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Antimicrobial Substances and Strategies to Avoid Bacterial and Fungal Effects in Leather Manufacturing

Haider Sabah ABDULHUSEIN[1*], Baidaa Mezher KADIM[2]

[1]Department of Microbiology, College of Veterinary Medicine, AL-Shatrah University, Thi-Qar, Iraq
[2] Department of Pathology, College of Applied and Medical Sciences, AL-Shatrah University, Thi-Qar, Iraq

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Abstract: Smart The leather production industry, existing for thousands of years, has continuously adjusted to meet modern standards for quality and environmental sustainability. Antimicrobial treatments are essential in leather manufacture to preserve the durability and hygiene of leather goods. These important treatments are utilized to prevent bacterial proliferation and deterioration of leather in order to fulfill environmental duty. Ideal temperature and moisture conditions of animal skin create a favorable habitat for microorganisms to grow. Review explores antibacterial chemicals, preservation methods for animal hides, and factors influencing bacterial growth. Various preventive techniques like salt, antibiotics, plant extracts, and electric currents are employed to combat bacterial damage in leather production. Even with high NaCl levels in the leather treatment liquid, numerous bacterial species can proliferate and generate detrimental enzymes, leading to substantial economic losses. These enzymes have detrimental effects on leather and leather goods, such as staining, unpleasant smell, and discoloration.

Deri İmalatında Antimikrobiyal Maddeler ve Bakteriyel ve Mantar Etkilerini Önlemeye Yönelik Stratejiler

Anahtar Kelimeler:
Lipolitik,
Proteolitik,
Antibiyotik,
Elektrik Akımı,
Antifungal ve Deri.

Özet: Binlerce yıldır var olan deri üretim endüstrisi, kalite ve çevresel sürdürülebilirlik açısından modern standartları karşılayacak şekilde sürekli olarak yenilenmektedir. Deri ürünlerinin dayanıklılığını ve hijyenini korumak için deri üretiminde antimikrobiyal işlemler esastır. Bu önemli işlemler, çevre görevini yerine getirmek amacıyla derinin bakteri üremesini ve bozulmasını önlemek için kullanılır. Hayvan derisinin ideal sıcaklık ve nem koşulları, mikroorganizmaların çoğalması için uygun bir yaşam alanı oluşturur. İnceleme antibakteriyel kimyasalları, hayvan derileri için koruma yöntemlerini ve bakteri üremesini etkileyen faktörleri araştırıyor. Deri üretiminde bakteriyel hasarlarla mücadele etmek için tuz, antibiyotik, bitki ekstraktları, elektrik akımı gibi çeşitli önleyici teknikler kullanılmaktadır. Deri işleme sıvısındaki yüksek NaCl seviyelerinde bile çok sayıda bakteri türü çoğalabilir ve zararlı enzimler üretebilir, bu da önemli ekonomik kayıplara yol açabilir. Bu enzimlerin deri ve deri eşyalar üzerinde lekelenme, hoş olmayan koku ve renk bozulması gibi zararlı etkileri vardır.

**Corresponding author: haidersa@shu.edu.iq*
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1. INTRODUCTION

Leather, obtained from animal hides, is a highly desirable material renowned for its resilience and adaptability. Nevertheless, the presence of microorganisms throughout the processing stage presents a notable difficulty. It is essential to incorporate antimicrobial medicines in order to handle these problems. This article provides an overview of the wide range of antimicrobial agents used in the leather manufacturing industry, highlighting their significance in maintaining the quality of leather products. The use of antimicrobial agents in leather manufacture involves a diverse array of compounds, such as biocides, fungicides, bactericides, and preservatives. Conventional chemical components, such as quaternary ammonium compounds and thiocyanates, are present with natural extracts, such as phenolics and tannins produced from plants. This section explores the many categories of antimicrobial agents used and their distinct functions in the process of leather treatment (Muñoz-Bonilla and Fernández-García, 2011). Gaining a comprehensive understanding of the mechanisms by which antimicrobial drugs operate is crucial for their successful implementation. Various drugs utilize a range of processes, including the disruption of microbial cell membranes and interference with enzyme activities. Offering valuable information on choosing agents customized to figure out specific issues encountered at various steps of leather processing (McDonnell and Russell, 1999). Antimicrobial compounds are used in many stages of the leather manufacturing process, beginning with the preservation of raw hides and continuing until the final finishing of leather goods. Biocidal treatments are employed to inhibit bacterial and fungal proliferation during the soaking, tanning, and coloring procedures, thereby guaranteeing the durability of the leather. Moreover, the final items are treated with antimicrobial coatings and finishes, which offer long-lasting defense against the growth of microorganisms while in use. This section elucidates the precise applications and benefits of antimicrobial therapies at each stage. Recently, there has been an increasing focus on implementing sustainable practices in the leather manufacturing industry. This section examines environmentally sustainable alternatives to conventional antimicrobial treatments, such as natural extracts possessing intrinsic antibacterial characteristics. The leather processing industry is progressively embracing environmentally-friendly technologies to reduce the ecological impact. The inclusion of sustainability and environmental impact factors is becoming essential in the choice of antimicrobial medicines (Quesada and et al., 2016). Although antimicrobial agents improve the quality of products, there are still challenges to overcome, such as regulatory limitations, potential toxicity, and the development of resistance by microorganisms. Ongoing research is focused on developing new formulations, controlled release systems driven by nanotechnology, and combinations of different antimicrobial agents. These advancements are shaping the future of antimicrobial agents in the leather manufacturing industry. This section examines these challenges and provides insights into future directions, highlighting the importance of effective and environmentally friendly antimicrobial strategies. Technological progress has significantly contributed to improving the use of antimicrobial agents in the production of leather in recent times. Nanotechnology has become a potent technique, facilitating the creation of nanocomposites and nanocoatings that possess improved antibacterial capabilities. Incorporating nanoparticles, namely silver nanoparticles, into leather materials has demonstrated potential in producing surfaces with long-lasting antibacterial properties, hence minimizing the requirement for frequent reapplication. The collaboration among academic institutions, industry stakeholders, and technological innovators has been crucial in driving progress in the development of antimicrobial solutions for the leather production industry. The development of breakthrough antimicrobial technologies has been achieved through collaborative efforts, which promote sustainable practices and tackle intricate issues. This section examines fruitful relationships and their contributions to the ongoing enhancement of antimicrobial applications in the leather industry.

