CHAPTER 34

FUNGI ASSOCIATED WITH SHEEP SKIN

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INTRODUCTION

The kingdom "Fungi" is a large, diverse group of organisms ranging from simple yeast cells (e.g., Candida spp.) to complex fruiting bodies producers (e.g., mushrooms and puffballs). Fungi found worldwide grow in a diverse environment and develop in several habitats where humidity, carbon, and nitrogen are available (Naranjo-Ortiz1 and Gabald 2019).
Fungi are eukaryotic microorganisms that digest food via extracellular enzymes and absorb simple nutrients through their cell walls. Most fungi reproduce by various spore types and have a body composed of microscopic hyphae. They are septated or non-septated tubes. Fungi are heterotrophs and gain their carbon and energy from external sources (Webester and Weber 2007).

Fungal Animal Relation- A General View Fungal Animal Relation -A General View

Fungal-invertebrate Relation

Fungi can grow on and in both invertebrate and vertebrate animals. Several fungi can attack insects, and others destroy nematodes, and in nature, they play an essential role in keeping populations of these animals within the expected size. Entomopathogens, are fungi that infect insects. Mainly, they belong to phyla Ascomycota, Zygomycota and Chytridiomycota. These fungi attack and consume several types of insects. They can change the behavior of infected ants after brain infection to produce "Zombie-ant" (Evans et al. 2011; Hughes et al. 2011). Entomopathogens such as *Beauveria bassiana* and *Metarhizium anisopliae* are so effective in killing insects that they are used as biological control agents for insect pests (Erler and Ates 2015). The order Entomophthorales includes many very specialized entomopathogens. A known example is *Entomophthora musae*, the fungus proliferating a mass of white conidia on dead flies (Carris et al. 2012).
Some fungi develop structures to capture nematodes. A common nematode predatois *Arthrobotrys oligospora,* a fungus with sticky networks of hyphae. When the worm in the soil touches the adhesive mycelia, it cannot escape. The predator fungus invades the worm cuticle and utilizes the interior body contents (Niu and Zhang 2011).

Fungal-vertebrate Relation

There are about 1.5 million fungi, and fortunately, a few are pathogens of vertebrates; they are about 300 species, some of these fungi can cause severe infections (Carris et al. 2012). Pathogenic fungi of vertebrates follow various pathogenic mechanisms. Some of them cause death even the fungus does not invade the animal body (Voyles et al. 2009).
There are common fungal diseases, "mycoses" for both humans and animals. The most common mycoses are the skin infections" dermatophytosis". They are restricted in dermis and related structures i.e., hairs, nails, claws, hooves, Wool, fur and feathers etc. (Ridzuan et al. 2021).
Several fungi use animal skin as a reservoir host that allows them to live and reproduce. The resident fungi of healthy animal skin may become pathogenic agents with predisposing conditions. *Candida* sp., for example, is the causative agent of superficial candidiasis in animals with weak immunity (Dworecka-Kaszak et al. 2020).

Fungal Lifestyle

Most fungi inhabit terrestrial environments, where they have been divided into three groups based on their modes of life. Saprotoph that feed on dead organic matters. Parasitic fungi, if they grow on living organisms and cause harm, and mutualistic if the living organism benefits.

Saprophytic Fungi "Decomposers"

Most members are terrestrial, but they live in most habitats on earth. Soil is the main reservoir of saprophytic fungi, where they grow on the upper layer of the damp part. The fungal population thrives in soil rich in decaying debris from plants and animals. The group play a critical role in the natural balance of ecosystems (Frąc et al. 2018).
The decomposer fungi group is active biodegradable. They hydrolyze complex plant tissues -cellulose and lignin- via cellulase and phenoloxidase.
In the soil, the role of fungal decomposers, and in fewer degrees bacteria and microphones, making it possible for members of the other kingdoms to live. Decomposer fungi reside in animal's skin and their appendages. And they play various roles here (Wilson 2005).

