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Abstract (150 words)

In history, all kinds of natural sources have been used to extract colorants for dyeing purposes, also lichen and mushrooms. Mushrooms in this article refer to macro fungi in terrestrial ecosystem, and the fungal bodies grown on ground. The focus lies in the Northern hemisphere context. Article highlights the use of lichen and mushroom colorants in textile dyeing in the past, and also introduces the current research on the topic. Mushroom colorants have been used in all continents and in applications varying from food to textiles. Article explains some of the colorant groups and dye structures, in connection to their properties, focusing especially on the qualities, such as colourfastness and safety for human and environment, which are important in the textile and packaging applications. Recent advances of mushroom colorants utilization are discussed as part of the circular economy and the production processes of more sustainable consumer commodities.

Keywords: macro fungi, textile, consumer, commodity, colourfastness, packaging, dye, chemical structure, compound, safety

1 Use of Lichen and Mushroom Colorants in History

Lichens and mushrooms produce compounds, which have been used as colorants in Europe, and also other parts of the world throughout history. Some of these compounds are peculiar, and not found in plants. Especially lichens were important in dyeing violet and purple colours. In the times of Mediterranean civilisations, which refer to the period from ancient times to the beginning of the Middle Ages (ca. 500 CE), violet and purple colours were most commonly obtained from molluscs. Mollusc and shellfish dyestuffs were laborious to obtain and thus very expensive.[1–4] Instead, lichens appeared abundantly on costal areas and were easier to collect. Also the dyeing process for lichen colorants was simpler. The only disadvantage was the poor light fastness. Hence, lichen dyes were used for cheaper textiles or as an under dye for the molluscs when producing for example the royal purple. In that way the use of the precious mollusc colorants was economized.[1–**Error! Reference source not found.**,5] Royal purple or Tyrian purple was the name of the colour obtained originally from molluscs. Tyrian purple refers to the place (Tyre, in Lebanon) which was the familiar dyeing centre where as royal purple refers to the high cost of the colorant, which allowed only the rich and wealthy to wear it.[**Error! Reference source not found.**] Recently, this precious purple dye, di-bromo-indigo, has been produced through manipulated biosynthesis by the bacteria *Escherichia coli*.[6]

To obtain purple colour from lichen, a fermentation process with ammonia was required. The purple lichen dyeing tradition seemed to be unique for the Mediterranean and European cultures[1], whereas the purple mollusc dyeing originated from Qatar in the Persian Gulf in the era about 2000 BC.[4] The lichen purple dyeing procedure is discussed in more detail later in the chapter 3.1.

In Northern Europe, Scotland and Scandinavia yellowish, brownish and reddish brown colours were obtained using a simpler hot dyeing method in which lichens were boiled in water together with mordanted or non-mordanted wool.[1,2,7–11] Similar simple dyeing methods were applied by the Native Americans when they used dyestuffs obtained from lichens in their traditional textiles.[1,2]

The investigations reveal that there is more information than suspected about the use of fungi for dyeing textiles in past centuries. It seems that fungi have been use as a source of colour on all continents, Europe, North Africa and Americas as well as Asia.[1] The Indigenous Americans obtained red colour from the fungus *Echinodontium tinctorium*. Also, in America furs were sometimes dyed with colorants obtained from mushrooms of *Boletus* species, as dyeing with alum mordants gave them a luxurious golden hue.[12,13] In Italy and France fungi belonging to polyporales were used to dye wool. In a few 15th century dyeing books, there are references to a substance called ”popo”, ”opoppo” or ”pococco”, which was used to obtain a yellow colour. The substance was also used to obtain an orange when dyed together with the red insect dye kermes. Several French books from the 17th century mention “agaric”, which is described as fungus, a parasite of larch. The investigations suggest that “popo” and “agaric” could be *Polyporus mori* or *Fomes fomentarius* and *Laricifomes officinalis*, respectively.[1] The dyeing recipes are very similar for “popo” and “agaric” and some recipes mention that grey and black shades can be obtained when mordanting with iron. It seems that “popo” and “agaric” have been used on an industrial scale for several centuries, from the 15th to 17th century, in the major European textile centres and goods have been traded internationally. Fungi were obtained from the Alps and Eastern Mediterranean countries.[1]

