Biology of Lichen polysaccharides and its Applications - a Review


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Abstract

Lichens are symbiotic organisms. The two different organisms involved in the symbiosis is referred as mycobiont which is a fungus and photobiont, which may be an alga or cyanobacteria. Lichens are well known for the production of unique lichen substances, some are potentially useful and biologically active compounds. Traditional and modern techniques were used for isolation and separation of secondary metabolites and polysaccharides from lichens. Freezing and thawing of material in aqueous extract was the traditional methods have been practised for isolation which was followed by dialysis and ethanol precipitation for further purification. Polysaccharides isolated from lichens consist of linear or scarcely substituted α- or β-glucans, galactomannans and few complex heteroglycans. Functions of these polysaccharides mainly depend on the presence of monosaccharides, water solubility, molecular weight, degree of branching, structure and configuration. Monosaccharides of the lichen polysaccharides can be determined using gas chromatography, methylation analysis, 1H and 13C-NMR spectroscopy. Lichen polysaccharides exhibits various properties such as anti-tumour, anti-viral, anti-oxidant, immunomodulatory and some biological effects. Lichens have been traditionally used for medicinal purposes throughout the ages, and its benefits have been correlated with their polysaccharide content. In this review, classification of lichens, lichen polysaccharides, extraction and analysis of polysaccharides and its applications were discussed.

Keywords: Lichens; Polysaccharides, Galactomannans; Chromatography, NMR spectroscopy; Immunomodulators.

1. Introduction

Lichens are unique organisms resulting from a symbiosis between fungi and algae. About 400 genera and more than 15000 distinct species of lichens have been identified. Currently about 13,500 fungal species have been identified in lichen symbiosis (Hawksworth et al., 1995; Kirk et al., 2001), but its number could be as high as 20,000 (Sipman and Aptroot 2001) after comprising “orphaned” species. According to Lumbsch et al., (2011) more than 10,000 of lichenized fungi have been estimated as undescribed species.

Lichens are well known for the production of unique biomolecular substances, some are potentially useful and biologically active compounds. They have the capability to grow in extreme condition. Two different organisms involved in the symbiosis are fungus which has heterotrophic mode of nutrition and photosynthetic partner either algae or cyanobacteria. Polysaccharides are essential bio-molecules exhibiting a variety of important biological functions and are directly involved in life processes. Among the identified lichen symbionts about 100 species have been studied for their polysaccharides composition (Cordeiro et al., 2005). Lichen polysaccharides have been reported to exhibit anti-
tumour, anti-viral, anti-oxidant, immunomodulatory and some biological effects.

2 Classifications of Lichens

Lichens are mainly classified based on nature and kinds of fruit bodies of the fungal partner.

A. Based on habitat
   a) Saxicolus - Grows on rocks, in cold climate. Eg: Peltigera
   b) Corticolus - Grows on bark of trees, in subtropical and tropical regions. Eg: Parmelia
   c) Terricolus - Grows on soil, in hot climate. Eg: Cladonia
   d) Lignicolus - Grows on wood, in tropical regions. Eg: Cyphellum

B. Based on group of fungal partner
   a. Ascolichens - Fungal member belongs to Ascomycetes. Based on the structure of the fruit body they are further divided into two series;
      i. Gynocarpeae - The fruit body is disc shaped and also known as Discolichen. Eg: Usnea
      ii. Pyrenocarpeae - The fruit body is flask shaped and also known as Pyrenolichen. Eg: Verrucaria
   b. Basidiolichen - Fungal member belongs to Basidiomycetes. Eg: Dictyonema
   c. Deuterolichen - Fungal member belongs to Deuteromycetes.

C. Based on thallus structure
   a) Leprose - The fungal mycelium envelops either single or small cluster of algal cells. Eg: Lepraria
   b) Crustose - Thallus is inconspicuous, flat and appears as a thin layer on substratum. Eg: Graphis
   c) Foliose - Thallus is flat, horizontally spreading with lobes. Eg: Parmelia
   d) Fruticose - Thallus are well developed, cylindrically branched, shrub-like, either grow erect or hang from the substratum. Eg: Usnea
   e) Filamentous lichens - Instead of fungal, the algal are more developed and filamentous. Eg: Ephebe

