

Review Article

Distribution Pattern of Keratinophilic Fungi in Different Ecological Conditions:

A Review

ABSTRACT

Keratin, An Insoluble Protein with Numerous Disulphide Bonds Is Highly Resistant to Proteases and Serves as One of The Major Defiant Pollutants. The keratinophilic fungi are known to use keratinous substances such as skin, hair, nail, fur, feather, etc. For their growth and survival. The Keratinolytic Potential of These Fungi Play an Important Role In Decomposition Of Keratin. The present review highlights the role of various ecological factors on the distribution pattern of keratinophilic fungi. Also, the effect of various biotic and abiotic factors on their growth is discussed. Among biotic factors growth is largely dependent on the presence of humans, birds, animals and abiotic factors include temperature, pH, humidity, organic matter in soil. Further, the potential keratinous substrates such as hairs, feathers, pellets are also described.

Keywords: [Keratinophilic fungi, keratinous substrate, ecological factors and decomposition.]

1. INTRODUCTION

A large number of microbes exist in the world. Microbes including bacteria, fungi, algae, protozoan etc where fungi are the second largest group of microorganisms after the insects [1]. Fungi are cosmopolitan in distribution; some are aquatic and others are terrestrial. Many are parasitic on plants, animals and human beings. The body consists of branched and filamentous hyphal forms, a net like structure called as mycelium. These are devoid of chlorophyll so heterotrophic in nature, hence considered as parasites, saprotrophs or symbionts.

Comment [yP1]: You can not write a sentence with initials capital.

Comment [yP2]: Not appropriate to write "pH" like this.

Comment [yP3]: Not a good start to write introduction with such a childish information

Fungi are found in different ecological habitats and depend on particular nutrition and environmental conditions for its perpetuation [2,3]. Fungi play a very important role in environment [4,5]. Ecological factors affect the distribution pattern of fungi [6,7]. Growth and reproduction of fungi are dependent on several environmental factors and even a minute change in these requirements cannot be tolerated [8,9]. Although the sustenance needs of fungi are simple but different fungi require different physical, chemical and physiological conditions [10]. The effect of different culture media and several physiological factors on fungal growth have been studied by several workers [11,12]. One of the environmental factors which affects spore germination is temperature [13]. There is an optimum, maximum and minimum temperature for spore germination [14]. Optimum temperature for fungal growth is 15-35^o C [15]. Not only temperature but pH also affects fungal growth directly or indirectly [16,17]. Optimum pH is 5-8 [12,18]. Soil acts as main reservoirs for all microorganisms including fungi [1].

Comment [yP4]: Not very convincing start. Needs some more appropriate and valuable information to prompt interest in reader.

2. Keratinophilic fungi

Keratinophilic fungi are those fungi which grow and perpetuate on keratinous substances such as skin, hair, nail, fur, feather, horn, hoof, beak of the birds. They use keratin as a source of carbon [19]. Keratinophilic fungi generally colonize keratinous substrates. Some of them are keratinolytic and are ecologically important as they can decompose α -keratins, insoluble fibrous proteins [20]. Those keratinophilic fungi which cause most of cutaneous infections are referred to as dermatophytes [21]. The dermatophytes have the ability to take over keratinous tissue of the body such as skin, hair and nails [22].

Keratinophilic fungi grow on various keratinous materials and break them into their low-molecular-weight components. Keratinophilic fungi include a variety of filamentous fungi, mainly comprising hyphomycetes, including dermatophytic and a large number of non-dermatophytic filamentous fungi and several other taxonomic groups. Generally,

keratinophilic non-dermatophytic filamentous fungi exist as saprophytes in soil and can even act as plant pathogens [23]. Keratinophilic fungi are ecologically important and exist in the nature with wide distribution patterns and cause human and animal mycological disorders [24]. Keratinophilic fungi are practically pathogenic saprotrophs mark out as opportunistic pathogens [25]. *Microsporiumgypseum*, *M. cookei*, *Chrysosporiumkeratynophilum* are pathogenic strains of these fungi which generally cause dermatomycoses in humans and animals.

Dermatophytes are group of fungi capable of infecting humans and other animals, growing on their keratinized tissue (skin, hair and nails) and cause dermatophytoses, commonly known as ringworm. They cause cutaneous infection and invade only non-living cornified layers as they cannot invade deeper tissues of host [26,27]. The causal organisms of dermatophytoses belong to three anamorphic genera namely *Epidermophyton*, *Microsporum* and *Trichophyton*. The genera can be distinguished on the basis of morphology and formation of conidia. [28,29,30].

A correlation was found between soil association and conidial production in dermatophytes, the less significantly a dermatophyte can grow on dissociated keratin, the less likely it is to form conidia. Formation of heterothallic teleomorphs is also influenced by the association with soil [32]. The arthroconidium is the structure found in association with infected hairs and skin scales. They may persist in environment for long and can serve as an environmental source of contagion.

Comment [yP5]: Sentence structure is not good. It has lost all its meaning

2.1 Types of keratinophilic fungi

Those keratinophilic fungi which invade the keratinous tissues such as skin, nails, hair and live parasitically in man and animals; share certain morphological features, constitutes a special group called dermatophytes. Deramtophytes can be classed into

Comment [yP6]: Poor use of English language

three ecological groups: anthropophilic, which use human being as its hosts, zoophilic, grows on animals and geophilic dermatophytes, occur in soil as saprophytes [31,33,23]. Anthropophilic fungi are known to infect humans and rarely infect animals [34]. Zoophilic fungi are associated with animals but can infect humans too. Geophilic fungi are dependent on keratinous waste like hairs, feathers, hooves and horns of animals after they have been shed. During the course of evolution, many of the geophilic fungi have adopted a pathogenic life cycle and are now serve as potential agents of fungal diseases in humans and animals. So, geophilic dermatophytes are known to be ancestral to the pathogenic dermatophytes as they have ability to decompose keratin and are closely associated with animals living in contact with soil [35]. These species cannot be clearly demarcated as they are interrelated to each other. Some zoophilic species can be isolated from soil as well as from fur of healthy animals [36]. Although geophiles are known to persists in soil, some geophilic dermatophytes overlap in ecology with zoophiles. Although anthropophilic species cause human dermatophytoses but there is a significant role of domestic animals also in transmission of dermatophytes to man, raising a need for humans to use appropriate measures when in contact with animals.