1.1. Antimicrobial

The antimicrobial chemical factors can be classified into two categories based on their application. The first category includes antimicrobial agents that are used to regulate the growth of bacteria in industrial and economic settings. These agents are utilized in various industries such as food, textile, fuel storage, paper manufacturing, cooling, and ventilation (Madigan and et al., 2009). The second category consists of chemical antimicrobial agents that are used to prevent the growth of harmful germs on human skin and inanimate surfaces. This category includes four groups: antiseptics, sanitizers, sterilants, and disinfectants (Madigan and et al., 2009). Antimicrobial agents have been extensively employed in many domains, including hides, plastics manufacturing facilities, food sectors, textile production industries, paper, pharmaceuticals, and cosmetics production, to eradicate bacteria or impede the growth of microorganisms. A wide range of antimicrobial compounds, such as Phenolics, detergents, peroxygen, heavy metals, chlorine dioxide, chlorine, nitrogen, and others, are extensively utilized across several sectors to effectively eliminate bacteria (Heseltine, 2001). The impact of antibacterial factors on bacteria varies from severe, such as bacterial eradication, to mild, such as inhibition of bacterial growth. These effects have been extensively examined by (Martinez, 2009), who have also highlighted the detrimental effects on bacterial proteins and lipids, the disruption of nucleic acids, and the interference with bacterial metabolisms.

1.2. Antimicrobial classification

The effects of antibiotics on bacteria can be categorized into bacteriostatic, which suppress bacterial growth, and bactericidal, which can eliminate germs. The effects of the first type, known as bacteriostatic, are reversible due to the ability of bacteria to resume growth and replication once the antibiotic agent is removed from the environment. The second group, which possesses bactericidal properties, is typically the optimal choice in leather industries for reducing the population of bacteria during the tanning process. On the other hand, the use of bacteriostatic antibiotic agents in leather processes without a specific plan contributes to the increasing development of antibiotic resistance. Bacteriostatic drugs specifically target the bacterial ribosome. Conversely, bactericidal drugs form irreversible bonds with their targets, leading to the inactivation of bacterial cells and ultimately causing bacterial death (Heseltine, 2001). Antibiotics are classified into five groups based on their mechanism of action: suppression of protein synthesis, damage to the cytoplasmic membrane, inhibition of cell wall formation, damage to nucleic acids, and disruption of bacterial metabolism. Each antibiotic has a distinct target on the bacterial cell. Once the antibiotic agents connect to the bacterial cell wall and penetrate it, they cling to the cell membrane. This causes a disruption in the exchange of cytoplasmic bacterial ions, specifically potassium ions (K+), leading to the leakage of cell contents and ultimately cell death (Martinez, 2009). Antimicrobial agents can be categorized into two categories: leaching agents and non-leaching agents. This classification is based on the antimicrobial ingredients used and the technique of treatment. There are three categories of antimicrobial agents commonly used in textile production: Antibacterial, Antiviral, and Antifungal factors.