D. Based on distribution of algal component in the thallus
   a) Homoisomeric thalli - Algal cells and fungal hyphae are uniformly distributed. Eg: Collema
   b) Heteromeric thalli -Algal cells forms an unique layer and fungal hyphae in different layer. Eg: Parmelia

3. Classification of Lichen Polysaccharides

Polysaccharides can be produced by both lichen symbionts. The mycobiant cell wall consists of three structurally different polysaccharides namely, α-glucans, β-glucans and galactomannans. They have linear, lightly substituted branched structure (Carbonero et al., 2005) and are from fungal origin. It is also been reported that in addition to the basic types of lichen polysaccharides, complex heteroglycans consisting of monosaccharides different from or in addition to galactose, glucose and mannose. Lichen polysaccharides, β-glucan and galactomannan type is been suggested to be of chemotaxonomic significance. The localisation of the lichen polysaccharides have not been established properly. The polysaccharides could either be a part of the fungal cell wall or reserve glucans, and they could also be intracellular or a part of the intercellular material which surrounds both algal and fungal cells.

Figure-1: Structurally different polysaccharides present in lichens. 1) β-glucans, 2) α-glucans, 3) galactomannans, 4) Lichenan, 5) Pustulan.

4. Lichen Polysaccharides - Extraction

Traditional and modern techniques were used for isolation and separation of polysaccharides from Lichens. Freezing and thawing of material in aqueous extract was the traditional methods have been practised for isolation which was followed by dialysis and ethanol precipitation for further purification. The water-soluble polysaccharide from U.esculenta was obtained using hot water extraction method and it was further purified using anion-exchange chromatography on a DEAE-cellulose column (Zhang et al., 2016).

The polysaccharides from Parmotrema centratum (contains unusual treitol and unexpected volemitol with galactose) was extracted with benzene-ethanol and hot water, the polysaccharides gets precipitated with methanol leaving low concentration of carbohydrates in supernatant (Iacomini et al., 1993). The aqueous extraction procedure is efficient since the yields were similar to extraction done with hot aqueous
**Table 1: Lichen species which have been known for polysaccharide content [Karunaratne et al., 2012].**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Polysaccharides</th>
<th>Lichen Species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Evenniin</td>
<td><em>Evernia prunastri</em></td>
<td>Shibata, 1973</td>
</tr>
<tr>
<td>3.</td>
<td>Acroscyphan</td>
<td><em>Acroscyphus, Sphaerophoroides</em></td>
<td>Shibata, 1973</td>
</tr>
<tr>
<td>4.</td>
<td>Thamnolan</td>
<td><em>Thamnolia subuliformis</em></td>
<td>Olafsdottir et al., 1999</td>
</tr>
<tr>
<td>8.</td>
<td>Galactomannan</td>
<td><em>Ramalina peruviana, R. dendriscoides, R. fraxinea, R. gracilis</em></td>
<td>Cordeiro et al., 2004</td>
</tr>
<tr>
<td>9.</td>
<td>Galacto Glucomannans</td>
<td><em>Parmotrema austrosinense, P. schindleri, P. tinctorum, Rimelia Cetrata and R. reticulate</em></td>
<td>Carbonero et al., 2005</td>
</tr>
<tr>
<td>10.</td>
<td>β-galactofuranan</td>
<td><em>Trebouxia sp.</em></td>
<td>Cordeiro et al., 2005</td>
</tr>
<tr>
<td>11.</td>
<td>Galactofuranomannan</td>
<td><em>Umbilicaria mammulata, Ramalina celastri, R. ecklonii, R. scopulorum, R. usnea</em></td>
<td>Carbonero et al., 2006</td>
</tr>
<tr>
<td>12.</td>
<td>Laminaran</td>
<td><em>Umbilicaria mammulata, Ramalina celastri, R. ecklonii, R. scopulorum, R. usnea, R. peruviana</em></td>
<td>Cordeiro et al., 2005, Carbonero et al., 2006</td>
</tr>
<tr>
<td>13.</td>
<td>Xylorhamno-Galactofuranan</td>
<td><em>Cladina confuse</em></td>
<td>Cordeiro et al., 2007</td>
</tr>
<tr>
<td>14.</td>
<td>Hetero polysaccharide</td>
<td><em>Ramalina gracilis</em></td>
<td>Cordeiro et al., 2008</td>
</tr>
<tr>
<td>15.</td>
<td>O-methylated Mannogalactan</td>
<td><em>Peltigera aphthosa</em></td>
<td>Cordeiro et al., 2010</td>
</tr>
<tr>
<td>16.</td>
<td>Colleman</td>
<td><em>Collema flaccidum, Peltigera canina, Collema leptosporum</em></td>
<td>Jenson et al., 2010</td>
</tr>
<tr>
<td>17.</td>
<td>HSSEP (HSSEP1, HSSEP P2)</td>
<td><em>U. esculenta</em></td>
<td>Wang et al., 2015</td>
</tr>
</tbody>
</table>
KOH. According to Bisht et al., 2014, the Peltigera sp. and Cladonia sp. were extracted with two separate solvents likely methanol and water. Mostly the precipitation followed by hot water extraction process is the preferred method for polysaccharides extraction from lichen species. Carbonero et al. (2006) extracted polysaccharides from lichen material at 100°C in hot water followed by alkaline treatment at 100°C. The alkaline solution used for the extraction of polysaccharides includes 2% KOH. Ingólfsdóttir et al. (1998) described that the polysaccharides from Cetraria islandica with light petroleum and methanol in soxhlet apparatus followed by ethanol precipitation and dialysis for purification. Further purification was carried out in anion-exchange chromatography with columns (3.5x23 ern) packed with DEAE Sepharose CL-6B (acetate form) and eluted by a linear gradient of 0-1.0 M NaCl. The successive extractions of polysaccharides from lichens with 5 and 24% cold aqueous potassium hydroxide was performed by Iacomini et al.,(1985) and compared the yield% in three different lichens namely Cladonia alpestris (REINDEER MOSS), Cladonia confusa, and Cladonia amaucrocea. The lichen Umblicaria pustulata was extracted continuously with ether and methanol followed by pre-extraction using 2% of sodium carbonate (Lindberg et al.,1954).The lichens Ramalina dendroides, R.fraxinea, R.gracilis and R.peruviana were extracted with chloroform and methanol, subjected to sequential extraction with 2% and 10% aqueous KOH and neutralized with acetic acid added to ethanol resulting in polysaccharides precipitates (Cordeiro et al., 2003). Lichen thalli of Cladina confusa, extracted with EtOH and 1:1 (v/v) CHCl3–MeOH in sequential extraction with water and 10% aq. KOH at 100 °C and resulting extracts were neutralized with acetic acid and the resulting polysaccharide precipitates were dissolved in water and dialyzed for purification (Cordeiro et al., 2007).