In Northern Europe, several authors refer to fungal colorants.[12–Error! Reference source not found.] In the book "Svenska Färge-Konst" Linder (1720) mentions old *Lactarius* (milk cap) as a source of a yellow colour.[15] Eighty years later Palmstruch (1804) mentions several mushrooms in his book "Svensk Botanik".[16] It seems that mushrooms were mainly used for food and medicine, but few times authors mention that they also gave colour to cotton and linen. The rare use of mushrooms for dyeing was obviously a result of the fact that fungi were not known very well. Most of the species were not identified at all and that caused doubt and confusion among people. During the Second World War, some experiments were carried out in Europe aiming at the use of fungi as a source of textile colorants.[14] But it was not until in 1970's when the American Miriam Rice published a book about dyeing with mushrooms that the colorants became popular among craft enthusiasts.[17] Due to recent objectives on diminishing the use of fossil resources and increasing biodegradable production together with sustainable design, natural colorants have gained growing research and economical interest. Extensive studies have been carried out to promote the use of natural colorants in a variety of fields in industry, *e.g*. food, cosmetics and textiles.[18]

2 Cultivation of Lichen and Mushrooms

Counter to general belief, lichens are not always rare. In fact, some lichens are weedy and they may grow fast.[1] Most lichens grow relatively slowly, thus their collection for dyeing purposes is questionable. Some researchers suggest that lichens could be harvested wisely.[1] According to the public right of access, however, in most countries,

lichens may not be collected from nature without the permission of the land owner,[19] and even if collecting, attention must be paid on the volume and location, so that actions do not pose a threat to the population. From the ecological point of view, fungi serve as an interesting source of raw material. Contrary to higher plants, which growth rates are rather slow, single cell algae and fungi can grow in high yields within a short period of time, even in several hours, and are thus more suitable and economical for colorant production, escpecially when taking advantage of the biotechnological fermentation procedures.[18,20,21,22] When collecting abundantly occurring mushrooms from nature, one is free of the ethical consideration of harming species' growth and population, because only the fruit bodies are collected and mycelium remains in the ground. From economical point of view, the exploitation of mushrooms in a larger scale could be beneficial for the rural areas promoting societal and cultural diversity when offering extra income for farmers and families, and hence helping to keep countryside vibrant. Eatable mushrooms are collected through networks already, and these could be utilized for collecting fungal material for colorant purposes as well.[19] Digital platform economy enable variety of ways for value creation, especially for individual small producers to join forces and deliver raw materials for the next step refiners. One example of this kind of activity is the Keraaja.fi portal,[23] which connects actors who are interested in trading NWFP (non-wood forest products) raw material and related products in Finland.

Due to the symbiotic relationship with their host trees ectomycorrhizal (ECM) fungi are rather difficult to cultivate,[24,25,26] but exceptions exists: *Boletales* and *Aminata* grow on substrates relatively easily contrary to *Russula* and *Cortinarius*, which are difficult to cultivate.[26] However, there are successful attempts to obtain aseptic cultures or even fruiting bodies of ECM fungi like *Cortinarius semisanguineus* (syn. *Dermocybe*

semisanguinea), which contains anthraquinone colorants suitable for dyeing,[28,29] and *Cantharellus cibarius*, a delicious eatable mushroom.[26,27,30-32] Recently many other ECM fungi have been cultivated successfully, as the research on in vitro studies and biotechnological processes has proceeded and expanded enormously.[18,21,22] One motivator for the in vitro studies has been the ECM fungi's ability to promote the growth of their host symbionts, i.e. trees, and it therefore becomes important to develop techniques to culture such beneficial fungi and benefit from their plant growth increasing properties in forestry.[33] In this respect, various *Cortinarius* species have been under investigation,[33] and this brings up interesting foresight for combining beneficial forest economy with biocolorant production, as several *Cortinarius* species are producers of anthraquinone colorants.[29]

