Medicinal Macrofungi as Cosmeceuticals: a Review

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Short title: Mushrooms as Cosmeceuticals

Medicinal Macrofungi as Cosmeceuticals: A Review

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ABSTRACT: Macrofungi (mushrooms) have been previously studied for their nutritional value and medicinal properties. However, there is still slow progress in the biotechnological application of macrofungi in cosmetic industry as cosmeceuticals and nutricosmetics. Currently, the cosmetic industry is in a constant search for valuable natural ingredients or extracts with relevant bioactive properties (anti-aging, anti-collagenase, anti-elastase, anti-hyaluronidase, anti-pigmentation, anti-inflammatory, antioxidant and anti-tyrosinase) to design formulations. Edible medicinal mushrooms are unlimited source of nutraceuticals and pharmaceuticals. They can be used as a source of ingredients to develop organic cosmeceuticals, nutriceuticals and nutracosmetics for topical and oral administration.

KEY WORDS: anti-aging, bioactive compounds, cosmeceuticals, enzyme inhibitors, medicinal mushrooms and macrofungi, nutracosmetics, nutricosmetics

ABBREVIATIONS: ABA, antibacterial activity; **ABTS**, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); **AD**, atopic dermatitis ; **AIA**, anti-inflammatory activity ; **AMA**, antimicrobial activity; **AOA**, antioxidant activity; **CWE**, cold-water extract; **EPS**, exopolysaccharide; **FIPs**, fungal immunomodulatory proteins; **FMG**, fucomannogalactan; **HaCaT**, human keratinocytes; **HWE**, hot-water extracts; **MRSA**, methicillin-resistant *Staphylococcus aureus*; **NF-κB**, nuclear factor-κB; **NO**, nitric oxid; **PUFA**, polyunsaturated fatty acids; **ROS**, reactive oxygen species; **SIRT1**, Sirtuin 1; **SPF**, sun protection factor; **TCM**, traditional Chinese medicine; **UV**, ultraviolet

I. INTRODUCTION

The natural process of aging, ultraviolet (UV) radiation and hormonal alterations affect the skin and other body parts, which result in the generation of reactive oxygen species (ROS) causing oxidative stress.[1] Cosmetic skin and hair care formulations based on naturally derived active ingredients, including plants and fungi, are currently preferred by consumers for their antioxidant effects.

Currently, the cosmetic industry is in a constant search for bioactive ingredients to design novel cosmeceuticals possessing lower toxicity.[2] Cosmeceuticals are products between cosmetics and pharmaceuticals containing bioingredients with anti-aging, anti-inflammatory, antioxidant, and photoprotective effects. They can be extracted from different organisms or obtained biotechnologically (cultivation, fermentation, enzymatic synthesis, etc.).

Recent progress in the biology and biotechnology of macrofungi (commonly referred to as mushrooms), genomics, proteomics and myco-pharmacology has contributed to their usage in medicine and food industries.[3] Macrofungi are also considered a valuable source of multi-functional cosmetic ingredients to be exploited as cosmeceuticals.[4,5,6] They are mainly used in

skin and hair care products, and the trend for their industrial usage is expected to increase over the years.[7]

Wild or cultivable, edible or inedible, medicinal or poisonous macrofungi are incorporated in many cosmetic products as producers of bioactive compounds (phenolics, glucans and other polysaccharides and terpenoids) with anti-aging, antibacterial, antifungal, anti-inflammatory, antioxidant, hypocholesterolemic, hypoglycemic, immune-modulating as well as anti-collagenase, anti-elastase, anti-hyaluronidase, anti-tyrosinase, wound-healing and other activities.[5,8-11] However, there are numerous undescribed or not yet cultivated mushroom species with a potential cosmetic application.[6,12,13]

Edible mushrooms are considered well-known untapped source of valuable food and nutraceuticals which can improve human health and quality of life. However, inedible or poisonous species (i.e., *Amanita muscaria, Ganoderma lucidum, Inonotus obliquus, Phellinus igniarius, Ramaria formosa,* etc.) represent a source of bioactive secondary metabolites to develop myco-pharmaceuticals (dietary supplements or nutriceuticals) with health-enhancing and therapeutic properties.[5,9] Macrofungi-derived nutraceuticals and nutriceuticals are obtained from mycelia and/or fruiting bodies and administered *per os* in the form of capsules, tablets, or extracts.[14,15]