Mutualistic

Mutualistic fungi are less in numbers than the other two groups The symbiotic relationship between plants and fungi attracted attention before that with animals. Studies have extensively and deeply referred to mycorrhiza and its

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applications (Figueiredo et al. 2021; Li et al. 2021). Endophytic fungi are used as a successful biological control agent in phytopathology. Mutualism with large animals needs high caution to assign authentic and allochthonous fungi associated with the animal bodies (Lavrinienko et al. 2021)

Mycobiota of animals either reside in the gut or on the coat. The gut mycobiota has a further health significance than normal skin flora (Nilsson et al. 2019; Richard and Sokol 2019).

Most studies of skin mycobiota were conducted for small animals and pets due to the widespread of home pets and their relation with human infections. The health impact of normal fungal flora on dogs and cat skin or domestic farm animals is their conversion to infectious agents (Lund et al. 1999; Meason-Smith et al. 2016; Dworecka-Kaszak et al. 2020).

Parasitism

The fungus lives on the plant or animal hosts. Parasites impair hosts and affect their functions. Most pathogenic (disease-causing) fungi are parasites. The fungal phytopathology is more harmful than those caused by other pathogens (Hussain and Usman, 2019). Fungal infections (Mycoses) are less epidemic than bacterial in animals except among immunocompromised cases, where are the main reason for mortality (Fisher et al. 2012).

Animal fungal diseases are classified as superficial, cutaneous, subcutaneous and systemic mycoses according to the level of the infected tissue. The harms of infection include suppressing animal activities, reducing product quantity and quality, and causing death in some systemic mycoses cases (De Hoog et al. 2000). Dermatophytes are skin fungal pathogens. They benefit from surface skin secretions and cause several skin diseases (Sindha et al. 2015). They may also penetrate the skin through a wound of insect bites or various accidents that damage the dermis. Dermatophytes are distributed worldwide and have attracted particular attention in public health (Rashidian et al. 2015).

Animal Skin Mycobiom (non-pathogenic)

Skin is the largest organ in the animal body. It acts as a barrier against the entry of microbes from the outside environment. The majority of microorganisms that live on it are harmless and even beneficial to the hosts. Bacteria, fungi, and viruses are commonly recorded from human and animal skin. They are variable in number and type depending on endogenous and exogenous factors. Previous studies showed that the two main factors determining the interaction status between fungi and animals are animal immunity level and the fungus biological activity (Mańkowska-Wierzbicka et al. 2015). Fungi can evade animal defense via various virulence factors. Ultimately the host response is the factor that determines if a microbe is a commensal or a pathogen (Cogen et al. 2008)

Skin mycobiome "mycobiota" is a part of microbiota. The term refers to a fungal community that inhabits animal skin. Mycobiome members utilize keratin, the essential protein of skin and its appendages, hairs, wool, fur etc. (Aho 1983; Dworecka-Kaszak et al. 2020). Mycobiomes favor the saprophytic living style on skin habitat and may transfer to parasitic where they are infectious factors. Either environmental effects or weak animal immunity predisposes change of fungal life mode (Casadevall and Pirofski 2000).

The different animals have their specific normal fungal flora and seem more diverse than humans. The mycobiome of dog's skin, for example, created dominant filamentous saprophytes *Cladosporium*, *Alternaria*, and *Epicoccum* (Meason-Smith et al. 2015).

Aho (1983) examined 246 dog hair samples. Thirty-two genera of filamentous fungi were recorded. *Cladosporium, Penicillium, Aspergillus*, and *Alternaria* were the highest number. In Egypt, Bagy (1986) recognized 16 genera from 98 samples of dog healthy hairpieces. In another study carried out in Serbia, *Aspergillus* sp., *Penicillium* sp., *Alternaria* sp., *Mucor* sp., and *Fusarium* sp. were isolated from 67 dog hairpieces. In Nigeria, Moses and Sunday (2001) isolated *Aspergillus* (5sp.), *Chrysosporium* (4sp.), *Fusarium* (2sp.), *Penicillium* sp., *Pithomyces* sp., *Geotricum* sp., *Alternaria* sp., and *Cladosporium* sp. from dog samples.

