Martínez-Vázquez et al. Annals of Microbiology (2021) 71:16
https://doi.org/10.1186/s13213-021-01627-7

Annals of Microbiology

ORIGINAL ARTICLE Open Access

Detection of multi-drug resistance and methicillin-resistant *Staphylococcus aureus* (MRSA) isolates from retail meat in Tamaulipas, Mexico

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Abstract

Purpose: Among the principal microorganisms transmitted to humans by foods of animal origin, *Staphylococcus aureus* stands out, causing a variety of diseases and with a wide potential for acquiring antimicrobial resistance. This work aimed to determine the prevalence of *S. aureus*, its multi-drug resistance (MDRSA), and the identification of methicillin-resistant *Staphylococcus aureus* (MRSA) in retail beef and pork in the state of Tamaulipas, Mexico.

Methods: *S. aureus* strains isolated from retail meat were characterized by microbiological and molecular methods to determine phenotypic drug-resistance and detect MRSA strains.

Results: Of the 106 samples (54 from beef and 52 from pork) from 11 different cities, we detected a prevalence of *S. aureus* of 44.3% (47/106). A total of 87 *S. aureus* strains were identified; these presented 54 resistance patterns to different antimicrobials with a high prevalence of MDRSA (85%) and a low prevalence of MRSA strains (3%).

Conclusion: These results indicate the presence of MDRSA and MRSA in retail beef and pork in Tamaulipas, representing a high risk for consumer health.

Keywords: *Staphylococcus aureus*, Multi-drug resistance, *mec*A, MRSA, Meat, Mexico

Introduction

Staphylococcus aureus (*S. aureus*) is a normal member of the bacterial microbiota in mammals and birds but, it can also cause a wide spectrum of diseases, such as soft tissue infections, bacteremia, septicemia, and pneumonia (Aklilu et al. 2010; García-Álvarez et al. 2011; Grema et al. 2015; Lozano et al. 2016). In recent years, reports of community-acquired *S. aureus* have increased with this being detected in farm, wild, and service animals (Grema et al. 2015; Lozano et al. 2016; Aires de Sousa 2017). Animals destined for human consumption harboring those bacteria can act as a transmitter (Ou et al. 2017) since large numbers of *Staphylococcus* can adhere to stainless steel surfaces where meats are manipulated and packaged (Karmi 2013); this can cause cross-contamination. The detection of *S. aureus* in meat is related to poor sanitary practices during processing and handling in retail outlets (Bettin et al. 2012; Igbinosa et al. 2016). Together with this, in cattle breeding, antibiotics may be used as prophylactics and to increase yields, estimating that worldwide, 80% of marketed antibiotics are administered to cattle (Ventola 2015; Haskell et al. 2018); however, in Mexico, since 2010 antibiotics use has been restricted but despise that in some case are still being used in cattle. This can result in the selection of resistant bacteria that later can be distributed in different environments favoring the dissemination of multi-drug-resistant *Staphylococcus aureus*

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(MDRSA) strains (Tanwar et al. 2014; Fan et al. 2015). Furthermore, methicillin-resistant *S. aureus* (MRSA) commonly exhibit multiple resistances to β-lactams, aminoglycosides, fluoroquinolones, and chloramphenicol (Normanno et al. 2007a, b; Guven et al. 2010). The prevalence of MDRSA and MRSA shows different ranges of contamination in raw meat, which varies by type of meat, sampling period, continent, and retail outlet (OU et al. 2017). Therefore, the aim of this study was to determine the prevalence of *S. aureus*, its multidrug resistance (MDRSA), and the identification of methicillin-resistant *Staphylococcus aureus* (MRSA) in retail sale of beef and pork in Tamaulipas, Mexico.

Materials and methods

Sample collection

Meat samples were collected between August 2013 and March 2014 from 55 supermarkets and retail stores (butcheries) located in 11 cities of Tamaulipas, Mexico. Five supermarkets from each city were randomly sampled. From each store, one ground beef and one ground pork samples were randomly purchased in 500-g packages. All packages were transported in ice containers and were only opened for processing in the laboratory of the Centro de Biotecnología Genómica of the Instituto Politécnico Nacional (Reynosa, Tamaulipas, Mexico).