2.1.1 Geophilic Fungi

Geophilic fungi are keratinophilic fungi that colonize keratinous substrates (feathers, hairs, animal remains) present in the soil, on soil surface and in other natural environments. They are keratinolytic fungi with special physiological function of decomposing native keratin. They utilize native keratin (chicken feathers) as carbon and energy source [37]. Geophilic dermatophytes includes *Trichophyton* Malmsten and *Microsporum* Gruby (anamorphs) and their respective teleomorphs: *Arthroderma* Berk.

and *Nannizzia* Stocklade. The *Chrysosporium* group consists of two keratinolytic genera, *Chrysosporium* Corda and *Myceliophthora* Cost (anamorphs). Their teleomorphs are classified in the genera *Arthroderma* Berk., *Aphanoascus* Zokal and *Ctenomyces* Eidam. or remain unknown [38].

Two new keratinophyton species were reported namely *Keratinophyton kautmanovae* sp. nov. and *K. keniense* sp. nov., from soil samples collected from two different locations of Africa and Europe. Study utilised data collected from phylogenetic studies involving the internal transcribed spacer (ITS) region and the nuclear large subunit (LSU) rDNA, as well as their unique phenotype. Besides, the *K. keniense* constitute the first described new species for this genus from Africa [39].

3. Keratinolytic potential

Keratin is an insoluble protein having fibrous helical structure with numerous disulfide bonds making it resistant to proteases but can be easily digested by keratinase enzymes [40]. Keratin is one of the main components of hair, skin and feathers and is also found in soil [41]. Natural keratin material consists of both keratinous as well as non-keratinous components along with other simpler compounds, e.g., amino acids, urea, which is up to 10% of the substrate's dry weight [42]. This enables growth of non-keratinolytic fungi also on native keratin [43].

Keratinases are known to provide pathogenicity to dermatophytes and help them to cause dermatophytoses or ringworm disease in humans and animals [44]. Keratinases are also of industrial application as they are used in several industries such as leather, poultry, cosmetics, diagnostics and pharmaceuticals [45, 46, 47, 48]. There are other applications of Keratinolytic enzymes in biotechnological field such as hydrolysis of poultry feathers and dehairing of bovine pelts [49]. Keratinases have also been shown to be useful in processing waste in the poultry and leather industries [50].

The process of fungal keratinolysis can be categorized under three phases namely deamination, sulphitolysis and proteolysis [51]. Deamination is the process of removal of

Comment [yP7]: Not academically nice English

ammonia conditioned by an elevated level of nitrogen in native keratin upto 16% in hair [51] and a low C: N ratio in these substrates, [38]. N-NH₄⁺ accumulation leads to alkalization of environment which is important for enzymatic disruption of many keratins' disulphide bridges responsible for its resistance to the activity of proteolytic enzymes. Sulphitolysis involves the disruption of S-S bonds and occurs with the help of inorganic sulphite released by the fungus [52,53]. This leads to denaturation of keratin and leads to proteolysis with alkaline or neutral proteases released by these fungi [51]. While growing saprophytically on native keratin, keratinolytic fungi leads to oxidation of 70% of carbon to CO₂, liberate 30-60% of nitrogen as ammonia and convert 30-50% of sulphur into sulphates [38]. This enables keratinolytic fungi to play a key role in recovering carbon, nitrogen and sulphur present in animal remains containing keratin. An investigation was done to analyse keratinolytic activity of 37 pigmented and non-pigmented strains of *Trichophyton ajelloi* collected from loamy soil and chernozem. It was concluded that in loamy soils, pigmented strains and in chernozem, non-pigmented strains proved to be highly efficacious in degrading keratin. On comparison, it was found that the strains isolated from loamy soils have better keratinolytic activity. They also noted the continuous increase in keratinase activity and soluble proteins in cultures throughout the experiment. The results were highly significant as keratinolytic property of *Trichophyton ajelloi* can be applied to synthesise sulfur containing fertilizers for the plants. Higher amount of ammonium ions was released by pigmented strains of the fungi obtained from loamy soils [54].

Comment [yP8]: Unwanted space between Carbon and nitrogen

Comment [yP9]: Ammonium should not be written as this

Comment [yP10]: Better mentioning such information in the form of some equation to tempt the reader.

4. Keratinous substrates

Birds' nests are one of the microenvironments consisting of variable amounts of keratinous substrate such as feathers, hairs, pellets, prey remains and have distinct levels of humidity and pH [55]. Some other substrates include hairs of wild animals [56,57], water [58], plant debris [59] and dung [60]. Besides, sewage sludge

accommodates high quantities of keratin remnants with specific physicochemical and microbiological characteristics. So, it can be presumed that keratinophilic fungi are found in plenty in a sludge environment.

In different aquatic habitats, quantitatively and qualitatively different communities of keratinophilic fungi are found. This might be due to difference in the levels of water contamination with sewage and natural environmental pollutants [61]. The distribution and occurrence of cycloheximide-resistant, keratinophilic and other fungi in aquatic habitats, including sludge and wastewater have been studied by various investigators [62].

5. Ecological factors affecting growth of keratinophilic fungi

5.1 Abiotic factors

The occurrence of dermatophytes is mainly dependent on the geographical location, season or living conditions and the climates to which the susceptible animal or human is exposed [63].

The variable distribution patterns of keratinophilic fungi depends on several environmental factors including biotic and abiotic. Among biotic factors, existence of keratinophilic fungi is largely dependent on the presence of humans, birds and animals [6, 64]. Abiotic factors include temperature, pH, soil moisture, chemical composition and content of the organic matter in soil. *T. ajelloi*, is an exception which can grow in soils with low pH.

5.1.1 Soil

Vanbreuseghem was the first to report the incidence of dermatophytes in soil by using the hair bait technique [65]. Since then, studies on keratinophilic fungi of soil were carried out throughout the world [66, 67,64,68,69]. The soil proves to be one of the complex microenvironments for the growth of several fungi. Fungal floras vary with the type of soils but most of them are cosmopolitan [70]. Soil is the principal habitat of fungi [71]. Soils with

abundant keratinous residues act as both a permanent or occasional pool for dermatophytes and other keratinophilic fungi and are a major source of potential infection for humans and animals [20]. Keratinous substrates provide the most favourable environment for the development of keratinophilic fungi [72]. In India, several keratinophilic fungi were reported from hospital dust and soil samples collected from various public places. Reports states that out of the total dermatophytes isolated from their soil samples, *Trichophytonmentagrophytes* occurred most commonly, followed by *Microsporumgypseum* and *Chrysosporiumtropicum*, *C. keratinophilum*, *M. nanum*, *T. terrestre* and *C. lobatum*. Out of the non-dermatophytes identified, *Aspergillus fumigatus* and *Penicilliumchrysogenum* were the most regularly occurring, with each contributing 5.4% to the total fungal flora, while *Microsporumfulvum* and *Candidaparapsilosis* contributed at least 1.2% [73].

