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Methicillin-Resistant *Staphylococcus aureus* and Vancomycin-Resistant *Staphylococcus aureus* in Ready-to-eat Meat Products

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Abstract

Staphylococcus aureus is an emerging opportunistic threat to both animal and human health. It is classified as a high-priority pathogen owing to its widespread nature, making it easy to enter the human food chain. This bacterium is highly versatile and can lead to diverse infections and several foodborne outbreaks all over the world, as it produces approximately 28 types of potent superantigens enterotoxins, the most common types of these toxins implicated in foodborne outbreaks are staphylococcal enterotoxins A, B, C, and D. Additionally, this pathogen can release another toxins which are responsible for another infections including: toxic shock syndrome, scale skin syndrome, folliculitis, and pneumonia, in addition to spreading factors facilitating its pathogenicity in the infected host. Moreover, *S. aureus* can cause various illnesses, including suppurative dermatitis, osteomyelitis, MRSA Heart Infection (Endocarditis), and septicemia. With the discovery of antimicrobial-resistant bacteria, *S. aureus* is one of the firstly pathogens developing multiple antimicrobial resistant to the antimicrobials used for its eradication and treatment in human through various mechanisms. Interestingly, the prevalence of *S. aureus* and its resistant strains varies across the different geographical regions in Egypt and worldwide, mainly influenced by the hygienic status, personal practices, and cultural traditions in the surveyed countries. This review provides concise and diverse information about the microbial characteristics, virulence factors, prevalence, and antibiotic resistance of *S. aureus*, MRSA, and VRSA, in ready-to-eat meat products, in Egypt and worldwide.

Keywords: *S. aureus*, Ready-to-eat meat products, Foodborne pathogens, MRSA, VRSA.

Introduction

Ready-to-eat (RTE) food is defined as food that is prepared and ready for consumption without further processing or requires only minimal steps, such as rewarming. However, despite its delicious taste, RTE food can be a silent source of foodborne pathogens. The preparation of RTE food involves various critical points through which it can be contaminated with such pathogens, including the quality of ingredients, the microbial status of the water used for washing food and utensils, the type of packaging material, the hygienic practices of all individuals involved in food processing, as well as the post-processing cross contamination of the prepared meals [1].

S. aureus is one of the most extensively studied foodborne pathogens related to RTE food after *Salmonella* and *E. coli* [2]. *S. aureus* is a versatile pathogen that can infect various types of food during processing, as it is an asymptomatic colonizer found in all warm-blooded mammals, including human, inhabiting their noses and skin, which facilitates its entry into the food chain. Moreover, many surveys have confirmed that red meat and its products, particularly in African countries, are considered an important vehicle for this bacterium [3, 4, 5]. This potential food vehicle; meat is rich in proteins that, upon breaking down into amino acids and low molecular weight peptides, may supply the nutrients necessary to support the survival of *S. aureus*.

The main cause of Staphylococcal foodborne outbreaks over the world is Staphylococcal enterotoxins as reported by EFSA and ECDC [6] when these powerful enterotoxins were the primary cause of 207 outbreaks involving 2268 patients, 113 hospitalizations and 1 death in 2023. Moreover, these

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secreted enterotoxins recorded 577 outbreaks involving 9092 cases during the period between 2010 and 2020 as mentioned by [7].

The adaptability of *S. aureus* to various stressful conditions enables it to be a major pathogenic agent in diverse food products, leading to life-threatening food poisoning outbreaks. *S. aureus* is a facultative anaerobic microbe has a strong salt and sugar tolerance, marked ability to survive at water activity levels as low as 0.83, allowing its persistence in even semi-dried food products. *S. aureus* can thrive in NaCl concentrations up to 15%, temperatures ranging from 7°C to 48.5°C, and a wide pH range of 4.2 to 9.3 [8].

Dissemination of *S. aureus* in the food chain is primarily attributed to the poor hygienic conditions of infected food workers, unclean utensils and machines used in meat plants, and inadequate food preparation environment [9]. Interestingly, *S. aureus* can invade and colonize various body tissues, including mammary glands, skin, mucous and serous membranes of the front nares, inguinal region, rectum, as well as internal organs of both humans and different animals, mainly cattle and chickens, leading to serious illnesses that are difficult to treat [10].