In addition to filamentous fungi, several yeasts inhabit animal skin. *Malassezia pachydermatis* is a common cutaneous lipophilic inhabitant of numerous warm-blooded animals. It can cause several cutaneous infections, especially in dogs (Charles et al. 2020). *Candida* sp also has a high prevalence on dog skin and can cause severe infections for animals or owners (Yurayart et al. 2011).

Studies showed that the properties of animal skin sites affect fungal communities. Meason-Smith et al. (2015) explained that canines have different mycobiota across the hairy and non-hairy body surface. Skin mycobiota surveys of several animals have been done during the previous years. The fungal flora of golden hamsters showed *Rhizopus* spp., *Penicillium* spp., *Cladosporium* spp., *A. fumigatus*, *A. flavus* and *Mucor* spp. were the most frequently isolated. These saprophytic moulds, besides the dominant yeasts *Malassezia* spp., *Rhodotorula* and *Candida* spp. showed no relation with age and gender of tested animals (Mahnaz et al. 2014). They also concluded that the fugal community does not depend upon animal age and gender.

The "normal" fungal flora of pet cats was diverse. Fifteen genera were isolated, including13 saprophytes (86.6%) and two dermatophytes. *Aspergillus, Alternaria, Penicillium* and *Cladosporium* spp. were the most frequently isolated saprophytes (Philpot and Berry 1984). Sixteen saprobic genera were isolated from goat hairs in Taif/KSA (Awad 2017). The study highlights the high diversity of fungal isolates of goatskin habitat. *Aspergillus* spp. and *Penicillium* spp. are predominant. In addition to the following keratinophilic (non-dermatophytes) isolates *Acremonium, Alternria, Boteryatricum, Chaetomium, Cochliobolus, Cladosporium, Curvularia, Geotrichum, Paecilomyces, Phoma, Rhizopus* and *Scopulariopsis* (Awad 2017). The same results were obtained several wrkors aroun the world (Ogawa et al. 2008; Nichita and Marcu 2010; Sallam and Alkolaibe 2010; Emenuga and Oyeka 2013; Luján-Roca et al. 2016).

From dromedary hair samples, 15 filamentous fungal genera were isolated. The predominant are *Aspergillus* followed by *Penicillium, Mucor, Alternaria, Rhizopus, Chrysosporium, Acremonium, Scoupolariopsis, Cladosporium Fusarium, Psuedallescheria* and *Stachybotrys.* The isolated yeasts were *Candida*, *Geotrichum* and *Malassezia* (Shokri and Khosravi 2011)

Christiane et al. (2011) collected 56 hair samples from healthy coat cattle. The samples harboured 30 different genera, among which the most frequent were: *Nigrospora, Fusarium, Curvularia, Alternaria, Epicoccum, Paecilomyces and Trichoderma*.

Animal Dermatophytes and human health

Dermatophytosis is a fungal infection of the dermis. It is caused by *Microsporum, Trichophyton* and *Epidermophyton. Microsporum canis, M. gypseum* and *Trichophyton mentagrophytes* are the most common dermatophytes of animals (Indarjulianto et al. 2017; Moriello et al. 2017).

Dermatophytes have attracted the attention of mycologists since the med of the twentieth century (Cooke 1952; Kaplan et al. 1957; Menges and Georg 1957). There has been a significant increase in dermatophytosis prevalence in humans and animals during the previous years. Etiologic fungi were isolated from many mammals worldwide, and they are the most frequent human mycoses (Hay et al. 2014). Studies of animal dermatophytosis covered the wild and domestic types, pets, experimental animals etc. (Aho 1983; Lopez-Martinez et al. 1984; Shatyha et al. 1988; Ahdy et al. 2016; Haggag et al. 2017; Dalis et al. 2019).

The incidence of *Microsporum* and *Trichophyton* is generally more than *Epidermophyton*. They were isolated from pigs, rabbits, dogs, goats, sheep, and cows (Efuntoye and Fashanu 2001). A study of dermatophytes in dogs, cast, horses, parrots, and calf demonstrated that *Trichphyton* occurred in the five types, *Microsporum* in three, and *Epidermstophyton* in cat samples only (Sever et al. 2021). The ecological type of dermatophytes (geophilic, anthropophilic, and zoophilic) determines the most influential factor. Khosravi and Mahmoudi (2003) collected 790 suspected dermatophytoses from 9 mammals and one bird type. The suspected samples showed 248 dermatophytes. The highest prevalent fungi were *Microsporum canis*, *Trichophyton verrucosum*, *T. mentagrophytes* and *M. gypseum*.

