Chapter

The Role of Leather Microbes in Human Health

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Abstract

Leather tanned from raw hides and skins have been used to cover and protect the human body since early man. The skin of an animal carries thousands of microbes. Some are beneficial and protect the animal while others are pathogenic and cause diseases. Some microbes have no defined roles in animals. These microbes end up in the human body through contact with the animal skin. In recent years, the human body has been studied as an ecosystem where trillions of microorganisms live as a community called microbiome. Humans need beneficial microbes like *Bacillus subtilis* on the skin surface to stay healthy. Many microbes need the human body to survive. Not many studies have looked into the close link between animal leather and the human microbiome. The assumption is that conventional leather processes inhibit the pathogens on skins from carrying any risk of microbial hazard to the human body. This chapter identifies endemic microbes of "animal skin microbiome" that withstand extreme acidity and alkalinity of leather manufacture and their transmission to humans. Some cause allergic reactions, skin lesion, infections or death to tannery employees with weakened immune systems. This promotes the need to look at leather product microbiome impact on human health.

Keywords: human health, human microbiome, leather-making processes, microbial hazard, pathogens, raw hide and skin and tanned leather

1. General introduction

Skin is the largest organ in the animal's body and acts as the entry point of microbes from the outside world [1, 2]. The diverse population of microbes found in human and animal resides on the skin. About 1000 different species of bacteria, fungi, viruses and other microbes live on the skin. The majority are harmless and even beneficial to human and animal hosts. Microbe colonisation of the skin is normally variable and relies on endogenous host factors, topographical location and exogenous environmental factors [3]. Over a long period of time, microbes, humans and other animals have established complex relationships with each other [2]. For example, to remain healthy, humans and other animals require microbes and many microbes also require specific environments provided by the human and the animal's bodies to sustain their lives. Humans, other animals, and microbes depend on these interactions to grow and stay healthy. Diverse species of microbes reside in different places in and on human and other animals and they are adapted to those conditions and places. Human, animals and their microbial flora form a complex ecosystem whose equilibrium acts as a reliable adaptation system [2]. In realisation

of this important complex relationship, the United States government in 2008 launched the human microbiome project. The above-mentioned project emphasised the need for comprehensive characterisation of different body parts for microbial communities of humans [4].

Microbiome research study in animals has lagged behind human research because of lack of investment, towards relating the animal microbiome in human health and disease [4]. "Animal microbiome" is wider in scope than humans, and as such, there is a lot of data specific to each animal species, their body parts, and their products. However, there is a need for animal products microbiome data as that of the human condition, particularly in One Health mindset concept. In this concept, it is necessary to consider the health of the animal and their products, as being closely linked to the health of humans. Globally everybody uses animal skin and leather products in one way or the other in their daily lives. This implies that microbes in them might be interacting with human health either positively or negatively. Microbiome research in this topic is still in nascent's stage and needs to be studied in detail to show the link as this is important, due to the fundamental biology of these invisible microbes in animal skins/leather products and their roles in human health.

2. Microbes reported in animal skins and leather products

Live animals bodies host thousands and thousands of microbes. Some are harmful while others are not. Among the pathogenic microbes are those which can cause diseases in animal and human. These diseases are known as zoonotic diseases. A zoonotic disease or zoonosis is defined as any disease of animals that can be transmitted to people [5]. The first recognised zoonoses with an occupational relationship relevant to the leather industry are those that cause skin lesions and have short incubation periods, such as ringworm infections, cutaneous anthrax and glanders [5]. Anthrax infection among tannery workers has been reported in Bangladesh [6]. The first documented case of anthrax in the United States of America occurred in Florida state in 1974. Cutaneous anthrax occurred due to contact with a goat skin bongo drum bought in Haiti while inhalation anthrax occurred in Scotland in 2006. This happened because of handling contaminated hide drums from West Africa [7]. The most common fungal disease in animal skin is ringworm, also known as *Dermatophytosis*. This is not a worm at all, but a fungus called *Dermatophytes* that grows on the skin. It affects workers who handle raw skins without wearing protective gears in the tanning industry [7].

Other microbes on the live animal skin only cause infection and damage to the skin [8]. It is yet to be known if they can affect humans that handle them. The most important bacterium that causes damage to the skin during the animal's life is *Dermatophilus congolensis*, which occurs as a secondary infection, in bovine demodicosis lesions. *Staphylococcus aureus, Staphylococcus albus*, and *Streptococcus pyogenes* are all reported to be associated with lesions of demodectic mange in sheepskin. *Staphylococcus aureus, Corynebacterium pyogenes, Pseudomonas aeruginosa, Bacillus subtilis*, and *Morexella bovis* have been isolated as secondary infections where bovine demodicosis was found to be present [8]. Some of these microbes have potential to cause pathogens on the host. They are normally transferred from the animal skin to human skin whenever people get into contact with the live animal in the fields or dead animal skin during slaughter. This is common in developing countries where not all skins that reach curing premises and tanneries come from licenced slaughterhouses. Some originate from individual homes; such skins are called "fallen hide/skin". Some

come from individual homes located deep in the interior villages, where veterinary services are lacking. This results into skins of a diseased animal, which have not been inspected by a veterinary inspector. The potential to infect the people handling them is always very high if they are affected by the zoonotic disease. This is the first stage of exposure to the workers in the leather manufacture chains and therefore it has become a source of concern about tannery worker health.