Material and Methods

Sources of RTE food contamination

Many studies suggest that the leading cause of food contamination with *S. aureus* is poor hygienic handling of food, poor personal hygiene before or after heat processing, followed by improper storage conditions that enable the growth and multiplication of the bacteria with production of staphylococcal enterotoxins within contaminated food, resulting in foodborne outbreaks [11, 12, 13].

Ray et al. [14] enumerated various pathways for the invasion of RTE food by microorganisms, including human mishandling, insufficient heat treatment, slow cooling, contaminated equipment, leaving food aside for extended periods before packaging, inappropriate packaging systems, and unhygienic distribution.

However, food handlers are the most common source of *S. aureus* during food preparation in unhygienic environment using contaminated cooking utensils, particularly when workers have hand or arm lesions or cough, as this bacterium is a common commensal of the skin and mucosal membranes of the nose and throat, with estimates indicating that 80% of healthy individuals carry it [15].

S. aureus as a serious foodborne pathogen

S. aureus is a problematic pathogen with various virulence factors essential for its survival and host infection. The organism's ability to produce multiple toxins, enzymes, and biofilms plays a significant role in its pathogenicity, including thermonuclease, hemolysins, coagulase, Staphylococcal hyaluronidase, Panton-Valentine leukocidin (PVL), staphylokinase, toxic shock syndrome toxin (TSST), adhesins, and surface proteins like protein A [16, 17].

Furthermore, this pathogen produces several pyrogenic exotoxins known as enterotoxins, also some strains of *S. aureus* show multidrug resistance to the most common clinically used antibiotics [18]. Several foodborne poisoning outbreaks have occurred worldwide due to consuming food containing staphylococcal enterotoxins (SEs) produced in contaminated food with *S. aureus* in response to various environmental conditions [19]. Malachowa and DeLeo [20] explained that *S. aureus* is highly adaptable to different nutritional and environmental stress factors, which sustains its ability to remain viable and infective across various settings by acquiring newly developed genes encoded on different mobile genetic elements.

Staphylococcus food poisoning is one of the major causes of hospitalization and foodborne outbreaks in many countries including USA, Europe, and France as mentioned by Fetsch and Johler [19]. Likewise, *S. aureus* reported as serious threaten as it can remain viable for long time on the initial contaminated surfaces and utensils with small dose of infective dose of one or more of staphylococcal enterotoxins (SEs), resulting in symptoms such as nausea, vomiting, abdominal pain, watery diarrhea, and chill, however, these cases are self-limiting, they may more sever in both elderly and children individuals. Symptoms generally appear nearly 3 hours after consumption of such contaminated food [21]. There are various types of SEs secreted by enterotoxigenic *S. aureus* strains, nearly about 28 different SEs identified in foodborne outbreaks. The 5 classical enterotoxins (SEA, SEB, SEC, SED, and SEE) are the most common toxins implicated in food poisoning outbreaks [22, 23].

SEs are superantigens proteins that can activate large numbers of T-cells of the host's immunity. Moreover, they exhibit significant resistance to heat, digestive enzymes, and acids such as pepsin and trypsin, facilitating outcome of human digestive immunity and withstanding conditions that could eliminate their secreting bacteria. A sufficient amount of the toxin is approximately 1 µg; however, 0.5 µg is enough to induce symptoms of poisoning [24].

Secretion of SEs can be stimulated by various stressed environmental factors in contaminated food, such as suitable temperature, NaCl concentration, and pH, which affect both the growth and secretion of these enterotoxins. The ability of producing bacteria to endure a wide range of osmotic sugar and salt concentrations could explain the involvement of different types of RTE food in Staphylococcus food poisoning outbreaks [25].

The growth of enterotoxigenic *S. aureus* strains until exceed 10^6 cells per each gram of such contaminated food is the starting point of enterotoxins production with subsequent food poisoning symptoms, moreover, production of these toxins is mainly organized by two factors including: storage temperature of prepared food and the ingredients of the meals itself [26]. Temperature is greatly influenced on SEs synthesis more than its effect on the bacterial growth; as it appears that the ideal SEA production is in a range of temperature between 10 °C and 45°C with a positive correlation with increased temperature in protein-rich meals [27]. Additionally, the emission of SEs is affected by pH, water activity, and NaCl concentration of RTE meals; as the acidic pH achieved by addition of lactic acid in certain types of meat products appeared to be have an inhibitory effect on the production of SEA [28], furthermore, SEB and SEC are the most types of these toxins affected by the availability of water in the surrounding media; as 0.86 is the minimal water activity, which permit enterotoxins production in the contaminated food [29]. Sihto et al. [30] reported that mild stress on *S. aureus* in 2% NaCl containing food was sufficient to induce SEs production.