The highest mycelial growth rates of ECM fungi have been reported among wood-rotting fungi.[34] The amounts of aseptic cultures in agar containing flasks varied from 1.1 to 94.9 mg / flask, the incubation time being 21 days.[34] Filamentous fungi, which do not form mycorrhiza, *i.e.* saprotrophs, are easy to cultivate and the growing procedures are utilized widely in production of eatable mushrooms. In vitro cultivations have been explored by utilizing for example wood shavings, saw dust, paddy husk, sugar cane bagasse, banana leaves, dried moringa stems and paddy straw as culture media. Also, shredded newspapers were found as a cost effective medium for culturing; the availability of paper waste being abundant.[35,36] In the case of basidiomycetous saprotrophs, the growth rates expressed as biological efficiency (calculated as fresh weight of fruit bodies per dry weight of substrate) may vary from average 50% up till even over 130%.[24,35]

In commercial production of eatable mushrooms, the first fungal bodies may usually be recognized within six weeks after the preparation of the culture medium and adapting spores. In nine weeks, one square meter may produce 15−30 kg of mushrooms.[37,38]

3 Colorant Structures in Lichens and Mushrooms

Lichens are cryptograms, symbiotic organisms comprised of alga and/or cyanobacteria, and fungal partners. The majority of all lichens have alga as their photosynthetic partner, i.e. photobiont, and only 10% cyanobacteria, and of those, more rare are the species having both cyanobacteria and algae as partners for the fungus.[39] Due to this symbiotic origin, lichens and fungi contain similar types of colorants (Table 1). There are colorants or precursors of colorants that are found from both lichen and fungi, also there are colorants that are typical for only lichens or mushrooms. Never the less, colorants belong to various classes of chemical structures, from which some are not found elsewhere in the nature.[1,7,21] Colorants in lichens and fungi are secondary metabolites and belong to polyketides. An interesting group are benzoquinone derivatives,[7] of which particularly, terphenylquinone compounds are found in species like *Sarcadon*, *Phellodon*, *Hydnellum* and *Telephora*, imparting a blue colour, rare in nature, to wool fibres.[1,7,12,14,17]

3.1 Lichen Dyes Orchils and Litmus

Both orchil and litmus are colorants, which have not been found in plants. They are formed from their colourless precursors through consecutive enzymatic hydrolysation,

decarboxylation and oxidation processes, respectively. Precursors of orchil and litmus exist in several species of lichen, *e.g*. *Roccella* and *Lecanora*.[7,40] The procedure for the ancient lichen purple was to prepare a water extract with ammonia and to let the liquid to stand in a warm place for several days.[3] The reaction occurred in a form of enzymatic hydrolysis, where the non-coloured compounds of lecanoric acid were first hydrolyzed to orsellinic acid and decarboxylated further on to orcinol. Orcihol oxidized in the air and formed the purple orceins, *e.g.* α-aminoorcein and α-hydroxyorcein, or litmus (Figure 1).[1,7] Orchil dye is a mixture of several other orceins among those mentioned earlier, *i.e*. β- and γ-aminoorcein, β- and γ- hydroxyorcein and β- and γ-aminoorceimine.[1] The colour of both litmus and orchil are pH-depended. In acidic environment the dyes form red cations while in the basic environment they are bluish violet in their anionic forms.[1,7] Lichens from *Rocella* spp. contain lecanoric acid, the precursor of orcein, from 3 to 4% of the dry weight.[7]