1.3. Antimicrobial resistance

Similar to other sectors, the rise of antimicrobial resistance presents a difficulty in the leather production field. The over dependence on specific antibacterial drugs can result in the emergence of resistant strains of microbes. This section emphasizes the significance of using antimicrobial agents in a careful and varied manner to reduce the likelihood of resistance. Continuing research on alternative substances and combination medicines seeks to offer solutions to this ever-changing dilemma (Birbir and et al., 2008). Antimicrobial resistance refers to the ability of microorganisms to resist the effects of antimicrobial drugs. Genes responsible for antibiotic resistance can be readily transferred between different species through three mechanisms: transformation, transduction, and conjugation. As a result, many antibiotics have recently become ineffective against bacteria and fungi (Russell, 2001; Madigan and et al., 2009; WHO, 2016). The World Health Organization's yearly reports in 2016 indicate a significant increase in the prevalence of antibiotic resistant bacteria worldwide (Berber, 2020). Consequently, bacteria possess the capacity to proliferate despite the use of antibiotics in the leather industry (Abdulhusein and Caglayan, 2022). In recent decades, the proliferation of antibiotic resistance has been attributed to the inadvertent and over utilization of antimicrobial drugs. Animal products, poultry, bird faces, and carcasses have been identified as significant sources of multidrug-resistant (MDR) pathogenic bio agents. MDR, or multidrug resistance, is a significant and recent problem that has adverse effects on both humans and animals (Vankar and Dwivedi, 2009; Kacaniova and Juhaniakova, 2011) identified antibiotic-resistant bacteria from the digestive system and milk of animals. These bacteria were classified as members of the Enterobacteriaceae family. Scientists are currently making efforts to identify new alternative bioactive compounds, instead of antibiotics, that do not have any negative effects on humans or the environment. Additionally, some of these materials may not have any impact on infectious bacteria (Abdulhusein and Caglayan, 2022). The rising consumer consciousness regarding hygiene and health has led to a surge in the demand for leather products treated with antimicrobial agents. Manufacturers have responded to the change in consumer tastes by integrating antimicrobial technologies into their products, not just for practical purposes but also as a commercial attribute. This section examines the convergence of consumer demand, marketing techniques, and the incorporation of antimicrobial agents to fulfill changing market expectations. Regulatory authorities closely examine the application of antimicrobial substances in consumer products, such as leather goods. This section provides an overview of the regulatory factors that must be taken into account when using antimicrobial treatments in the leather sector Adherence to standards and regulations guarantees the safety and effectiveness of antimicrobial agents, addressing concerns regarding human health and environmental consequences. This text examines cases in which certain agents or technology has successfully tackled microbiological obstacles, highlighting their practical applications and resulting consequences. Real-world examples offer useful insights into the varied applications and achievements of antimicrobial therapies in various contexts.

1.4. Bacterial and Fungal effects on leathers

The presence of abundant moisture and protein content in animal raw skins makes them an ideal breeding ground for microorganisms, leading to microbial proliferation (Skóra, 2014a). Animal skins host a variety of microorganisms, including bacteria such as Corynebacterium, Bacillus, Staphylococcus, and Clostridium, as well as fungi such as Aspergillus, Penicillium, Candida, Cryptococcus, and Paecilomyces (Bayramoğlu, 2006). These biological components possess the capacity to proliferate fast and generate various lipolytic and proteolytic enzymes, resulting in the deterioration of leather, unpleasant odour, discoloration, increased brittleness, and loss of elasticity (Bielak and Syguła-Cholewińska, 2017; Gendaszewska and et al., 2022). Conversely, certain microbes do not pose a threat to human health (Baird and et al., 2006). Given the high concentration of bacteria present in the soaking solution and the presence of several opportunistic species on animal skins, it is necessary to apply bactericides during leather processing (Williams and et al., 2005; Berber and et al., 2010). In order to prevent microbial decay, a range of antimicrobial substances are employed during the various stages of leather production. These substances can be categorized into two groups: natural materials and chemical materials. The chemical materials can further be classified as either fungicidal or bactericidal. Examples of these substances include isothiazoles, Bronopol, benzothiazole, phenols, polyvinyl, pyridines, tolysulfone compounds, quaternary (Tissier and Chesnais, 2001; Khalili and et al., 2003; Falkiewicz-Dulik, 2020). Although the majority of these chemicals are typically considered non-toxic (Khalili and et al., 2003) a small portion of them are actually toxic. Excessive use of these chemicals can have harmful effects on both humans and animals. Additionally, these materials are known to contribute to water pollution and are unsuitable for use in the food and leather industries (Karavana and et al., 2011; Bugra and et al., 2011; Deselnicu and et al., 2014; Dorota and et al., 2022), Some chemicals, like polyhalogenated phenolic compounds and pentachlorophenol, have been prohibited because they are highly dangerous (Türkan and et al., 2013). Regrettably, certain materials have been found to induce occupational illnesses, including renal, hepatic, and respiratory system ailments (Afşar and et al., 2010). Consequently, numerous antimicrobial agents derived from animals, plants, and microorganisms have been utilized in leather tanning processes, as they possess natural properties that are non-toxic or have low toxicity levels (Veyselova and et al., 2013). Researchers have utilized various antibacterial agents, including sodium sulphate, alkyl phenol ethoxylates, 1-2 dichlorobenzene, sodium bisulphate, potassium dimethyldithiocarbonate, acetic acid, potassium dimethyldithiocarbamate, sodium-orthophenylphenate, 5-chloro-2-methyl-4-isothiazolin-3-one, trichloro-S-triazinetrione, ortho-benzyl-para-chlorophenol, sodium salt of o-phenylphenate, and methylene bis (thiocyanate), in both the leather and paper industries (Yang and et al., 2012). The paper industry has utilized a mixture of benzothiazole and copper II, as well as silver nanoparticles (Muthusubramanian and Mitra, 2006), and 2-bromo-2-nitropropane-1,3-diol, for their bactericidal properties (Akpolat and et al., 2015). Bacteria with the ability to break down lipids and proteins. Simultaneously with bacterial activity, a variety of primary and secondary metabolites are being synthesized. These include colors, toxins, vitamins, and enzymes. Protease and lipase are crucial enzymes in the leather industry as they can be utilized in many phases of leather production. However, if present in large concentrations in the soak liquor, both of these can cause negative effects on the finishing leather. In recent years, researchers have intensified their investigations on proteolytic and lipolytic bacteria to explore novel approaches for reducing bacterial populations in tanning. Additionally, they are investigating the potential use of these enzymes in bio-tanning processes, albeit in their crude form and with limited quantities Bacteria have the ability to break down lipids and proteins. Extensive research has been carried out to assess the capacity of lipolytic and proteolytic bacteria, which are obtained from leather businesses during tanning procedures. Approximately 43% of the samples obtained from salted sheep skin consisted of somewhat halophilic bacteria, and the remaining 56% consisted of extreme halophilic archaea (Skóra and et al., 2014b). All severe halophilic isolates, including as Halorubrum lipolyticum, Halococcus dombrowskii, Halococcus morrhuae, and Halococcus dombrowskii, exhibited positive proteolytic activity (Skóra and et al., 2014b). Previous investigation that was isolated Enterobacter cloacae, Pseudomonas luteola, Bacillus pumilus, and Bacillus licheinformis from soak liquor. The researchers examined the lipolytic activity of these isolates and found that all of them were capable of producing a lipolytic enzyme. Additionally, Vibrio fluvialis, Enterococcus faecium, and Staphylococcus intermedius were also tested for their proteolytic activity, and all of them showed positive results. In Turkey, six isolates (which are including Bacillus mojavensis, Bacillus cereus, Bacillusamyloliquefaciens, Bacillus licheniformis, Bacillustoyonesis, and Bacillusvelenzensis) were obtained from different tanneries. These isolates were identified through molecular analysis, and their capacity to produce lipase and protease was examined (Yang and et al., 2012). The findings revealed that all isolates were positive for protease activity. However, only Bacillus cereus was negative for lipase production (Abdulhusein and Caglayan, 2022). In addition, prior search isolated bacterial and fungal species from the air of leather industries most of these microorganisms are pathogens such as Cryptococcus albidus, Penicillium echinulatum, Candida parapsilosis, Cladosporium cladosporioides, Penicillium crustosum, Penicillium chrysogenum, Penicillium commune, Corynebacterium lubricantis, Staphylococcus gallinarum, Pantoea agglomerans, Bacillus pumilus, Acinetobacter johnsonii, A. calcoaceticus, Bacillus cereus, Nocardiopsis dassonvillei, Bacillussubtilis and Pseudomonas putida (Orlita, 2004; Castellanos-Arévalo and et al., 2016). While lipolytic and proteolytic bacteria can have detrimental effects on leather, as these microbes have the ability to permeate the layers of skin and create damaging enzymes that result in skin degradation, spots, skin discoloration, and unpleasant odors, as shown in the accompanying photographs.