S. aureus secretes various types of hemolysin toxins (alpha, beta, gamma, and delta); their primary functions include host tissue invasion, facilitating spread, and nutrient uptake. α-Hemolysin is the most common, exerting a damaging effect on different types of host cells, including epithelial cells, endothelial cells, erythrocytes, and monocytes, hence it can induce cell death. Β-Hemolysin significantly impacts the plasma membrane of human immune cells, resulting in its degradation into phosphorylcholine and ceramides. γ- and δ-hemolysins have a greatly diminished effect on human immunity [31].

One of the life-threatening illnesses is toxic shock syndrome, which is mediated by toxic shock syndrome toxin, a pyrogenic polypeptide toxin encoded by the (*tsst-1*) gene in some strains of *S. aureus*. This syndrome is characterized by fever, hypotension, and multiple organ failure due to excessive fluid and electrolyte loss from the infected patient. All of these actions can occur as a response to excessive non-conventional T-cell activation and cytokine release in the susceptible host [32].

The ability of *S. aureus* to adhere to any surface and form a biofilm is one of the most critical issues, as it facilitates the persistence of this pathogen on both biotic and abiotic surfaces. The biofilm is an extracellular matrix generated by bacterial colony adhesion and extracellular polymeric substances composed mainly of oligosaccharides, DNA, and proteins released during bacterial growth [8]. The biofilm enables the bacteria to sustain different environmental stressors, such as cleaning agents, disinfectants, and antimicrobials, through preventing chemicals or chemotherapeutics from reaching their target due to limited diffusion or repulsion caused by the biofilm matrix itself [33]. Moreover, the biofilm may enhance the virulence of this pathogen against host immunity, which raises the risk of such infection and hardens its treatment [34]. Hence, the ability of *S. aureus* to form biofilms serves as a serious weapon in its pathogenesis and control measures. The biofilm formation feature of MRSA adds an extra level of difficulty of the problem of antimicrobial resistance; as the slow-growing state of the bacteria encapsulated within the polymeric matrix of the biofilm can limit the action of β-lactams antibiotics, which depends on the suppression of active cellular process of wall synthesis of the invading bacteria, hence *S. aureus* can resist methicillin through two mechanisms: the first is the limitation of antibiotic spread in the matrix of the biofilm, while the second is the inhibition of the antibiotic action itself [35]. The process of biofilm formation is a two-step course; the first is the bacterial attachment to the invading surface via capsular antigen, then production of multilayers of polysaccharide biofilm surrounding the bacteria increasing its resistance to be more than one thousand of the planktonic cells to the antibiotics and sanitizers [36]. In food industry, the ability of *S. aureus* to form a biofilm is a critical issues, as the stress factors encountered by the bacteria during food processing is a strong signal that triggers production of strong biofilm act a as a shield to protect the bacteria from any threat, hence the biofilm tend to raise the pathogenic tolerance to many used disinfectants, increasing the risk of food contamination [37].

Methods of detection of MRSA & VRSA in food

Detection of MRSA in food samples depends on the molecular identification of *mecA* gene, which carried on staphylococcal cassette chromosome *mec* (SCC*mec*), a DNA fragment ranging from 21 to 67 kb in size present as mobile genetic element carried the different genes horizontally among the bacterial cells [38]. Many studies confirmed that mecA gene is the reliable genetic marker for MRSA [5, 17, and 34]. On the other hand, VRSA detection requires the genetic analysis of the bacterial DNA, and finding of one of the *van* genes including: *vanA*, *vanB*, or *vanC* genes as discussed by [39]. Other available methods for detection of MRSA include colony morphology on the specific media, Gram staining reaction, and biochemical testing of catalase, hyaluronidase, and coagulase, in addition to crossing priming amplification (CPA). CPA relies on isothermal nucleic acid amplification strategy which can amplify the DNA extracted from *S. aureus*, then it depends on the visual display of the colored result within 40 minutes, hence this method overcomes PCR method by the short time required to obtain the final results [40].

