide measures for mitigating the public health threat associated with this MDR bacterial pathogens. Also, other bacterial pathogens of clinical significance can acquire such determinants of antibiotic resistance from pathogens harbouring antibiotic resistant gene(s). Future research should be conducted in areas where there are scanty studies, involving a variety of foods of animal origin.

What is known about this topic

- *Antimicrobial resistance is a serious public health threat affecting humans and animals with differing geographic distribution;*
- *Foods of animal origin such as milk and milk products play an important role in the transfer of antibiotic-resistant bacterial pathogens to man;*
- *Data on the occurrence of multidrug resistant Staphylococcus aureus in milk and milk products is largely restricted to developed countries of the world.*

What this study adds

- *Multidrug resistant Staphylococcus aureus in milk and milk products as an important public health threat in Nigeria and the need for continuous monitoring;*
- *Understanding the danger that the occurrence of MDR S. aureus in milk and milk products pose to human health;*
- *Provision of baseline data on the occurrence of MDR S. aureus in milk and milk products in different parts of Nigeria.*

Competing interests

The authors declare no conflict of interests.

Authors' contributions

YA conceptualized and designed the study, drafted the manuscript; RCR conceptualized the study, data acquisition and edited the manuscript; IOA supervised and coordinated the research, analyzed data; BOO and MSA took charge of data acquisition and revision of the manuscript. All authors gave approval for the final version of the manuscript to be published.

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Tables and figures

Table 1: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in north-central Nigeria: FCT, Benue, Kogi, Kwara, Niger, Nasarawa and Plateau states

Table 1 (suite): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in north-central Nigeria: FCT, Benue, Kogi, Kwara, Niger, Nasarawa and Plateau states

Table 2: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto and Zamfara states

Table 2 (suite): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara states

Table 2 (suite 1): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara states

Table 3: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in southeast Nigeria: Abia, Anambra, Imo, Ebonyi, and Enugu states

Table 4: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in southwest Nigeria: Oyo, Ondo, Osun, Lagos, Ogun, and Ekiti states

Figure 1: PRISMA 2020 flow diagram for systematic reviews

Figure 2: a graph showing the lowest and highest prevalence of MDR *S. aureus*from milk and milk products in the geopolitical zones of Nigeria; Key: NC - north-central, NW - northwest, NE - northeast, SW - southwest, SE - southeast, SS - south-south

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Table 1: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in north-central Nigeria: FCT, Benue, Kogi, Kwara, Niger, Nasarawa and plateau states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Benue	120	NN	17.2	11	GEN, STR, TET	7	NR
					GEN, STR, TET, AMX		
					GEN, LEN, STR, TET AMX		
					GEN, CPX, NPX, RFP, TET, AMX		
					CPX, NFX, LEN, STR FLX, TET, AMX		
					TET, NFX, FLX, GEN, LEN, ERY, STR		
					CPX, NFX, GEN, LEN, STR, FLX, AMX, RFP, CHL TET		
Plateau	339	RM	33.3	12	NR	Nil	NR
Niger	90	RM NN KDR	60.1	10	NR	Nil	NR
Nasarawa	100	RM NN KDR	30.0	10	NR	Nil	NR
Plateau	32	RM	21.9	18	NR	Nil	NR
Nasarawa	15	RM	100	10	NR	Nil	NR

Key: RM - raw milk, NN - *nono*, KDR - *kindirmo*, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, AMP - ampicillin, AMO - amoxicillin, TET - tetracycline, SUL - Sulphamethoxazole/trimethoprim, FOX - cefoxitin, ERY - erythromycin, GEN - gentamicin, STR - streptomycin, AMX - amoxicillin, Len - lincomycin, CPX - ciprofloxacin, NPX - norfloxacin, RFP - rifampicin, FLX - cloxacillin, CHL - chloramphenicol

Table 1 (suite): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in north-central Nigeria: FCT, Benue, Kogi, Kwara, Niger, Nasarawa and Plateau states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Nasarawa	123	KDR	9.76	10	NOR, AMO AMO, STR AMO, AMP, LEV AMO, CHL, AMP, LEV NOR, AMO, RIF, AMP AMO, STR, RIF, AMP AMO, STR, ERY, AMP GEN, AMO, CHL, AMP, LEV NOR, AMO, STR, RIF, AMP NOR, GEN, AMO, RIF, AMP, LEV	10	0.2 -0.6
Nasarawa	180	RM NN KDR	5.0	11	AMP, AMO, FOX AMP, AMO, FOX, TET AMP, AMO, FOX, TET, SUL AMP, AMO, FOX, ERY, TET AMP, AMO, FOX, ERY, SUL	5	0.3 - 0.5
Nasarawa	180	RM NN KDR	5.0	11	AMP, AMO, FOX AMP, AMO, FOX, TET AMP, AMO, FOX, TET AMP, AMO, FOX, TET, SUL AMP, AMO, FOX, ERY, TET AMO, AMO, FOX, ERY, SUL	5.0	0.3 - 0.5
FCT	300	NN	7.0	12	NR	Nil	NR