3.2 Yellowish, Brownish and Reddish Colorants from Lichen

Atranorin and gyrophoric acid are found only in lichens, for example the former in *Parmelia* spp. and *Xanthoria parietina* and the latter in *Ochrolechia tartarea* and *Lasallia pustulata*. Salizinic acid, the derivative of atranorin, is found in several *Parmelia* spp., for example in *Parmelia saxatilis*. These lichens have been used to dye yellowish, reddish and brownish hues for the woollen materials used in tweeds and tartans in the Scottish highlands.[1,7,8] Dyeing with these lichens is also common in Scandinavia. For the colorants two types of dyeing methods are used: the process with ammonia, which considers the consecutive enzymatic hydrolysation, decarboxylation

and oxidation processes, and the water boiling method, where the lichens are treated in water together with the textile material.[1,2,8] With the ammonium procedure more violet tones are obtained.

3.3 Blue Terphenylquinones from Mushrooms

Terphenylquinone derivatives are the main colorants to produce the blue colour in dyeing processes with mushrooms. Blue hues may be obtained from *Sarcodon*, *Phellodon* and *Hydnellum* as well as from *Telephora* spp.. *Hapalopilus nidulans* contains polyporic acid 20–40% of its fresh weight.[7] *Tapinella atrotomentosa* (syn. *Paxillus atrotomentosus*) and *Telephora palmata* contain pigments notably less amounts. *T. atrotomentosa* contain atromentin and telephofic acid together from 2 to 4% where as *T. palmata* contains telephoric acid less than 1% of the dry weight.[7,41] Atromentin is responsible for the brown colour in *T. atrotomentosa*, and it occurs as colourless precursors, leucomentins 2 and 3 in the fungal flesh.[42-45] When extracting colourants from mushrooms with water, colourless leucomentins can convert into spiromentin, and dye liquor turns strong violet. Very easily however, the violet siromentin[46] converts further, and the colour obtained in fibres is brown due to formed atromentin (Figure 2).

There are two species of *Sarcadon*, which are very often mixed with each other: *S. imbricatus* and *S. squamosus*.[47] It was thought, that *Sarcadon imbricatus* imparted the blue colour to the wool fibres. However, very often the blue was not obtained and this confused dyers. Finally, the DNA investigations revealed that there are two different

Sarcadon species, from which one grows with pine (*Pinus sylvestris)* and the other with spruce (*Picea abies*). Mushrooms collected from pine forest seem to give stronger blue colours than those collected from spruce forests.[47] Blue producing colourants in *Sarcadon* spp. are terphenylquinone derivatives, such as teleporic acid and polyporic acid .

The dyeing experiments with the above-mentioned fungi show that to obtain a strong blue colour great amounts of mushrooms are needed. Greyish and light blue colours may be obtained when the fresh weight of mushrooms is 10 or 20 times greater than the weight of the textile material to be dyed. For a stronger colour the amount of at least 30 times of the weight of the fibre is needed.[48] Thus, even though the obtained blue colours are interesting due to shades rare among natural dyes, it is obvious that the concentrations of colorants are too low to make utilization in large-scale production economical. However, natural compounds have often other unique, for example medicinal, properties, which make them valuable. Terphenylquinones possess antimicrobial properties, and those add value when considering refining and future uses of these compounds.[45,49]

3.4 Anthraquinones

Anthraquinones is a versatile group of compounds the total about 700 derivatives being identified in nature. Approximately one third of compounds have been found from plants and two thirds from lichens and fungi, whereas in bacteria and animals (insects) they are found to a much lesser extent.[22] Antraquinones are one of the most stable

natural colour producing structures and therefore they have had importance as dyes in history, and as commercial synthetic colorants. Anthraquinones are relatively lightfast and they give a bright colour. The best ancient red colours obtained from madder, cochineal and kermes were from anthraquinone based compounds. Natural anthraquinones have gained growing interest as colouring agents for beverages, sweets and other foods.[18,20,50,51] In addition, cosmetic industry utilizes natural anthraquinone colorants more and more in all kinds of products including lipsticks and hair dyes.[20,52-54]

Some of the best mushrooms for dyeing are the ones belonging to *Cortinarius* species. The richly coloured appearances in brown, red, olive green and even violet colours reveal the fruit bodies to contain great amounts of colorants. Especially, the subgroup of *Dermocybe* is favoured by dyers.

