Investigation of meca- and mecC-positive Staphylococcus aureus from raw milk and traditional artisanal dairy foods

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Abstract

The recent emergence of LA-MRSA and their identification in people in contact with livestock has increased their importance for dairy sector and has led to the need to check MRSA presence in dairy foods. Therefore, a total of 285 dairy food samples were analyzed for the presence of MRSA. The 285 samples included raw milk (50 samples), traditional cheeses consisting of white-pickled cheese (50 samples) and Tulum cheese (50 samples), yogurt (25 samples), butter (25 samples), traditional clotted cream (20 samples), pastry cream (50 samples), and traditional Maras ice-cream (15 samples). The isolation procedure of S. aureus followed the EN/ISO 6888–1 (01/2004) method. Out of 99 presumptive isolates, 27 S. aureus isolate were identified by both MALDI-TOF MS and PCR. Overall, 15 out of 285 samples (5.26%) were contaminated by S. aureus; however, mean contamination level of S. aureus between different types of foods was observed as the highest in pastry creams with 6.4 × 10² CFU/g. No S. aureus was isolated in yogurt, butter, traditional clotted cream, and traditional Maras ice-cream samples. Strains with MRSA characteristics were investigated by real-time PCR (RT-PCR)-targeting meca and mecC genes. Out of 27 S. aureus strains, 4 strains carried a gene meca in 2 strains, isolated from raw milk (sample no: 27) and a white-pickled cheese (sample no: 46); 2 strains carried mecC gene, isolated from 2 different pastry creams (sample no: 33 and 44), and only a strain isolated from a pastry cream (sample no: 21) harbored both meca and mecC genes. None of the strains from Tulum cheeses were positive with either meca or mecC genes. This study revealed the relationship of MRSA with raw milk and traditional artisanal dairy products. Extra preventive measures to avoid MRSA-contaminated dairy foods must be applied as their consumption poses a potential risk to public health.

Keywords

Staphylococcus aureus; methicillin-resistance; MRSA; meca; mecC; raw milk; dairy foods; artisanal; traditional; MALDI-TOF MS; real-time PCR

Introduction

Methicillin-resistant Staphylococcus aureus (MRSA) has become one of the most serious life-threatening antibiotic-resistant bacteria since its emergence among humans in association with healthcare units in the 1960s. In addition to the Hospital-Acquired MRSA (HA-MRSA) and the Community-Acquired MRSA (CA-MRSA) strains, there is an emerging problem of MRSA colonization in food-producing animals [Livestock-Acquired MRSA (LA-MRSA)] due to the widespread improper use of antibiotics in the veterinary sector and their zoonotic transmission to people in contact with livestock. This has also raised concerns on the presence of foodborne MRSA variants which may occur by human contamination of carcasses and meat products at abattoir or meat processing plants and of raw milk and traditional artisanal dairy foods at smallholder dairy farms due to the manual handling during processing which underscores the need to check MRSA in...
animal-derived foods to reduce their risk to public health.\textsuperscript{[8–10]} Moreover, the presence of MRSA in the environment of dairy farms and on the dairy processing surfaces may also be a source of MRSA contamination of foods due to its survival for several months.\textsuperscript{[5,11,12]}

Many reports\textsuperscript{[9,13–25]} have identified the presence of MRSA in different raw milk and dairy products from different regions worldwide with varied prevalence. The first MRSA foodborne outbreak was occurred in 1992 as reported by Kluytmans et al.\textsuperscript{[26]} Since then, foodborne-acquired MRSA outbreaks have been also reported.\textsuperscript{[27]}