Key: RM - raw milk, NN - *nono*, KDR - *kindirmo*, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, AMP - ampicillin, AMO - amoxicillin, TET - tetracycline, SUL - Sulphamethoxazole/trimethoprim, FOX - cefoxitin, ERY - erythromycin, GEN - gentamicin, STR - streptomycin, AMX - amoxicillin, NOR - norfloxacin, RIP - rifampicin, ,CHL - chloramphenicol, LEV - levofloxacin

Table 2: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto and Zamfara states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Kaduna	372	RM YG KDR	12.6	12	NR	Nil	NR
Kaduna	280	YG NN	3.21	13	OX, SXT, MET, CIP, C, E, P, CN, VA OX, SXT, MET, AMP, AK, CIP, C, CFM, P, TE, CN OX, SXT, MET, AMP, C, E, P, TE OX, SXT, MET, AMP, AK, CIP, C, E, P, TE, CN, VA OX, MET, AMP, AK, CFM, P, TE, CN, VA OX, MET, AMP, AK, CIP, C, E, CFM, P, CN, VA OX, MET, CIP, C, E, P, CN OX, MET, C, E, P, CN, VA OX, SXT, MET, AMP, AK, CIP, C, E, P, TE, CN, VA	9	0.54 - 0.92
Kaduna	360	RM	15.3	12	NR	Nil	0.20 - 0.90
Kaduna	160	KDR MS	17.5	9	VA, E, FOX		
					E, AUG, FOX		
					VA, TE, E, FOX		
					VA, TE, E, FOX		
					VA, TE, AUG, FOX		
					VA, TE, E, FOX		
					VA, TE, E, FOX		
					VA, TE, E, FOX, SXT, AUG		

Key: RM - raw milk, KDR - *kindirmo*, NN - *nono*, YG - yoghurt, MS - *manshanu*, PM - packaged milk, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, OX - oxacillin, SXT - Sulphamethoxazole/trimethoprim, MET - methicillin, AK - amikacin, CFM - cefixime, AUG - augmentin, CXM - cefuroxime, E - erythromycin, P - penicillin, C - chloramphenicol, FOX - cefoxitin, CN - gentamicin, TE - tetracycline, VA - vancomycin, AMP - ampicillin, CIP - ciprofloxacin.

Table 2 (suite): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto and Zamfara states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Kaduna	360	RM	7.8	12	AML, AMP, E, P, TE, VA, W	28	0.40 - 0.80
					AML, AMP, C, CIP, CN, R, P, S, TE		
					AML, AMP, E, P, S, TE, VA,		
					AML, AMP, C, CN, E, NA, P, S, TE		
					C, CN, E, NA, P, S,TE		
					AML, C, E, P, TE, VA		
					AML, AMP, C, CN, E, NA, P, S, TE		
					AML, AMP, C, E, P, TE, VA		
					AML, AMP, C, E, P, TE, VA		
					AML, AMP, C, CN, E, P, TE, VA		
					AML, AMP, C, CN, E, NA, P, TE		
					C, CN, P, S, E, VA		
					AML, AMP, C, CN, NA, P, S, TE		
					AML, AMP, CIP, E, NA, P, TE		
					AML, AMP, E, P, TE, VA, W		
					AML, AMP, E, P, W		
					AML, AMP, E, NA, P, TE		
					AML, AMP, C, E, P, TE, VA, W		
					AML, AMP, CN, E, NA, P, S, TE		
					AML, AMP, CN, NA, P, S, TE		
					AML, AMP, E, NA, P, TE, VA, W		
					AML, E, P, TE, VA, W		
					AML, AMP, NA, P, S		
					AML, AMP, NA, P, TE		
					AML, AMP, P, VA, W		
					AML, AMP, CN, E, P, VA		
					AML, AMP, E, P, S, TE, VA, W		
					AML, AMP, C, NA, P, TE, VA, W		
					AML, AMP, CN, E, NA, P, TE, VA, W		

Key: RM - raw milk, KDR - *kindirmo*, NN - *nono*, YG - yoghurt, MS - *manshanu*, PM - packaged milk, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, OX - oxacillin, SXT - Sulphamethoxazole/trimethoprim, MET - methicillin, AK - amikacin, CFM - cefixime, AUG - augmentin, CXM - cefuroxime, E - erythromycin, P - penicillin, C - chloramphenicol, FOX - cefoxitin, CN - gentamicin, TE - tetracycline, VA - vancomycin, AMP - ampicillin, CIP - ciprofloxacin