Results and Discussion

Prevalence of S. aureus in RTE meat products in Delta region

In Egypt, different studies recorded the prevalence of *S. aureus* in RTE food samples gathered from various restaurants and street vendors to evaluate different levels of hygienic safety of the sold meals in our local market. Saif et al. [41] found that 50.8% (61/120) samples of RTE meat products including: beef kofta, shawarma, burger, and luncheon collected from street vendors in Benha city were contaminated with *S. aureus*. Higher results recorded by Mahros et al. [17], who found that 83.1% (187/225) of hot dog and burger sandwiches purchased from public restaurants in Mansoura city were positive for *S. aureus*.

However, lower results detected by Zakaria et al. [42], who carried a study on RTE chicken burger, sausage, and luncheon reporting that 11.3% (17/150) were contaminated with *S. aureus*. In Zagazig city, Morshdy et al. [43] reported that 22% (33/150) of various RTE chicken burger, fillet, luncheon, nuggets, and pané samples were positive for *S. aureus*. Different prevalence of *S. aureus* in RTE meat samples discussed in (Table1).

In our review, we collected data on 1659 RTE meat products sold in different food outlets across various districts in Egypt. Of these samples, 743 (44.8%) were contaminated with *S. aureus* at different levels. This contamination may be attributed to the variety of meat processing methods and the unhygienic practices of the workers involved in preparing and packaging of these products. The hygienic practices are critical points for the introduction of pathogens, as *S. aureus* is a commensal human flora inhabitant of the skin and mucous membrane of the nose, mouth, and throat. Additionally, the ambient temperature in Egypt ranges between 35 and 37°C, which encourages the survival and growth of *S. aureus* in initially contaminated meat products [55].

Prevalence of S. aureus in RTE meat products around the developing countries

S. aureus is a worldwide serious pathogen as it considers the main cause of several food poisoning outbreaks; hence many authors analyzed different types of RTE meat products to confirm its existence, prevalence, and characterization. Wu et al. [56 analyzed 645 RTE meat products selected from the favorable Chinese food to reported that 79 (12.2%) of the tested samples were positive for *S. aureus*. Lower results detected by Lin et al. [57], who examined 1209 RTE meat products collected from different restaurants in Sichuan province, China and recording that 31 (2.6%) were contaminated with *S. aureus*.

In a Nigerian study, Omoruyi and Ibegbulam [58] made a survey on the microbiological quality of most common consumed RTE food including 20 meat pies recording that all of the tested samples (100%) were hygienically unsatisfactory for human consumption due to contamination with *S. aureus*. Various rates of *S. aureus* in RTE meat products in previous studies recorded in different countries illustrated in (Table 2).

Interestingly, we observed significant variations in the prevalence of *S. aureus* contamination rates among different countries worldwide. Our review included about 6626 RTE meat samples, within which only 441 (6.7%) were contaminated with *S. aureus*. Notably, Nigeria and Turkey showed the highest contamination rate, while RTE meat-based food sold in Algeria, Thailand, South Africa, Ghana, and Brazil showed a rate lower than 50% of the tested samples, indicating they were hygienically unacceptable. On the contrary, lower contamination rates were recorded by researchers in Libya, Afghanistan, Cameron, and Jordan. This variation in the incidence rates of *S. aureus* in RTE food influenced by several factors, including washing raw ingredients with contaminated water, the use of dirty equipment and utensils such as cutting tools, initial microbial contamination of meat with inadequate heat treatment, cross contamination between cooked and raw foods, prolonged food storage, and unhygienic personal practice during food preparation, processing, and packaging [70, 71].

Development of Antimicrobial-Resistant S. aureus

The increase in the emergence of antimicrobial-resistant bacteria has become a significant health challenge, leading to a rise in prolonged hospital stays, treatment failure, extensive treatment costs, and eventually, deaths. *S. aureus* is one of the most commonly occurring bacteria, developing resistance to most of the antimicrobials used to treat it. *S. aureus* first developed resistance to penicillin and methicillin in 1961 within American hospitals; subsequently, it was isolated from cattle with mastitis in Belgium, as reported by Krumova-Valcheva [72]. Nowadays, these bacteria continue to develop resistance to many available antimicrobial drugs, including vancomycin, linezolid, and daptomycin, which are used as a final line treatments for humans and animals [73].