Figure 1 and fIigure 2 represent one of our previous study about the deterioration effects of bacteria on sheep skin and goat skin after treatment with mixed culture containing lipolytic and proteolytic Haloversatile bacteria which were isolated from salt samples used for skin preservation after it was skinned from the animal.

1.5. Fungicidal Agents

Microorganisms present on animal skin have no impact on the animal while it is alive. However, once an animal is slaughtered, these microorganisms can have detrimental consequences on the animal's skin as they begin to develop and multiply (Gobalakrishnan and Saravanan, 2017). In the leather industry, fungicidal substances, whether chemical or natural, are used during various phases of processing to prevent the growth of fungi during storage and transformation (Gobalakrishnan and Saravanan, 2017). The utilization of antimicrobial drugs should be restricted in order to mitigate antimicrobial resistance and prevent adverse environmental impacts (Niculescu and et al., 2017). In order to alleviate the adverse effects of antimicrobial agents on humans and their surroundings, researchers are actively seeking alternative biocides that are environmentally benign. One such approach involves exploring the potential of plant-derived biocides, as demonstrated by (Širvaitytė and et al., 2012). One of the reasons why natural ingredients are increasingly used in leather production is due to the changing preferences of consumers. Several recent studies have examined and evaluated the biological functions of essential oils as antimicrobial agents. These investigations have determined that essential oils possess bactericidal and fungicidal properties (Akter and et al., 2023). The antimicrobial activity of four different dyes was assessed against various bacteria and fungi. The results showed that the dyes had antibacterial effects but no effect on the tested fungi (Koizhaiganova and et al., 2015). In another study conducted by (Ţârlea and et al., 2009a), Ag-HA (Silver-doped hydroxyapatite) was utilized as an antibacterial agent in the leather finishing process. The Ag-HA was specifically developed using a microwave technique. The researcher assessed the antibacterial efficacy of Ag-HA using qualitative and quantitative analysis of tested microorganisms. The findings demonstrated that Ag-HA has promising antimicrobial properties (Ţârlea and et al., 2009a).