Isolation and identification of Staphylococcus aureus

Microbiological analysis was performed according to the national Mexican standard for pathogen detection in foods (NOM-210-SSA-2014). Briefly, 25 g of ground meat from each sample was mixed with 225 mL of lactose broth. The broth was incubated for 24 h at 37 °C to enrich growth. Following incubation, samples were cultured for 24–48 h at 37 °C on mannitol salt agar (MSA) plates (Becton Dickinson & Co.). After incubation, presumptive colonies with morphological characteristics of *S. aureus* were selected. Three presumptive *S. aureus* colonies per meat sample were randomly selected for purification using trypticase soy agar (TSA) (BD Becton Dickinson & Co.). All suspect colonies were confirmed by the coagulase test (Quinn et al. 2002).

PCR identification of Staphylococcus aureus

DNA was extracted from the prospective *S. aureus* strains using the cell lysis method. One-day-old colonies were picked, suspended in MiliQ water, and lysed by incubation at 95 °C for 15 min, followed by centrifugation at 13, 000×*g* for 3 min. A PCR reaction was used to identify *S. aureus* by nuclease gene using reference primers SA-1 GCGATTGATGGTGATACGGTT and SA-2 CAAGCC TTGACGAACTAAAGC were used to amplify a 276 bp fragment (Wang et al. 1997).

The total reaction volume of 20 μL contained buffer 1×, $MgCl_2$ 25 mM, dNTPs 10 mM, primer 10 mM, Taq DNA polymerase 5 U. Verification of PCR products was performed in electrophoresis using 2.5% agarose gel with 0.5× TBE and SYBR gold at 100 V for 45 min. A molecular weight marker was used (100 bp Promega). All PCR included *S. aureus* ATCC 25923 as positive control and the negative control consisted of all contents of the reaction mixture excluding template DNA which was substituted with 1 μL sterile water. The DNA bands were visualized and photographed under UV light.

Antimicrobial susceptibility testing

Antimicrobial susceptibility patterns were tested by the agar disc diffusion method using Muller-Hinton agar (Becton Dickinson & Co.), according to the Clinical and Laboratory Standards Institute guidelines (CLSI 2017). The antimicrobial disks were individually firmly placed on the inoculated plate. The plates were incubated at 37 °C for 24 h. A total of 14 antimicrobial agents were tested: ampicillin (AM; 10 μg), cephalothin (CF; 30 μg), cefotaxime (CTX; 30 μg), cefepime (FEP; 30 μg), cefuroxime (CXM; 30 μg), dicloxacillin (DC; 1 μg), erythromycin (E; 15 μg), gentamicin (GE; 10 μg), levofloxacin (LEV; 5 μg), penicillin (PE; 10 U), tetracycline (TET; 30 μg), trimethoprim/sulfamethoxazole (SXT; 25 μg), oxacillin (OX; 1 μg), and vancomycin (V; 30 μg). After incubation, the diameter of the clear zone of inhibition around each antimicrobial disk was measured in millimeters and the results were interpreted according to interpretative criteria provided by the CLSI. These drugs are representative of the major classes of antimicrobials important to both veterinary and human medicine.

Detection of antimicrobial resistance genes

All *S. aureus* isolates were tested for *mec*A presence using a PCR assay (Bhutia et al. 2012).

The primers for the amplification of *mec*A gene were MECAP4 TCCAGATTACAACTTCACCAGG and ME CAP7 CCACTTCATATC TTGTAACG.

The reactions were prepared in volumes of 20 μL and amplifications were performed using buffer 1×, $MgCl_2$ 25 mM, dNTPs 10 mM, primers 10 mM, Taq DNA polymerase 5 U and sterile water. All PCR reactions were analyzed by electrophoresis on 1.5% agarose gel in 1× TBE buffer. The sizes of the amplification products were estimated by comparison with a 100 bp molecular size ladder.

