Potential of bryophytes in prevention and medication of COVID-19

Afroz Alam※
Department of Bioscience and Biotechnology, Banasthali Vidyapith, Banasthali-304022, Rajasthan, India

1. Introduction

Due to parasitic nature, viruses are obligate intracellular organisms and utilize the host cells system for its replication and spread (Casadevall, 2008; Helms et al., 2015). These infective agents are visible through Electron microscope, but images taken by transmission electron microscope only provide the morphological insight (Goldsmith and Miller, 2009). Though, morphologically these viruses have variable external structures, but they have nucleic acid and capsid called nucleocapsid as common aspect (Tellingshuizen and Kuhn, 2000). They have been classified variously, viz., classification proposed by Holmes, Baltimore and LHT system on the basis of certain parameters, such as genome, capsid and host specificity, etc. However, the system was developed in the year 1971 by David Baltimore (a Nobel laureate, 1975) for classifying viruses based on the type of genome and its replication strategy is the most recognized and accepted classification.

1.1 Viral epidemics in past

There are no historic hints about the beginning and progression of viruses, but the world has seen many pandemics affecting loads of individuals and mourned millions of deaths. For instance, many pandemics were reported, viz., Spanish flu (1918-1920); Ebola viral disease (2014-2016), Zika virus, Chikungunya, Dengue in many countries that resulted into millions of deaths and still active to some extent at present also. A lethal addition in this tally is Coronavirus (SARS-CoV-2) which appeared in December, 2019 and affecting 107,415,710 of people worldwide and caused 2,351,367 deaths. However on a positive note, 79,346,885 people have been recovered (https://www.worldometers.info/coronavirus/ retrieved on 10.2.2021). On the basis of data regarding SARS-CoV-19 one thing is very much evident that level of immunity is the basic difference between life and death when anyone infected with this virus.

1.2 SARS-CoV-19

The name coronavirus is not new to pathology, but the earlier forms of it were only related to mild disease symptoms like common cold and cough. However, in the year 2003, a novel strain was introduced from bats to cats and then to humans. This existence caused severe acute respiratory syndrome (SARS) in humans and designated as SARS-CoV (Lu and Liu, 2012). Afterwards in 2012, another strain was passes from the camels to humans and designated as Middle East Respiratory Syndrome (MERS), and in the year 2019, a novel strain had appeared though, it was closely related to SARS-CoV-1 yet showed certain differences on the basis of its phylogenetic study, hence named as novel coronavirus SARS-CoV-2 (Wu et al., 2020). It is probably transmitted from bats (Zhou et al., 2020), sea food/animal market in Wuhan, China (WHO, 2020).

So, the evolutionary trends show that the coronavirus is also evolving like other viruses and challenging the human beings to fight for their survival.

1.3 Significance of immunity against viral attacks

A robust resistant mechanism of human being constantly protects themselves against different viral attacks. The immune system is the main responsible system that fight against the invader and protects them from various infections. The other advantage of the immune system is to fight against the infections caused by the viruses. It can be treated through the conventional medicines, but when this system weakens, it results into the start of many long-lasting diseases like COVID-19 that cannot be treated perfectly through conventional medicines. Many recent reports indicated a close interaction between Covid-19 and the immune response of an

Keywords
Antiviral
Antioxidant
Bryophytes
Coronavirus
COVID-19
Viruses

Article Info
Article history
Received 6 April 2021
Revised 29 May 2021
Accepted 30 May 2021
Published Online 30 June 2021

Abstract
Severe acute respiratory syndrome Corona Virus-2 (SARS-CoV-2) is the latest adherent in the family Coronaviridae. It is an extremely transmissible and transmits through interaction/droplets. Early response in an infected person includes deregulations of cytokine followed by failure of the immune system. World Health Organization (WHO) stated it as worldwide wellbeing emergency regarding this pandemic. The death tally is ever increasing since the first report in Wuhan (China) in December 2019. Consequently, the scientific community of the world started the work on his remedy and suggested the obligatory precautionary actions. Though, few vaccines have been developed, yet the best option is still to take preventive measures at present in future also. Among all preventive measures, the use of herbs in our diet is the easiest and best. Many herbs with great antioxidant profiles and antiviral potential are known to us. But, usually angiosperms are the first choice to be utilized and other plants such as bryophytes have been neglected for their use as remedy to treat many diseases caused by viruses. The purpose of this review to explore and compile those bryophytes which would be the possible candidates as remedy against coronavirus as immunity boosters.
infected person. This activated immune response due to SARS-CoV-2 in an infected individual can be alienated into two stages, the initial incubation or non-severe and the following severe stage (Shi et al., 2020). If the immune response of the infected person is sturdy, then the progression of initial stage to second stage is retarded which help in the early elimination of the virus. Accordingly, the resistance enhancing approaches are very important to provide protection at this stage. All this depends upon the all-inclusive health of the persons so that an endogenous immune response can prevent the viral activities at the initial stage (Shi et al., 2020). If the immunity of the infected individual is weak then the virus will thrive and replicate easily which results in the massive damage to the affected parts of the body, especially the tissues of lungs which become severely exaggerated and result into deadly respiratory disorders at the next stage of infection (Xu et al., 2020). It has been seen that SARS-CoV-2 affects respiration, kidney functions, liver metabolism, gastrointestinal tract, cardiac and central nervous system (Huang et al., 2020; Liu et al., 2020) subsequently many deaths have been happened due to the multiple organ failure.