As soon as the animal is slaughtered the processes of decay on the flesh side begins. Animal skin undergoes microbiological decay since as an organic material it is a source of food for microbes [8]. Organisms involved in hide and skin putrefaction in slaughterhouses include *Staphylococci* and *Micrococcus* organisms. The majority of *Staphylococci* isolated so far includes *Staphylococcus xylosus, Staphylococcus sciuri, Staphylococcus cohnii, Staphylococcus simulans, Staphylococcus hyicus* and *Staphylococcus epidermidis*. The *Micrococcus* found in this study was *Micrococcus varians* [9]. In one study, 414 micro-organisms from 80 cattle hide and 80 sheep skin swab samples were isolated in Sudan. Out of the above figure, 134 isolates were characterised from fresh and washed cattle hides and sheep skins which included;- *Staphylococcus spp., Micrococcus spp., Corynebacterium spp., Aerococcus homorri, Enterococcus casseliflavus, Aerococcus viridans, Enterococcus faecalis, Gemella haemolysans, Stomatococcus spp., Pseudomonas spp*. and *Escherichia coli*. The samples taken from the slaughterhouse hides and skins were predominately *Staphylococcus spp., Micrococcus spp., Bacillus spp*. and *Corynebacterium spp*. along with *Staphylococcus albus*, *Streptococcus pyogenes, Pseudomonas aeruginosa, Bacillus subtilis* and *Corynebacterium pyogenes* [10].

From the slaughterhouses, the skins are normally moved to curing premises for preservation before they are delivered to the tannery for processing into leather. Preservation methods used range from sun drying, air drying on frames, salting, brining and chilling. Although these methods stop putrefaction of hides and skins, some microbes still survive and eventually move to the tanning process. Bacteria isolated from hides and skins delivered directly to the tannery without prior treatment include *Staphylococcus spp., Micrococcus spp., Corynebacterium spp., Lactobacillus jensenii, Streptococcus spp., Enterococcus spp., Stomatococcus mucilaginous, Bacillus spp., Aerococcus viridans, Pseudomonas vulgaris biogroup II, Escherichia coli* and *Pseudomonas spp.*

Hides and skins showing signs of putrefaction in the curing premises normally give off an offensive odour and show hair slipping on the grain side. Bacteria involved in putrefaction of those areas have been identified as *Staphylococcus saccharolyticus, Staphylococcus capitis, Staphylococcus hyicus, Micrococcus lylae, Corynebacterium bovis, Cory xerosis, Lactobacillus jensenii, Bacillus cereus, Staphylococcus intermedius, Bacillus amylogliguesta, Staphylococcus saprophyticus, Staphylococcus auricularis, Staphylococcus hominis, Staphylococcus epidermidis, Staphylococcus xylosus, Micrococcus varians and Micrococcus lentus*. In general *Staphylococcus spp., Micrococcus spp., Corynebacterium spp., Bacillus spp., E. coli* and *Pseudomonas spp* were found to be common [10]. The following bacteria; *Staphylococcus gallinarum, Dermacoccus nishinomiyaensis, Gardnerella vaginalis* and *Staphylococcus equorum* were isolated from putrefied hides and skins for the first time [10]. *Staphylococcus chromogenes, Staphylococcus xylosus, Staphylococcus kloosii* and *Bacillus mycoides* were found to be growing well in dried hides and skins [11]. The *Staphylococcus spp*. and *Micrococcus spp*. are therefore considered to be part of the normal microflora of cattle hides and sheep skins [11, 12].

Gram-positive and Gram-negative bacteria have also been isolated from goat and sheepskins. Gram-positive bacteria were identified to be 78.7% [13]. The isolated bacteria were identified as *Bacillus cereus, Bacillus subtilis, Bacillus megaterium, Lactobacillus casei, Lactobacillus acidophilus, Lactobacillus fermentum, Micrococcus*

luteus, Neisseria flavescens, Neisseria sicca, Proteus mirabilis, Proteus spp, Pseudomonas spp, Staphylococcus luteus, Staphylococcus aureus, Staphylococcus epidermis, and *Streptococcus faecalis*. The writers found out that the Gram-positive Bacilli and Cocci with proteolytic activity are the most responsible for the degradation of goat and sheep skins [13]. These microbes might end up on the bodies of workers in the leather manufacture chain. Their consequences on the health of these tannery workers could be detrimental if they are potentially pathogenic.