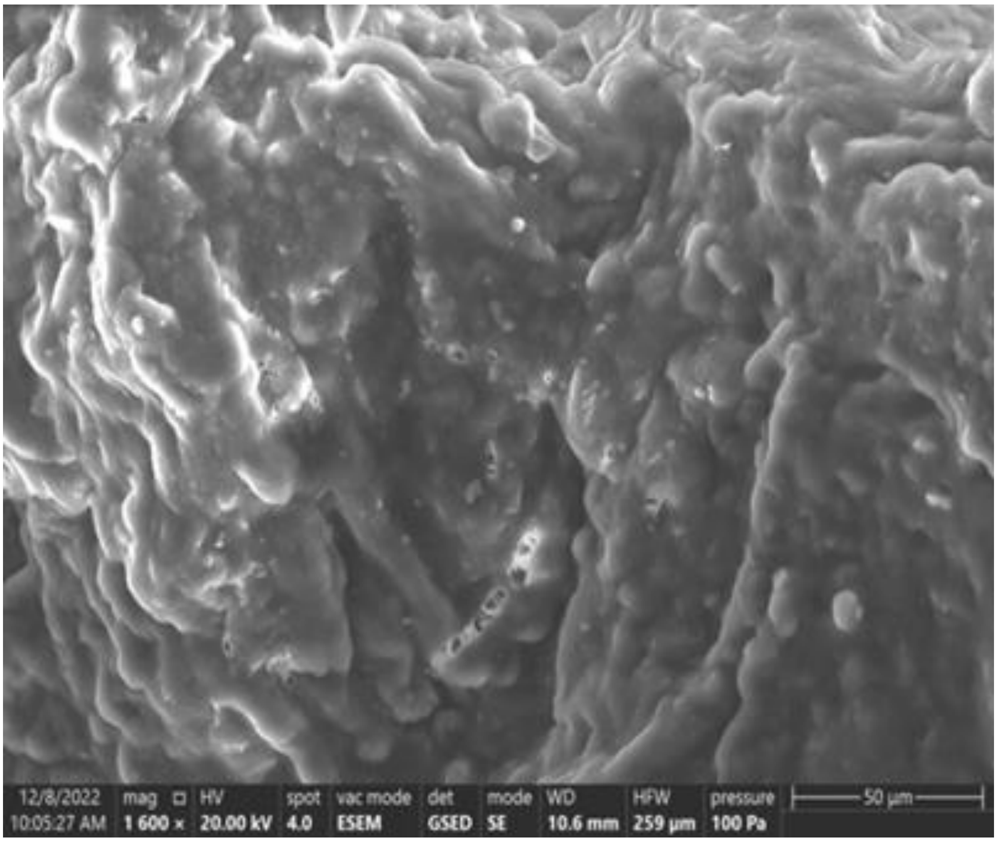

Figure 1. Sheep skin treated with mixed culture of Lipolytic and proteolytic bacteria isolated from leather industries (50 µm).

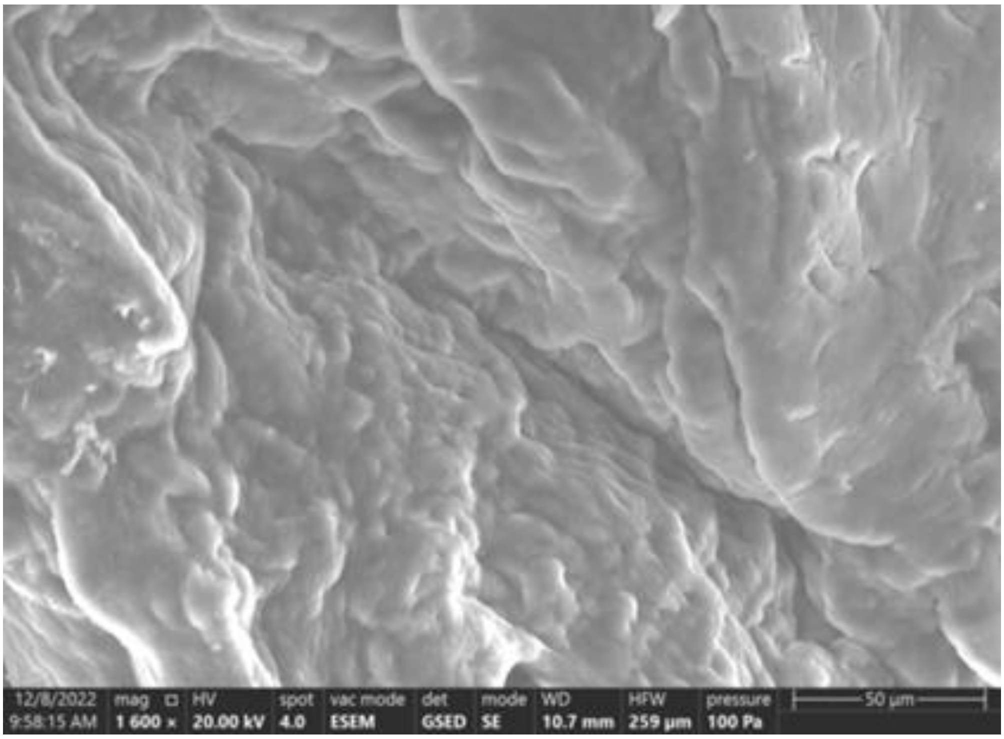

Figure 2. Goat skin treated with mixed culture of Lipolytic and proteolytic bacteria isolated from leather industries (50 µm).