Nine dermatophytes were isolated from dog and cat hair and skin samples (Bernardo et al. 2005). They were *Microsporum gypseum, M. cookie, M. persicolor, M. canis, M. nanum, M. vangreuseghemii, Trichophyton mentagrophytes, T. Terrestre terrestre* and *T. ajelloi*. Murmu et al. (2015) reported that *M. canis* was the highest incidence of dermatophytes in dogs, cats, and humans compared to other species.

Animal skin mycobiota can be a source of human infections. Dermatophytes may be transmitted from wild or domestic animals to humans. The transmission depends on the degree of direct contact or through contaminated fomites or breeding cages and soil beds of infected animals. The environmental changes and human living style also affect fungal transmission. *Microsporum cains* is the most etiologic dermatophyte of cats. It is transmitted after direct contact or fallen hairpieces (Frymus et al. 2013). The agent *T. equinum* transmutes from the infected horse by direct contact or fomites (Overy et al. 2015).

The mouse favus disease is caused by *T. quinckeanum,* and it is transmitted to humans by cats that prey on the infected mice (Szathmary 1966). Several dermatophytes transmitted to humans from wild animals, the hunting and truffle dogs are the common transmitters from infected Preis or soil (Moretti et al. 2013). Previous studies conducted in Europe, America and Africa recorded dermatophytes from several animal types such as boars, Florida panthers, wild felines, Grant's gazelles, marmots, Eastern cottontail and free-living red foxes (Mancianti et al. 1997; Rotstein et al. 1999; Albano et al. 2013; Gallo et al. 2005a, b). The undomesticated hunting cats were more infected than domestic, which indicates that fungus is contracted from rodents or soil (Drouot et al. 2009).

Fungi on Sheep wool/a view of Fungal Community

Sheep infections were studied intensively worldwide, especially the zoonoses and influential economic groups. Parasites have been studied more than fungi (Swar and Shnawa 2021). Sheep wool has diverse mycobiota, including dermatophytes, opportunistic fungi, and keratinophilic/saprophytic. It seems that sheepskin provides a suitable environment for fungal growth and multiplication. The keratinous fibers are soft, flexible and keep heat. These properties enhance the growth of dermatophytes and keratinophilic fungi. In the subtropical region and middle east countries, the free grazing of sheep is commonly followed (Fig. 1). Roaming of sheep herd causes increasing in total expected count and diversity of sheep wool fungal contamination.

S Several studies were conducted on wool fungi and the most related works were selected for the current review. These include Shtayeh et al. (1989), Abdel-Gawad (1997), Al-Bader et al. (2000), El-Said et al. (2009), and Sallam and Al-Kolaibe (2010). The studies have been carried in Meddle East Region include Jordan, KSA, Libya, Iraq, and Yemen respectively. A total of 70 genera were recorded (Table 1). Although studies were temporally and spatially diverse; eight genera were found prevalent in all studies with prevalence of 8.75%. These genera include *Acremonium Alternaria*, *Aspergillus*, *Chaetomium*, *Chrysosporium*, *Emericella*, *Penicillium* and *Chaetomium*.

Alternaria, Aspergillus, Chrysosporium, Emericella, Penicillium and Chaetomium were recorded as predominant isolates (Al-Bader et al. 2000; El-Said et al, 2009; Sallam and Al-Kolaibe, 2010).

In recent work, Al-Bader (2018) explained that (*Chaetomium* and Penicillium beside *Cladosporium*) were the highest occurrence% among 16 genera isolated from north of Iraq (Fig. 2).

Acremonium, *Alternaria*, *Aspergillus*, *Chaetomium*, *Chrysosporium*, *Emericella*, *Penicillium*, *Scopulariopsis*.