Currently, macrofungi-derived numerous commercial products, such as cosmeceuticals (applied topically, i.e., creams, lotions, and ointments) and nutracosmetics (administered *per os*) are available in the market. Their usage is significantly high due to minimal regulation and safety compared to traditional drugs.[16,17]

The current review reports the main genera and species of macrofungi presently used, or patented to be used, in formulations of cosmeceuticals and nutracosmetics, such as *Agaricus*

subrufescens, *A. bisporus*, *Choiromyces maeandriformis*, *Ophiocordyceps sinensis*, *Ganoderma lingzhi*, *G. lucidum*, *Grifola frondosa*, *Hypsizygus ulmarium*, *Inonotus obliquus*, *Lentinula edodes*, *Polyporus* spp., *Phellinus* spp., *Schizophyllum commune*, *Trametes versicolor*, *Tremella fuciformis*, and *Tuber* spp. (Table 1).

We also describe the main ranges of human cosmetic and cosmeceutical products incorporating macrofungi or their extracts as anti-aging, antioxidant, hair and skin care, anti-acne or perfumers. Cosmetic brands include Bliss (Hut.com Ltd., Cheshire, UK), La Roche (F. Hoffmann-La Roche Ltd., Basel, Switzerland), Nu-Derm (Obagi Medical Products Inc., Irvine, CA, USA), SensiClear (Mission Scientific Skincare Inc., Gold River, CA, USA) and others (Table 2).

II. MACROFUNGI-DERIVED BIOACTIVE COMPOUNDS AS POTENTIAL COSMECEUTICALS

Over the past years, growing consumers' demand for natural low toxicity organic products with effective skin and hair repairing effects have caused cosmetic industry to search for alternative ingredients. Macrofungi are considered sources of bioactive compounds increasingly used as cosmeceutical ingredients. Scientific data showed that medicinal, edible and inedible mushrooms are resources of raw extracts, fractions of extracts, bioactive molecules, i.e. fatty acids, phenolics, peptides, polysaccharides, terpenoids, vitamins and volatile organic compounds, some of them being also enzyme-inhibitory compounds; that large spectrum of bioactive natural sources possess significant anti-aging, anti-inflammatory, antioxidant, anti-pigmentation, antimicrobial, anti-wrinkle, moisturizing, and skin-whitening effects, may act as inhibitors of collagenase, elastase, hyaluronidase and be used to regulate tyrosinase activity; consequently, they may be potentially used as natural cosmeceuticals or nutracosmetics.

However, the mechanisms behind the mentioned bioactivities are still unknown.

Antioxidants against harmful free radicals and cellular damage are the most demanded cosmeceuticals since their topical administration is essential for protection of aging skin. Skin hyperpigmentation is caused by several factors that upregulate melanogenesis and controlling this unwanted process is a major challenge in dermatology and cosmetology to develop safe and effective anti-melanogenic products. Macrofungi-derived compounds, such as *p*-coumaric acid, can be used to reduce oxidative stress and inflammation, as anti-aging, and skin whitening agents.[18] Previous studies have shown that *p*-coumaric acid inhibited melanin synthesis in murine melanoma cells, human epidermal melanocytes, showed efficient transdermal delivery and functional efficacy in reducing erythema development and skin UV-induced pigmentation, therefore has a potential to be used as a skin-lightening ingredient.[19]

The bioactive peptides with plant and animal origins can have a beneficial effect on multiple physiological pathways in the skin which makes them ideal candidates for development of cosmeceuticals. Significant antioxidant and dermatoprotective effects of these peptides after topical application or *per os* administration were revealed which suggests that they can be used in skin care formulations as functional ingredients. However, the mechanisms underlying the skin-protective effect have not been completely elucidated.[20]