Ţârlea et al., 2009a; 2009b evaluated the effectiveness of newly developed antimicrobial agents, which were synthesized by modifying the chemical structure of existing substances through chemical substitutions such as sulphonation of nitro, methoxy, methyl, and chloro instead of 2-amino benzothiazole-6. The results showed positive antifungal activity against Aspergillusniger in the production of cattle skin. However, these agents were found to be ineffective against Trichoderma viride (Neffati and et al., 2011; Ţârlea and et al., 2009b). In a study conducted by Niculescu et al. (2017), coriander essential oil was employed as an antifungal agent in the concluding stages of leather production. The findings indicated that a minimum concentration of 65% of this essential oil should be utilized during the leather finishing process (Širvaitytė and et al., 2012). Another study conducted by Neffati et al. (2011), Sreelatha et al. (2009), and Zoubiri et al. (2010) explored the medicinal significance of the Coriander plant (Bayramoglu, 2007; Sreelatha and et al., 2009; Zoubiri and Baaliouamer, 2010). The study revealed that Coriander not only acts as an antibacterial agent but also functions as a scavenging agent. Bayramoglu (2007) and Bayramoglu et al. (2009) examined the bioactive properties of essential oil extracted from Origanum species using steam distillation methods (Pranab and et al., 2009). They found that this oil can be used as an alternative antimicrobial agent against gram positive bacteria and as an antifungal material in the pickling leather process. In their study, Gendaszewska et al., (2022) examined the fungicidal properties of extracts derived from tea tree and thyme essential oils against three different fungus species (Aspergillus niger, Candida albicans and Chaetomium globosum) (Baird and et al., 2006). Upon completion of the leather finishing process, the findings indicated that thyme essential oil exhibited antifungal properties against all three types of fungi at a concentration of 5%. Conversely, the use of tea tree essential oil on leather samples only showed bioactivity against Candida. In addition, in China, nano-particles, specifically a combination of nano-ZnO, isothiazolinelcetone, acrylic resin, and tween, have been utilized as an antimicrobial agent for leather. The mixture, applied at a concentration of 0.8 g/l, demonstrated a pH of 6.0 and exhibited a significant and lasting effectiveness in inhibiting fungal growth, with a success rate of 97% (Berechet and et al., 2016a). Researchers have evidently intensified their efforts to discover new antimicrobial agents that can effectively reduce the presence of microbes on leather surfaces or in the soaking liquor used during the leather processing. Numerous studies have been conducted to identify appropriate ingredients with antifungal properties, such as Essential oils of Orange, Clove, Lavender, Origanum and Cinnamon were extracted and tested against Trichophyton interdigitale (Radwan and et al., 2014). Also the growth of Molds and Candida albicans were stopped by Essential oils of Cinnamon, Clove and Thyme (Berechet and et al., 2016b). Furthermore, the growth of Aspergillus niger and Candida albicans in leather industry was stopped by Carvacol, O-Cymol, Tymol, Geranuim, Rosemary and Pine essential oils (Deselnıcu and Chirilă, 2018). The plant extracts (Tanacetumvulgare, Compositae family) were tested against Epidermophyton floccosum and Trichophyton interdigitale (Miu and et al., 2020). Also the Plant extracts were investigated against Trichophyton interdigitale (Iyigundogdu and et al., 2016). Sodium pentaboratepentahydrate and triclosan have inhibitory effects against Aspergillus niger, Trichophyton mentagrophytes and Candida albicans (Chirilă and et al., 2017). The growth of Trichophyton interdigitale was inhibited by Essential oils of Thyme (Ilieș and et al., 2021). Essential oils of Citrus limon, Melaleuca alternifolia, Mentha piperita, Origanum vulgar, Lavandula angustifolia and Marjoram were tested against Aspergillus spp., Botrys sp., Penicillinum sp., Mucor sp., Candida guillermondii and Cladosporium sp. (Bailey, 2003).