Table 2 (suite 1): prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in northwest Nigeria: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto and Zamfara states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Sokoto	NR	PM	NR	7	NR	Nil	NR
Kano	NR	RM	97.7	10	FOX AMP, FOX AML, FOX AML, FOX, CXM AML, SXT, FOX AMP, AML, FOX AMP, AML, FOX, CXM AMP, AML, FOX, SXT AMP, AML, TET, FOX AMP, AML, CL, FOX AMP, AML, CL, SXT, FOX AMP, AML, SXT, FOX, CXM AMP, GEN, CL, TET, FOX AMP, AML, FOX, CXM, TET AMP, AML, TET, FOX, CXM AMP, AML, TET, SXT, FOX AMP, AML, GEN, TET, FOX, CXM AMP, AML, CL, SXT, FOX, CXM AMP, AML, SXT, FOX, CXM, CL AMP, AML, OFL, CL, SXT, FOX AMP, AML, TET, SXT, FOX, CL AMP, AML, CL, TET, FOX, CXM AMP, AML, GEN, CL, SXT, FOX, CXM AMP, AML, CL, TET, SXT, FOX, CXM AMP, AML, GEN, CL, SXT, FOX, CXM AMP, AML, GEN, CL, TET, SXT,FOX AMP, AML, GEN, CL, TET, SXT, FOX, CXM AMP, AML, CIP, GEN, CL, TET, SXT, FOX, CXM	28	NR

Key: RM - raw milk, KDR - *kindirmo*, NN - *nono*, YG - yoghurt, MS - *manshanu*, PM - packaged milk, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, OX - oxacillin, SXT - Sulphamethoxazole/trimethoprim, MET - methicillin, AK - amikacin, CFM - cefixime, AUG - augmentin, CXM - cefuroxime, E - erythromycin, P - penicillin, C - chloramphenicol, FOX - cefoxitin, CN - gentamicin, TE - tetracycline, VA - vancomycin, AMP - ampicillin, CIP - ciprofloxacin

Table 3: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in southwest Nigeria: Oyo, Ondo, Osun, Lagos, Ogun, and Ekiti states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Oyo	10	CEM	NR	12	NR	Nil	NR
Oyo	5	Raw milk	NR	8	NR	Nil	NR
Lagos	14	Ice-cream	NR	8	NR	Nil	NR
Oyo	165	Raw milk	13.9	11	NR	Nil	NR
Ogun	64	Raw milk	14.0	7	NR	Nil	NR
Ogun	200	RM, Cheese	26.0	11	NR	Nil	NR

Key: S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns,NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, CEM - canned evaporated milk

Table 4: prevalence of multi-drug resistance *Staphylococcus aureus* from milk and milk products in southeast Nigeria: Abia, Anambra, Imo, Ebonyi, and Enugu states

State	S/size	S/type	Prev. (%)	NAT	ARP	NRP	MARI
Abia	4	Raw milk	NR	NR	NR	Nil	NR
Enugu	225	Roasted meat	9.4	17	FA	Nil	NR
					TE		
					FA, TE		
					FA, VA		
					FA, MUP		
					TE, SXT		
					FA, CC, E		
					FA, OX, FOX		
					FA, TE, OX, FOX		
					FA, CC, VA, ER, TE		
					FA, CC, VA, ER, OX, FOX		
					S, SXT, KA, GE, TB, MUP		
Abia	50	Cows' swabs	58.0	8	NR	Nil	NR

Key: RM - raw milk, KDR - *kindirmo*, NN - *nono*, YG - yoghurt, MS - *manshanu*, PM - packaged milk, S/Size - sample size, S/type - sample type, NR - not reported, Prev. - prevalence, NAT - number of antibiotics tested, ARP - antibiotic resistance patterns, NRP - number of resistance patterns, MARI - multiple antibiotics resistance index, OX - oxacillin, SXT - Sulphamethoxazole/trimethoprim, MET - methicillin, AK - amikacin, CFM - cefixime, AUG - augmentin, CXM - cefuroxime, E - erythromycin, P - penicillin, C - chloramphenicol, FOX - cefoxitin, CN - gentamicin, TE - tetracycline, VA - vancomycin, AMP - ampicillin, CIP - ciprofloxacin