Phenolic compounds and tocopherols derived from edible mushrooms *Boletus edulis, Lentinula edodes* and *Xerocomus badius* are the most responsible for their AOA.[21] The exopolysaccharide (EPS-1) isolated from fermentation broths of rare, valuable edible medicinal polypore fungus *Abortiporus biennis* also possesses prominent radical-scavenging and macrophage-stimulatory activities *in vitro* and could be explored as a functional ingredient with potential applications in medical and cosmetic industries.[22] Sclerotia of medicinal polyporoid

species *Polyporus umbellatus* have been used in traditional Chinese medicine (TCM) to treat oedema due to its diuretic effect. It contained bioactive compounds responsible for AOA and AIA and was used as an ingredient in several biotech products.[23]

Polysaccharides, triterpenes, and fungal immunomodulatory proteins (FIPs) found in *Ganoderma* species have been exploited for potential ingredients in the cosmetic industry to develop new cosmeceuticals and nutracosmetics with antioxidant, antibacterial, anti-inflammatory, and melanin-inhibitory effects. However, numerous questions need to be addressed before FIPs can be accepted and used in cosmetic products.[24]

Tyrosinase is an enzyme which has a key role in the formation of melanin. *Ganoderma lucidum* extract was found to have potent anti-tyrosinase activity and is part of several cosmetic, skin-lightening beauty products in China.[25,26] *G. lucidum* also contains α/β-D-glucans, alkaloids, triterpenoids (ganoderic acids, ganoderenic acids, ganoderol, ganoderiol, lucidenic acids), sterols (ergosterol), proteins (LZ-8, LZ-9), nucleosides (adenosine, inosine, uridine), and nucleotides (adenine, guanine) with different pharmacological potential.[9] Various marketed products of *G. lucidum* with nutritional and cosmeceutical value are already available in the market.[27]

AOA and ABA of secondary metabolites of *Pleurotus* species have also been reported.[28] *In vitro* safety of ethanolic extracts derived from *G. lucidum* and *P. ostreatus* incorporated into base cosmetic creams was evaluated. The absence of toxicity for keratinocytes and fibroblasts in a concentration-dependent manner was revealed. Protocatechuic and syringic acids were the only compounds permeating from *G. lucidum* extract. These results have shown the safety of studied extracts as skin care ingredients.[29]

Extracellular polysaccharides derived from medicinal mushroom *Grifola frondosa* (GF-EPS) were applicable in the development of functional cosmeceuticals. The GF-EPS, together

with mycelial extract of *G. frondosa* (GF-MPS), showed AOA, stimulatory effect on collagen biosynthesis and anti-melanogenesis activities, without significant cytotoxicity. GF-EPS and GF-MPS were shown to be promising cosmetic ingredients.[30] Chemical constituents isolated from medicinal bracket fungus *Phellinus igniarius* could also be used as ingredients to develop anti-inflammatory cosmetic products.[31]

Edible medicinal cultivated mushroom *Schizophyllum commune* contains phenolics and β-glucans beneficial to skin health. However, data on the development of *Sch. commune* as a cosmeceutical ingredient is lacking. The optimal water extraction conditions at 30°C for 1 h were suggested for effective antioxidant and anti-tyirosinase properties of β-glucans in *Sch. commune*.[32] The β-glucans isolated from ethanol extracts of *Sch. commune* also showed potent AOA and may be used as cosmeceuticals.[33]

Edible mushroom *Tremella fuciformis* has attracted increasing attention due to its various bioactivities. The polysaccharides extracted from *T. fuciformis*, mainly consisting of mannose and uronic acid, could efficiently reduce water and collagen losses of the skin, and inhibit the increase of glycosaminoglycans. Moreover, after oral treatment with polysaccharides a histopathological study showed that, UV-induced structural alterations of the skin were alleviated, as well as repairing endogenous collagen breakdown and increasing AOA compared to the irradiated control group (without treatment). Thus, polysaccharides from *T. fuciformis* can be used as a skin-protective cosmetic ingridient.[34]

Atopic dermatitis (AD) is an inflammatory skin disease usually accompanied by *Staphylococcus aureus* (MRSA) infection due to cutaneous barrier-function damage. Benzenoid aromatic compound, coenzyme Q_0 isolated from *Antrodia cinnamomea*, possesses ABA and AIA. The strongest anti-MRSA activity was achieved by inhibiting DNA polymerase,

topoisomerases, reducing the ribosomal proteins, as well as downregulating the expression of interleukin (IL)-6, chemokine (C-C motif) ligand (CCL)5, and CCL17 in HaCaT cells, respectively. CoQ_0 at 0.5 μg/mL could recover the filaggrin decreased by HaCaT activation to the normal control and is effective in mitigating AD symptoms associated with bacterial infection.[35]