The misuse and overuse of antimicrobials in the veterinary field, either as growth promoters or as treatments of infections, as well as in human medicine, is the main cause of the development of antimicrobial drug resistance genes. These genes have entered the population food chain not only through direct contact with animals but also via food of animal origin, particularly from certain species known to be common reservoirs for multidrug-resistant *S. aureus*, including pigs, cattle, and poultry [74].

Mecithillin (β-lactams antimicrobial) was the drug of choice for the treatment of *S. aureus* infections for only two years, while some strains of *S. aureus* could produce a modified penicillin-binding protein known as PBP2a. The PBP2a blocks the activity of most of β-lactams as the inhibitory control unit of transpeptidation reactions that link peptidoglycan chains, the key element of bacterial cell walls. Hence, the bacteria can cross-link a stable peptidoglycan layer in their cell wall, preserving their cytoplasmic contents [35]. Mecithillin-resistant *S. aureus* (MRSA) not only deactivates the action of mecithillin, but also renders penicillins, cephalosporins, and carbapenems inactive against bacterial strains expressing PBP2a.

An additional pathway for resistance to β-lactams is the synthesis of β-lactamases, which is a group of enzymes encoded by the *blaZ* gene carried by certain plasmids [75]. However, these enzymes have restricted substrates, including natural penicillins and aminopenicillins.

The resistance mechanism to β-lactams is encoded by the *mecA* gene located on staphylococcal chromosomal cassette mec (SCC*mec*) cassettes, which are classified as mobile genetic elements present within the genomes of methicillin-resistant *S. aureus* strains, but not in susceptible strains, and can be transmitted either vertically or horizontally within bacterial generations. [75]. The *mecA* gene is not only confined to *S. aureus*, but it can also be detected in 64 species belonging to the genus Staphylococcus. The *mecA* gene is the most commonly identified one in MRSA; moreover, the *mecC* gene is also detected in many human and animal cases [76].

Overall, due to the widespread concern over MRSA contamination of food, a detailed investigation of the prevalence of this serious pathogen will be discussed, including the type and number of examined samples and the percentage of *mecA*-positive isolates among the recovered *S. aureus* isolates (Table 3-4).

In the last two decades, the global increase in vancomycin-resistant *S. aureus* (VRSA) prevalence has become an emerging health issue, as vancomycin has been described as the final resort for treating difficult cases of *S. aureus* infections. Until 2020, the highest prevalence of VRSA among *S. aureus* isolates was recorded in Africa at 16%, followed by 5%,4%,3%, and 1% in Asia, North America, South America, and Europe, respectively [86].

Vancomycin is one of the oldest glycopeptide antibiotics, first used to treat MRSA infections at the end of the 1980s. In 2002, the first isolate of *S. aureus* showing complete resistance to vancomycin was recorded in the USA [87]. Vancomycin resistance is mediated by *van* gene clusters, which originated from *Enterococcus faecalis* and were then transmitted to MRSA in a mixed infection in mice [88]. Although several gene clusters are responsible for the resistance of bacteria to vancomycin, including *vanA*, *vanB*, *vanD*, *vanF*, *vanI*, *vanM*, *vanC*, *vanE*, *vanG*, *vanL*, and *vanN*, which have been confirmed until now, the *vanA* gene is the most common one identified in food and clinical samples [88].

Unfortunately, few studies reported the incidences of VRSA in RTE meat products as most studies depend on the disc diffusion method which is not accurate method for detection of vancomycin resistant *S. aureus* strains. In Egypt, Saber et al. [53] recorded a high prevalence of VRSA by 26.7% among the *S. aureus* isolates recovered from shawarma and burger sandwiches collected from different restaurants in Al-Sharkia government. In contrary, El-Elshebrawy et al. [34] recorded that only 3.9% of *S. aureus* isolates in tested chicken sandwiches were VRSA. Further studies in Egypt and worldwide discussed in (Table 5-6)The continuously emerged antimicrobial resistance of *S. aureus* can be attributed to the high level of chemical pollution by heavy metals, polyfluoroalkyl compounds (PAFS), disinfectants, and pesticides which used in cleaning, sanitation and disinfection process in animal farms; hence subjecting of such pathogen to these chemicals result in appearance of what is called co-resistance, and co-selection make the bacteria resistant to multiple antimicrobial [95].