1.6. Antibacterial Agents

Biocides are substances, whether synthetic or derived from nature, that possess the ability to inhibit the growth or kill microorganisms. Bactericidal and bacteriostatic chemicals have been employed for temporary preservation of leather, typically ranging from a few days to a few weeks. Historically, chlorinated chemicals and mercury phenoles have been commonly utilized as bactericidal agents. Both of these items have practical applications, but they also have negative effects on the environment, which is why they have been prohibited (Shakeel and et al., 2019). Biocides have been commonly used in combination with dyes and surfactants during the storage and processing of leather to protect salty skin and prevent bacterial and fungus growth (Shakeel and et al., 2019). In their study, Shakeel et al. (2019) synthesized a novel class of formazan dyes comprising a combination of (2-phenyl 2-4-sulfophenyl-hydrazono methyl diazenyl) benzoic acid and (2-aminobenzoic acid). These dyes were then reacted with 4-[(2Z)-2-benzylidenehydrazinyl] benzene sulfonic acid (Ding and et al., 2022). The synthesized dyes were tested against both Gram-positive and Gram-negative bacteria, including Bacillussubtilis, Klebsiella, Escherichiacoli, and Staphylococcusaureus. Additionally, their effectiveness was evaluated against various fungi commonly found in leather industries, such as Trichoderma harzianum, Aspergillus chevalieri, Aspergillus candidus, Aspergillus flavus, Penicillium stipitatum, and Aspergillus niger. The leather's antibacterial properties have been attained using pre-tanning procedures (Singh, 2014). In a recent study conducted by Ding et al., (2022), a novel antibacterial agent was developed by combining Polyurethane with ciprofloxacin. The resulting chemical was then evaluated against Gram-negative bacteria (Escherichia coli) and Gram-positive bacteria (Staphylococcus aureus) (Singh, 2014). The results demonstrate that the chemical exhibits a strong bacteriostatic impact on both isolates by inhibiting the DNA gyrase of these isolates. The findings from the studies conducted by Bayramoglu (2007) and Bayramoglu et al. (2008) demonstrated that Oregano essential oils had superior bactericidal properties compared to the commercial antibiotic agents commonly utilized in leather processing (Pranab and et al., 2009). In the fatliquoring process conducted by Bielak et al., (2017), the antimicrobial properties of three types of plant extracts (specifically essential oils) were tested (Gendaszewska and et al., 2022). These extracts, namely thyme, cinnamon, and oregano, were mixed with leather at a concentration of 5% of the skin weight. The objective was to evaluate their effectiveness against Candida albicans, Staphylococcus aureus, and Escherichiacoli. The results revealed that the aforementioned essential oils exhibited significant antibacterial and antifungal activity. In their study, Veyselova et al. (2013) examined the effectiveness of a combination of QAC (quaternary ammonium compound), specifically 12.5% benzyl dimethyl ammonium chloride and 12.5% didecyl dimethyl ammonium chloride, when applied to soaking water in leather industries (Yang and et al., 2012). The researchers tested the combination against various gram positive bacteria (including Bacillus licheniformis, Staphylococcus intermedius, and Bacillus pumilus) as well as gram-negative bacteria (including Enterococcus faecium, Vibrio fluvialis, Enterobacter cloacae, and Pseudomonas luteola). The results showed that this combination exhibited antimicrobial properties against all tested isolates, with the effectiveness depending on the concentration used. The study examined the minimum concentration of Sodium Dimethyl-dithio carbamate, an ingredient with antibacterial properties, against antibiotic resistant bacteria (ARB) that were resistant to penicillin, streptomycin, meropenem, ampicillin, and spectinomycin. The concentrations of Sodium Dimethyl-dithio carbamate used were 10 µg, 25 µg, 10 µg, 10 µg, and 25 µg respectively. The results showed that Sodium Dimethyl-dithio carbamate exhibited antimicrobial effects against a mixed bacterial culture at a concentration of 1000 µg/l. The antibacterial properties of acetone extracts from four lichen species (Usnea sp., Hypogymnia physodes, Pseudevernia furfuracea, and Everniadivaricata) were investigated against six Gram-positive Bacillus sp. isolates. All isolates exhibited positive catalase, protease, and oxidase activity. The results revealed that these extracts were capable of killing certain isolates at a specific concentration, while inhibiting others at the same concentration Abdulhusein and Caglayan, 2022). Lichens, such as Cetraria sp. and Lobaria sp., have been utilized in the leather industry as natural and alternative antibacterial agents for an extended period of time (Khattab and et al., 2019). In the textiles industry, a combination of synthetic and natural materials has been used to create novel antibacterial properties. The antimicrobial efficacy of sodium pentaborate pentahydrate and triclosan has been evaluated against several bacteria including Escherichiacoli, Staphylococcusaureus, Salmonella enterica, Staphylococcusepidermidis, Klebsiella pneumoniae, and Methicillin-ResistantStaphylococcusaureus (Chirilă and et al., 2017). Lanthanide-doped strontium aluminum oxide was studied in gotton industry aganist Escherichiacoli, Staphylococcusaureus and Candidaalbicans (Khan and et al., 2019). The study examined the antibacterial effects of Chitosan and Dielectric barrier discharge (DBD) plasma-treated materials that were impregnated with alkyl dimethyl benzyl ammonium chloride. The materials tested included Polyester, nonwoven cellulose/polyester, woven cotton, and Jute-cotton blended denim. The antibacterial activity was evaluated against Staphylococcusaureus and Escherichiacoli, as reported by (Song and et al., 2019; Chen and et al., 2019). The antimicrobial efficacy of Rose bengal against Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus, and Bacillus subtilis was evaluated on a fabric blend of wool and acrylic (Shahid-Ul-Islam and et al., 2019). The antimicrobial efficacy of Chitosan–silver nanoparticles (Dong and et al., 2019) and Lycium ruthenicum Murray extract (Yıldız and Eryuruk, 2018) was evaluated against Escherichiacoli and Staphylococcusaureus on wool fabrics. The antibacterial agent Quat silane was utilized against Staphylococcusaureus in cotton and elastane fabrics (Sadeghi-Kiakhani and et al., 2020). The study conducted by Sadeghi-Kiakhani et al., (2020) employed chitosan-silver nanoparticles as an antibacterial agent to combat Escherichiacoli and Staphylococcusaureus in the linen industry (Franco and et al., 2019). In addition, the application of 6mer-HNP1 (Aslanidou and Karapanagiotis, 2018), silane quaternary ammonium salt, and silica nanoparticles (Birbir and et al., 2013) in the silk industry was found to be effective in inhibiting bacterial growth.