Yellow strain *Flammulina velutipes* (FVY) has become popular among customers due to its distinct texture different from *F. velutipes* white strain (FVW). The physicochemical properties and AOA of FVY and FVW strains were evaluated. The results showed that FVY-80 possesses the highest AOA based on 2,2-diphenyl-1-picrylhydrazyl (DPPH) (IC_{50} = 2.22 mg/mL) and 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS) radical assay (IC_{50} = 2.04 mg/mL). FVY-80 significantly reduced the ROS content in L929 cell by 55.96% and was suggested as the best source for cosmeceutical ingredient.[36]

The study of ABA, AOA and sun protection factor (SPF) of ethyl acetate extracts of mycelia of selected edible mushrooms revealed ABA against *Staphylococcus epidermidis*, *Escherichia coli*, *Micrococcus luteus* and *Bacillus megaterium*, high SPF activity (34.02 at 200 μg/mL) and AOA, particularly of cultural broth extracted from *F. velutipes*, *P. florida,* and *P. ostreatus.* The results showed the presence of bioactive ingredients in these fungi with promising application in cosmeceuticals.[37]

Anti-melanogenetic activity and AIA of hot water extracts (HWE) of culinary-medicinal mushrooms *Agaricus bisporus* (white and brown), *G. lucidum*, *Hypsizygus marmoreus*, *Pleurotus floridanus*, and *P. pulmonarius* were evaluated. Brown *A. bisporus* reduced intracellular melanin content to the largest extent (up to 57.05 ± 3.90 %) without a cytotoxic effect on B16F10 melanoma cells, as well as showed anti-tyrosinase activity to 17.93 ± 2.65 %.

The extract obtained from brown *A. bisporus* has AIA decreasing the levels of NO and TNF-αand can be used to develop skin-whitening and anti-inflammatory products. Other mushroom extracts showed moderate activity.[38]

The ethanolic extract from *Agaricus blazei* (=*A. brasiliensis*) (ABM) was incorporated into a semi-solid base cosmetic cream (safety tests for nutraceutical applications) and cell viability effects of the extract, and of the final cream formulation, on a keratinocyte cell line (HaCaT) (safety tests for cosmeceutical applications) were studied. The study detected proteins, carbohydrates, and a low-fat content. Overall, 22 fatty acids including 53% of polyunsaturated fatty acids (PUFA)were estimated the most abundant fraction. The cell viabilities of Caco-2 and HT29 cell lines were maintained up to 100 μg/mL. After incorporation into the base cream, a formulation with a pale-yellow colour and favourable pH was obtained. The viability of HaCaT cells in the presence of the extract and the final cream formulation was maintained in a concentration-dependent manner, which indicates the safety of this extract for use in cosmetic industry. The results suggest that ABM residues can be used as an inexpensive and sustainable source of nutraceutical and cosmeceutical ingredients.[25]

Bioactive compounds extracted from macrofungi showed that the extract of *Trametes versicolor* suppressed the UV-induced cellular senescence in HaCaT cells possibly through augmenting Sirtuin 1 (SIRT1) protein expression.[39] Phenolic compounds (cinnamic acid, *p*-coumaric acid, *p*-hydroxybenzoic acid, pyrogallol) with strong AOA and ABA against *Bacillus subtilis, E. coli, Listeria monocytogenes, Salmonella typhimurium, S. aureus* were detected in *Macrocybe lobayensis.* As a natural antioxidant and antibacterial agent, this fungus was suggested to be used in pharmaceutical, cosmetic or food industries.[40]

Macrofungi are also producers of bioactive compounds with anti-aging tyrosinase,

hyaluronidase, collagenase and elastase enzymes inhibitory effects which are incorporated in many cosmetic products (Tables 1 and 2).[5,8,9,11]