The results of close related works on fungi associated with wool (Table-1) recorded (70) fungal genera. Shtayeh et al.1989; Abdel-Gawad 1997; Al-Bader et al. 2000; El-Said et al. 2009; Sallam and AL-Kolaibe 2010). Although studies were temporally and spatially diverse; eight genera (8.75%) were found prevalent in all studies. Acremonium (1), Alternaria (2), Aspergillus (3), Chaetomium (4), Chrysosporium (5), Emericella (6), Penicillium (7), Scopulariopsis (8).

El-Said et al. (2009) mentioned that Aspergillus, Chaetomium, Emericella, Alternaria and Chochiobolus were predominant, while Sallam and AL-Kolaibe (2010) recorded (Chrysosporium, Aspergillus, and Scopulariopsis) as the highest occurrence genera. The genera (Aspergillus, Penicillium and Alternaria) showed a high prevalence (Al-Bader et al. 2000). In recent work, Al-Bader (2018) explained that Aspergillus and Penicillium beside Cladosporium were the highest occurrence% among 16 genera isolated from wool (Fig. 2).

Through an intensive work related to sheep and fungi interaction, the researchers mentioned remarkable results, such as recording a new species from animal's skin including *Microsporum cookie and Microsporum distortum* (Ajello 1959; di Menna and Marples 1952). Abdullah et al. (2000) isolated and identify a new species of Cephaliophora from shhep wool. A rare case of fungal growth inside sheep hydatid cyst was observed by Al-Bader et al. (2000).

The primary origin habitat of sheep wool mycobiota is soil. They can utilize various waste keratinous materials such as nails, hairs, horns, feathers, hooves, wool hairs, and stratum corneum.

Fungal genera (Table-1) showed a keratinophilic affinity, they are commonly isolated from soil by baiting method. Kumar and Kuaswaha (2021) used five types of keratinized substrate, human hair, cattle hair, human nail, horn, and feather. They recorded 32 fungal genera and *Chrysosporium* inhabited all types of baits.

Kumawa et al. (2019) recorded sixteen genera from semi-arid soil in Rajasthan, India, *Chrysosporium, Fusarium*, and *Aspergillus* showed the highest frequency%. While, Abdulla and Osman (2018) isolated ten genera, Aspergillus had the predominant frequency of 86.8%.

Nineteen species belonging to 11 genera were isolated. *Chrysosporium* and *Aspergillus* had high frequency (Eze et al. 2019). Six genera were diagnosed from soil samples in Libya, and *Aspergillus* was the highest frequency (Altayyar et al. 2016).

Fungi on sheep skin: an industrial impact view

Sheep wool is one of the most significant textile raw materials used for human commodities. The physical properties of wool fibers and their keratin content make them a target for keratinolytic and keratinophilic fungi. *Chrysosporium, Aspergillus*, and *Penicillium*, for example, can readily colonize wool hairs and destroy the structure of the fibers Soomro 2000). Moreover, fungi on sheep wool may be the reason for developing respiratory infections in tannery workers.

Also, biodeterioration is globally considered as one of the critical factors that can impair the properties of leather and the products made from them. During the industrial

Table 1: Fungal genera of sheep wool recorded in five studies (Middle-east countries)