Soil acts as connecting epidemiological and evolutionary link that connects geophilic, zoophilic and anthropophilic keratinophilic fungi [66]. The diversity of keratinolytic fungi was analysed in soil samples collected from Jhansi, India. The isolates include both the keratinolytic and phytopathogenic fungi and reported the significant presence of *Graphiumkeratinophilum*, *Candida albicans*, *Microsporumfulvum*, *Chrysosporiumlobatum*, *Onocladium flavum*, *Alternaria alternata*, *Aspergillus niger*, *Penicillium citrinum*. 75% of the fungi belongs to the Onygenales order of division Ascomycota. They concluded that the biodiversity of fungi is affected by the different factors in addition to the existence of animals in the area [74].

5.1.2 Soil pH

Böhme and Ziegler were the first to report the variance in species composition of keratinophilic fungi with reference to pH range. Enzymes of keratinophilic fungi are generally active at pH 6.9 [75]. The keratinophilic fungi can be divided into three groups on the basis of pH values namely acidophilic *Arthroderma uncinatum*, *A. curreyi* and *Chrysosporiumtropicum*, neutrophilic *Nannizaiincurvata* and alkalophilic *A. quadrifidum*,

Comment [yP11]: Why were? Are you reporting something you did?

Ctenomyces serratus and *Chrysosporium keratinophilum* [76]. The effect of soil pH and climate types on the frequency of keratinophilic fungi was investigated by analyzing soil samples collected from Iran and concluded that there is a relation between frequency of keratinophilic fungi and the soil pH [77]. Some reports states that keratinophilic fungi are not seen in soils with low pH such as 3 to 4.5 [75]. The correlation between soil pH and spread of dermatophytes in Jaipur city was tested. From pH range 7 to 9, *Trichophyton verrucosum*, *Microsporium audouinii* and *M. canis* were isolated whereas from pH range 6.5 to 9.5, *Chrysosporium tropicum* followed by *Trichophyton mentagrophytes* were isolated. Results concluded that garden soil and roadside soil with pH 6.5 to 8.5 were most favourable for the occurrence of keratinophilic fungi except *Fusarium moniliforme* which can be isolated from acidic soil of pH 3 [78]. Fungi were recovered from neutral soil with pH 7 including *Exserophilum* sp., *Microsporium audouinii*, *Trichophyton verrucosum* for the first time from Jaipur, India [79]. The highest growth was reported at pH 5-7. Among which *Chrysosporium indicum* was recovered at pH 3 and remaining two isolates from pH 7 and concluded that extremes values of pH are not suitable for fungal growth [80]. *Arthroderma multifidum*, showed highest growth at pH 8 [81]. pH 7.5 proved to be optimal for mycelia growth whereas sporulation was highest at pH 6.5 [82]. Low and high pH such as 5.5 and 8.5 is not much effective for growth and sporulation. The effect of pH on the growth of keratinophilic fungi was analysed and it was found that pH 7.00 to 7.99 is the most favourable. *Chrysosporium indicum* was found from pH 8.00 to 8.99 whereas *Fusarium solani*, *Microsporium canis* and *Trichophyton mentagrophytes* from pH 7.00 to 7.99 [83]. Species generally grow in pH range of 5.8 to 9.1 [84].

5.1.3. Soil moisture

A positive correlation has been found between number of isolates and moisture content of soil [71]. *Arthroderma uncinatum* and *Ctenomyces serratus* shows highest spore germination at 90-100 % relative humidity [55].

5.1.4 Organic matter content

High distribution frequency generally occurs in rural than in urban areas and also in stables due to the high organic matter [85]. The existence of keratinophilic fungi in waterlogged soils of paddy field were examined at several stages of cultivation namely transplantation, tillering, milking and maturation. Reports identified 14 species of *Chrysosporium* all-round the cropping season. Among them *C. keratinophilum* followed by *C. tropicum* were the most prevalent geophilic species [69].

5.1.5 Chemical composition of soil

The uneven distribution is found due to dissimilar physiology and resistance to variations in environmental factors. The species diversity of keratinophilic fungi was analyzed in four different soil types having different physiological and chemical properties. Identification included *Chrysosporium* sp. and geophilic dermatophytes namely *Trichophyton ajelloi* and studies concluded that occurrence of *Trichophyton ajelloi* was high in acidic soils whereas prevalence of *Chrysosporium keratinophilum* increased with an increase in the content of humus, nitrogen, CaCO₃ and phosphorus in the soils [86]. Garden soils were proved to be more appropriate for fungal growth than playground soils due to high organic debris, keratinous substrates and plant litter present in these soils [87]. Higher proliferation rates of keratinophilic fungi occur in loamy soil, chernozem and rendzina which have high amount of slit and clay in comparison with sandy soil which have high content of sand.

5.1.6 Depth of soil

The relation between occurrence of keratinophilic fungi and depth of soil was studied by collecting forty soil samples from surface, 10, 20 and 30cm depth. The study revealed that number of species decreased with increased sampling depth [88].

5.1.7 Temperature

Keratinophilic fungi shows maximum growth at 25-30^o C i.e., mesophilic in their occurrence. *Chrysosporium keratinophilum*, *C. tropicum*, *C. queenslandicum* occur at 37^oC. Optimum temperature range for most of the keratinophilic fungi is 25-27^oC and above 40^oC there is no

fungal growth [55]. The limited heterogeneity of keratinophilic fungi was reported due to hot and arid climate [89].

Very high or very low temperature disturbs the growth of fungi [8]. Three keratinophilic fungi were isolated from Jaipur, India and highest growth was reported at 25°C to 35°C temperature. Among these *Chrysosporium indicum* was recovered from 15°C to 35°C temperature and remaining two isolates were observed at 35°C. Extremes values of temperature are not suitable for fungal growth [80].

Arthrodermamultifidum, a keratinophilic fungi was isolated from soils of poultry farmhouse of Rajasthan, India showing highest growth at 25°C temperature [81]. 30°C temperature was reported to be the most optimal for mycelia growth and sporulation [82]. Survival period of dermatophytic and keratinophilic fungi was investigated in unsterilized soil, sterilized soil and Sabouraud's dextrose-agar medium at three different temperature conditions and verified 11±1°C to be the most suitable temperature condition for all tested fungi up to two years of studies [90].

5.1.8 Humidity

The effect of humidity was studied on the perpetuation and reproduction of geophilic keratinophilic fungi isolated from soil samples collected from Public Park. They analyzed that a positive correlation occurs between growth and humidity. They isolated *Chrysosporiumtropicum* and *Trichophyton mentagrophytes* and concluded that *Chrysosporiumtropicum* manifested highest growth and sporulation at 75% and 50-95% relative humidity respectively while *Trichophyton mentagrophytes* showed highest growth and sporulation at 95% and 62-95% relative humidity respectively [8].