Methicillin resistance in \textit{S. aureus} is not mediated by plasmid-borne-lactamase. MRSA synthesizes a penicillin-binding protein (PBP2a), encoded by the \textit{mecA} gene on a mobile genetic element of Staphylococcal cassette chromosome mec (SCCmec), which has a role in counteracting the inhibitory effect of currently available β-lactam antibiotics, including methicillin, oxacillin, penicillin, cephalosporin, carbapenem, and their derivatives, by preventing them from effectively binding to cell wall proteins.\textsuperscript{[28,29]} \textit{mecA} gene is not unique to \textit{S. aureus} but has been reported in other staphylococcal species (\textit{S. sciuri}, \textit{S. pseudintermedius}, \textit{S. intermedius}, \textit{S. vitulinus}, \textit{S. epidermidis}, \textit{S. haemolyticus}).\textsuperscript{[30]} In addition to the \textit{mecA} gene, there is also the \textit{mecC} gene which is found in \textit{S. aureus} cattle and human isolates exhibiting ~69% nucleotide identity with the \textit{mecA} gene. Although \textit{mecA}- and \textit{mecC}-encoded proteins show different biochemical properties, \textit{mecC} still confers methicillin resistance.\textsuperscript{[30–32]} Hence, the detection of this gene should be included in screening correct differentiative identification of \textit{mecA}- and \textit{mecC}-\textit{S. aureus} strains as MRSA by PCR-based methods.\textsuperscript{[33]} Therefore, in our study, not only the \textit{mecA} gene but also the \textit{mecC} gene were investigated to reveal the presence of MRSA in raw milk and traditional artisanal dairy products by RTiPCR.

Traditionally manufactured artisanal dairy foods such as White-pickled cheeses, Tulum cheeses, clotted creams, and Maras ice-creams are very popular in Turkey. The small-scale production of these dairy foods requires extensive manual processing by the dairy workers, usually under neglected hygienic conditions which favor the growth of \textit{S. aureus}. Although methicillin profiles of clinical \textit{S. aureus} isolates are well-studied, there is a little information on foodborne MRSA in Turkey. Therefore, this study aimed to determine the presence of MRSA in raw milk and traditional artisanal dairy foods in Central Anatolia and the Mediterranean Regions of Turkey. To the best of our knowledge, this is the initial study to show the prevalence of MRSA strains in raw milk and some traditional artisanal dairy products in Turkey by MALDI-TOF MS identification and RTiPCR analysis of both \textit{mecA} and \textit{mecC} genes.

**MATERIALS AND METHODS**

**Collection and preparation of samples for analysis**

During January 2020 – April 2021, a total of 285 samples of raw milk and unpackaged artisanal dairy products (Table 1) were collected on a random basis at various villagers, local bazaars, retail outlets,

| Sample type                  | Number of samples |
|------------------------------|-------------------|
| Raw milk                     | 50                |
| \textit{Traditional cheeses} | 50                |
| White-pickled cheese         | 50                |
| Tulum cheese                 | 25                |
| Yogurt                       | 25                |
| Butter                       | 25                |
| Traditional clotted cream    | 20                |
| Pastry cream                 | 50                |
| Traditional Maras ice cream  | 15                |

Total: 285
and raw milk collection areas in Central Anatolia and Mediterranean Regions of Turkey. All samples were placed in an ice-cooled box and then transported to the laboratory on ice bags for analysis that was initiated within 2–5 h of collection. The isolation and the quantitative analysis of *S. aureus* were performed according to the EN/ISO 6888–1 (01/2004) method with 25 g samples were transferred into sterile Stomatcher bags containing 225 mL of sterile ¼ strength Ringer’s solution (Merck, Germany). The samples (except then raw milk) were then homogenized for 60 s at maximum speed in a Stomacher blender (Seward Stomacher 80, UK). The resulting solutions and the raw milk samples were 10-fold serially diluted with sterile ¼ strength Ringer’s solution to a factor of 10⁰. In the case of butter and traditional Maras ice-cream samples, 25 g from each sample were left to melt in a thermostatically controlled water bath at 40–42°C for less than 10 min before their serial dilutions were made.

**Bacterial isolation and enumeration**

Aliquots of suitable diluted solutions were spread plated at volumes of 0.1 mL on Baird-Parker agar supplemented with egg yolk tellurite emulsion (Merck, Germany) and incubated under aerobic conditions at 37°C for 24–48 h. Typical staphylococcal colonies (black, shiny, convex colonies with 2 to 5 mm clear zones, with or without an opaque zone) were counted after 24 h of incubation. If present, 5 egg yolk reaction-positive colonies were chosen from each sample for further identification. Additionally, even the colonies that were not likely to be typical were investigated to ensure that no cultured staphylococci were inadvertently missed from subsequent analysis. Such isolates were selected for species identification based on MALDI-TOF MS and PCR analysis. Samples were categorized as positive if at least one colony-forming unit (CFU) was isolated. In the samples with more than one CFU, all colonies were selected for MALDI-TOF MS identification (which served as a reference for PCR for expediting the identification confirmation), and the identified *S. aureus* colonies were then confirmed by PCR analysis.