5. Lichen Polysaccharides Analysis

The initial characterization of lichen polysaccharides was performed in the early 1980s (Gorin and Iacomini et al., 1984). Polysaccharides isolated from lichens primarily consist of linear or scarcely substituted α- or β-glucans. Secondly, several galactomannan-type structures have also been reported, and thirdly a few complex heteroglycans, including a totally new rhamno-pyranosylgalactofuranan structure, were recently being described. According to Yanaki et al. (1986) and Bohn and BeMiller, (1995), functional activity of polysaccharides mainly depends on water solubility, monosaccharide composition, molecular weight, degree of branching, structure and configuration.

i. Determination of total sugar, uronic acid and protein contents: Total sugar content was determined by the phenol-sulfuric acid method using glucose as a standard (Dubois et al., 1956). The protein content was determined according to the Coomassie-brilliant blue method (Lowry et al., 1956) using bovine serum albumin as a standard. Uronic acid content was measured by the m-hydroxydiphenyl method with galacturonic acid as a standard (Blumenkrantz et al., 1973). It has been reported that the two fractions of lichen extracts named as HSSEP1 and HSSEP2 are acid polysaccharides with 0.73% and 0.54% of uronic acid content, respectively. The protein content in the two polysaccharide fractions remained undetectable. The total sugar content in HSSEP1 and HSSEP2 were 95.00% and 98.80%, respectively (Wang et al., 2015).

ii. Monosaccharide composition of the polysaccharides: Monosaccharide components of the polysaccharides from Ramalina peruviana and their ratios were determined by hydrolysis with 2 M TFA for 8 h at 100°C, followed by conversion to alditol acetates (GC-MS) by successive NaBH4 reduction and acetylation with Ac2O-pyridine. Polysaccharides in the R.peruviana is mannose, galactose and glucose in a 25:41:34 ratio (Cordeiro et al., 2004). Monosaccharide components of major acidic and neutral polysaccharide fractions from hot aqueous extract of Cetraria islandica was found to be glucose, galactose and mannose (Ingólfsdottir et al., 1998). Galactoglucomannans were isolated from the mycobiont of Parmotrema species including P.austrosiense, P.delicatum, P. mantiqueirense, P. schindleri, P. tinctorum and Rimelia cetrata and R.reticulata by Carbonero et al. (2005b). These galacto-glucomannans consisted of (1→6)-linked main chain of α-Manp units, which were substituted preferentially at O-2 and O-4 by α-Galp and β-Galp nonreducing end-units.