Ref. No.	Shtayeh et al (1989)	Abdel-Gawad (1997)	Al-bader et al. (2000)	El-Said et al. (2009)	Sallam & ALKoliabe (2010)
1	*Acremonium*	*Acremonium*	*Acremonium*	*Acremonium*	*Acremonium*
2	*Alternaria*	*Alternaria*	*Alternaria*	*Alternaria*	*Alternaria*
3	*Arthroderma*	-	*Arthroderma*	-	-
4	*Aspergillus*	*Aspergillus*	*Aspergillus.*	*Aspergillus*	*Aspergillus*
5	-	-	*Botryotrichum*	*Botyotricum*	-
6	*Chaetomium*	*Chaetomium*	*Chaetomium*	*Chaetomium*	*Chaetomium*
7	*Cladosporium*	-	*Cladosporium*	*Cladosporium*	*.Cladosporiu*
8	*Chrysosporium*	*Chrysosporium*	*Chrysosporium.*	*Chrysosporium*	*Chrysoporium.*
9	-	*Chociobolus*	-	*Chociobolus*	-
10	*Drechslera*	-	*Drechslera*	-	-
11	*Emericella*	*Emericella*	*Emericella*	*Emericella*	*Emericella*
12	-	-	*Fusarium*	*Fusarium*	*Fusarium*
13	-	-	*Geotrichum*	-	*Geotrichum*
14	-	-	*Humicola*	*Humicola*	-
15	-	-	*Microascus*	*Microascus*	-
16	*Mortierella*	-	*Mortierella*	-	-
17	-	*Mucor*	*Mucor*	*Mucor*	-
18	-	*Nectaria*	-	*Nectaria*	-
19	*Paecilomyces*	-	*Paecilomyces*	*Paecilomyces*	-
20	*Penicillium*	*Penicillium*	*Penicillium*	*Penicillium*	*Penicillium*
21	-	*Rhizopus*	*Rhizopus*	*Rhizopus sp.*	*Rhizopus*
22	*Socpulariopsis*	*Scopulariopsis*	*Scopulariopsis*	*Scopulariopsis*	*Scopulariopsis*
23	-	*Stachybotrys*	*Stachybotrys*	-	-
24	*Trichoderma*	-	*Trichoderma*	*Tricoderma*	-
25	-	*Tritirchium*	-	-	*Tritirchium*
26	-	*Ulocladium*	*Ulocladium*	*Ulocladium*	-
27	*Sterile hyphae*	-	*Sterile mycelia*	*Sterile mycelia*	*Sterile mycelium*
28	*Candida*	-	*Candida*	-	*Candida*
The isolated dermatophytes and the rare genera					
29	*Aphanoascus*	*Monodicytes*	*Cephaliophora*	*Circinella*	*Eurotium*
30	*Botrytis*	*Myrothecium*	*Exserohilum*	*Curvelaria*	*Thermoascus*
	Ctenmyces	*Pleospora*	*Papulospora*	*Gilmanella*	*Thermomyces*
31	*Doratomyces*	*Setosphaeria*	*Phoma*	*Mycospherella*	*Trichophyton*
32	*Exophiala*	*Trichophyton*	*Preussia*	*Nigrospora*	-
33	*Giliocladium*	-	*Spedonium*	*Setosphaeria*	-
34	*Harosporum*	-	*Thielavia*	*Torula sp.*	-
35	*Memnoniella*	-	-	*Trichophyton*	-
36	*Microsporum*	-	-	-	-
37	*Monilia*	-	-	-	-
38	*Monoascus*	-	-	-	-
39	*Phialophora*	-	-	-	-
40	*Staphylotricum*	-	-	-	-
41	*Trichocladium*	-	-	-	-
42	*Trichophyton*	-	.-	-	-
43	*Trichosporrella*	-	-	-	-
44	*Trichothecium*	-	-	-	-
45	*Verticillium*	-	-	-	-
46	*Wallemia*	-	-	-	-

Fig. 1: Free grazing of sheep-Iraq.