**MALDI-TOF MS and PCR identification**

Identification of presumptive isolates was done via their unique protein profiles (mass spectrum) generated by the MALDI-TOF MS device (Bruker Microflex LT, Germany) and then matched to a reference database of known microbial spectra (Main SPeectra; MSP). For microbial biomass analysis, the direct transfer method previously described by Cameron et al. was used. For this, a single colony was taken from each presumptive isolate with the help of a sterile wooden applicator stick and placed onto a special steel MSP 96-spot target (Bruker Daltonics, Germany), followed by smearing a thin film of colony material onto this steel MSP 96-spot target in duplicate. The spots were allowed to air dry at room temperature. Subsequently, the spots were overlaid with 1.0 μL of a saturated solution of the α-cyano-4-hydroxycinnamic acid matrix (HCCA matrix) in 50% acetonitrile, 47.5% water, and 2.5% trifluoroacetic acid (Sigma-Aldrich, Canada) using single-use pipette tips and air-dried at room temperature. The MSP 96-spot target was placed in the MALDI-TOF MS device, and the system was operated using the optimized method for the identification of microorganisms in linear positive ion mode at a 2 000–20 000 Da mass range. A 60 Hz nitrogen laser was employed at 337 nm as the ion source. To get the spectra, laser pulses consisting of 40 packets of 240 were applied in the measurement of each bacterial colony. Each sample was studied in triplicate and the highest readings were included in the analysis. All targets were calibrated using the Bacterial Test Standard (Bruker Daltonics, Germany) and included *S. aureus* ATCC 29213 and *Escherichia coli* ATCC 25922 control classification samples in duplicate. To confirm that target cleaning was effective and no residual bacterial material from a previous run remained, one spot on each target contained the only matrix with no bacterial sample.
Strains that were identified by MALDI-TOF MS as *S. aureus*, were further confirmed by using the PCR-based amplification of the *nuc* gene encoding the thermonuclease enzyme specific for *S. aureus*, which was previously described by Brakstad et al.\[^{35}\] In addition, the contamination of *S. aureus* in dairy food groups was statistically analyzed by IBM SPSS Statistics 23 program. For this, all suspensions were first treated with high pure PCR template preparation (HPPTP) kit (Roche Diagnostics, Germany) to extract and purify DNA, according to the manufacturer’s protocol. The resulting solution was the template DNA and was subjected to PCR. All confirmed 27 *S. aureus* strains were stored at −80°C in Brain Heart Infusion (BHI) broth (Merck, Germany) containing 25% glycerol (Sigma-Aldrich, the USA) until further characterization of their MRSA potential.

**Detection of MRSA genes**

The presence of MRSA was investigated via RTiPCR-targeting *mecA* and *mecC* genes. The sequences of all the primers and probes used are shown in Table 2. RTiPCR assay was performed in 1.5 h by a LightCycler\(^\text{®}\) 480 (Roche Diagnostics, Germany) in a 20-µL volume containing 9 µL of PCR grade water, 2 µL of each primer and probe (10x conc.), 4 µL of LightCycler\(^\text{®}\) TaqMan\(^\text{®}\) master mix (5x conc.) (Roche Diagnostics, Germany) and 5 µL of sample DNA. The RTiPCR amplification reaction conditions include an initial denaturation step at 95°C for 10 min, and then 45 cycles of amplification steps at 95°C for 10 s, 60°C for 20 s, and 72°C for 1 s, followed by a cooling step at 40°C for 30 s. This RTiPCR assay amplifies and simultaneously detects fragments of *mecA* and *mecC* genes of MRSA by using the sequence-specific primers in a PCR. All the runs in this study were carried out in duplicates and in each test, DNA of pure reference strains (*S. aureus* NCTC 12493 as *mecA*-positive *S. aureus* and *S. aureus* NCTC 13552 as *mecC*-positive *S. aureus*) served as positive controls and ultra-pure H₂O was served as the negative control, respectively. A sample was suspected to be MRSA positive when the RTiPCR resulted in a threshold cycle (C\(_T\)) value of 33 or lower.