Bloodred webcap, Cortinarius sanguineus

Cortinarius is one of the largest genus of agarics containing more than 900 defined species in Europe, and many yet undefined.[55] *Cortinarius* species are also found on other continents, extensively in the Northern hemisphere like North America but also south in Australasia.[56]

In the fungus *C. sanguineus*, emodin- and dermocybin-1-β-D-glycopyranosides are the most abundant anthraquinones. In the fresh fungi even 90% of the pigments exist as glycosides.[57] The most important biosynthetic route to anthraquinones seem to be the acetate-malonate pathway, which includes suitable folding and condensation of a polyketide chain derived from acetate units (Figure 2). According to acetate-malonate

pathway, the biosynthetic relationships show that the yellow compounds emodin, physcion and endocrocin exist in the beginning of the synthetic pathway where as the red compounds dermocybin, dermorubin and 5-chlorodermorubin are more complicated in structure and occur in the latter part of the syntheses pathway.[41] This may be verified in dyeing experiments, which reveal that young mushrooms give more yellowish and orange colours were as old mushrooms give dark red and reddish brown colours.

Since fungi are structurally and functionally simpler organisms than higher plants, *e.g*. they do not have photosynthesis, the isolation of secondary metabolites is quite easy. Hynninen *et al*. developed a preparative scale isolation method for the anthraquinone colorants from the forest grown mushrooms.[58] In the procedure fresh fungal bodies were used (Figure 3). As known, most natural colorants exist as glycosides in living organisms. Glycosidic compounds are in most cases so water soluble that it is even inconvenient for dyeing – they remain rather in the dye solution than move into fibres. In the isolating procedure the endogenous β-glucosidase enzyme of the fungus breaks down the glucosidase linkage and thus the colorants can be obtained as free aglycones, which more readily travel into fibres and are therefore more effective in dyeing. In addition, it was noticed, that during the drying process of the fruit bodies the glycoside linkages were partly broken down by themselves. It seems that during the evaporation of water the cell membranes disrupted enabling the β-glucosidase enzymes and anthraquinone-glycosides to meet resulting aglycones. Thus, in the preparative scale colorant isolation it is advantageous to dry the mushrooms as the primary step. Drying is cost-effective; it reduces the mass and enables easy storage for years. Also the dry fruit bodies can be crushed, which decreases space required for storage. From 10 kg of fresh mushrooms, which is about 1 kg in dry weight, 60 g of anthraquinone powder was

obtained.[58] This means 6% pigment content, which is fairly good. For plants the colorant content from the dry mass is often under 5%, for example *Rubia tinctorum* contains anthraquinones around 2–3% of the dry weight,[59] and requires several years growing.

The isolation process yielded colorants in powder form, which is useful for storage and application in various materials, because the amount of dye and its concentration can be easily measured. This enhances the repeatability of the dyeing and colouring result.

Räisänen *et al*. applied pure anthraquinone dyes, obtained by previously described isolation procedure, as mordant, acid and disperse dyes both for natural and synthetic fibres. The results showed that the dyeing was successful. The dye uptakes of natural anthraquinones were in most cases over 70 and in the disperse dyeing processes even nearly 100%.[60–62] The colour fastness of the dyed materials varied from low to excellent among the different fibres and dyeing techniques (Table 2). Excellent results, in terms of evenness and fastness of colour, were obtained for high temperature disperse dyed polyester. When aiming for more sustainable textile colouring processes waterless techniques could be applied. The fungal antraquinone emodin was applied successfully to biodegradable polylactic acid (PLA) fabric using super critical carbon dioxide (SC-CO_2) as solvent. Results revealed that fibres were throughout coloured and the fastness properties were of high quality.[63]

As a conclusion, natural anthraquinone compounds can produce bright hues with good colourfastness properties in both natural and synthetic materials. Natural resources could be utilized more widely for anthraquinone dye production, because the total

synthesis of anthraquinones is quite cumbersome, frequently requiring toxic reagents, such as heavy metal salts. Also, utilization of natural processes diminishes the formation of toxic side products.