Ascomycetous *Cordyceps* (= *Ophiocordyceps*) species is a unique source of bioactive cordycepin with anti-aging property and represents a potential ingredient for cosmeceutical applications.[41]

Evaluation of skin care benefits of ethyl acetate, ethanol and hot water mycelial extracts from valuable medicinal fungus *O. sinensis* exhibited *in vitro* moderate or significant anti-collagenase and photoprotective activity with a SPF up to 25. The ethyl acetate extracts showed the highest anti-tyrosinase and anti-elastase activity at 0.14 – 0.47 mg/mL**,** comparable to arbutin and epigallocatechin gallate. These results revealed the potential of *O. sinensis* as a source of cosmetic bioingredients for skin-care products.[42]

The tyrosinase-inhibitory effect, AIA, AOA and ABA of ethanolic extracts obtained from *A. bisporus*, *P. ostreatus*, and *L. edodes* were reported and their cosmeceutical potential has been evaluated. The phenolic acids and ergosterol were suggested as basic ingredients for cosmetic creams. The formulations presented 85 - 100% of these compounds can further be exploited as cosmeceuticals.[8]

AOA of mushroom-derived biomolecules could provide a skin-lightening effect by inhibition of tyrosinase, while anti-collagenase and anti-elastase activities can help to restore skin elasticity. Three different polysaccharide extracts obtained from *G. lucidum* were screened for their antioxidant, anti-collagenase and anti-elastase activities. In this study, smaller quantities of proteins, phenols and flavonoids were detected, as well. None of the analysed extracts showed overt toxicity to HaCaT cells at concentrations up to 2 mg/mL and displayed superior scavenging ability on ABTS and DPPH radicals. The hot water crude polysaccharide (HWCP) extract and

partially purified (HWPP) fraction were found to be effective inhibitors of lipid peroxidation (LPx) with a two-fold higher inhibition of LPx compared with ascorbic acid (EC_{50} = 1.65 ± 0.08 mg/mL), a common supplement in cosmeceutical formulations. HWCP showed the strongest anti-tyrosinase activity and inhibition of skin extracellular matrix degradation enzymes. Thus, *G. lucidum* may be considered as a promising source of natural cosmeceutical ingredients. The ethanolic extracts obtained from *A. bisporus* and *P. ostreatus* can be used as a source of cosmeceutical ingredients since they possess antioxidant, anti-tyrosinase and antimicrobial effects. All extracts may be used in free or encapsulated forms in cosmeceutical formulations. The encapsulated forms will provide a controlled release of the cosmeceutical ingredients resulting bioactivity control.[43,44]

The chemical content and cosmetic properties, such as inhibition of tyrosinase and hyaluronidase activity, SPF values of mycelial extracts derived from *Ganoderma applanatum*, *Laetiporus sulphureus*, and *T. versicolor* have been reported.[45] The total amount of phenolic acids in the extracts ranged from 2.69 mg/100 g (*G. applanatum*) to 10.30 mg/100 g (*T. versicolor*) dry weight, the total amount of sterols at 48.40 mg/100 g (*T. versicolor*) to 201.04 mg/100 g (*L. sulphureus*) dry weight, and indoles at 2.90 mg/100 g (*G. applanatum*) to 16.74 mg/100 g (*L. sulphureus*) dry weight. Kojic acid was revealed in the extracts of *L. sulphureus* and *G. applanatum*. *L. sulphureus* extract caused a dose-dependent anti-hyaluronidase activity, while all other extracts inhibited tyrosinase activity. The extract of *G. applanatum* exhibited an SPF value of ~ 9. The screened species may be used as bioingredients in the formulation of cosmeceuticals.[45]

The assessment of HWE and cold-water extract (CWE) from fruiting bodies of cultivated macrofungi *Auricularia polytricha, P. ostreatus, G. lucidum,* and *Sch. commune* revealed their

huge cosmeceutical potential. Total phenolic, polysaccharide and glucan contents were determined, the AOA was estimated. Anti-hyaluronidase activity was used as an indicator of anti-aging and anti-inflammatory properties, while anti-tyrosinase activity was evaluated to assess the whitening property of these extracts. The total polysaccharide content of *P. ostreatus* extracts was the highest, while extracts from *G. lucidum* contained the lowest level of glucan (10.12 – 10.67%). CWE from *Sch. commune* exhibited 98.15% anti-tyrosinase activity and 94.82% AOA. *G. lucidum* HWE revealed the strongest anti-hyaluronidase activity (72.78%). The cosmeceutical properties of these mushrooms can be mainly attributed to the combination of polysaccharides and phenolics. Overall, CWE of *Sch. commune* and HWE of *G. lucidum* revealed the best outcome and suggested them for further study as potential cosmeceuticals.[46]