1.4 Active sites of coronavirus

The structural investigation provided the basis for the vaccine development against COVID-19 and according to those the envelope protein (E-protein) is the minutest amid the main structural proteins having excited cytoplasmic tail and hydrophobic domain. Missing this vivacious protein expressively depresses viral load with undeveloped and ineffectual descendants (Schoeman and Fielding, 2019). Whereas, the membranous protein is responsible for the maintenance of virus capsid’s shape and stabilization the overall balance of nucleocapsid by integrating the cellular golgi tool for freshly formed virions (Prajapat et al., 2020). The spike (S-glyco protein) is the distinctive ectodomain of COVID-19, which provide the all essential binding of virus particle on the specific receptors (Gordon et al., 2020) which is followed by the release of nucleocapsid (N-protein) after bulging the membrane into the cell. Like other RNA viruses, the replication and transcription of m-RNA genome starts from 5' end, followed by the immune hyperactivity and pulmonary devastation. Hence, the most decisive part in the pathogenicity is performed by the S-glycoprotein (Perlm and Netland, 2009). A study discovered that the binding propensity of S-glycoprotein to ACE2 in SARS-CoV-2 is about 10-to-20 times higher and with easier communication from person to person than the other known strains of this virus (Adhikari et al., 2020).

1.5 Potential of plants against the COVID-19

Many countries including China have explored the possibility of the utilization of Traditional Medicine system against the COVID-19. Consequently, the conventional remedies and traditional medications have been found useful in the augmentation the resistance against viral attacks. As evident that the floristic wealth on this planet is a huge reservoir of medicinally important plants and they are the valuable source of numerous bioactive compounds/secondary metabolites that act as paragon for drug findings. Since the outbreak of COVID-19, many plants have been evaluated for their potential as anti-COVID and many interesting results have been obtained (Mugisha et al., 2014; Lamorde et al., 2010; Nyamukuru et al., 2017; Khan, 2020; Mehrorta, 2020). It seems that angiosperms are the preferred plants for such studies and the second most abundant group of plants, i.e., bryophytes have been neglected.

To fill this lacuna, some of the bryophytes have been enlisted in this article that have shown antiviral potential in past.

According to many reports’ bryophytes are ubiquitous remedy amid many tribes of the world and these tiny plants being used to cure several diseases, viz., to cure skin diseases, hepatic disorders, cardiovascular diseases, inflammations, microbial infection, wound, etc., since olden times (Alam, 2012; Alam and Sharma, 2015; Chandra et al., 2017). However, recent attempts on the evaluation of bryophytes for their pharmaceuticals and nutraceutical impeding show that these amphibious plants have significant antioxidative, antitumor, and antimicrobial properties.

1.6 Bioactivity of compounds found in bryophytes

Bryophytes create an assemblage of minor plants which form indispensable part of terrestrial flora. These plants prefer to grow in shade where the water availability is sufficient (Glime and Saxena, 1991). Ecologically, these plants always regarded as vital but for therapeutic potential some what neglect in past. However, in current scenario of herbal formulations, these amphibian plants are more and more explored for their therapeutics utilities. But still less than 10% of bryophytes have been explored for their phytochemistry (Asakawa, 2004). On the basis of attempts made on these plants, it is evident that these plants possess worthy bioactive compounds. These bioactive secondary metabolites have shown varied biological activities, viz., antimicrobial, antiviral, antitumor, cytotoxic, cardioprotective, allergy triggering, etc. (Asakawa et al., 2014).