5.1.9 Seasonal variations

Floor dust samples were collected from January to December 2005 and following dermatophytes were obtained-*Aphanoascusfulvescens*, *Aphanoascus sp.*,

Arthrodermacuniculi, *Chrysosporiumlucknowense*, *Gymnoascusuncinatus* and *Trichophyton rubrum*. Keratinophilic fungi showed a peak in April and decline in November [91].

The effect of seasonal fluctuations on distribution pattern of keratinophilic fungi was studied in 19 samples collected from Baghdad swimming pools in the course of four seasons. *Aspergillus* genus was found abundantly, followed by *Trichophyton* and *Fusarium* and conclusion was drawn that the summer season is the most favourable for fungal infection [92]. The seasonal variation and niche preference of keratinophilic fungi was also analyzed [93]. The keratinophilic fungi were observed in a wetland agro ecosystem in Kerala, India. Maximum species were recorded in North East monsoon season followed by early summer (29 species), late summer (19 species) and south west monsoon season (18 species). Due to the presence of maximum organic matter and keratinous materials Vembanadu wetland agro ecosystem proves to be the best environment for perpetuation of keratinophilic fungi. These fungi are symbolic of environmental pollution [94]. Climatic conditions during monsoon season favour the growth and sporulation of the fungi [90].

5.2 Biotic factors

5.2.1 Birds and animals

Isolation rates of keratinophilic fungi are higher in soil samples gathered from the farm lands and poultries [50]. The distribution of keratinophilic fungi is largely dependent on physical and chemical properties of the nests such as humidity, pH. Nest is a potential source of pathogenic infections and acts as reservoirs of geophilic fungi causing dermatomycoses and systemic mycoses in humans and mammals [95]. The mycoflora of hair of cows, donkeys, rabbits, cats and dogs were evaluated and analysed the occurrence frequency of keratinophilic fungal species in these samples and reported that majority of them were either mycotic agents or isolated from animal and human lesions. Seven species of dermatophytes were recovered. They concluded that maximum dermatophytes were recovered from cats followed by cows, rabbits, donkeys, dogs and discussed that these animals play important role in transmission of these fungi [96].

Comment [yP12]: See this formatting the line spacing why it is different for this

The keratinophilic fungi were also studied in clovenhooves and horns of goats and sheep where *Chrysosporium* was the most commonly reported genus on the different substrates [97]. The highest frequency was reported from animal resorts as compared to street soil samples [98]. The frequency of keratinophilic fungi is higher in compost with higher feather proportion. *Chrysosporium* group was predominantly found [99]. The occurrence of keratinophilic fungi was screened in soils stressed by the presence of animals and presence of opportunistic pathogen (*Pseudallescheria boydii*) was reported. Commonly occurring fungi were *Trichophyton ajelloi*, geophilic dermatophytes *Microsporium gypseum*, *Chrysosporium keratinophilum* and *Chrysosporium queenslandicum* [100]. The isolation frequency of keratinophilic fungi was higher from terrestrial birds mainly water fowl and migratory birds are an important vehicle for dissemination of dermatophytes [101]. Keratinophilic fungi occur amply in soil from fold-grazed pasture than non-fold-grazed pasture due to the occurrence of high animal activity in fold grazed pasture [102]. The presence of keratinophilic fungi and dermatophytes were analyzed from playground soils of Ujjain, India and it was observed that their occurrence is also affected by the vertebrate and human activity. On administering these fungal samples in Juvenile pteropodid bats it was found that oral candidiasis is usual in domestic pteropodid bats [103]. The occurrence of Keratinophilic and Keratinolytic Fungi was studied inside and outside of three caves in Tatra Mts., Slovakia (Brestovská, Demänovská L'adová and Demänovská Slobody). It was observed that maximum fungal species were from inside of caves and highest values of the Shannon diversity index was recorded inside the Demänovská Slobody Cave. This was the first report of *Arthroderma boreum*, *Arthroderma singulare*, *Chrysosporium europae*, *Chrysosporium siglerae*, *Keratinophyton wagneri*, and *Penicillium charlesii* in underground sites. *Arthroderma quadrifidum* was the most common fungal species in their samples. A positive correlation was specified between fungal biodiversity of this group and anthropogenic and animal activity in these sites [104].

5.2.2 Humans

The invasion of human hair by *Trichophyton mentagrophytes*, *T. rubrum* and *T. ajelloi* was studied. It was observed that mycelium penetrates into the cuticle and digestion of cortex was noticeable maximum by *T. mentagrophytes* [105]. Keratinophilic fungi are more in urban areas than in rural areas because in urban areas human population and their activities, substrate and source of the keratin required for keratinophilic fungi is higher than the rural area. *Engyodontium album* was isolated for the first time from Iran soil [77].

Comment [yP13]: Not a comprehensive heading

The process of keratinolysis and its morphological expression in hair digestion was studied and found that some of the species showed surface erosion and radial penetration [106]. The degradation of human hair by keratinophilic fungi was studied by using the biochemical and microscopic analysis. Reports states that all test fungi employed human hair as carbon and nitrogen source. *M. gypseum* exhibited maximum activity whereas *Auxarthronconjugatum* showed minimum hair degradation activity [107]. Various keratinous substrates were studied such as human hair, cattle hair, human nail, horn and feather and recorded *Chrysosporium*, *Microsporum*, *Trichophyton* genera on all substrates. Management of keratinous waste is essential for lowering the risk of dermatophytosis [108]. *Chrysosporiumpannicola* was the most frequent species from soils of Malwa region (M.P.) [109].

Comment [yP14]: How as you are reporting a review

Comment [yP15]: Don't understand what are you trying to convey

4. CONCLUSION

[Dermatophytes do not cause life threatening infection but can cause hair and nail loss, inflammation, pustules, itching and scaling (dermatophytoses) as they are constantly associated parasites of humans. Keratinous waste is one of the major recalcitrant pollutants in nature. Keratinophilic fungi possess the potential biotechnological applications which can be utilized to degrade keratinous waste and to recycle the poultry waste for the protection of environment. Fungal keratinases prove to be eco-friendly alternative for decomposing and recycling pollutant in nature. Using keratinophilic fungi for hydrolysis of keratin not only proves to be ecologically safe but also economically fruitful. Keratinophilic fungi act as nature's keratin degrading machines. The keratinolytic potential of fungi is important ecologically as it allows the degradation of keratinous waste present in soil. The fermentation broth of fungi and isolated keratinases can be of potential application in leather and textile industry. The presence of keratinophilic fungi act as bioindicator of environmental pollution with animal faeces, hair, plant debris and other keratinous substrate. The hydrolyzed keratinous products can be used as fertilizers for plants (N, S) and feed for animals (amino acids). They can be used in agricultural practice due to their keratinolytic activity. There is still scope of isolation of many more keratinophilic fungi from Indian soils and there is need for further ecological studies of this important group of microbes as their distribution, disease

cycle and keratinolytic potential is affected by a variety of ecological factors. Understanding the role of ecological factors on survival of these fungi can help researchers to study management of these fungi.]