The fraction from Cladina confusa subjected to monosaccharide analysis with 5.8% yield, consisted mainly of galactose (40.5%), glucose (34%) and rhamnose (15.5%), with small amounts of xylose (6%) and mannose (4%) (Cordeiro et al., 2007). The water-soluble material from Cladonia amaucrocea, obtained from the Fehling solution-precipitated polysaccharide with 71% yield contained mannose (50%), galactose (29%), and glucose (20%). The hot-water-extracted polysaccharide (1% yield) contained mannose (20%), galactose (20%), and glucose (61%). However, hot aqueous KOH extraction has the yield of 11% and composed of mannose (36%), galactose (23%), and glucose (40%) was determined through monosaccharide analysis.
Figure 2. Images of Lichens.  a) Parmotrema tinctorum, b) Parmotrema indicum [Hale], c) Heterodermia pseudospeciosa, d) Heterodermia japonica, e) Usnea stigma toide, f) Cladonia cartilaginea Müll, g) Ramalina conduplicans Vain, h) Sticta weigeli (Ach.) Vain.
Benzene-ethanol extracted polysaccharides (0.12% yield) from *C. alpestris* was subjected to monosaccharides analysis resulting with glucose (91%), mannose (5%), and galactose (3%) (Iacomi et al., 1985). The monosaccharide compositions analysis revealed that the polysaccharides isolated from *Umbilicaria esculenta*, HSSEP1 was composed of galactose, glucose and mannose in a ratio of 12%, 76% and 12% respectively, while HSSEP2 mainly consisted of glucose (Wang et al., 2015).

**iii. Determination of functional groups:** To determine functional groups present in the sample was analysed through Fourier-transform infrared (FT-IR) spectra. Wang et al., 2015 analysed IR spectrum for polysaccharides fractions (HSSEP1 & HSSEP2) from lichen *Umbilicaria esculenta* Nicolet 5700 spectrometer (Thermo) at the range from 400 to 4000 cm⁻¹. The peaks at 3399 cm⁻¹ (HSSEP1) and 3353 cm⁻¹ (HSSEP2) were due to the hydroxyl stretching vibration and the peaks at 2923 cm⁻¹ (HSSEP1) and 2892 cm⁻¹ (HSSEP2) were due to the C-H stretching vibration. The band 1731 cm⁻¹ (HSSEP1) and 1731 cm⁻¹ (HSSEP2) represented the presence of uronic acids. The peaks that appeared at approximately 811 cm⁻¹ of HSSEP1 were attributed to D-galactose or D-mannose. The peaks at 914 cm⁻¹ of HSSEP2 were assigned to glucose.

The FT-IR spectrum of fraction (UP2) from *Umbilicaria esculenta* showed the distinct characteristic absorption peaks of polysaccharides. The strong and broad peak at 3410 cm⁻¹ was mainly due to O-H stretching vibration. The bands in the region of 2925 cm⁻¹ and 1650 cm⁻¹ were assigned to C-H stretching vibrations and associated water. The peak at 1245 cm⁻¹ was attributed to deformation vibrations of the C-H bond. The strong band around 1050 cm⁻¹ was ascribed to the pyranose ring. The mannan content of the sample presented its typical absorption peaks at 810 cm⁻¹ (Zhang et al., 2016).The polysaccharides fraction (Ge3) from *Gyrophora esculenta* was analysed for its functional groups which resulted with peaks at 3280 cm⁻¹ represents the N-H stretch, 1730-1720 cm⁻¹ represents ester-amide carbynol and acetyl carbynol, 1603 cm-1(phenyl) and peak at 980 cm-1 (β-glucosidic linkage) (Nishikawa et al., 1969).