Many curing premises use salt to preserve green hides and skins. In the salted cattle hides and sheepskins the following bacteria have been isolated; *Staphylococcus spp, Micrococcus spp., Corynebacterium spp., Enterococcus spp., Stomatococcus mucilaginosus, Bacillus spp., Moraxella bovis, Proteus vulgaris biogroup II, Pseudomonas spp.* and *Escherichia coli* [14]. These bacteria are considered salt-resistant species especially *Staphylococcus, Micrococcus, Corynebacterium, Stomatococcus, Lactobacillus*, and *Bacillus*. The writers consider them halophilic bacteria since they can grow well in salt concentrations of 5–15% [15]. Other reported studies indicate that on a salted raw hide, the proliferation of halophilic bacteria results in the production of a range of pigments giving red and violet spots. From these coloured spots *Micrococcus roseus, Micrococcus luteus* and *Micrococcus morrhuae* have most frequently been isolated [15, 16]. Fungi have also been confirmed to be natural inhabitants of hides/skins. Fungi species can tolerate high NaCI concentrations of 20–30% (w/v) [17]. This is a higher concentration than that tolerated by bacteria. *Aspergillus terreus, Aspergillus niger, Aspergillus fumigatus, Penicillium restrictum, Penicillium citrinum, Altemia spp*. and *Cladosporium spp.* were isolated from salted sheepskins [17]. From the curing premises, the raw hides and skins are taken to tanneries for processing. The first stage of tanning is the beamhouse yard.

In the beamhouse operations, six perforation-causing strains of bacteria have been isolated and identified as belonging to *Bacillus subtilis, Bacillus megaterium, Bacillus anthracoides, Bacillus pumilus* and *Pseudomonas aeruginosa*. They were isolated from soaking water for raw skin in the beam house [18]. An environmental mycological survey carried out at the liming section of the Tannery and Footwear Corporation (TAFCO) at Kanpur, India, in 1985, isolated and characterised 33 fungal species. *Aspergillus spp*. and *Penicillium spp*. were the two predominantly isolated fungal species. The other isolated species were *Alternaria spp., Cephalosporium spp., Chaetomium spp., Cladosporium spp., Cunninghamella spp., CUNularia spp., Drechslera spp., Fusarium spp., Mucor spp., Phoma spp., Rhizopus spp.* and *Trichoderma spp* [18]. The following isolated fungal species from beamhouse have been reported to have potential allergens. They include *Aspergillus flavus, Aspergillus oryzae, Aspergillus sulphureus, Aspergillus sydowii, Aspergillus terreus, Mucor geophila and Rhizopus stolonifer* [18]. Various fungal species such as *Penicillium spp., Aspergillus spp., Alternaria spp., Scopulariopsis spp.* and *Cladosporium spp.* have also been isolated from 14 tanneries in Istanbul, Turkey. *Penicillium spp*. was found to be the most commonly isolated fungal species followed by *Aspergillus spp* [19]. The authors, therefore concluded that the allergen from the isolated fungal species may be the reason for the development of respiratory infections in tannery workers thus the need to pay more attention to the skin microbes from leather industries even those which are undergoing processing.

From the beamhouse yard, the leather processing moves to tanyard operation. Here we have chrome-tanned leather (known technically as wet blue) with the formation of red spots which is a frequent phenomenon in the tanned leather. The originators of the red colour on tanned leather have been identified as *Paecilomyces ehrlichii* (=*Penicillium klebanii*), *Penicillium aculeatum, Penicillium purpurogenum* and *Penicillium Roseopurpureum* [20]. The red spots on the wet blue are not limited to one type of leather only, since these fungi attack and cause red colouration

even in box sides, horse chevreau, pig-skin splits and goat skins, among others. From tanyard operations, leather processing moves to crust and finishing yard. During drying of finished leathers, moulds may also develop due to favourable humidities and temperatures inside the drying rooms [20]. On the other hand, the biodeterioration becomes visible as spots of various sizes in green, yellow-brown, dark-brown, grey and brown-green shades on the finished leather. Associated with this type of damage, various workers have isolated *Aspergillus ochraceus, Aspergillus wentii, Penicillium rugulosum, Penicillium funiculosum, Penicillium variotii* and *V. glaucum*. They are noted for attacking skin substrates with high grease content, but a far larger range of fungal types than these cause damage during leather drying process.

Major damage on finished leathers is caused by fungi. The types of fungus that are encountered in tanneries are well-known contaminants of leather materials [21]. Those that are frequently isolated includes; *Penicillium chrysogenum, Penicillium luteum, Penicillium brevicompactum, Penicillium decumbens, Penicillium rugulosum, Penicillium aculeatum, Penicillium funiculosum, Aspergillus niger, Aspergillus fumigatus, Aspergillus ochraceus, Aspergillus wentii, Aspergillus < avus-oryzae (group), Mucor mucedo, Rhizopus nigricans, Paecilomyces variotii, S. brevicaulis, V. glaucum* and *Trichoderma viride.* The above mentioned fungi utilise tanning conditions for their growth and development, hence they can even be found on the finished leathers as well as on the surface of vegetable-tanning solutions. In these solutions, they cause fermentation of the tanning agent due to the effect of "tannase" enzymes especially in the production of vegetable-tanned sole leathers. A poor growth of the yeasts *Candida albicans* and the moderate growth of *Staphylococcus aureus* were observed on the finished leather specimen [21]. The reported researches have proved that *Penicillium, Aspergillus*, and *Trichoderma* are the main microbes growing on the wet blue leather [22].