3.5 Other Colorants of Fungi

Yellows from grevillines

In the fruiting bodies of *Suillus* species several types of grevillines can be found.[44] They impart colour variations from yellow to red.[1,7,64] Boletales can be used for dyeing but the intensity of the obtained colours in textile materials are weak (Table 1).

Yellow-orange colours from pulvinic acid derivatives

Pulvinic acid and its derivatives form yellow and orange-red colours in fungi of Boletales species and lichen *Sticta aurata*. Dimers of pulvinic acids have been found in the brown outer layer of the cap of the *Boletus erythropus*.[64] The decarboxylation products of pulvinic acids, *e.g.* chamonixin, involution, gyrocyanin and gyroporin, cause the characteristic blueing of the flesh of many fungi of Boletales species when the mushroom is cut and the flesh get into touch with air.[1,7,44,64]

Brown from badiones

The famous dyeing mushroom *Pisolithus arhizus* contains colourants belonging to badione group, and produces brown colours. Norbadione A occurs in the fungus as potassium salts and exists in amount of over 25% of the dry weight of the fungus.

Badione A, bisnorbadioquinone A and pisoquinone may also occur as minor compounds.[1,44]

4 Stability of Lichen and Mushroom Colorants

The properties of the products have to fulfil the requirements of the consumers. Even in past centuries, the textile trade required quality control, testing and regulations.[65] Consumers are aware of factors, such as cost, expected wear of life and preferred methods of cleaning, which affect their satisfaction with a product, but these factors are often connected with the level of colourfastness exhibited by the item. One of the important properties of dyed material is the fastness of the colour. The level of colour fastness desired in a product is determined primarily by its intended use. Low light-fastness may be acceptable for items, that are inexpensive, and whose lifetime is short, for example paper. Also, textiles that are not directly exposed to light may be acceptable with lower light fastness properties. In contrast, excellent light fastness is required for interior and furnishing fabrics, since their expected use phase is longer than clothes'.

Light fastness is among the most important properties that must be satisfactory for textile dyes. On fading, most samples show loss and dulling of the colour, accompanied by a change of hue.[66] Most natural dyes initially fade rapidly, then continue to fade at a slower rate. Most of the light-fast natural dyes, such as the anthraquinones, fade gradually at a constant rate.[67] A significant number of natural dyes, when treated in weakly alkaline solution, show marked changes in hue. Natural compounds contain OH-groups, the deprotonation of which is pH-dependent. In many cases, ionisation has an

effect on the colour of the compound, as it causes a bathochromic shift in the electron absorption spectrum of the dye molecule.[68,69] The tendency to change colour makes it necessary to have accurate knowledge of the pH of alkaline solutions for the washing of textiles dyed with natural dyestuffs. Apparently, repeated washings under mildly alkaline conditions do not have a cumulative effect and therefore, after several washings textiles reach a state of stability.[66]

ISO (International Organization for Standardization) has published several standards for colourfastness tests. Most commonly used method to test the light fastness is the ISO 105-B02 protocol, in which the dyed samples are exposed to xenon arc lamp together with the standard blue scale. The rating values vary in the range 1–8, 8 being the best value. The light fastness properties of the woollen materials dyed with the blue terphenylquinone colorants of *Sarcadon squamosus* varied from 3 to 5, which is rather low for textile dyeing purposes.[48] Similar values were obtained for wool dyed with *Tapinella atrotomentosa* containing also terphenylquinones.[70] The low fastness properties of terphenylquinone compounds were noticed already in ancient times among lichen dyes.[1] The colour fastness is highly depended on the dyeing method, for example the used mordant, and the applied fibre as the colourant interacts with its surrounding and formed forces have an effect of the total stability of the system. For example the fungal anthraquinone dye received colourfastness values ranging from 3 to 5 when used as mordant dye for wool,[70,61] value 6 when used as acid dye for wool[62] and value 6–7 when used as disperse dye for polyester.[18,60]