**iv. Determination of molecular weight of Polysaccharides:** The purified polysaccharide fractions obtained from the anion-exchange chromatographic separations were followed by high pressure gel permeation chromatography (HP-GPC) on p-Bondagel E-500 and E-1000 columns equilibrated with 0.05 M Na-phosphate buffer pH 6.0 containing 0.15 M NaCl. Eluates were monitored by refractometric and UV detectors (206 nm). Calibration was performed using dextrans of known molecular weight. The mean molecular weight of the polysaccharide fractions from *Cetraria islandica* ranged approximately from 18,000 to 2 million (Ingólfsdottir et al.,1998).The homogeneity and molecular weight (Mr) of water-soluble polysaccharides were determined by steric exclusion chromatography (SEC), using multi detection equipment in which a differential refractometer (Waters) and a multi angle laser light scattering apparatus. The eluent was 0.1 M NaNO₃ in column of Sepharose CL-6B Then it was eluted with 0.2 M NaOH. The column was calibrated for molecular mass using dextrans with Mₙ of 81.6*10⁵, 26.6*10⁴, 5.0*10⁵ and 2.0*10⁴. Steric exclusion chromatography of *R. peruviana* α-D glucan (isolichenan), which contained 100% glucose was inferred that it has a Mₙ of 103 kD, dn/dc 0.115 and was eluted as a single peak (Cordeiro et al.,2003).

A Waters size exclusion chromatography (SEC) apparatus coupled to a differential refractometer (RI) was used for examination of soluble fractions of polysaccharides from *Umbilicaria mammulata*. Four Waters Ultrahydrogel 2000/500/250/120 were connected in series and coupled with a multidetection equipment. It gave a homogeneous profile when analyzed by HPSEC with Mₙw 48*10⁵ and differential refractive index increment of the solvent-solute solution with respect to a change in solute concentration (dn/dc) was found to be 0.133 (Carbonero et al., 2006).

**v. Methylation analysis:** *Ramalina dendriscoides*, *R. fraxinea*, *R. gracilis* and *R. peruviana* samples were partially O-methylated using NaOH–Me₂SO–MeI. The per-O-methylated polysaccharides were converted into partially O-methylated alditol acetates by successive treatments with 3% MeOH–HCl for 2h at100ºC, 0.5 M H₂SO₄ for 14 h at100ºC reduction with NaBH₄ and acetylation with Ac₂O-pyridine. The products were examined by capillary GC-MS, typical electron impact breakdown profiles and retention times were identified. Methylation analysis of the *R. peruviana* indicated the presence of 2.4,6- and 2,3,6-tri-O-methylglucitol acetatesin a molar ratio of 1:2.1(Cordeiro et al., 2003).From the methylation analysis of the galactomannans, presence of non-reducing end units of Galp (36.0–39.7%) and Manp (2.0–3.0%), as well 6-O- (19.0–26.0%), 4,6-di-O-(30.0–32.7%) and 2,4,6-tri-O-substituted Manp residues (5.0–9.0%) were observed (Cordeiro et al., 2004). Xylohamnogalactofuranan (Cordeiro et al., 2007) denotes the presence of (1→3)-linked galactofuranosyl units in the main-chain with side chains in position 6 on approximately 6.4% of the units and xylose was detected only as non-reducing end units, together with galactofuranosyl units when they are subjected to methylation.
A complex polysaccharide, Ths-3, isolated from the water extract of the lichen Thamnolia subuliformis subjected to methylation analysis showed that the heteroglycan is predominated, primarily (1→3)-linked galactofuranosyl units with side chains in position 6 on approximately 7% of the units, and secondarily (1→2)-linked rhamnopyranosyl units with branches on either C3 or C4. The side chains have differentially substituted rhamnosyl units as the predominating structural element with terminal xylose, glucose and mannose whereas xylose is only present as non-reducing terminal units (Olafsdottir et al., 1999).

iii. $^1$H and $^{13}$C-NMR spectroscopy: $^1$H and $^{13}$C-NMR analysis for Ramalina peruviana were performed at 50°C, the water soluble samples were dissolved in D$_2$O and the water insoluble in Me$_2$SO-d$_6$. According to $^{13}$C-NMR spectrum the water-insoluble fraction was obtained in high yield (18.0%) and contained a mixture of (1-3),(1-4)-linked α-glucan (nigeran) and (1-3)-linked β-glucan (laminaran) (Cordeiro et al., 2004). $^1$H and $^{13}$C-NMR spectroscopy of lichens of genus Ramalina namely R. dendriscoides, R. fraxinea, R. gracilis and R. peruviana showed high-field C-1 signals at δ100.2 and δ 99.3, showing an α-configuration, with other signals at δ 82.5 and δ 78.9 which corresponds to O-substituted C-3 and C-4, respectively, and δ 60.5 and δ 60.1 to unsubstituted C-6, similar to those of a previously described from R. celastri (Stuelp et al., 1999), and Cladina spp. (Carbonero et al., 2002).