A new kind of bacterial defect, different from well-known bacteria-borne defects (like hair slip, red discolouration, and grain pilling) on the leather has also been identified. It is called the bio-film. A biofilm defect is explained to be composed of a single or multiple species of bacteria, embedded in the polyanionic extracellular polymeric substances which are attached to the surface of leather [23]. Different bacterial and fungal species, for example, the Genus of *Bacillus, Corynebacterium, Clostridium, Staphylococcus, Penicillium, Aspergillus, Paecilomyces, Candida*, and *Cryptococcus* are responsible for destruction and degradation of leather and their products [24, 25]; therefore, these microbes with potential pathogens could pose a real threat to the health of tannery workers and even the population that use leather goods.

Finished leather is normally used to make leather items like the belt, purse, shoes, upholstery and boots, among others. A study carried out around 2015 in Mauritius found that purses used by almost everybody globally could be a potential reservoir for bacteria, in particular, those made out of leather and synthetic materials [26]. In roughly half of the purses sampled in that study, there was only a single type of bacterial growth isolated and identified. In the other half of the samples, there was the identification of mixed growth. In most cases, these microbes are normally carried harmlessly on the skin of most people. It is reported by some authors that infection only occur if a person has a weak immune system or if the skin is wounded, allowing the bacteria to enter the body [26]. Therefore, it is worth noting that even finished leather items are potential sources of pathogenic microbes. Besides that, finished leather products such as footwear may be colonised by fungi and bacteria [27]. The carbon source for bacterial growth is sweat compounds of footwear users and other compounds contained in shoe materials. Footwear, especially those often and intensively used, provides an ideal

environment for microbial growth, including pathogenic species, causing athlete's foot (tinea pedis) and bacterial foot infections. This is connected with a favourable temperature and high moisture content inside the shoes, enhancing microbial growth [27]: A poor growth of yeasts *Candida albicans* and moderate growth of *Staphylococcus aureus* was observed under specimens of leather finished without essential oils. However, no growth of *Escherichia coli* was recorded [28], thus microbes in the raw skin go beyond the tanning process and therefore it is relevant to take note of the leather microbiome and their possible effect on human health. This can be done by adding effective fungicides and bacteriocides on processed leather with less effect on human health.

3. Reported cases of beneficial microbes on humans from leather products

Micro-organisms with the symbiotic relationship with the skin occupy a wide range of skin niches and can protect it against invasion by harmful organisms. One such type of bacteria that is known to protect the skin is *Bacillus subtilis*. It produces bacitracin on the skin surface, a toxin that helps it in fighting with other intruding microbes [1, 2]. These skin microflora may also have a role in educating billions of T cells, making them ready to respond to similarly marked pathogen [3]. Most of the time in our lifetime, we share our bodies harmoniously with the 90 trillion or so microbes [29]. By simply taking or applying antibiotics, we could be disturbing the stable ecosystem in our body by killing not only disease-causing micro-organisms but also good bacteria, like *Lactobacillus acidophilus* which protects the body against pathogenic bacteria. A balanced co-existence between microbes and human bodies requires appropriate use of antibiotic and reserving the good role these organisms play in the animal and human health. Some resident microbes are known to protect animals against pathogens. Evidence attributed to this comes mainly from studies performed with germ-free animals, which were found to be extremely sensitive to infection and some died following the administration of a pathogen [30].

Microbes on the skin and other parts of the body have been known to protect it against environmental toxic materials, such as heavy metals, hydrazine, fungal, plant toxins, oxalic acid among others [30]. It is also speculated that changes in temperature, present problem to some animals that cannot use their skin to regulate their body temperature. This regards how to carry out cellular metabolism at both high and low temperatures. Some microbiotas can help solve this problem by providing enzymes optimised for different temperatures. On the other hand, an animal's microbial symbiotic partners may as well play a significant role in helping select the trait of endothermy. The constant high temperature of the surrounding environment speeds up bacterial fermentation by providing rapid and sustained energy input for the host. These benefits become apparent when comparing conventional to germ-free mammals, which sometimes require one-third more food to maintain the same body mass [30]. Some good bacteria inhibit fungal growth in parts of the skins. For, an example in the forearm of a human there are over 100 species of bacteria that keep the skin healthy. On average, it is reported that the skin supports about 1 trillion bacteria species. The most common among them are *Staphylococcus, Streptococcus*, and *Corynebacterium,* which metabolise sweat on skin surface to produce the bad odour. Most of these mentioned bacteria actually help to keep the skin healthy by competing with dangerous pathogens for nutrients and growth space. *Firmicutes* and *Bacteroides* are known to break down carbohydrates and make essential nutrients like vitamins K and B12 for the animal's body development. They also block out harmful bacteria from invading the skin.