**RESULTS AND DISCUSSION**

**Presence of *S. aureus* in raw milk and traditional artisanal dairy foods**

A total of 285 dairy foods (n = 285) (Table 1) were examined for the presence of *S. aureus* and MRSA by using MALDI-TOF MS and RTiPCR analysis, respectively. Out of 99 presumptive isolates, 27 *S. aureus* were identified by MALDI-TOF MS. The other isolates were mainly identified as either *Macrococcus caseolyticus*, *Enterococcus faecalis*, or other species of *Staphylococcus* (*S. carnosus, S. warneri, S. xylosus*, and *S. epidermidis*) and hence were not included in further PCR identification assay (data not shown). PCR identified all 27 isolates as *S. aureus* (*nuc*-positive) with 100% agreement with MALTI-TOF MS analysis. Among them, 1 was isolated from a raw milk, 13 from 7 White-pickled cheese, 6 from 3 Tulum cheese, and 7 from 4 pastry cream samples (Table 3). However, as a result of Pearson’s chi-square test using IBM SPSS Statistics 23, no statistically significant difference was found between the dairy food groups (raw milk, White-pickled cheese, Tulum cheese, and pastry cream) and the presence of *S. aureus* in these groups (\(p = 0.144\)). A \(p\) value <0.05 was considered statistically

### Table 2. Oligonucleotide primer and probes used for molecular identification of MRSA.

| Oligonucleotide | Sequence (5′-3′) | Reference |
|-----------------|-----------------|-----------|
| *mecA*-forward  | GATTATGCTCAGTACTGCTATCC | [36] |
| *mecA*-reverse  | TTCGTACTCATGCATACATAATG | |
| *mecA*-probe    | FAM-CCCTCAAAGGGTGAATTATTAGCCTTGAAGCA-BHQ1 | |
| mecc-forward    | GCAAGCTAAGAATCATCAGACAC | |
| mecc-reverse    | TCTTGCTACCTTGCTCAAATTTT | |
| *mecC*-probe    | FAM-CCGCAATTGCATTAGCATTAGGAGCCA-BHQ2 | |

FAM: 6-carboxyfluorescein, BHQ: black hole quencher
Table 3. Presence of *S. aureus* and MRSA in raw milk and traditional artisanal dairy foods.

| Sample type                | Sample contamination status | *S. aureus*-contaminated sample (no) | Number of *S. aureus* (nuc-positive strains) | Number of MRSA *mecA*-positive strains | Number of MRSA *mecC*-positive strains |
|----------------------------|----------------------------|--------------------------------------|----------------------------------------------|----------------------------------------|----------------------------------------|
| Raw milk                   | 1                          | Raw milk (27)                        | 1                                            | 1                                      | -                                      |
| *Traditional cheeses*      |                            |                                      |                                              |                                        |                                        |
| White-pickled cheese       | 7                          | White-pickled cheese (1)             | 2                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (5)             | 2                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (11)            | 2                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (23)            | 1                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (37)            | 4                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (39)            | 1                                            | -                                      | -                                      |
|                            |                            | White-pickled cheese (46)            | 1                                            | 1                                      | -                                      |
| Tulum cheese               | 3                          | Tulum cheese (3)                     | 1                                            | -                                      | -                                      |
|                            |                            | Tulum cheese (20)                    | 4                                            | -                                      | -                                      |
|                            |                            | Tulum cheese (29)                    | 1                                            | -                                      | -                                      |
| Yogurt                     | 0                          | -                                    | -                                            | -                                      | -                                      |
| Butter                     | 0                          | -                                    | -                                            | -                                      | -                                      |
| Traditional clotted cream  | 0                          | -                                    | -                                            | -                                      | -                                      |
| Pastry cream               | 4                          | Pastry cream (21)                    | 2                                            | 1*                                     | 1*                                     |
|                            |                            | Pastry cream (33)                    | 3                                            | -                                      | 1                                      |
|                            |                            | Pastry cream (41)                    | 1                                            | -                                      | -                                      |
|                            |                            | Pastry cream (44)                    | 1                                            | -                                      | 1                                      |
| Traditional Maras ice cream| 0                          | -                                    | -                                            | -                                      | -                                      |
| TOTAL                      | 15                         | 270                                  | 27                                           | 2                                      | 3                                      |

*: The same strain
significant. Overall, 15 out of 285 samples (5.26%) were contaminated by *S. aureus*. The mean contamination level of *S. aureus* was highest in pastry creams, with $6.4 \times 10^4$ CFU/g, $8.5 \times 10^5$ CFU/g in White-pickled cheeses, $4.2 \times 10^3$ CFU/Ml in raw milk, and $2.7 \times 10^2$ CFU/Ml in Tulum cheeses. Every 4 samples of pastry creams and 7 samples of White-pickled cheeses exceeded the maximum tolerable limit ($10^5$ CFU/g) for *S. aureus* in creams and cheeses as set by the Turkish Food Codex for microbiological criteria.\(^{[35]}\) As none of these samples exceeded the upper limit of $10^5$ CFU/g of *S. aureus* set by European Commission Regulation (EC) No 2073/2005,\(^{[38]}\) no enterotoxin analysis was done, which was also not the aim of this study.