Results and discussion

Prevalence of Staphylococcus aureus

A total of 106 meat samples (54 from beef and 52 from pork) from 55 businesses in 11 different cities were analyzed. Of the samples, 44.3% (47/106) were positive for *S. aureus*, confirmed by coagulase and PCR. *S. aureus* was detected in 9 of the 11 cities sampled. The city with

the greatest prevalence was Altamira with 8.4% (9/106); the lowest prevalence was recorded in Matamoros with 1.8% (2/106). Río Bravo and Valle Hermoso did not have *S. aureus* strains (Table 1). *S. aureus* was more frequently isolated in pork, 50% (26/52), while in beef, it was isolated in 38.8% (21/54).

One of the main routes of transmission is the food of animal origin, such as meat. In this work, a global prevalence of *S. aureus* of 44.3% (47/106 samples), and a prevalence by type of meat of 50% (26/52) for pork and 38.8% (21/54) for beef was found. In both cases, the prevalence was higher than the mean (29.2%) reported in a global meta-analysis by Ou et al. (2017) that includes different raw meats from several countries. Additionally, in the USA, a prevalence lower than our results was found. For example, Haskell et al. (2018) reported a prevalence of *S. aureus* of 30.8% in pork and 20.8% in beef; Ge et al. (2017), 22.6% in pork and 24.5% in beef; Thapaliya et al. (2017), 34.6% in pork and 24.4% in beef; and Buyukcangaz et al. (2013), 49.2 in pork and 27% in beef. This variety of results in the prevalence of *S. aureus* can be due to the practices of handling in each region or country and the type of meat (Zehra et al. 2019). However, considering the type of meat, this work and reported studies, coincide in reporting a greater prevalence of *S. aureus* in pork. The presence of *S. aureus* can represent a risk but correct cooking of the meat can inactivate these contaminants. However, when handling raw meat, this can come into contact with other raw foods, surfaces, or utensils, contaminating other foods or recontaminating the meat or be distributed in the water when washing utensils (Arguello et al. 2013).

Antimicrobial susceptibility

Of the 106 meat samples included in this study, 3 colonies were isolated and identified from each, obtaining a total of 318 strains. From this total of samples, only 47 were positive for *S. aureus*, obtaining from each sample 1 or more positive strains. In this way, from 47 positive samples, a total of 141 strains were analyzed with only 87 strains (87/141) being confirmed positive for *S. aureus*. This indicates a prevalence of 39.0% (34/87) in beef and 60.9% (53/87) in pork. Later, phenotypic antimicrobial susceptibility testing of the 87 strains was performed. As a result, 87.7% (85/87) of the *S. aureus* were resistant to at least one antibiotic and only 2.2% of the strains (2/87) did not show any resistance to any of the 14 antibiotics tested (Table 2). When observing the individual results of each antibiotic, the strains showed the highest percentages of resistance to dicloxacillin (DC) and penicillin (PE), both with 86.2% (75/87), followed by ampicillin (AM) with 85.0%, and oxacillin (OX) with 80.4% (Table 2). In contrast, strains were susceptible to gentamicin (GE) in 90.8% and to levofloxacin (LEV) in 81.6%. None of the analyzed strains was susceptible to the 14 antibiotics tested (Table 2). When analyzing the resistance combination to the different antibiotics of each of the 87 strains, a total of 54 resistance patterns were observed. Of these, 12 patterns repeated and 42 were unique (Table 3). According to the formula described by Selim et al. (2013), strains that showed resistance to more than 4 antibiotics were considered multiresistant, thus, 85% (74/87) were MDRSA, 70% (61/87) exhibited simultaneous resistance to 4 to 9 antibiotics, and a single strain (isolated from beef from Victoria City) was resistant to 100% of the antibiotics tested (14/14).