Challenges on food industries regarding MRSA & VRSA

Food industry faces significant challenges due to the emergence of MRSA in the food chain. MRSA can contaminate raw meat, vegetables, and processed meat sandwiches [96]. The existence of MRSA foodborne pathogen throughout the human food chain is a critical public health issue, aside from the food poisoning outbreaks caused by the bacteria and their enterotoxins, which are responsible for many human diseases, MRSA can transmit the resistance genes to the consumers, reducing treatment options and increasing the morbidity and mortality [97].Furthermore, the ability of MRSA to produce an ideal biofilm reducing the efficacy of most of detergents and sanitizers used in the hygienic practices in environment of food plants and slaughterhouses [98]. Moreover, controlling MRSA and VRSA requires strict hygienic measures, regular screening in food production environments, and effective antibiotic stewardship in animal farming. These efforts increase operational costs and demand enhanced monitoring systems, making MRSA a complex and persistent threat to food safety and consumer health.

Trails considering Control and prevention of MRSA & VRSA in RTE meat products

Several recent trails have explored effective strategies for the prevention and control of MRSA and VRSA in processed meat products. Firstly, various natural antimicrobials, such as clove essential oils, has demonstrated strong inhibitory effects against MRSA owing to the active compounds eugenol, which suggested having inhibitory effect exceeding 98% in a period of 8 hours on the growing *S. aureus* [99]. Secondly, Hu et al.,[100] reported that the essential oils extracted from Litsea cubeba have a destructive effect on the cell membrane of MRSA with subsequent leakage of the intracellular components. Moreover, Chinese cinnamon and red thyme recorded a significant suppressive action of the most pathogens threat the food industry including MRSA in a study conducted by [101]. All of these natural preservatives overcome the synthetic ones, which preserve the product at the expense of the consumer health.

Furthermore, the golden key to prevent the existence of MRSA and VRSA in RTE meals is improving hygienic handling and personal practices in food processing facilities, which is shown significant reduction in the contamination rate of these foodborne pathogens [102]. Gamma irradiation is another intervention, where doses around 3 KGy have successfully eliminated MRSA in poultry meat without any deleterious effect on the meat quality [103]. Innovative packaging approaches, including antimicrobial films containing plant extracts or silver nanoparticles, have also contributed in the reduction of MRSA growth curve during storage period [104]. These trails collectively underscore the importance of integrated control measures combinig natural antimicrobials, advanced processing techniques, strict hygiene protocols, as well as the periodical surveillance studies to ensure food safety and limit the spread of MRSA and VRSA through meat products.

Conclusion

This review provides inclusive data on *S. aureus* and MRSA infections in ready-to-eat meat products. It discusses the virulence factors, prevalence, antibiotic resistance of *S. aureus*, and the different mechanisms of MRSA development and its prevalence. The data indicate that *S. aureus* and its antibiotic-resistant strains pose a significant public health risk. Therefore, critical measures should be implemented for regulating antibiotic use in veterinary medicine to prevent the transmission of these resistant bacteria to humans via the food chain, and also require a great wake-up call for public health authorities to establish high hygienic standards in all restaurants and food outlets to safeguard human health globally.

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Declaration of Conflict of Interest

The authors declare that there is no conflict of interest.

TABLE 1. Prevalence of S. aureus in different RTE meat products sold in Delta region

Type of product	Region	Number of tested samples	Number (%) of *S. aureus* +ve	Reference
Beef burger, luncheon, shawerma, and sausage	Dakahlia Governorate	80 (20 each of)	15 (18.75%)	[33]
Beef luncheon and chicken luncheon	Cairo Governorate	120 (60 each of)	8 (6.7%)	[34]
Beef shawerma, hawawshi, and kofta	El-Qalyobia governorate	105 (35 each of)	28 (26.7%)	[35]
Beef Kofta (40), burger (40), hawawshi (35), beef shawerma (35), and beef sausage (25)	Sohag governorate	175	14 (8%)	[36]
Beef kofta shawerma, sausage, and liver	El-Qalyobia governorate	100 (25 each of)	58 (58%)	[37]
Beef kofta and luncheon	El-Gharbia governorate	50 (25 each of)	15 (30%)	[38]
Beef kofta, luncheon, burger, shawarma, hawawshi, liver, and sausage	Al-Sharqia Governorate	140 (20 each of)	95 (67.9%)	[39]
Beef kofta and liver	El-Qalyobia governorate	60 (30 each of)	20 (33.3%)	[40]
Beef kofta shawarma, burger, and luncheon	El-Qalyobia governorate	120 (30 each of)	61 (50.8%)	[30]
Chicken burger, sausage, and luncheon	El-Qalyobia governorate	150 (50 each of)	17 (11.3%)	[31]