Other evidence suggested by different authors, states that commensal skin microbes are necessary and sufficient for the generation of optimal skin immunity. This has been observed from germ-free mice in an experiment. The mice failed to mount an adequate immune response to *Leishmania* disease. Recolonisation of the mice gut with microbes was unable to restore cutaneous immune function to this animal, but exposing the skin of these mice to *S. epidermidis* alone was sufficient to restore the effect or T cell levels and rescue the immune deficiency from total collapse. These observations according to the writer were linked to IL-1 signalling, as germ-free mice showed significant decreases in cutaneous IL-1α production. The evidence adduced here suggests that communication between commensal microbes and skin-resident cells is important for proper tuning of the local inflammatory milieu [1, 2, 30]. The potential impacts of commensal microbiota from leather on the response and development of an effective immune environment on the human skin are still unclear and therefore require further studies.

Fungi are also beneficial partners in symbiosis with the animal's skin [31]. This microbe has the ability to grow on vertebrate animal skins. Some fungi species can attack insects and nematodes in the skin and in the long run play an important role in keeping populations of these animals under control. Insect-attacking fungi are called "*Entomopathogens*," and they include a wide range of fungi in phyla *Ascomycota, Zygomycota*, and *Chytridiomycota*. Some of the best-known and most spectacular *Entomopathogens* among them belong to the *Ascomycota* genus *Ophiocordyceps* [31]. Beneficial microbes that are not mentioned here have other roles inside the animal's body. There are also some microbes with unknown roles in the skin of the animals yet they occur there abundantly. Some have been isolated but others are yet to be isolated and cultured. They make the study of leather microbiome necessary.

4. Mechanism of microbes transfer from animal skins and leather products to humans

The human skin might also be affected by the microbes from the animal's skin with which they get into close contact [32]. Previous studies as reported by other authors on European populations have shown that the skin microbial communities of dog owners are closely similar to the microbial communities of their dogs than those of other dogs. The report goes on to confirm that close contact with dogs significantly influences the microbial communities on the human hand that touches them regularly [33, 34]. Research on animal owners in Madagascar in Africa found out the connection between human skin and animal skin microbes. As expected, the animal skin microbiota was established to be more similar to its owner's body parts [35]. Animal owner and non-owner body parts after comparison were found to be made up of similar proportions of *Proteobacteria*, *Actinobacteria, Bacteroidetes, Firmicutes* (the four dominant human skin bacterial phyla) and *Cyanobacteria* [36]. In contrast, their animals were majorly dominated by *Proteobacteria* (88.5%). Animal owner's skins were found to have higher proportions of *Actinobacteria* and *Firmicutes*. The authors further found out that contact with the animal might not really be a major driver of skin microbial communities on their owners. This is because, certain bacterial taxa may be better suited to colonising human skin than animal skin, perhaps based on differences attributed to factors such as hair, sweat glands, pH or host genetics [37]. These findings suggest that interactions within the shared environment of all humans, regardless of animal ownership, can homogenise the skin microbiome, but that different body sites may harbour distinct microbial communities due to dispersal from environmental microbes [37, 38].

Animal hides and skins could also act as a mechanism for the transmission of bacteria and other microbes, due to its high content of moisture and nutrients (carbohydrates, fats, and proteins). These raw materials for making leather also contribute to the indoor environment of a tannery. The indoor environment inside the tanning industry has been associated with some human diseases attributed to biological agents. Conducted studies report that livestock and tannery workers have contracted diseases such as *Tetanus, Anthrax, Leptospirosis, 'Q' fever, Brucellosis, afta epizootic, Dermatosis and Micotoxicosis* due to infection and contamination of raw hide or skin, poor working conditions and to some extent processed leather. In addition, the above, genuses of fungi have also been reported in this environment, and they include species such as *Aspergillus niger* and *Penicillium glaucum*. Yeast genera that include *Rhodotorula*, *Cladosporium Torulopsis* have also been reported. Prolonged exposure of tannery workers to the tannery environment and their processed products has been closely linked with the development of allergies and asthma as well as the long-term exposure to fungi microbes. This ends up in the development of respiratory infections and other diseases [39]. For example, in Bangladesh, the common health problems diagnosed among the tannery workers were reported as shown in **Table 1**.

On the other hand, it would be interesting to determine if the above-mentioned taxa, are transient members of the human skin community as a result of temporary contact between the human body and this animal by-product, or it is due to long-term contact with animals and their products (and the shared environment) results in fundamental shifts in human skin communities that allow taxa that are typically considered animal and their products microbes to become residents [41]. When a beneficial microbe of animal skin is transferred to the human skin through the use of leather products, where there are a resident species of the same genera, what happens between the introduced species and indigenous microbes is still unknown. For example, *Bacillus subtilis* is known to protect the skin against other microbes.