Comment [yP16]: Why this bracket is here for?

REFERENCES

1. Marchisio VF. Keratinophilic fungi: their role in nature and degradation of keratinic substrates. *Biology of dermatophytes and other keratinophilic fungi*. 2000; 17: 86-92.
2. Albert S, Pandya B, Padhiar A. Evaluation of colony characteristics and enzymatic activity of some fungi for potential use in co-culture for bio pulping. *Asian J Biol Life Sci*. 2012; 1(2): 83-89.
3. Mishra PK, Khan FN. Effect of different growth media and physical factors on biomass production of *Trichoderma viride*. *People's Journal of Scientific Research*. 2015; 8(2): 11-16.
4. Sharma A, Sharma M, Chandra S. Influence of temperature and relative humidity on growth and sporulation of some common dermatophytes. *Indian Journal of Fundamental and Applied Life Sciences*. 2012; 2(4): 1-6.
5. Sharma R, Choudhary N. Isolation of keratinophilic fungi from soils samples of agricultural fields of Saharanpur (UP), India. *Int J Curr Microbiol Appl Sci*. 2015; 4(7): 229-237.
6. Deshmukh SK, Verekar SA. The occurrence of dermatophytes and other keratinophilic fungi from the soils of Himachal Pradesh (India). *Czech Mycol*. 2006; 58(1/2): 117-124.
7. Ogbonna CIC, Pugh GJF. Keratinophilic fungi from Nigerian soil. *Mycopathologia*. 1987; 99(2): 115-118. doi: 10.1007/BF00436915.
8. Sharma M, Sharma M. Influence of environmental factors on the growth and sporulation of geophilic keratinophiles from soil samples of Public Park. *Asian J Exp Sci*. 2009; 23(1): 307-312.
9. Singh A, Sharma R. Biocontrol and environmental studies on paper degrading mycoflora isolated from Sanganer area, Jaipur, India. *Int J Curr Microbiol Appl Sci*. 2014; 3(8): 948-956.
10. Smith RJ, Grula EA. Nutritional requirements for conidial germination and hyphal growth of *Beauveria bassiana*. *J InvertebrPathol*. 1981; 37(3): 222-230. doi: 10.1016/0022-2011(81)90079-3.

11. Kim YK, Xiao CL, Rogers JD. Influence of culture media and environmental factors on mycelial growth and pycnidial production of *Sphaeropsispyripitrescens*. *Mycologia*. 2005; 97(1): 25-32. doi: 10.1080/15572536.2006.11832835.
12. Saha A, Mandal P, Dasgupta S, Saha D. Influence of culture media and environmental factors on mycelial growth and sporulation of *Lasiodiplodiatheobromae*(Pat.) Griffon and Maubl. *J Environ Biol*. 2008; 29(3): 407-410.
13. Cabanillas HE, Jones WA. Effects of temperature and culture media on vegetative growth of an entomopathogenic fungus *Isaria* sp. (Hypocreales: Clavicipitaceae) naturally affecting the whitefly, *Bemisia tabaci* in Texas. *Mycopathologia*. 2009; 167(5): 263-271. doi: 10.1007/s11046-008-9176-2.
14. Verma V. Effect of temperature and hydrogen ion concentration on three pathogenic fungi. *Sydowia*. 1969; 23(1): 164-168.
15. Sharma M, Sharma M. Influence of culture media on mycelial growth and sporulation of some soil dermatophytes compared to their clinical isolates. *J MicrobiolAntimicrob*. 2011; 3(8): 196-200.
16. Simpfendorfer S, Harden TJ, Murray GM. Effect of temperature and pH on the growth and sporulation of *Phytophthora clandestina*. *Australas Plant Pathol*. 2001; 30(1): 1-5. doi: 10.1071/AP00054.
17. Abubakar A, Suberu HA, Bello IM, Abdulkadir R, Daudu OA, Lateef AA. Effect of pH on mycelial growth and sporulation of *Aspergillus parasiticus*. *J. Plant Sci*. 2013; 1(4): 64-67. doi: 10.11648/j.jps.20130104.13.
18. Zhao H, Huang L, Xiao CL, Liu J, Wei J, Gao X. Influence of culture media and environmental factors on mycelial growth and conidial production of *Diplocarpon mali*. *Lett Appl Microbiol*. 2010; 50(6): 639-644. doi: 10.1111/j.1472-765X.2010.02847. x.
19. Cook RC. *Fungi, man and his environment*. Longman publisher: London, UK; 1977.
20. Filipello Marchisio V. Keratinolytic and keratinophilic fungi of children's sandpits in the city of Turin. *Mycopathologia*. 1986; 94(3): 163-172. doi: 10.1007/BF00454595.
21. Elewski BE. Onychomycosis: pathogenesis, diagnosis, and management. *Clin Microbiol Rev*. 1998; 11(3): 415-429. doi: 10.1128/cmr.11.3.415.
22. Weitzman I, Summerbell RC. The dermatophytes. *Clin Microbiol Rev*. 1995; 8(2): 240-259. doi: 10.1128/cmr.8.2.240.