Table 1 Prevalence of *Staphylococcus aureus* in 11 locations in Tamaulipas

Locations	Prevalence total		Pork				Beef			
			Sample		Strains		Sample		Strains	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Victoria	6/10	60	4/5	80	4/26	15.3	2/5	40	2/21	9.5
Reynosa	5/10	50	3/5	60	3/26	11.5	2/5	40	2/21	9.5
Matamoros	2/10	20	0/5	0	0/26	0	2/5	40	2/21	9.5
Tampico	5/10	50	2/5	40	2/26	7.6	3/5	60	3/21	14.2
Altamira	9/10	90	5/5	100	5/26	19.2	4/5	80	4/21	19
Rio Bravo	0/10	0	0	0	0	0	0	0	0	0
Miguel Alemán	3/10	30	2/5	40	2/26	7.6	1/5	20	1/21	4.7
Valle Hermoso	0/10	0	0	0	0	0	0	0	0	0
Hidalgo	5/10	50	3/5	60	3/26	11.5	2/5	40	2/21	9.5
Nuevo Laredo	7/10	70	4/5	80	4/26	15.3	3/5	60	3/21	14.2
Mante	5/10	50	3/5	60	3/26	11.5	2/5	40	2/21	9.5

Table 2 Resistance patterns of *S aureus* isolated in meat from Tamaulipas

No. antimicrobial resistance	Pattern codes	Resistance pattern																Pattern prevalence	Multidrug prevalence
0	P0																		2/87 (2.2%)
1	P1															LEV		1/87 (1.1%)	3/87 (3.4%)
	P2									STX								1/87 (1.1%)	
	P3	DC																1/87 (1.1%)	
2	P4	DC															GE	1/87 (1.1%)	4/87 (4.5%)
	P5	DC								STX								1/87 (1.1%)	
	P6	DC							TE									2/87 (2.2%)	
3	P7	DC		AM												LEV		1/87 (1.1%)	4/87 (4.5%)
	P8	DC	PE	AM														1/87 (1.1%)	
	P9	DC		AM	OX													1/87 (1.1%)	
	P10	DC	PE		OX													1/87 (1.1%)	
4	P11	DC	PE	AM							FEP							3/87 (3.4%)	11/87 (12.6%)
	P12		PE	AM	OX				TE									1/87 (1.1%)	
	P13		PE	AM	OX		E											2/87 (2.2%)	
	P14	DC	PE	AM	OX													2/87 (2.2%)	
	P15	DC	PE	AM				CF										1/87 (1.1%)	
	P16	DC			OX	V			TE									1/87 (1.1%)	
	P17	DC	PE		OX	V												1/87 (1.1%)	
5	P18	DC	PE	AM	OX						FEP							2/87 (2.2%)	7/87 (8.0%)
	P19	DC	PE	AM	OX	V												3/87 (3.4%)	
	P20	DC	PE	AM			E	CF										1/87 (1.1%)	
	P21	DC	PE	AM	OX		E											1/87 (1.1%)	
6	P22		PE	AM	OX	V	E			STX								2/87 (2.2%)	9/87 (10.3%)
	P23		PE	AM			E	CF		STX							GE	1/87 (1.1%)	
	P24		PE	AM	OX		E		TE		FEP							1/87 (1.1%)	
	P25		PE	AM	OX	V	E		TE									1/87 (1.1%)	
	P26	DC	PE	AM	OX					STX	FEP							1/87 (1.1%)	
	P27	DC	PE		OX			CF	TE	STX								1/87 (1.1%)	
	P28	DC	PE	AM	OX		E		TE									1/87 (1.1%)	
	P29	DC	PE	AM	OX				TE	STX								1/87 (1.1%)	
7	P30	DC	PE	AM	OX			CF	TE	STX								1/87 (1.1%)	18/87 (20.6%)
	P31	DC	PE	AM	OX				TE	STX		CTX						1/87 (1.1%)	
	P32	DC	PE	AM	OX		E	CF	TE									1/87 (1.1%)	
	P33	DC	PE	AM	OX		E		TE		FEP							1/87 (1.1%)	
	P34	DC	PE	AM	OX	V	E	CF										11/87 (12.6%)	
	P35	DC	PE	AM	OX	V	E		TE									1/87 (1.1%)	
	P36	DC	PE	AM	OX	V		CF					CXM					1/87 (1.1%)	
	P37	DC	PE	AM	OX	V			TE		FEP							1/87 (1.1%)	
8	P38	DC	PE	AM	OX	V	E			STX						LEV		1/87 (1.1%)	6/87 (6.8%)
	P39	DC	PE	AM	OX	V	E	CF	TE		FEP		CXM					1/87 (1.1%)	
	P40	DC	PE	AM	OX	V	E	CF				CTX						1/87 (1.1%)	
	P41	DC	PE	AM	OX	V	E	CF	TE									2/87 (2.2%)	
	P42	DC	PE	AM	OX	V	E		TE	STX								1/87 (1.1%)	