Liverworts are the preferred plants as they were used as cure for skin infections and liver ailments since the olden times (Friederich et al., 1999; Saroya, 2011; Gokbulut et al., 2012). Mosses are comparatively lesser explored for their therapeutic uses than the liverworts though they have more diversity than the liverworts, while hornworts yet to emerge as medicinally important plants. The secondary metabolites identified in bryophytes are usually flavonoids, terpenoids, bibenzyls, etc., along with few fatty acids and acetophenols, etc. (Asakawa et al., 2014).

Being resurrection plants, they produce various secondary metabolites to reinforce their defense to cope up with environmental stress, especially the desiccation (Xie and Lou, 2009; Dey and De, 2012; Alam et al., 2019). Since these plants are delicate and have no specific morphological and anatomical adaptation for defense therefore, they have well developed active defense at molecular and chemical level.

The antioxidant defense system delivers fortification to the cellular membranes and organelles to avoid damages due to oxidative burst under stress situations. When stressed, the reactive oxygen species (ROS) react with imperative constituents of the cell, viz., proteins and lipids of cellular membranes resulting into the disturbance in cell integrity eventually causing cell destruction. These antioxidants are, therefore, present hugely in the bryophytes, therefore these plants are well able to serve as a valuable reservoir for medicinally important phytochemicals (Aslanbaba et al., 2017). Considering this, few bryophytes were evaluated for their bioactive compounds, for instance, in the liverwort, Marchantia polymorpha, was characterized for an antioxidant enzyme peroxidase and it was reported that this peroxidase of liverwort is significantly different from any well-known peroxidase of tracheophytes (Hirata et al.,...
Both, antioxidant and free radical scavenging activities are of great significance for medical practitioners and dieticians. The occurrence of excessive free radicals is thought to have a crucial role in the development of many diseases (Castro and Freeman, 2001). Oxidative progressions may also decline the constancy and value of drugs and foods. These reactive oxygen species (ROS) and reactive nitrogen species (RNS) are generated during the environmental stresses and among all plants, the bryophytes have a special position because the dominant haploid (n) gametophytic phase in their life cycle. Consequently, few species have been evaluated for their tolerances against drought and floods (Robinson et al., 2002; Wasley et al., 2006) and extraordinary nitrogen concentrations (Koranda et al., 2007). It was found that these plants are well able to adapt and answer to these stresses because of their superior and highly effectual antioxidative defense mechanism which comprises of defensive non-enzymatic as well as enzymatic strategies that competently hunt the harmful ROS and avert the damaging possessions of these nasty free radicals (Breusegem et al., 2001).

Recently, bryophytes like Claspodium crispiolium and Anomodon attenuates showed remarkable occurrence of cytotoxic and/or antitumor compounds that have been isolated and identified as an samitocin P-3. While, ohiouensins and pallidisetums compounds were isolated from Polytrichum spp. (Sabovljević, et al., 2016).

1.7 Antiviral activities

Viruses are unique type of pathogens. They are nucleo-protein particles with complete dependency on the host cell machinery to survive and replicate (Webster’s et al., 1998). Antiviral activity has been reported in numerous plants including bryophytes. Interestingly, there wer no evidence available regarding the infectivity of viruses to any bryophytes in past which proves that bryophytes have strict defense response in the form of their chemical constituents against the viruses. Hence, numerous bryophyte species have been identified having antiviral action against many animal and plant viruses, viz., Herpes simplex type 1, Polio type 1, Potato virus X(PVX), Zuccchini Yellow Mosaic Virus (ZYMV), etc. Therefore, now the bryophytes have been recognized as a new reservoir of antiviral secondary metabolites.

Recently, few attempts have been made to find out the antiviral compounds in many bryophytes and bioflavonoids were reported to cause a controlling effect on a broad range of viral strains (Hillhouse, 2003). The secondary metabolites recognized in the bryophytes are basically terpenoids, flavonoids and bibenzyls. Among the investigated taxa, liverworts appeared as the main sources of these terpenoids, flavonoids and alkaloids (Chaudhary and Kumar, 2011).

Mosses such as Inhibryum sp., Trichostomum sp. and Barbula convoluta have been screened for antiviral properties and substantial antiviral activity was reported against Zucchini Yellow Mosaic Virus (ZYMV), the melanic extracts of these taxa have shown about 90% inhibitory effect on the virus due to their high phenolic contents (Abdel-Shafi et al., 2017).