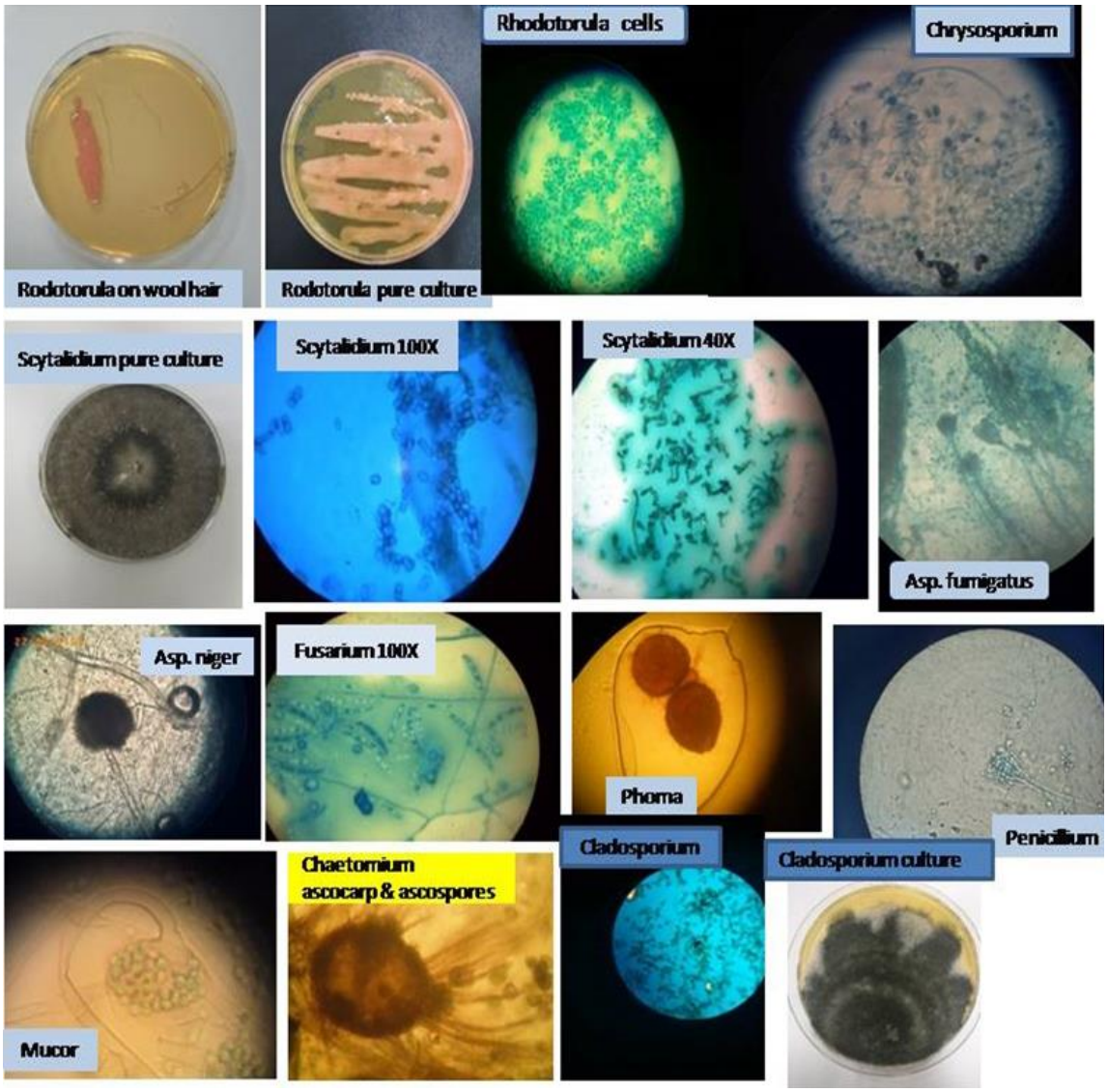

Fig. 2: A number of fungi isolated from wool hair (Al-Bader 2018).

processing of sheepskin, several fungi tolerate the high NaCl concentrations (20–30%) w/v. *Aspergillus*, *Penicillium* and *Alternaria* were isolated from salted sheep skin (Ozdilli et al. 2007). Fungi were isolated during all processing stages. From an Indian factory of the leather industry, fourteen genera were isolated with *Aspergillus* and *Penicillium* as predominant fungi (Srinath et al. 2002). The active protease producer fungi deteriorate processed leathers. Penicillium sp., for example, can grow and multiply during processing stages and cause significant effects on leather quality (Wilson 2005). During the drying stage of leathers, fungi may also develop because of the favorable temperature and humidity (Ozgunay et al. 2010). Generally, fungi are the most causative agents for industrially treated leather damage. They include *Penicillium, Aspergillus,*

Mucor, Rhizopus, Paecilomyces, and *Trichoderma* which survive during tanning conditions. They utilize the tanning agent depending on tanninase secretion. *Candida albicans* and *Staphylococcus aureus* showed poor and moderate growth on finished leather samples (Orlita 2001). Depending on the previous information, the leather products (e.g., footwear) will be the source of fungal infection as tinea pedis. To prevent or reduce mycoses from a different leather product, they should be treated with a suitable fungicide.

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