An culinary-medicinal mushroom *A. bisporus* is rich in nutrients and minerals, and possesses potential anticancer, antioxidant, anti-obesity, and anti-inflammatory properties. The revealed anti-tyrosinase activity and ergothioneine with skin-whitening properties have shown that this fungus is not only a source of nutraceuticals and pharmaceuticals, but also cosmeceutical products.[1]

Many commercially available macrofungi-derived cosmetic products have replaced synthetic compounds that have long-term adverse effects.[47] However, the use of macrofungi and their extracts obtained from fruiting bodies or mycelia as cosmeceuticals need to undergo several steps of biotechnological cultivation and production (extraction optimization, assessment of efficacy and safety) to be produced as a cosmetic product. Previous reports regarding stability, compatibility, and toxicological studies of macrofungi also need to be considered.[48]

III. CONCLUSIONS

Macrofungi (mushrooms) have been regarded as a traditional source of natural low- and

high-molecular-weight secondary metabolites and used for centuries to prevent and treat many diseases; however, over the past decade, they are being exploited for potential ingredients in the cosmetic industry. Several species and their extracts derived from fruiting bodies and/or mycelia are either used or patented to be used as cosmeceuticals and nutracosmetics for their anti-aging, anti-wrinkle, skin-whitening and moisturizing, wound-healing, anti-collagenase, anti-elastase, anti-hyaluronidase, anti-tyrosinase, anti-hyperpigmentation, anti-inflammatory, and antioxidant effects. Among known biodiversity, only a few taxonomically identified and cultivated species are utilized as cosmeceuticals. Further evaluation of natural resources of macrofungi will promote their exploitation in cosmetic industry. Advances in fungal biology and biotechnology, genomics, proteomics, metabolomics, as well as systems pharmacology and molecular cosmetology, study of the molecular mechanisms of medicinal and cosmetic effects of macrofungi will support the discovery of new species to be used in the formulation of organic cosmetic products and cosmeceuticals.

Currently, different mushroom-derived cosmeceuticals and nutracosmetics with various properties are available in the multi-billion-dollar cosmetic market. Despite the availability of a number of products, the industry is largely unregulated, and consumers should consult a doctor prior to the use of these products. Recent developments in cosmeceutical biotechnology, including nano-systems and nano-delivery technologies, have been introduced to improve the efficacy and safety of usage of organic products in commercial production of anti-aging cosmeceuticals. Further realization of clinical studies, manufacturing of high-quality standardized products, and sustainable production of cosmeceuticals under controlled conditions are warranted.

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TABLE 1: Medicinal macrofungi-derived bioactive compounds and their cosmetic effects

Mushroom species	**Bioactive compounds**	**Cosmetic effects**	**Refs.**
Abortiporus biennis (Bull.) Singer	Exopolysaccharides	AOA	22
Agaricus bisporus (J.E. Lange) Imbach	Caffeic, chlorogenic, cinnamic, ferulic, gallic, *p*-hydroxybenzoic, *p*-coumaric and protocatechuic acids, alkaloids, polyphenols	AOA, AIA, ABA, anti-tyrosinase	1,8,38,43,54
Agaricus subrufescens Peck	Polysaccharides, benzenoid aromatic compound	AOA, anti-pigmentation	29
Amanita muscaria (L.) Lam.	β-D-Glucan, FMG	AIA	49
Antrodia cinnamomea T.T. Chang & W.N. Chou.	Benzenoid aromatic compound coenzyme Q_0	ABA, AIA	35
Auricularia polytricha (Mont.)Sacc.	Phenolics, glucans	Anti-hyaluronidase, anti-tyrosinase, AIA	46
Boletus edulis Bull.	Ergothioneine, glutathione	AOA	50
Calocybe gambosa (Fr.) Donk	Ascorbic acid (vitamin C)	Anti-radiation, stimulating collagen synthesis	51
Clitocybe aurantiaca (Wulfen) Studer-Steinhäuslin [= *Hygrophoropsis aurantiaca* (Wulfen)	Clitocybin A, D	Anti-elastase, stimulation procollagen synthesis, AOA	52,53