In this study, no *S. aureus* was isolated in any of yogurt, butter, traditional clotted cream, and traditional Maras ice-cream samples. In contrast, it was previously been found by other workers in 23% of ice-creams in northern Turkey\(^{[22]}\); 40% of yogurts, 28% of butter, and 74% of ice-creams in Egypt\(^{[39]}\); 5.3% of butter (in which *S. aureus* counts were above $10^5$ CFU/g), 5.6% of creams, and 5.9% of traditional ice-creams in Iran\(^{[40]}\); 38% of ice-creams in Libya\(^{[41]}\); 10.0% of ice-creams in northern India.\(^{[42]}\) High numbers of *S. aureus* (~$1.4 \times 10^6$ CFU/Ml) were isolated from ice-creams in Rio de Janeiro, Brazil.\(^{[43]}\)

The high percentages of *S. aureus* in those studies could have been the result from the contamination of raw milk at the farm level from the milk-producing animal and the environment, utensils used for milking, or from dairy workers during the artisanal processing at different stages.\(^{[26]}\) On the other hand, no *S. aureus* was detected in ice-creams in China\(^{[44]}\) and in Northern Ireland,\(^{[45]}\) and in yogurts in Iran\(^{[40]}\) which are consistent with the findings of our study. The presence of *S. aureus* in this study was 2% in raw milk, which is lower compared to the studies with raw milk (42%) in Egypt\(^{[39]}\) and 9.1% in northern Italy.\(^{[16]}\) This may be the result of the legal prohibition of raw milk sale by street vendors in Turkey. Raw milk can only be sold by specially licensed farms and dairy firms in Turkey, and requires special labeling rules and undergo regular testing to check the microbial content of raw milk. In addition, the responsible authorities try to impose severe inspection measures for monitoring the informal sale of dairy foods in Turkey. The presence of *S. aureus* in this study was 14% in White-pickled cheeses, 6% in Tulum cheeses, and 8% in pastry creams. The presence of *S. aureus* in cheeses was higher compared to the study with the same traditional cheeses (6%) by Can and Celik\(^{[46]}\) in Turkey, and with the study of Huber et al.\(^{[47]}\) who did not find any MRSA in 200 raw milk cheeses. A higher prevalence of *S. aureus* and in raw milk and dairy foods has also been reported in other countries.\(^{[19,28,48]}\)