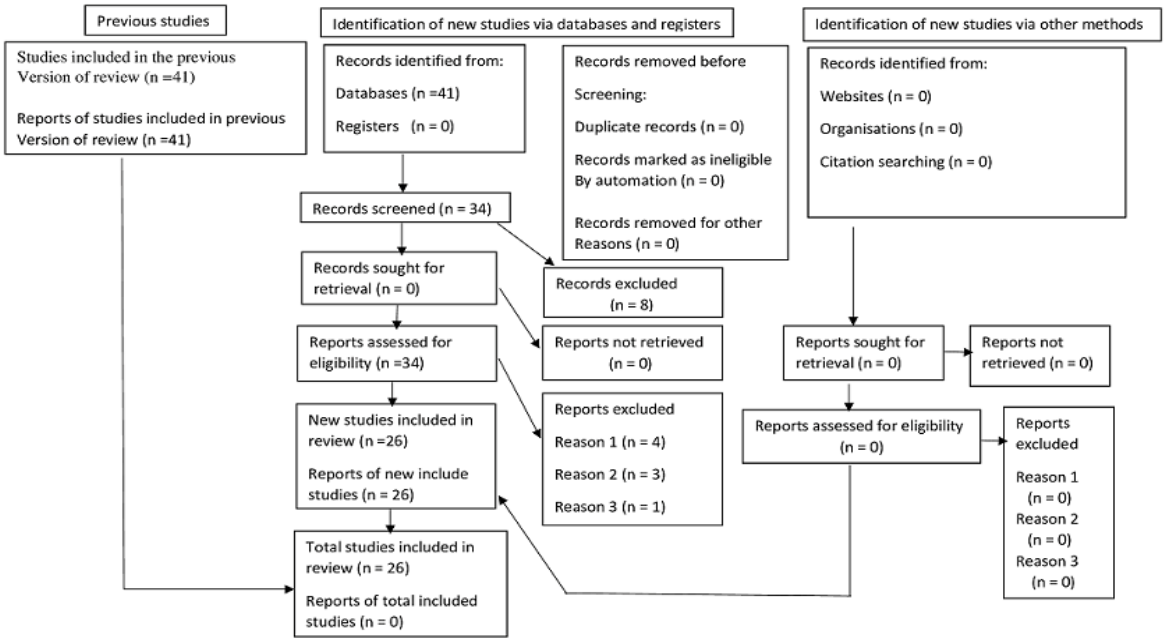

Figure 1: PRISMA 2020 flow diagram for systematic reviews

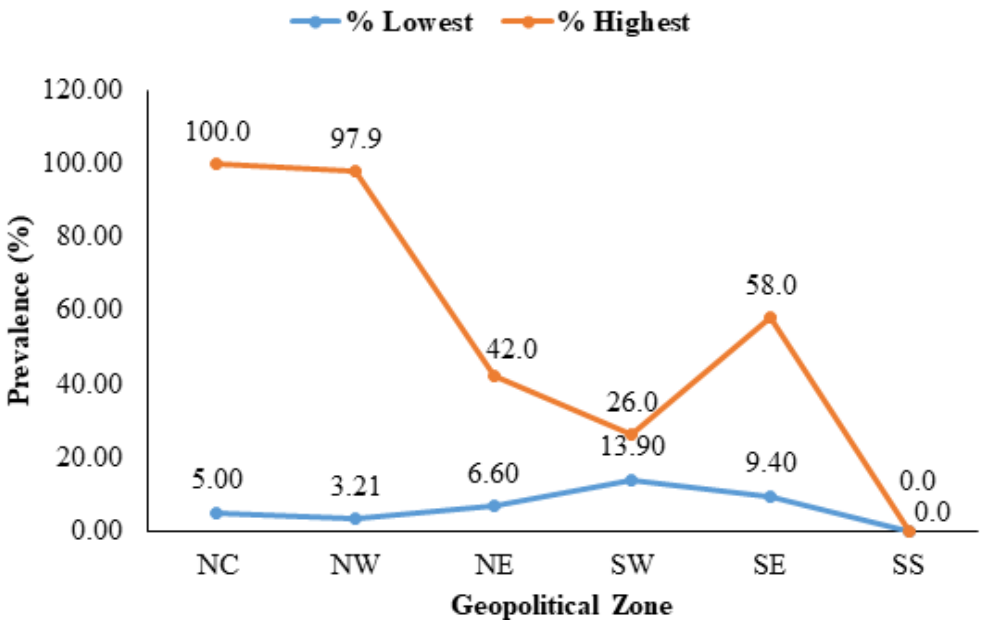

Figure 2: a graph showing the lowest and highest prevalence of MDR *S. aureus* from milk and milk products in the geopolitical zones of Nigeria; Key: NC - north-central, NW - northwest, NE - northeast, SW - southwest, SE - southeast, SS - south-south