Maire]			
Coprinus comatus (O.F. Muller)	Tocopherols (vitamin E)	Reducing UV damage to skin	51
Ophiocordyceps sinensis (Berkeley) G.H. Sung et al.	Cordycepin	Anti-pigmentation, anti-collagenase, anti-tyrosinase, anti-elastase, photoprotective	41,42
Cyclocybe aegerita (V. Brig.) Vizzini	Ergothioneine, glutathione	AOA	50
Flammulina velutipes (Curtis) Singer	Glycosides	AIA, AOA	4,36, 37
Ganoderma lucidum (Curtis) P. Karst.	Polysaccharides, triterpenes, FIPs	Anti-tyrosinase, melanin inhibitory, AIA	9,25, 26,27 ,29,3 8,44
Grifola frondosa (Dicks.) Gray	Extracellular polysaccharides, β-glucan, gallic and tannic acids	AOA, stimulation of collagen biosynthetic, anti-melanogenesis	30,54
Grifola gargal Singer	Ergothioneine	Suppressed TNF-α-mediated activation of NF-κB	55
Inonotus sanghuang Sheng H. Wu, T. Hatt. & Y. C. Dai	Chlorogenic acid, icarisid II, isorhamnetin, quercetin, quercitrin, rutin	AOA	56
Laccaria amethystina Cooke	Laccaridiones A, B	Anti-collagenase	57
Laetiporus sulphurous (Bull.) Murrill	Phenolic acids	Anti-hyaluronidase, anti-tyrosinase	45

Lentinula edodes (Berk.) Pegler	Polysaccharides, β-glucan lentinan, eritadenine, phenolics, tocopherols	Anti-tyrosinase, AIA, AOA, ABA	8, 21
Macrocybe lobayensis (R. Heim) Pegler & Lodge	Phenolic compounds (cinnamic acid, p-coumaric acid, p-hydroxybenzoic acid, pyrogallol)	AOA, ABA	40
Macrolepiota procera (Scop.) Singer	Lanostane triterpenoids	Inhibition of NO production	58
Neolentinus lepideus (Fr.) Redhead & Ginns	1,3- Dihydroisobenzofuran-4,5,7-triol,5-methoxy-1,3-dihydroisobenzofuran-4,7-diol, lepidepyrone	Anti-tyrosinase, anti-hyaluronidase	59
Pleurotus eryngii (DC.) Quél.	Cinnamic, *p*-coumaric and *p*-hydroxy-phenylacetic acids, ergosterol	AOA	60
Pleurotus eryngii var. *ferulae* (Lanzi) Saccardo	Ergosterol, nicotinic acid, pleurone, (24*E*)-3β-hydroxycucurbita-5,24-diene-26-oic acid	Anti-elastase	37,61
Pleurotus ostreatus var. *florida*	Phenolics, gallic acid	ABA, AOA, anti-pigmentation	37
Pleurotus ostreatus (Jacq.) P. Kumm.	Alkaloids, phenolics, gallic acid	AMA, AOA, AIA, anti-pigmentation, anti-tyrosinase	4,8,28,29, 37
Phellinus igniarius (L.) Quél.	Nepetidin, betulic acid	NF-κB inhibitory	31