Diseases reported among tannery workers	Number of cases reported (%)
Asthma	138 (49.9)
Diarrhoea	198 (71.7)
Jaundice/typhoid	120 (43.5)
Blood pressure	144 (52.2)
Gastrointestinal problem	198 (71.7)
Eye problem	129 (46.7)
Scabies	204 (73.9)
Nail discoloration	192 (69.6)
Urticaria	165 (59.7)
Miliaria and folliculitis	156 (56.6)
Contact dermatitis	108 (39.13)
Sores	105 (38.04)
Pruritus	90 (32.61)
Hand eczema	81 (29.35)
Fungal infection	75 (27.2)

Table 1.
Prevalence of diseases including occupational dermatitis among tannery workers of Bangladesh (adapted from Mahamudul [40]).

What happens when the one from animal skin/leather product is introduced into the human skin which is occupied by resident human *Bacillus subtilis*?. This is still unclear and provides an area worth looking into in future studies of the leather microbiome. This is because it is not known whether they live mutually, commensally, compete or they kill one another to get or retain the space. Clear explanation about this interaction is now necessary considering the fact that leather plays a basic role in human daily life.

5. Possible reported ways to hinder the transmission pathway of microbes to humans

The microorganisms grow on raw hides firstly because of their ability to hydrolyse the proteins present. This is due to their proteolysis degrading effect of the raw hide/skin substance [42]. In the literature, various authors have shown concern with halophilic micro-organisms and the problem of the colouration of cured hides/skins. The role of halophilic and non-halophilic bacteria producing or not producing coloured spots on salted hide/skin is still not yet clear, because the individual types can manifest themselves successively to a point that their individual hydrolytic effects are hidden from detection by various methods. Various bacterial species isolated from fresh calf skins are reported to have the ability to withstand a high level of salt (NaCI) concentrations (1.5–9% w/v) [42]. These isolated bacterial species included *Bacillus coli, Bacillus proteus, Bacillus megaterium, Bacillus mycoides, Bacillus subtilis, Staphylococcus albus, Staphylococcus aureus, Sarcina lutea* and *Micrococcus roseus*. *Bacillus subtilis* and *Bacillus mycoides* were found to survive in the dormant state at a high salt concentration (20% w/v) [42]. Bacteria called *Mesophiles*, such as *tuberculosis* known to be causing *Mycobacterium tuberculosis* can survive best at normal room temperature and are likely to thrive longer than cold-loving *Psychrophiles* or heat-loving *Thermophiles.* Other microbes do form exoskeleton-like spores as a defence mechanism, like the bacteria called *Staphylococcus aureus*. It is responsible for toxic shock syndrome and wound infections. The *Bacillus anthracis*, anthrax-causing bacteria, can also form spores and survive tens to hundreds of years [6]. The use of salt as a bacteriostat is to inhibit the growth of these microbes on the green hides and skin in curing premises.

When converting skin into finished leather, collagen which is the basic fibre component must be protected since many characteristics of finished leather, particularly its durability, rely on collagen protein. Thus, bactericides with a broad spectrum are widely preferred in the main soaking process to stop bacterial attacks. However, fungi and bacteria displaying proteolytic and lipolytic activities at a remarkable level on raw hides and skins and in the pre-tanning floats should be taken into consideration and monitored. This is due to, the fact that these microbes are able to survive in extreme conditions [43]. A number of bacterial species such as *Bacillus sp*., *Pseudomonas sp*., *Alcaligenes sp., Escherichia coli*, and *Shewanella alga* are reported to have Cr^{6+} detoxification capability due to the presence of reductases enzyme soluble in cytosol [44]. In *Pseudomonas maltophilia* and *Bacillus megaterium*, the Cr^{6+} reduction is associated with membrane cell fractions [16]. However, at present, it is still unclear whether the reduction of Cr^{5+} to Cr^{4+} and Cr^{4+} to Cr^{3+} is coordinated or enzymes regulated process. The NADH, NADPH, and electrons from the endogenous reservoir are suspected to be the electron donors in the Cr^{6+} reduction process. However, unlike Cr^{6+} reductases enzymes isolated from aerobes microbes, the Cr^{6+} reducing activities of anaerobes microbes are associated with their electron transfer systems ubiquitously catalysing the electron shuttle alone [16]. During the reduction reaction, the enzyme Cr^{6+} reductase (ChrR) transiently

reduces Cr^{6+} with a one-electron shuttle reaction to form Cr^{5+} followed by a two-electron transfer to form Cr^{3+} [46]. Although a proportion of the Cr^{5+} intermediate is spontaneously reoxidised to generate reactive oxygen species (ROS), its reduction reaction through two-electron transfer catalysed by ChrR reduces the chances to produce harmful radicals which can harm the cell. Several facultative anaerobes such as *Pseudomonas dechromaticans, Pseudomonas chromatophila, Aeromonas chromatica, Mycobacterium spp, Geobacter metallireducens, Shewanella putrefaciens, Pantoea agglomerans*, and *Agrobacterium radiobacter* EPS-916 are also reported to catalyse the biotransformation change of Cr^{6+} to Cr^{3+} under anoxic conditions [45].