Type of product	Region	Number of tested samples	Number (%) of *S. aureus* +ve	Reference
beef burger and hot dog	Al-Dakahlia Governorate	225	187 (83.1%)	[17]
Beef liver, beef burger, sausage, shawarma, and kofta	Al-Sharkia Governorate	240	168 (70%)	[41]
Beef shawarma and burger	Al-Sharkia Governorate	64	15 (23.4%)	[42]
Chicken burger, fillet, luncheon, nuggets, and panne	Al-Sharkia Governorate	150 (30 each of)	33 (22%)	[32]
Chicken crispy sandwiches	Al-Dakahlia Governorate	90	38 (42.2%)	[5]
grilled and fried beef, grilled and fried chicken	Al-Menoufia Government	120 (30 each of)	31 (25.8%)	[43]

TABLE 2. Prevalence of *S. aureus* in different RTE meat products sold in different countries all over the world

Type of product	Country	Number of tested samples	Number (%) of *S. aureus* +ve	Reference
sausage sandwiches	**Turkey**	270	191 (70.7%)	[48]
Shawarma sandwiches	**Jordon**	100 (80 chicken, 20 beef)	8 (8%)	[49]
Beef sandwiches	**Brazil**	25	5 (20%)	[50]
chicken meals	**Thailand**	45	12 (26.7%)	[51]
Sausage, dried meat, meat with sauce, fried meat, smoked meat	**China**	4047	32 (0.79%)	[52]
Roasted and spiced RTE meat	**Nigeria**	105	17 (16.2%)	[53]
Beef products	**China**	645	79 (12.2%)	[45]
RTE chicken, beef head meat, beef intestine	**South Africa**	115	25%	[54]
beef products	**China**	1209	31 (2.6%)	[46]
Grilled beef	**Ghana**	36	9 (25%)	[55]
Beef burger, ground meat, beef sausage	**Libya**	44	8 (18%)	[56]
RTE meat-based meals	**Algeria**	55	21 (38.2%)	[22]
RTE hot meat pot	**Cameron**	70	7(10%)	[57]
RTE meat pie	**Nigeria**	20	20 (100%)	[47]
Chapli kebab, Shami steak, Liver kebab, beef burger, sausage	**Afghanistan**	100 (20 each of)	13 (13%)	[58]

TABLE 3. Prevalence of MRSA in different RTE meat products in Egypt

Type of product	Region	Number of tested samples	Percent (%) of MRSA among *S. aureus* isolates	Reference
Beef products (minced meat, luncheon, burger, sausage, and beef steak)	El-Gharbia Province	100 (20 each of)	35%	[67]
Beef luncheon and chicken nuggets	Al-Sharqia Governorate	80	8.8%	[68]
Beef smoked sausage	Al-Sharqia Governorate	50	8%	[39]
Beef burger and hot dog	Dakahlia Governorate	225	22.6%	[17]

Type of product	Region	Number of tested samples	Percent (%) of MRSA among *S. aureus* isolates	Reference
Chicken luncheon, beef burger, and sausage	Al-Qalubiya Governorate	150 (50 each of)	2.6%	[31]
Beef sausage, burger, luncheon and pasterami	Alexandria Governorate	100 (25 each of)	12%	[69]
Beef burger and hotdogs sandwiches	Dakahlia Governorate	100 (50 each of)	44.3%	[70]
Beef burger, sausage, and chicken pane	Alexandria Governorate	60 (20 each of)	15%	[71]
Beef shawarma and burger	Sharkia Governorate	64	23.4%	[42]
Chicken burger, fillet, luncheon, nuggets, and panne	Sharkia Governorate	150 (30 each of)	33 %	[32]
Chicken sandwiches	Dakahlia Governorate	90	23.7%	[29]