23. Gugnani HC. Nondermatophytic filamentous keratinophilic fungi and their role in human infection. *Rev Iberoam Micol.* 2000; 17: 109-114.
24. Mohamed S, Ali-Shtayeh MF, Jamous R. Keratinophilic fungi and related dermatophytes in polluted soil and water habitats. In: *Biology of dermatophytes and other keratinophilic fungi.* (Eds.: Kushawaha, R.K.S., Guarro, J.). Revistalberoamericana de Micologia, Spain; 2000.
25. Rippon JW. Host specificity in dermatophytes. In: *Proceedings of VIIIth Congress of the International Society of Human and Animal Mycology*, Baxter M de. Palmerston North, New Zealand. Massey University Press; 1982.
26. Cas ED. Parasitic adaptation of pathogenic fungi to mammalian hosts. *CRC Crit Rev Microbiol.* 1986; 13(2): 173-218. doi:10.3109/10408418609108738.
27. King RD, Khan HA, Foye JC, Greenberg JH, Jones HE. Transferrin, iron, and dermatophytes. I. Serum dermatophyte inhibitory component definitively identified as unsaturated transferrin. *J Lab Clin Med.* 1975; 86(2): 204-212.
28. Ajello L. A taxonomic review of the dermatophytes and related species. *Sabouraudia: J Med Vet Myco.* 1968; 6(2):147-159. doi: 10.1080/00362176885190271.
29. Ajello L. Taxonomy of the dermatophytes: a review of their imperfect and perfect states. In: *Recent advances in medical and veterinary mycology* (K. Iwata ed.). University of Tokyo Press, Tokyo; 1977.
30. Matsumoto T, Ajello L. Current taxonomic concepts pertaining to the dermatophytes and related fungi. *Int J Dermatol.* 1987; 26(8): 491-499. doi: 10.1111/j.1365-4362.1987.tb02288.x.
31. Rippon JW. *Medical mycology: the pathogenic fungi and the pathogenic actinomycetes.* In: *Medical mycology: the pathogenic fungi and the pathogenic actinomycetes* Saunderscompany. 3rd ed. W.B. Saunders Company Philadelphia USA; 1988.
32. Kwon-Chung KJ, Bennett JE. *Medical Mycology.* Lea and Febiger: Philadelphia, PA, USA; 1992. ISBN, 812114639, 661-662.
33. Kwon-Chung KJ. Cryptococcosis. *Medical mycology.* 1992; 397-446.
34. Mayr A. Infections which humans in the household transmit to dogs and cats. *Zentralbl Bakteriol Mikrobiol Hyg B Umwelthyg Krankenhaushyg Arbeitshyg Prav Med.* 1989; 187(4-6): 508-526.
35. Chmel L. Zoophilic dermatophytes and infections in man. *Med Mycol.* 1980; 8: 61-66.

Comment [yP17]: I am concerned about which information you have gotten from this reference as this is a preview of a book only.

36. Ozegetic L. Wild animals as reservoirs of human pathogenic dermatophytes. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene*. 1980; 8: 369-380.
37. Kornilowicz-Kowalska T. Studies on the decomposition of keratin wastes by saprotrophic microfungi. I. Criteria for evaluating keratinolytic activity. *Acta Myco*. 1997; 32(1): 51-79.
38. Currah RS. Taxonomy of the onygenales: arthrodermataceae, gymnoascaceae, myxotrichaceae and onygenaceae. *Mycotaxon*. 1985; 24: 1-216.
39. Labuda R, Scheffnacker V, Schüller A, Voleková B, Kubátová A, Kandemir H, *et al.*, Two novel members of Onygenales, *Keratinophytonkautmanovae* and *K. keniense* spp. nov. from soil. *Sci Rep*. 2024; 14(1): 16525. doi: 10.1038/s41598-024-67475-y.
40. Grant WD, Long PE. Environmental Microbiology. In: *The Natural Environment and the Biogeochemical Cycles. The Handbook of Environmental Chemistry. vol 1 / 1D.* Springer: Berlin, Heidelberg; 1985. doi: 10.1007/978-3-540-39209-5_4.
41. Rajak RC, Parwekar S, Malviya H, Hasija SK. Keratin degradation by fungi isolated from the grounds of a gelatin factory in Jabalpur, India. *Mycopathologia*. 1991; 114(2): 83-87.
42. Mercer EH. The fine structure keratin. *Text. Res. J.* 1958; 28: 860–866. doi: 10.1177/004051755702701104.
43. Kornilowicz T. Studies on mycoflora colonizing raw keratin wastes in arable soil. *Acta Mycologica*. 1992; 27(2): 231-245. doi: 10.5586/am.1992.022.
44. Dexter HH. Ascomycetes the dermatophytes. fungi pathogenic for human and animal. *J Mykosen*. 1997; 12: 129-135.
45. Lin X, Lee CG, Casale ES, Shih JC. Purification and characterization of a keratinase from a feather-degrading *Bacillus licheniformis* strain. *Appl Environ Microbiol*. 1992; 58(10): 3271-3275. doi: 10.1128/aem.58.10.3271-3275.
46. Raju AA, Chandrababu NK, Samivelu N, Rose C, Rao NM. Eco-friendly enzymatic dehairing using extracellular proteases from a *Bacillus* species isolate. *The Journal of the American Leather Chemists Association (USA)*. 1996; 91(5): 115-119.
47. Williams CM, Lee CG, Garlich JD, Shih JC. Evaluation of a bacterial feather fermentation product, feather-lysate, as a feed protein. *Poult Sci*. 1991; 70(1): 85-94. doi: 10.3382/ps.0700085.
48. Dalev P, Neitchew V. Reactivity of alkaline protease to keratin and collagen containing substances. *Appl Biochem Biotechnol*. 1991; 27(2): 131-138. doi: 10.1007/BF02921521.

Comment [yP18]: You should reconsider formatting

49. Riffel A, Lucas F, Heeb P, Brandelli A. Characterization of a new keratinolytic bacterium that completely degrades native feather keratin. *Arch Microbiol.* 2003; 179(4): 258-265. doi: 10.1007/s00203-003-0525-8.
50. Soomro IH, Kazi YF, Zardari M, Shar AH. Isolation of keratinophilic fungi from soil in Khairpur city, Sindh, Pakistan. *Banglad J Microbiol.* 2007; 24(1): 79-80.
51. Kunert J. Physiology of keratinophilic fungi. *Rev Iberoam Micol.* 2000; 1: 77-85.
52. Kunert J. Keratin decomposition by dermatophytes. I. Sulfite production as a possible way of substrate denaturation. *Z AllgMikrobiol.* 1973; 13(6): 489-498. doi: 10.1002/jobm.19730130606.
53. Kunert J. Keratin decomposition by dermatophytes II. Presence of S-sulfocysteine and cysteic acid in soluble decomposition products. *Z AllgMikrobiol.* 1976; 16(2): 97-105. doi: 10.1002/jobm.19760160203.
54. Bohacz J, Mozejko M. Keratinolytic activity of pigmented and non-pigmented soil strains of *Trichophyton ajelloi*. *Int Biodeterior Biodegradation.* 2024; 186: 105704. doi: 10.1016/j.ibiod.2023.105704.
55. Pugh GJF, Evans MD. Keratinophilic fungi associated with birds: I. Fungi isolated from feathers, nests and soils. *T Brit Mycol Soc.* 1970; 54(2): 233-240.
56. Alteras I, Nesterov V, Ciolofan I. The occurrence of dermatophytes in wild animals from Rumania. *Sabouraudia: J Med Vet Myco.* 1966; 4(4): 215-218. doi: 10.1080/00362176685190491.
57. Alteras I, Feuerman EJ, Grunwald M, Shvili, D. Tinea capitis due to *Microsporum canis* in infants. *Mycopathologia.* 1984; 86(2): 89-91. doi: 10.1007/BF00436492.
58. Simordova M. Dermatophytes and other keratinophilic fungi in surface and waste water. *Mykosen.* 1970; 13: 467-471.
59. Balabanoff VA, Usunov P. Organic waste matter of plant origin-natural source of primitive dermatophytes. I. Communication. *Mycopathol Mycol Appl.* 1967; 33(1): 43-48. doi: 10.1007/BF02049789.
60. Caretta G, Del Frate G, Piontelli E, Todaro F. Keratinophilic mycoflora [fungi] from the hair and excrements [of cows], forage and farm soil: considerations on their distribution. *RivParassitol.* 1976; 333-361.
61. Ali-Shtayeh MS, Jamous RM, Abu-Ghdeib SI. Ecology of cycloheximide-resistant fungi in field soils receiving raw city wastewater or normal irrigation water. *Mycopathologia.* 1998; 144(1): 39-55. doi: 10.1023/A:1006952926293.
62. Cooke W, Pipes WO. The occurrence of fungi in activated sludge. *Mycopathol Mycol Appl.* 1970; 40(3): 249-270. doi: 10.1007/BF02051779.