Table 2 Resistance patterns of *S aureus* isolated in meat from Tamaulipas *(Continued)*

No. antimicrobial resistance	Pattern codes	Resistance pattern														Pattern prevalence	Multidrug prevalence
9	P43	DC	PE	AM	OX			CF	TE	STX		CTX	CXM			1/87 (1.1%)	13/87 (14.9%)
	P44	DC	PE	AM	OX	V	E	CF				CTX	CXM			4/87 (4.5%)	
	P45	DC	PE	AM	OX			CF		STX	FEP	CTX	CXM			1/87 (1.1%)	
	P46	DC	PE	AM	OX				TE	STX	FEP	CTX	CXM			1/87 (1.1%)	
	P47	DC	PE	AM	OX		E	CF	TE	STX		CTX				1/87 (1.1%)	
	P48	DC	PE	AM	OX	V	E		TE		FEP	CTX				1/87 (1.1%)	
	P49	DC	PE	AM	OX	V	E	CF	TE				CXM			1/87 (1.1%)	
	P50	DC	PE	AM	OX	V	E	CF	TE	STX						3/87 (3.4%)	
10	P51	DC	PE	AM	OX		E		TE	STX	FEP	CTX	CXM			1/87 (1.1%)	1/87 (1.1%)
11	P52	DC	PE	AM	OX		E	CF	TE	STX	FEP	CTX	CXM			1/87 (1.1%)	8/87 (9.1%)
	P53	DC	PE	AM	OX	V		CF	TE	STX	FEP	CTX	CXM			7/87 (8.0%)	
12																	0/87 (0%)
13																	0/87 (0%)
14	P54	DC	PE	AM	OX	V	E	CF	TE	STX	FEP	CTX	CXM	LEV	GE	1/87 (1.1%)	1/87 (1.1%)

AM ampicillin, *CF* cephalotin, *CTX* cefotaxim, *FEP* cefepime, *CXM* cefuroxime, *DC* dicloxacillin, *E* erythromycin, *GE* gentamicin, *LEV* levofloxacin, *PE* penicillin, *TE* tetracycline, *SXT* trimethoprim/sulfamethoxazole, *OX* oxacillin, *V* vancomycin

The prevalence percentage of *S. aureus* (44.3%) in the samples in this work, which indicates inadequate handling of raw pork and beef marketed in Tamaulipas, Mexico, highlights the need for good handling practices in raw meat to provide the consumer with safe food and prevent the spread of MDRSA strains.

The selection of multi-drug-resistant strains makes it harder to treat *S. aureus* infections. The FDA in 2017 reported that of the antibiotics used in raising animals for consumption, 42% are applied to cattle and 36% to pigs (FDA 2018). In our results, of the 87 strains identified as *S. aureus*, 97.7% (85/87) showed resistance to one of the 14 antibiotics tested and 85% (74/87) were multi-resistant to 4 to 11 antibiotics. Of the 85% (74/87) that were multi-resistant, 20.2% (15/87) were strains from Altamira, 14.8% (11/74) were from Nuevo Laredo, 13.5% from Victoria and 13.5% from Tampico (10/87 each), and 9.1% (8/74) were from Hidalgo. This level of