**Presence of MRSA in raw milk and traditional artisanal dairy foods**

All *S. aureus* strains were further investigated for meCA and meCC genes by RTiPCR. Out of 27 *S. aureus*, 4 strains carried one gene [meCA gene in 2 strains, isolated from raw milk (sample no: 27) and a White-pickled cheese (sample no: 46); meCC gene in 2 strains, isolated from two different pastry creams (sample no: 33 and 44)], and only a strain isolated from a pastry cream (sample no: 21) harbored both meCA and meCC genes (Figs. 1 and 2). None of the strains from Tulum cheeses were positive with either meC genes. In summary, MRSA was detected in 5 among 285 (1.7%) raw milk traditional artisanal dairy foods in this study, and the frequency the frequency of MRSA among *S. aureus*-contaminated dairy foods was 33.3% (5/15) (Table 3). In a comparison of the obtained data with those of other studies, a higher prevalence of MRSA (15.4% and 53%) was detected in milk and dairy products in Egypt [Ahmed et al.\(^{[39]}\) and Al-Ashmawy et al.,\(^{[9]}\) respectively], in contrasts to bulk tank milk (4.4%) in Germany\(^{[48]}\) and milk and dairy products (3%) in Greece.\(^{[49]}\) Riva et al.\(^{[20]}\) found the prevalence of *S. aureus* and MRSA in raw milk to be 9.1% and 1.8%, respectively in Italy. On the other hand, the prevalence of MRSA in milk in dairy products reported by other researchers\(^{[16,50]}\) is in agreement with the findings of our study. Caruso et al.\(^{[51]}\) found it as 1.2% and Haran et al.\(^{[23]}\) as 1.3% among bulk tank milk in southern Italy and Minnesota-the USA, respectively which is a little lesser than the frequency observed in our study. The differences in contamination percentages by both *S. aureus* and MRSA of raw milk and traditional artisanal dairy
| LightCycler® 480 Well No | Strain No | Contaminated Dairy Food (Sample No) | LightCycler® 480 Well No | Strain No | Contaminated Dairy Food (Sample No) |
|-------------------------|-----------|-----------------------------------|-------------------------|-----------|-----------------------------------|
| A1                      | 1         | White-pickled cheese (1)          | H2                      | 16        | White-pickled cheese (37)         |
| B1                      | 2         | White-pickled cheese (1)          | A3                      | 17        | White-pickled cheese (37)         |
| C1                      | 3         | White-pickled cheese (5)          | B3                      | 18        | Pastry cream (21)                 |
| D1                      | 4         | White-pickled cheese (5)          | C3                      | 19        | Pastry cream (21)                 |
| E1                      | 5         | Raw milk (27)                     | D3                      | 20        | Pastry cream (33)                 |
| F1                      | 6         | White-pickled cheese (11)         | E3                      | 21        | Pastry cream (33)                 |
| G1                      | 7         | White-pickled cheese (11)         | F3                      | 22        | Pastry cream (33)                 |
| H1                      | 8         | Tulum cheese (3)                  | G3                      | 23        | Pastry cream (41)                 |
| A2                      | 9         | Tulum cheese (20)                 | H3                      | 24        | Pastry cream (44)                 |
| B2                      | 10        | Tulum cheese (20)                 | A4                      | 25        | Tulum cheese (29)                 |
| C2                      | 11        | Tulum cheese (20)                 | B4                      | 26        | White-pickled cheese (39)         |
| D2                      | 12        | Tulum cheese (20)                 | C4                      | 27        | White-pickled cheese (46)         |
| E2                      | 13        | White-pickled cheese (23)         | A6                      | NTC       |                                   |
| F2                      | 14        | White-pickled cheese (37)         | G5                      | PTC       |                                   |
| G2                      | 15        | White-pickled cheese (37)         | H5                      | PTC       |                                   |

NTC: Negative control; PTC: Positive control

**Figure 1.** RT-qPCR analysis for meCA gene in *S. aureus* isolated from raw milks and traditional artisanal dairy foods.

foods may arise from the differences in handling practices of the animals, and hygienic conditions during milking, staff, and artisanal processing through the dairy chain. In addition, to control the transmission of MRSA into the dairy food chain, doing a broad study based on screening of MRSA in herds, dairy workers, milk, and traditional artisanal dairy foods may help to prevent the incidence of MRSA in the future and thereby safeguarding Turkish dairy industry, at least in terms of this pathogen.
The burden of MRSA disease is 100-fold higher than that of tuberculosis, and much higher than that of HIV-AIDS. MRSA in raw milk should be of minor importance as a food safety issue, as commercial milk is almost always heat-treated before consumption. However, there may be some exceptions in the use of raw milk in the processing of traditional dairy products. MRSA continues to be an important public health concern given its ability to colonize and infect humans and food-producing animals and then to contaminate animal-derived foods. Therefore, the examination of milk and artisanal dairy foods to detect MRSA is necessary to help prevent foodborne associated-MRSA outbreaks. The recovery of identical MRSA strains in dairy farms and people in close contact with food-producing animals suggest a clear link for the transmission of these strains between humans and food-
producing animals. MRSA associated with milk and dairy products might be related to human contamination rather than contamination with animal origins. The presence of MRSA in traditional artisanal dairy foods may constitute a route of transmitting MRSA to humans, leading to the dissemination of this pathogen in the community. Continuous monitoring and further improvement in the hygienic quality of raw milk and during artisanal dairy processing is necessary to reduce MRSA contamination and public health threats. Hence, effective good manufacturing practices (GMPs) and good hygiene practices (GHPs) should be applied throughout the production chain of animal-derived foods from the primary production in the dairy farms to the processing and retail facilities, as based on the principle of “from farm to fork.”

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