63. Boyanowski KJ, Ihrke PJ, Moriello KA, Kass PH. Isolation of fungal flora from the hair coats of shelter cats in the Pacific coastal USA. *Vet Dermatol.* 2000; 11(2): 143-150. doi: 10.1046/j.1365-3164.2000.00161.x.
64. Saxena P, Kumar A, Shrivastava JN. Diversity of keratinophilic mycoflora in the soil of Agra (India). *Folia Microbiol.* 2004; 49(4): 430-434. doi: 10.1007/BF02931605.
65. Vanbreuseghem R. Technique biologique pour l'isolement des dermatophytes du sol. *Ann Soc Belg Med Trop.* 1952; 32(2): 173-178.
66. Papini R, Mancianti F, Grassotti G, Cardini G. Survey of keratinophilic fungi isolated from city park soils of Pisa, Italy. *Mycopathologia.* 1998; 143(1): 17-23. doi: 10.1023/A:1006919707839.
67. Deshmukh SK. Isolation of dermatophytes and other keratinophilic fungi from the vicinity of salt pan soils of Mumbai, India. *Mycopathologia.* 2004; 157(3): 265-267. doi: 10.1023/B:MYCO.0000024174.69248.8d.
68. Mahmoudabadi AZ, Zarrin M. Isolation of dermatophytes and related keratinophilic fungi from the two public parks in Ahvaz. *Jundishapur J Microbiol.* 2008; 1(1): 20-23.
69. Shrivastava JN, Satsangi GP, Kumar A. Incidence of keratinophilic fungi in waterlogged condition of paddy soil. *J Environ Biol.* 2007; 29(1): 125-126.
70. Ainsworth GC, Sussman AS. *The Fungi. An advanced treatise. Volume III. The fungal population.* Academic Press: New York and London; 1968.
71. Chmel L, Hasilíková A, Hraško J, Vláčilíková A. The influence of some ecological factors on keratinophilic fungi in the soil. *Sabouraudia: J Med Vet Myco.* 1972; 10(1): 26-34. doi: 10.1080/0036217728519007.
72. Moalaei H, Zeyni F, Hashemi J, Pihet M, Mahmoudi M. Isolation of keratinophilic fungi from soil samples of forests and farm yards. *Iran J Public Health.* 2006; 35(4): 62-69.
73. Vidyasagar GM, Hosmani N, Shivkumar D. Keratinophilic fungi isolated from hospital dust and soils of public places at Gulbarga, India. *Mycopathologia.* 2005; 159(1): 13-21. doi: 10.1007/s11046-004-9483-1.
74. Rizvi G, Sinha P. Study on the diversification of keratinolytic fungi in surrounding areas of Jhansi. *Zeichen Journal.* 2023; 9(2): 1-7.
75. Böhme H, Ziegler H. Verbreitung und keratinophilie von *anixiopsis stercoraria* (hansen) hansen. *Archiv für klinische und experimentelle Dermatologie.* 1965; 223(4): 422-428. doi: 10.1007/BF00523552.
76. Hubalek Z. Fungi associated with free-living birds in Czechoslovakia and Yugoslavia. *Academia Acta*

Scientiarum Naturalium Academiae Scientiarum Bohemoslovacae Brno. 1974; 8(3): 1-62.

77. Kachuei R, Emami M, Naeimi B, Diba K. Isolation of keratinophilic fungi from soil in Isfahan province, Iran. *J Mycol Med*. 2012; 22(1): 8-13. doi: 10.1016/j.mycmed.2011.11.002.
78. Jain N, Sharma M. Distribution of dermatophytes and other related fungi in Jaipur city, with particular reference to soil pH. *Mycoses*. 2011; 54(1): 52-58. doi: 10.1111/j.1439-0507.2009.01751.x.
79. Jain N, Sharma M. A descriptive study of keratinophilic fungal flora of animal and bird habitat, Jaipur, Rajasthan. *Afr J Microbiol Res*. 2012; 6(42): 6973-6977. doi: 10.5897/AJMR12.897.
80. Sharma V, Sharma A, Seth R. Effect of temperature and pH variations on growth pattern of keratinophilic fungi from Jaipur, India. *Entomol. appl. sci*. 2016; 3(5): 177-181.
81. Kumawat TK, Sharma A, Bhadauria S. Influence of liquid culture media, temperature and hydrogen ion concentration on the growth of mycelium and sporulation of *Arthroderma multifidum*. *Int. J Pharm Sci Rev Res*. 2016; 41(2): 136-141.
82. Khan AM, Bhadauria S, Yadav R. Effect of environmental factors on isolation, mycelial growth and sporulation of keratinophilic fungi. *Pramana Research Journal*. 2019; 9(6): 147-158.
83. Kumawat TK, Sharma A, Sharma V, Chandra S, Bhadauria S. A study on the prevalence of keratinophilic fungal biota of semi-arid region of Rajasthan, India. *J King Saud Univ Sci*. 2020; 32(1): 1014-1020. doi: 10.1016/j.jksus.2019.09.008.
84. Thomas BT, Popoola OD, Oyeyipo FM. Predominance of Keratinophilic Fungi and Dermatophytes Species in Dumpsite Locations in Ogun State, Nigeria. *Nigerian Journal of Basic and Applied Sciences*. 2021; 29(1): 23-33. doi: 10.4314/njbas.v29i1.3.
85. Anane S, Al-Yasiri MHY, Normand AC, Ranque S. Distribution of keratinophilic fungi in soil across Tunisia: a descriptive study and review of the literature. *Mycopathologia*. 2015; 180(1): 61-68. doi: 10.1007/s11046-015-9870-9.
86. Bohacz J, Kornilłowicz-Kowalska T. Species diversity of keratinophilic fungi in various soil types. *Cent Eur J Biol*. 2012; 7(2): 259-266. doi: 10.2478/s11535-012-0008-5.