Pholiota nameko **(**T. Itô) S. Ito & S. Imai	β-D-Glucan	AIA	62
Polyporus umbellatus (Pers.) Fr.	Polysaccharides, steroids, ergosteol, terpenoids	AIA, ABA, AOA	23
Ramaria formosa (Pers.) Quél.	Axinysone A, *ent*-aristolone, nambinone A, ramarin A, B	Anti-elastase	63
Sarcodon leucopus (Pers.) Maas Geest. & Nannf.	Sarcoviolin β, episarcoviolin β	AOA	64
Schizophyllum commune Fr.	Phenolics, α- and β-glucans	Anti-pigmentation, anti-tyrosinase, AOA	32,33
Suillus bellinii (Inzenga) Kuntze	Cinnamic, *p*-hydroxyphenylacetic and protocatechuic acids, ergosterol	AOA	60
Trametes versicolor (L.) Lloyd	Protein SIRT1, phenolic acids	Anti-tyrosinase, anti-hyaluronidase, AOA	39,45
Tremella fuciformis Berk.	Mannose, polysaccharides, uronic acid	Reduce the water and collagen losses, inhibit the increase of glycosaminoglycans, skin protection, AOA	34
Tuber spp.	Polysaccharides, volatile compounds	AMA, AIA, wound-healing	65
Tylopilus ballouii (Peck) Singer	FMG	Inhibition of superoxide and hydroxyl radicals	66
Volvariella bombycina (Schaeff.)	Isodeoxyhelicobasidin,	Anti-elastase, AMA	4

Singer	alkaloids	AIA, AOA	

ABA, antibacterial activity; **AIA**: anti-inflammatory activity; **AMA**, antimicrobial activity; **AOA**, antioxidant activity; **FIPs**, fungal immunomodulatory proteins; **FMG**, fucomannogalactan; **NF-κB**, nuclear factor-κB; **SIRT1**, Sirtuin 1; **SPF**, sun protection factor; **UV**, ultraviolet.

TABLE 2: Medicinal macrofungi incorporated in different cosmetic products

Mushroom species	**Cosmetic Product**	**Cosmetic Effect**
Agaricus subrufescens	Vitamega Facial Moisturizing Mask	Renews and revitalizes skin
Albatrellus confluens (Alb. & Schw. ex Fr.) Kotl.	REN Clean Skincare Evercalm Ultra Comforting Rescue Mask	Skin feels smooth with even tone
Ophiocordyceps sinensis	Kosé Sekkisei Cream	Moisturizer, suppress melanin production
Ganoderma lucidum	Eminence Organic Skin Care Birch Water Purifying Essence	Anti-aging, provides hydration
	Yves Saint Laurent Temps Majeur Elixir De Nuit	Anti-aging
	Dr. Andrew Weil for Origins™ Mega-Mushroom Skin-Relief Micellar Cleanser	Anti-aging
	Shiseido: Ultimune Power Infusing Concentrate	Anti-aging, anti-inflammatory
	Tela Beauty Organics Encore Dri Styling Cream	Hair protection

Inonotus obliquus (Fr.) Pilát	Supermood - The Perfect Day Cream	Antioxidant, skin moisturizer
	Root Science, Reborn Organic Face Mask	Anti-inflammatory, soothes irritated skin
Lentinula edodes	Griffin+Row Naturally Effective Skincare	Anti-inflammatory, skin brightening
	Aveeno Positively Ageless, Daily Exfoliating Cleanser	Anti-aging, skin lifting
	One Love Organics Vitamin D Moisture Mist	Skin lightener, moisturizer and toner
Pleurotus ostreatus	Hankook Sansim Hyoum Jin Firming Cream	Enhances elasticity, skin tight and vitalize
Polyporus umbellatus	iS Clinical Active Serum	Brightens and revitalizes skin
Schizophyllum commune	Alqvimia Eternal Youth Maximum Recovery Face Cream	Brightens, unifies skin tone
	Alqvimia Eternal Youth Cream Facial Máxima Regeneración	Anti-aging, skin lifting
	Sulwhasoo Hydro-Aid, cream	Hydrates, revitalizes skin and promotes clear
Tremella fuciformis	Eminence Organic Skin Care Birch Water Purifying Essence	Antioxidant, enhances skin elasticity

	Dr. Dennis Gross Skincare Alpha Beta® Pore Perfecting Cleansing Gel	Enhances skin elasticity, skin firming
	La Prairie Advanced Marine Biology Night Solution	Moisturizes, nourishes, revitalizes
Tuber spp.	Black Orchid Tom Ford, Jo Malone Red Truffle 21, Estée Lauder Re-Nutriv skin cream, Perigold truffle magnetic face mask	Perfumes with truffles' aroma, moisturizes, nourishes