1.7. Physical methods

The antimicrobial efficacy of Chitosan–silver nanoparticles (Dong and et al., 2019) and Lyciumruthenicum Murray extract (Yıldız and Eryuruk, 2018) was evaluated against Escherichiacoli and Staphylococcusaureus on wool fabrics. The antibacterial agent Quatsilane was utilized against Staphylococcusaureus in cotton and elastane fabrics (Sadeghi-Kiakhani and et al., 2020). The study conducted by Sadeghi-Kiakhani et al. (2020) employed chitosan-silver nanoparticles as an antibacterial agent to combat Escherichiacoli and Staphylococcusaureus in the linen industry (Franco and et al., 2019). In addition, the application of 6mer-HNP1 (Aslanidou and Karapanagiotis, 2018), silane quaternary ammonium salt, and silica nanoparticles (Birbir and et al., 2013) in the silk industry was found to be effective in inhibiting bacterial growth. Despite the use of various antimicrobial agents, such as NaCl and Boric acid, in skin processes to eliminate microbes in soak liquor and on the skin's surface, bacteria have developed antibiotic resistance mechanisms. This type of resistance has been transmitted vertically and horizontally among different species (Devlieghere and et al., 2013). Furthermore, the excessive utilization of antimicrobial agents has been identified as the primary cause of environmental contamination. Furthermore, the excessive utilization of antimicrobial agents has been identified as the primary cause of environmental contamination. Consequently, researchers endeavored to identify novel ways that are both environmentally benign and possess potent antibacterial properties, while avoiding any adverse impacts. Many of newly alternative approaches have been discovered and applied in order to minimize the bacterial numbers or kill it’s in different aspects such as food preservation sectors, among these technologies are PEF (pulsed electric fields), electrolyzed water, UV decontamination, high power ultrasound, oscillating magnetic fields, Radiation, high intensity laser, ionization, and high pressure homogenization (Tsong, 1990). Two distinct forms of electric current have been widely employed to hinder or eradicate halophilic bacteria and extreme halophilic arachea that are found in salt, soak liquor, and salted animal hides used in leather tanning procedures. Furthermore, both alternate and direct electric currents have been utilized for the purpose of eradicating bacterial populations and decontaminating various food and liquid goods. There are two processes by which electric current can deactivate bacterial development and destroy germs. Firstly, electroporation involves subjecting bacteria to high voltage, which temporarily alters the components of the bacterial membrane, including the lipid bilayer and proteins. Another phenomenon is referred to as electric annihilation. Both procedures involve the perforation of the bacterium cell wall, allowing the inside bacterial material to escape and ultimately leading to bacterial death (Martin-Belloso and Elez-Martinez, 2005; Kumar and et al., 2016). Several variables influence the process of electric current in bacterial inhibition, such as the pH level of the medium, temperature, conductivity of the medium, species of microorganisms being examined, and the duration and type of electric current. Electric current exerts fatal effects on molds, yeasts, and the morphology of vegetative bacteria. However, there has been shown resistance to bacterial spores. Bacteria have greater resilience compared to yeast cells. In addition, Gram-negative bacteria exhibit greater sensitivity to pulse electric field compared to Gram-positive bacteria. In food sector this approach has been used to kill Bacillus subtilis, Listeria monocytogenus, Staphylococcus aureus, Escherichiacoli, Lactobacillus brevis and Saccharomyces cervisiae in pea soup, milk, skim milk, liquid egg, yoghurt and apple juice respectively. The study conducted by Birbir (2013) demonstrated the combined use of alternating and direct electric current to effectively combat six different gram positive and negative isolates in a liquid medium containing 2% NaCl (Devlieghere and et al., 2004). The results revealed a significant reduction in the number of colonies within short treatment duration. While electric current technologies are highly efficient in combating resistant germs without the need for toxic chemicals, their application in the leather industry remains complex. Electric current can be utilized in various areas, not just limited to food production. In addition, several physical methods such as irradiation, electron beam therapy, and chilling techniques have been employed to safeguard skins following salting and washing procedures. The cooling method can be classified into two categories: cooling by ice and cooling in a vacuum. Researchers actually favor the use of chemicals over physical methods for short-term preservation of leather because chemical approaches do not require any specialized equipment for application.

2. CONCLUSION

The textiles and leather industries have significantly boosted economic prosperity in countries like the US, China, Bangladesh, India, Italy, and Turkey. To enhance product quality, countries are exploring innovative techniques and using antimicrobial agents with bactericidal activity and non-leaching properties. Bacteriostatic agents are preferred in apparel manufacturing, while bactericidal agents are used in medical and industrial contexts. Antimicrobial compounds are essential in modern leather production for quality, longevity, and cleanliness. This review examined various antimicrobial agents, their operation methods, and environmental impact. The use of efficient and eco-friendly methods is crucial for the future of leather production, ensuring product excellence, sustainability, and customer satisfaction. Overall, the industry should continue to evolve by embracing innovative and sustainable practices to navigate obstacles and meet market demands effectively.

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Conceptualization – Kadim BM, writing-original draft preparation – Abdulhusein HS; writing-review and editing- Abdulhusein HS; collecting data and articles from different sites and journals. Both authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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