Table 3 Antimicrobial susceptibility results of *Staphylococcus aureus* isolated in meats from Tamaulipas

Group	Microbial agent		Antimicrobial susceptibility					
			R	%	*I*	%	*S*	%
B-lactams	Ampicillin	AM	**74/87**	85.0	**0/87**	0.0	**13/87**	14.9
	Dicloxacillin	DC	**75/87**	86.2	**12/87**	13.7	**0/87**	0.0
	Penicillin	PE	**75/87**	86.2	**0/87**	0.0	**12/87**	13.7
	Oxacillin	OX	**70/87**	80.4	**4/87**	4.5	**13/87**	14.9
Cefalosporin	Cefalotin	CF	**42/87**	48.2	**15/87**	17.2	**30/87**	34.4
	Cefotaxime	CTX	**21/87**	24.1	**52/87**	59.7	**14/87**	16.0
	Cefepime	FEP	**27/87**	31.0	**35/87**	40.2	**25/87**	28.7
	Cefuroxim	CXM	**20/87**	22.8	**45/87**	51.7	**22/87**	25.2
Macrolides	Erythromycin	E	**43/87**	49.4	**35/87**	40.2	**9/87**	10.3
Aminoglycosides	Gentamicin	GE	**3/87**	3.4	**5/87**	5.7	**79/87**	90.8
Quinolones	Levofloxacin	LEV	**5/87**	5.7	**11/87**	12.6	**71/87**	81.6
Tetracyclines	Tetracycline	TE	**37/87**	42.5	**30/87**	34.4	**20/87**	22.9
Sulfonamides	Sulfamethoxazole/trimethoprim	STX	**29/87**	33.3	**10/87**	11.4	**48/87**	55.1
Glycopeptides	Vancomycin	V	**45/87**	51.7	**36/87**	41.3	**6/87**	6.8

MDRSA is greater than results reported (10.4%) in meat isolates by Ge et al. (2017) or those reported (23%) by Thapalypa et al. (2017) in *S. aureus*. Considering the resistance patterns, in this case there were 54 different patterns; this is slightly less than that reported by Pekana et al. (2018) (64 patterns in 87 strains of *S. aureus*) in bovine canals of Africa. The pattern identified as "P34" showed greater prevalence, repeating its multi-resistance to 7 antibiotics in 11 different strains (11/87; 12.6%) without a specific geographic distribution (1 strain in Altamira, 1 in Nuevo Laredo, 3 in Miguel Alemán, 2 in Reynosa, and 4 in Victoria City). This was followed by "P54", which was multi-resistant to 11 antibiotics with a prevalence of 8.0% (7/87), belonging to 6 strains from Altamira and 1 from Victoria City. "P44" was resistant to 4 antibiotics with a prevalence of 4.5% (4/87), with 3 isolated in Hidalgo and 1 in Nuevo Laredo. The remaining patterns were repeated in two or three strains with a prevalence between 2.2 and 3.4%. The strains that were multi-resistant to 7 to 14 antibiotics came mainly from Altamira, Hidalgo, and Victoria City. The multi-resistant combination that repeated the most was DC-PE-AM-OX-TE, which coincides with the antibiotics most frequently used in cattle breeding. The 86.2% resistance to penicillin that was detected, agrees with that reported in similar work from different countries, within a range of 69 to 100% (Cho et al. 2014; Dehkordi et al. 2017; Ge et al. 2017; Pekana et al. 2018; Wu et al. 2018; Zehra et al. 2019). On the other hand, the 80.4% resistance to oxacillin detected is much higher than that published by other authors, who obtained values lower than 10% (Cho et al. 2014; Fan et al. 2015; Ge et al. 2017; Zehra et al. 2019). The 57.4% resistance to tetracyclines falls in the range reported by other authors, between 38.7% and 84% (Tang et al. 2017; Ge et al. 2017; Wu et al. 2018; Zehra et al. 2019). In the USA, 52% of *S. aureus* isolated from meat and chicken samples are multi-resistant to penicillin, ampicillin, and tetracyclines (Waters et al. 2011), and recently similar resistance was reported from Pakistan (Sadiq et al. 2020), which is consistent with our results. In Mexico, we did not find data on the consumption of antibiotics in cattle breeding. However, the Food and Drug Administration (FDA) in the USA reports that tetracyclines are applied in 44% in cattle, 45% in pigs, and only 10% in chicken, turkey, and other species (FDA 2018), while penicillins are used only in 14% in cattle, 61% in turkey, and 25% in other species (FDA 2018). Additionally, the presence of MRSA has been documented in foods, which could be of animal or human origin (Waters et al. 2011; Ogata et al. 2012). In this study, the mean presence of MRSA was identified in 3.4% (3/87) of the analyzed strains. The prevalence of MRSA in beef was 2.9% (1/34) and for pork, 3.7% (2/53). This prevalence is within the range of 0.3 to 20% reported in similar work. One example of this are the results published by Haskell et al. (2018) with a prevalence of MRSA in beef of 2.8% (1/36) and in pork of 18% (7/38); Ge et al. (2017), 1.7% in beef and 1.9% in pork; and Thapaliya et al. (2017), 1.3% in beef and 1.9% in pork. The *S. aureus* strains identified as MRSA in this study were multi-resistant to 10 to 14 different antibiotics in groups such as aminoglycosides and tetracyclines (2 strains from Altamira and 1 from Victoria City). This has been widely reported by several authors (Wang et al. 2014; Reynaga et al. 2016; Abreu et al. 2019); although this prevalence could be considered low, the presence of MRSA strains resistant to multiple drugs in food represents a potential threat to consumers and emphasizes the need for better control of sources of contamination (Wang et al. 2014).