Biodeterioration is reported to be an important factor that can impair aesthetic, functional and other properties of leather and other biopolymers or organic materials and the products made from them globally. This process takes place particularly under conditions of high relative humidity that enable bacteria, actinomycetes fungi or other microbes to grow fast [15]. Biodeterioration in the leather industry has been mentioned to results from the activity of macro- and micro-organisms on raw hides and skins, during leather manufacture and also during storage of finished leathers and leather articles [20, 46, 47]. Because of its protein and lipids nature, leather provides a suitable substrate for many micro-organisms. The biodeterioration process also happens on detanning (removal of chrome tannin on leather) effect and growth of *Penicillium spp*. The cross-link between collagen protein and chromium tanning agent is weakened during the biodeterioration reaction. It is speculated that protease enzymes that are produced by the *Penicillium spp* could be the degrading agent for chromium tanned leather. At the beginning of biodeterioration reaction, the *Penicillium spp* could be using the uncross-linked collagen protein as nourishment to grow and multiply, leading to the damaging of the collagen molecule. The *Penicillium spp* growth and multiplication makes tanning effect much weaker and susceptible. The detanned chromium leather becomes much easier for the *Penicillium spp* digesting enzymes and the biodeterioration begin slowly until the whole leather is affected completely [48].

In most cases, the *Pseudomonas spp* are normally present on the skin surface. Fur and skin layer might also contribute to the *Bacillus spp*. The presence of antibiotic-resistant plasmid harbouring *E.coli* has also been reported in leather and leather products [49]. *Staphylococcus aureus* generally has been present in epidermal and dermal layers of the animal's skin. These isolates were detected to have antigenic structures that enable them to resist antibiotics. The resistance development may be due to the nonspecific mechanism with gene regulation of plasmids and chromosomes, which may be heritable or transferable due to the presence of the resistance factor (R-factor) [49]. These structures enable the microbes to withstand extreme alkalinity and acidity in the tanning process; as such these microbes pose a real health hazard to the tannery workers.

Various studies have been carried out in order to develop clean or cleaner technologies to reduce the pollution load during leather manufacturing processes. These clean and cleaner technologies are also known by other name as best available technologies (BAT) [50]. Initially, it was assumed that the replacement of hazardous chemicals with non-hazardous chemicals may provide suitable conditions for microbial growth because of the shift in pH concentration. The growth and survival of micro-organisms, particularly pathogenic bacteria related to health issues, at various stages of the leather manufacturing processes (both conventional and BAT) has been investigated using *Bacillus cereus, Pseudomonas aeruginosa,* and *Staphylococcus*. At the end of the study, no considerable differences were observed between the effect of the conventional and BAT leather making processes on these bacterial growths. This study confirmed one fundamental issue of interest and concern, that is, the ability of bacterial cells to recover and regenerate during

leather manufacture [50]. This is an important point to note when dealing with processed leather and leather products and their relation to the health of tannery workers.

Careful consideration is still necessary regarding pathogen-related health issues even though the bacterial (*Bacillus cereus, Pseudomonas aeruginosa*, and *Staphylococcus*) counts were found to be low in processed leather. This is because, the risk of bacterial infections in humans may depend on many other factors, such as the tannery environment, the leather making procedures and the personnel involved in leather making processes. There is a likelihood that pathogenic bacteria may still be present and caution is recommended when dealing with hides/skins and leather products at any stage. Growth and proliferation of fungi in the hide/skin and leather products also still require investigation, as various studies have shown that leather production may provide suitable conditions for fungal growth as BAT studies reported here did not include fungal study [51]. In addition to the above mentioned, areas for further qualitative and quantitative analysis is required to determine the presence of microorganisms in the tannery based solid waste as well, such as sludge, the fleshing, shavings, hair, buffing dust, and trimmings which are generated during leather processing. This is due to the fact that these wastes are now being recycled into different products and used for different purposes by the general populace.

6. Pathogenic microbes on humans and on the leather products

Although the majority of the isolated microbial species are non-harmful and do not cause infections to humans, studies also show that some species in the genera *Bacillus, Staphylococcus, Pseudomonas, Klebsiella, Aspergillus,* and *Candida* are considered pathogens or potential pathogens [52]. These microbes and others associated with animal skin and leather product cause diseases in human. For example, *Escherichia coli* and *Enterobacter species* can cause urinary tract infection, wound infection and abscesses septicaemia. *Lactobacilli species* are a rare cause of septicaemia, endocarditis, and meningitis [52]. *Staphylococcus epidermidis, Staphylococcus aureus* is the most common microbes found on the human skin and nose. About 25% of healthy people in the world carry these bacteria, according to the Centre for Disease Control and Prevention (CDC). *Staphylococcus* bacteria coexist peacefully on our body. If a person with low immunity gets the infection from someone else's *Staphylococcus*, the bacteria can cause nasty skin infections, and pneumonia [52].