Natural compounds contain plenty of O- or OH-groups through which colorants may attach directly to the textile fibres. The other possibility is to form coordination linkages

with the metal atoms of the mordants. It seems that the low light and washing fastness of many lichen and fungal dyes is not due to lack of appropriate functional groups, but the general three dimensional structure of the compound. The colorants have one or more single bonds in their chemical structure and these single bonds enable the molecules to twist. Due to twisting, the functional groups end up in a position where they are unable to form linkages between each other or between the molecule and the fibre. Hence, molecules are not flat. It is known that for dyeing purposes flat and firm dyestuffs, like anthraquinones, are better than very three dimensional. Flat molecules may approach the fibre surface more closely and thus attach to the fibres more strongly. It is evident that anthraquinones have outstanding fastness properties compared to other chemical groups in fungal and lichen dyestuffs. Dyeing is a manifold phenomenon in which physical and chemical interactions exist. Close distances of dye molecules with the fibres enable charge-transfer forces, van der Waals forces, hydrophobic interaction and even π-π-interaction to occur. In addition to covalent, coordination, ionic and hydroxyl bonds have a remarkable effect for the fixation.[71]

5 New Approaches to Lichen and Fungal Colorants

Recently, more focus has been laid on studies to exploit other unique properties of natural compounds. Fungi and lichens have been used for centuries as medicines and now these medicinal properties have been recognized as a growing opportunity in textile markets (Räisänen 2018; Räisänen et al. 2020, Suthar et al. 2021).[19]

Emodin is probably the most widely distributed anthraquinone, being present in moulds, higher fungi, lichens, flowering plants and insects.[72] For pharmaceutical studies, emodin has been obtained from fungi, which have been cultivated on a culture medium, and several fungal species have been used as producers (Caro et al. 2017). *Penicilliopsis clavariaeformis* Solms[73], *Penicillium oxalicum* and other related species are already hosts for anthraquinone production in industrial scale (Caro et al. 2017).

Natural compounds have UV-protective properties and when applied to textiles they protect human skin from hazardous solar ultraviolet radiation.[74] It seems that the cleavage of hydrogen bonds in the molecules of the natural dyes contributes to their capacity to absorb UV-radiation.[74] Also the antimicrobial activity of natural colorants wakes new ideas to be considered when developing protective clothing or home textiles such as bed linen, towels and carpets. According to Singh *et al.,* the concentration of dye increased the bactericidal properties of dyed textile. The antimicrobial properties seem to be related to the dye structure, especially the presence of functional groups in it.[49] Modern textiles are required to have high degrees of chemical and photolytic stability in order to maintain their structure and colour. Antimicrobial agents are added particularly to natural fibres to make them resistant to biological degradation. In this respect, the antimicrobial activity of natural colorants could be taken into account.[49]

It is important to test the dyes also for their safety to human and the environment. Natural origin alone does not guarantee safety. For example, some anthraquinones, such as emodin and its chloroderivatives, have been found to have toxic or carcinogenic properties.[75–77] On the other hand the toxic effect is always dependent on the dose. Natural dyes are in most cases mixtures, and the effect of mixtures is different from

purified compound. If additional values of natural colourants are to be developed, it is essential to consider whether the product would be purified or a mixture, as in the purification step, desirable activities may be lost or decreased.

Many natural colorants have found applications in electronics as the conjugated double ponds in organic structure enable π electron flow and conductivity. This expands the aims of searching new natural compounds and their production methods. From the economical perspective, it seems obvious that not all natural colorants are suitable in large-scale utilization. From the sustainability and diversity point of view however, natural colorants offer great potential for capsule collections, unique well-designed artefacts, and counterforce for mass production.

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