Methicillin-resistant Staphylococcus aureus

Of the 87 *S. aureus* strains analyzed, in 3.4% (3/87), the presence of *mec*A was detected, confirming these as MRSA. A total of three MRSA strains that were identified also showed multi-drug resistance to 10 to 14 antibiotics. Two MRSA strains were found in pork from Altamira (one multi-resistant to 10 antibiotics and another to 12), and one strain was isolated in beef from Victoria City (multi-resistant to 14 antibiotics tested).

To our knowledge, this is the first work of resistance profiles and methicillin resistance in *S. aureus* present in beef and pork sold in retail locations in different municipalities of Tamaulipas that shows that the meat of production animals, in addition to being a health risk, is also a potential vehicle for the transmission of *S. aureus* with antimicrobial resistance.

This study showed a high prevalence of *S. aureus* (44.3%) in meat marketed in Tamaulipas, with a high level of multi-resistance (85%) that represents a potential risk to consumer health and a multi-resistance reservoir. This risk increases by having the presence of methicillin-resistant *S. aureus* strains (MRSA 3.4%). Therefore, better control in handling meat is suggested, with stricter sanitary conditions, both in the handlers, as well as in the utensils and surfaces, avoiding in this way, direct or cross-contamination of retail meat.

Acknowledgements

AVMV, VBG, and GRS are COFAA and EDI are scholarship recipients of the Instituto Politécnico Nacional and members of the National Researchers System (SNI).

Authors' contributions

AVMV and RFM contributed to the microbiological laboratory and data analyses, helped in the study design, and integrated the first draft. IBGA did the molecular analysis of the strains. GRS prepared tables and contributed to design the work that led to the submission, and VBG helped in the drug-resistance tests, interpreted results, and contributed to revise the manuscript and approved the final version. All authors read and approved the final manuscript.

Funding
Not applicable.

Availability of data and materials
Data is available under request.

Declarations

Ethics approval and consent to participate
Not applicable

Consent for publication
All coauthors have consent and approve the paper for publication.

Competing interests
None of the authors of this study has any financial interest or conflict with industries or parties.

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Received: 23 November 2020 Accepted: 1 March 2021
Published online: 30 March 2021

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