Klebsiella species may cause urinary tract infection, respiratory infection, and septicaemia. *Klebsiella pneumoniae, Klebsiella oxytoca, Klebsiella granulomatis* bacteria are generally found in human intestines, where they generally exist peacefully with others. However, different types of the bacteria can spread in the body and cause infection in sick patients in hospital environment, including pneumonia, blood infections, skin infections, and meningitis. *Haemophilus influenza* bacteria was mistakenly believed to be the culprit behind flu virus outbreaks long ago when it was first discovered in 1892. While most strains do not cause disease in humans, the bacteria can cause respiratory tract and heart valve infections and sexually transmitted chancre sores in those with weakened immune systems [52, 49]. *Streptococcus mitis, Streptococcus salivarius, Streptococcus mutans, Streptococcus pneumonia, Streptococcus pyogenes* bacteria range greatly in their potential to cause disease and how they are spread in the environment. Group A of the *Streptococcus*, generally lives harmoniously in the throat or on the skin but can cause mild illnesses such as strep throat and skin infections. Group B of *Streptococcus* infections tend to be more severe and are more common in older or sick adults with the weak immune

system. Group B infections are reported to be the leading cause of meningitis and blood infections in newborn children.

Neisseria gonorrhoeae, Neisseria meningitidis, Neisseria lactamica, Neisseria cinerea, Neisseria polysaccharea, Neisseria mucosa, Neisseria flavescens, Neisseria sicca, Neisseria subflava, Neisseria elongata, Neisseria gonorrhoeae and *Neisseria meningitidis* are bacteria that live in humans. Only two *Neisseria spp* causes disease. These types are most notoriously known for causing meningitis and gonorrhoeae, which thrive in mucous membranes and they are normally spread through sexual contact. *Neisseria* generally live in the upper respiratory tract and are not harmful to humans. *Bacteroides caccae, Bacteroides distasonis, Bacteroides eggerthii, Bacteroides fragilis, Bacteroides merdae, Bacteroides ovatus, Bacteroides stercoris, Bacteroides thetaiotaomicron, Bacteroides uniformis, Bacteroides vulgatus* bacteria have a complicated relationship with humans [52, 49]. When they are isolated from the gut, they assist in breaking down food and synthesising nutrients and energy for the body to use. When they escape the intestines, they can cause deadly infections in the blood and even form abscesses all over the body which is normally seen on the skin as signs of infection.

Clostridium perfringens, Clostridium difficile, Clostridium tetani (only transiently associated with humans, do not colonise the intestines) bacteria are commonly found in the soil and human intestines, and generally do not cause problems. A few strains of *clostridium* can produce potent toxins, including botulism, tetanus, and an irritation of the intestines and cause a mild to a life-threatening illness called *Clostridium difficile*, which causes inflammation of the intestines. *Mycobacterium* bacteria is most notorious for causing severe illnesses such as tuberculosis, leprosy, and Hansen's disease, though most species of *Mycobacteria i*n nature are benign in humans, unless in cases of those who have weakened immune systems. The *Pseudomonas aeruginosa* microbe is extremely versatile and can live in a wide range of environments, including soil, water, animals, plants, sewage, and hospitals in addition to humans. It seldom makes healthy people sick, but more typically causes blood infections and pneumonia in those who are hospitalised or have weakened immune systems. *Mycoplasmas* are particularly tricky to detect, diagnose, and eradicate in the human body. Though *Mycobacteria* belong to the normal flora in humans, most species of *Mycobacteria* are harmful and can cause respiratory and urinary tract infections [52, 49]. Thus microbes found in animal skins and are able to survive through the leather tanning process and reach human skin might cause diseases in people with weak immune system.

7. Conclusion

The most common bacteria found growing on leather purses are *Micrococcus* and *Staphylococcus* species each accounting for around two-thirds, followed by *Bacillus* (14%). *Micrococcus* was found to be more common on the men's purses, while *Bacillus* was found only on women's purses. In general, the study found out that the most common bacteria and fungus prevalence in leather are *Micrococcus*, *Bacillus, Staphylococcus, Aspergillus spp, Trichoderma* and *Penicillium spp*. Some are non-harmful and do not cause infections in humans. Other species within the genera of *Bacillus, Staphylococcus, Pseudomonas, Klebsiella, Aspergillus,* and *Candida* are pathogens or potential pathogens; therefore, they need to be monitored and controlled in skin and leather products to avoid their cross transfer as they can spread diseases in human. Thus, further studies on "leather microbiome" are of the essence to human health and disease.

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Conflict of interest

I don't have any conflict of interest in this work.

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