Two fractions SAF-S and SAF-P (Cordeiro et al., 2007) were taken from Cladina confuse, where fraction SAF-P was composed of xylose only and NMR spectroscopy showed exclusively five signals, a low-field C-1 signal at δ 101.8, indicating β-Xylp units, and others at δ75.6 (O-substituted C-4), 74.0 (C-3), 72.7 (C-2) and 63.3 (C-5), characteristic of β-(1→4)-linked Xylp units. The fraction SAF-S consisted mainly of galactose (65.5%) and rhamnose (25.0%), with small amounts of xylose (9.5%) and its $^{13}$C-NMR spectrum is predominated by signals from galactofuranosyl units (δ 107.2 and 108.7). The configuration of the glycosidic linkage in the (1-3)-linked galactofuranosyl units was determined by $^1$H and $^{13}$C NMR spectroscopy (Olafsdottir et al., 1999).

6. Application of Lichen Polysaccharides

Lichens have been used as ecological indicator, medicine and other economic purposes for over 100 years and these beneficial effects have been linked to some amount with their polysaccharide content. Though only a fraction of the world’s lichen species has been investigated for polysaccharide constituents, unusual structures have already emerged leading to various applications. Many lichens are known to have immune-modulating properties, potent antibiotic, anti-tumour, anti-viral as well as antioxidant properties which are mostly attributed to the secondary metabolites and may be applied in the food industry and pharmacology. It was reported that polysaccharide from Umbilicaria proboscidea, with (1- 6)-linked β-glucan backbone, had implicit to induce anti-inflammatory effects. The polysaccharides separated from the lichens of Umbilicaria species, consisting mainly of (1 - 6)-β-glucan, showed a remarkable anti-tumor effect.

The polysaccharide components of U.esculenta have been proved to exhibit anti-tumor, anti-HIV, and anti-thrombotic activities. Trebouxia (family: Chlorophyceae) as phycobiont, indicating that it is the source of the L-glucan and can be used as a marker (chemo typing polysaccharide) assisting in the classic taxonomy of lichenized fungi. The L-glucan has also been suggested as a morphological characteristic of Cladoniform lichens. Lichen polysaccharides may be a potential source of immune preventive drugs for treatment of cancer as well as autoimmune disorders.

Lichens have been used for medicinal purposes throughout the ages, and beneficial claims have to been correlated with their polysaccharide content. The importance of the three-dimensional structure of β-glucans for anti-tumour activity is well established and also been demonstrated for lentinan, a (1-3)-β-glucan isolated from the fungus Lentinus edodes, which has been used clinically for adjuvant cancer therapy in Japan. It can be expected that the above condition applies for other (1-3)-β-glucans including the lichen polysaccharides. Immunomodulating effects, i.e., increased phagocytic activity and anti-complementary activity also been confirmed for chromatographically purified lichen polysaccharides, namely α-glucan, galactomannan and rhamnogalactan. Hence it is worthwhile to study the in-vivo immunological activity of these and other lichen polysaccharides in detail.

7. Conclusion

Therefore from studies investigating biological activity expressed by lichen polysaccharides, the therapeutic effects claimed from the use of particular lichens, such as Cetraria islandica, Lobaria pulmonaria, and Umbilicaria species, can be in part attributed to the polysaccharides. Lichen polysaccharides unquestionably deserve further study in
regard to biological activity, including studies into mechanism of action and structural-activity relationships. Unlike bacterial polysaccharides, the polysaccharides isolated from lichens don’t exhibit any wide range of variations in sugar content. The major sugars are limited to glucose, galactose and mannose with arabinose and xylose present in minor quantities in addition to other sugars such as rhamnose. Other lichen species also should be investigated, based on potential source and biological activity. As far as biological activity is concerned, very few studies have been reported and it would be worthwhile further investigating the effects of immune-modulating property of the polysaccharides.

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