87. Rizwana H, Abdulaziz Al Hazzani A, Siddiqui I. Prevalence of dermatophytes and other keratinophilic fungi from soils of public parks and playgrounds of Riyadh, Saudi Arabia. *J Anim Plant Sci.* 2012; 22(4): 948-53.
88. Irum F, Suhail M, Abro H. Keratinophilic fungi from the soil of district, Jamshoro, Sindh, Pakistan. *Pak J Bot.* 2007; 39(4): 1377-1382.
89. Deshmukh SK, Mandeel QA, Verekar SA. Keratinophilic fungi from selected soils of Bahrain. *Mycopathologia.* 2008; 165(3): 143-147; doi: 10.1007/s11046-007-9067-y.
90. Jain N, Sharma M. Influence of Temperature and Culture Conditions on the Survival of Keratinophilic and Dermatophytic Fungi. *Braz Arch Biol Technol.* 2022; 65: 1-7. doi: 10.1590/1678-4324-2022210337.
91. Maghraby TA, Gherbawy YA, Hussein MA. Keratinophilic fungi inhabiting floor dusts of student houses at the South Valley University in Egypt. *Aerobiologia.* 2008; 24(2): 99-106. doi: 10.1007/s10453-008-9089-z.
92. Mohammad TH, Habeb KA. Epidemiological study of keratinophilic fungi in Baghdad swimming pools. *Baghdad Sci. J.* 2014; 11(3): 1122-1129.
93. Hamm PS, Mueller RC, Kuske CR, Porras-Alfaro A. Keratinophilic fungi: Specialized fungal communities in a desert ecosystem identified using cultured-based and Illumina sequencing approaches. *Microbiol Res.* 2020; 239: 126530. doi: 10.1016/j.micres.2020.126530.
94. Thomas M, Thangavel M. Keratinophilic Fungi in Wetland Agroecosystem, Saudi Journal of Pathology and Microbiology. 2017; 2(5): 179-184. doi: 10.21276/sjpm.
95. Kornilowicz-Kowalska T, Kitowski I, Iglík H. Geophilic dermatophytes and other keratinophilic fungi in the nests of wetland birds. *Acta Mycol.* 2011; 46(1): 83-107.
96. Ali-Shtayeh MS, Arda HM, Hassouna M, Shaheen SF. Keratinophilic fungi on the hair of cows, donkeys, rabbits, cats, and dogs from the West Bank of Jordan. *Mycopathologia.* 1988; 104(2): 109-121. doi: 10.1007/BF00436936.
97. Abdel-Hafez All, Moharram AM, Abdel-Gawad KM. Survey of keratinophilic and saprobic fungi in the clovenhooves and horns of goats and sheep from Egypt. *J Basic Microbiol.* 1990; 30(1): 13-20. doi: 10.1002/jobm.3620300105.
98. Rezaei-Matehkolaei A, Jahangiri A, Mahmoudabadi AZ, Najafzadeh MJ, Nouripour-Sisakht S, *et al.*, Morpho-molecular characterization of soil inhabitant dermatophytes from Ahvaz, Southwest of Iran, a high occurrence of *Microsporiumfulvum*. *Mycopathologia.* 2017; 182(7): 691-699. doi: 10.1007/s11046-017-0116-x.

99. Bohacz J, Kornilowicz-Kowalska T. Fungal diversity and keratinolytic activity of fungi from lignocellulosic composts with chicken feathers. *Process Biochem.* 2019; 80: 119-128. doi: 10.1016/j.procbio.2019.02.012.
100. Kačinová J, Tančinová D, Labuda R. Keratinophilic fungi in soils stressed by occurrence of animals. *J MicrobiolBiotechnol Food Sci.* 2013; 2(1): 1436-1446.
101. Nardoni S, Mancianti F. Survey of Keratinophilic Fungi from Feathers of Birds in Tuscany. *Biology.* 2021; 10(12): 1-7. doi: 10.3390/biology10121317.
102. Javoreková S, Labuda R, Maková J, Novák J, Medo J, Majerčíková K. Keratinophilic fungi isolated from soils of long-term fold-grazed, degraded pastures in national parks of Slovakia. *Mycopathologia.* 2012; 174(3): 239-245. doi: 10.1007/s11046-012-9543-x.
103. Singh S. The Occurrence of Keratinophilic Fungi and Related Dermatophytes from Playground Soils of Ujjain, India. *Central Asian Journal of Medical and Natural Science.* 2022; 3(1): 229-236. doi: 10.17605/cajmns.v3i1.739.
104. Ogórek R, Suchodolski J, Piecuch A, Przywara K, Višňovská Z. Keratinophilic and Keratinolytic Fungi in Cave Ecosystems: A Culture-Based Study of Brestovská Cave and DemänovskáĽadová and Slobody Caves (Slovakia). *Appl Sci.* 2022; 12(3): 1-17. doi: 10.3390/app12031455.
105. Baxter M, Mann PR. Electron microscopic studies of the invasion of human hair in vitro by three keratinophilic fungi. *Sabouraudia: J Med Vet Myco.* 1969; 7(1): 33-37. doi: 10.1080/00362177085190061.
106. Marchisio VF, Fusconi A, Rigo S. Keratinolysis and its morphological expression in hair digestion by airborne fungi. *Mycopathologia.* 1994; 127(2): 103-115. doi: 10.1007/BF01103066.
107. Deshmukh SK, Agrawal SC. In vitro Degradation of Human Hair by some Keratinophilic Fungi: In vitro Abbaumenschlicher Haare durcheinigekeratinophilePilze. *Mycoses.* 1982; 25(8): 454-458. doi: 10.1111/j.1439-0507.1982.tb01965.x.
108. Kumar J, Kushwaha RKS. Keratinophilic fungi on various keratinous substrate: Hazardous to human and animal population. *Nat. J. Pharm. Sci.* 2021; 1(1): 01-07.
109. Jain SK, Maida N, Rathore G, Pandey AK. Degradation of Keratinous Substrate by Fungi from Soils of Ujjaini Madhya Pradesh. *Int. j. sci. res. Multidiscip.* 2022; 8(5): 87-89.

UNDER PEER REVIEW