TABLE 4. Prevalence of MRSA in different RTE meat products sold in different countries all over the world

Type of product	Region	Number of tested samples	Prevalence (%) of MRSA among *S. aureus* isolates	Reference
Cooked chicken products	China	31	9.7%	[72]
RTE chicken and beef meals	Turkey	150	38.6%	[73]
Cooked chicken meat	China	153	10.1%	[52]
Meat and chicken barbecue	Iran	113	10.6%	[74]
Roast chicken, salt-baked chicken, and stewed meat sausage	China	645	7.4%	[45]
Street RTE meat products	Bangladesh	112	6.3%	[75]
RTE meat products	China	1209	3.2%	[46]
RTE hot meat pot	Cameron	70	2(28.6%)	[57]
Chapli kebab, Shami steak, Liver kebab, beef burger, sausage	Afghanistan	100 (20 each of)	31.25%	[58]

TABLE 5. Prevalence of VRSA in different RTE meat products sold in Egypt

Type of product	Region	Number of tested samples	Prevalence(%) of VRSA among S. aureus isolates	Reference
Chicken carcasses	Dakahlia Governorate	200	17(5.9%)	[5]
beef burger and hot dog	Dakahlia Governorate	225	4(2.1%)	[17]
Beef shawarma and burger	Sharkia Governorate	64	4(26.7%)	[42]
Beef and chicken products	Kafr El-Sheikh governorate	49	5 (10.2%)	[79]
Chicken crispy sandwiches	Dakahlia Governorate	90	3(3.9%)	[29]
grilled and fried beef , grilled fried chicken	Menoufia Government	120 (30 each of)	1(3.2%)	[43]

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الميكروب العنقودي الذهبي المقاوم للميثيسيلين و الميكروب العنقودي الذهبي المقاوم للفانكوميسين في منتجات اللحوم

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الملخص

تعد المكورات العنقودية الذهبية تهديدا خطيرا متزايدا لصحة الحيوان و الإنسان حيث تصنف هذة الجراثيم كمسبب مرضي ذي أولوية بالغة و ذلك طبقا لتصنيف منظمة الصحة العالمية نظرا لإنتشارها الواسع إلي جانب أنها تملك عوامل ضراوة متعددة و خطيرة ، كما ان كونها من الجراثيم المتعايشة علي الجلد و الأغشية المخاطية للإنسان و الحيوان كذلك في الجهاز التنفسي له مما يسهل دخولها إلي سلسلة الغذاء البشري و الذي بدوره يؤدي إلي العديد من حالات التسمم الغذائي في مصر و العديد من دول العالم. تسبب العدوي بالميكروب العنقودي الذهبي الكثير من الاعراض الاكلينيكية للحيوان و التي يصاحبها خسائر رمالية كبيرة، كما أنها تسبب أمراض عديدة و خطيرة للجنس البشري و تشمل: التسمم الغذائي، الإلتهاب الرئوي، التهاب العظام، التهاب الغشاء المبطن للقلب، و التسمم الدموي. يعرف الميكروب العنقودي الذهبي بأنه واحد من اهم مسببات جائحات التسمم الغذائي حول العالم بعد البكتيريا الإشريكية القولونية و بكتيريا السالمونيلا حيث انه يفرز مايزيد عن ثماني و عشرين نوعا من السموم المعوية التي تستثير أعداد هائلة من الخلايا و الأجسام المناعية في جسم العائل المصاب و التي قد تنتهي بالوفاة. هذا البحث المرجعي يعرض بإيجاز طرق تلوث منتجات اللحوم و الوجبات الجاهزة بالميكروب العنقودي الذهبي، عوامل نموها بالأطعمة المصابة، عوامل ضراوتها و السموم التي تفرزها في الأطعمة المصابة، مقاومتها للمضادات الحيوية، مدي انتشارها في منتجات اللحوم الجاهزة للأكل في مصر و بعض البلاد حول العالم.

الكلمات الدالة: الميكروب العنقودي الذهبي، الأمراض المنقولة بالغذاء، مقاومة للميثيسيلين، مقاومة للفانكوميسين.