Phytoconstituents obtained from bryophytes, viz., Marchantins A, B and D, perrottetin F, and paleatin B exhibited anti-HIV-1 activity (Asakawa and Ludwickzuk, 2017) confirming the antiviral potential of bryophytes.
2. Material and Methods

A simple method was implemented to register those plants either having the property to cure the viral infections closely related to the coronavirus or they have the possessions to offer relief from the peculiar symptoms pragmatic in the COVID-19 patients where they can trigger and reinforce the immune system. The literature search was carried out using keywords like, immune-enhancer bryophytes, medicinal bryophytes, ethnobotany, antiviral bryophytes, etc. The list of some of the bryophytes is specified (Table 1) along with their family, traditional uses, bioactive compounds and consuming methodology.

Table 1: List of some bryophytes and their reported compounds showing antioxidant activity and antiviral potential (Asakawa and Ludwiczuk, 2018; Gahtori and Chaturvedi, 2019; Sabovljević, and Sabovljević, 2020)

| Sl. No. | Name of bryophyte | Antioxidant compounds |
|---------|-------------------|-----------------------|
| 1.      | Anomodon rostratus | Phenolics             |
| 2.      | Asterella angusta  | Asterelin A, asterelin B, 11-O- demethylmarcantin I, and dihydroptachyto ]ladibenzo[uramin [bis(bibenzyl)] |
| 3.      | Atichum undulatum  | Phenolics             |
| 4.      | Atrichum angustatum| Phenolics             |
| 5.      | Barbula sp.        | Triglycerides         |
| 6.      | Bryum caspidatum   | Phenolics             |
| 7.      | Bryum moravicum    | Phenolics             |
| 8.      | Campylopus sp.     | 1-o-methylohydroensin-B, 1-o-methyldihydroxyohioensin-B |
| 9.      | Chiloscyphus polyanthus (Plate 1: Figure 1) | Diplophyllin, sesquiterpene, lactones, diplophylloide-14, tulipinolide |
| 10.     | Conocephalum conicum (Plate 1: Figure 2) | Tulipinolide, Zaluzanin-C |
| 11.     | Dicranium sp.      | Triglycerides         |
| 12.     | Diplophyllum albicans (Plate 1: Figure 3) | Diplophylline |
| 13.     | Diplophyllum taxifolium | Diplophylline |
| 14.     | Dumortiera hirutu (Plate 1: Figure 4) | RiccardinD [macrocyclicbis(bibenzyl)] ]Cell wall peroxidases and tyrosinases |
| 15.     | Fissidens sp.      | Phenolics             |
| 16.     | Frullania muscicola | 3-Hydroxy-42 - methoxylibenzy7,4–dimethyl-apigenin |
| 17.     | Frullania tamarisci (Plate 1: Figure 5) | Antileukemic compounds |
| 18.     | Haplocladium microphyllum | Phenolics |
| 19.     | Hyophila involuta  | Phenolics             |
| 20.     | Jungemannia subalata | Subulatin |
| 21.     | Lophocolea heterophylla | Subulatin |
| 22.     | Lunulari acruciata | Flavonoids and sesquiterpenes |
| 23.     | Marchantia paleacea var.diptera | Superoxide dismutase |
| 24.     | Marchantia palma | neomarchantin A, marchantins A and B |
| 25.     | Marchantia polymorpha (Plate 1: Figure 6) | Plagiochin E, riccardin H, marchantin E, neomarchantin A, marchantins A and B, Custunolide, α-himachalen, cuparenemarchantin, δ-elemene |
| 26.     | Mastigophor adicllados | Sesquiterpenoids |
| 27.     | Mnium sp. (Plate 2: Figure 7) | Bicyclohumulenone, plagiochline A, plagiochline,plagiochline B, menthanemonoterpenoid, triterpenoidal saponins, riccardinsA and B, sacullatal |
| 28.     | Pallavicinia lyelli (Plate 2: Figure 8) | Ascorbate peroxidase, δ-elemene, calamene, Bicyclohumulenone, plagiochline A, plagiochline,plagiochline B, menthanemonoterpenoids,triterpenoidal saponins, riccardins A and B, sacullatal |
| 29.     | Philonotis fontana (Plate 2: Figure 9) | p-hydroxycinnamic acid, Triterpenoidal saponins, p-hydroxycinnamic acid, 7–8-dihydroxycoumarin |
| 30.     | Plagiochaema appendiculatum | Prevent lipid peroxidation and increase antioxidant enzymes |
| 31.     | Plagiochila sp. (Plate 2: Figure 10) | Bicyclohumulenone, plagiochline A, plagiochline,plagiochline B, menthanemonoterpenoids,triterpenoidal saponins, riccardins A and B, sacullatal |
| 32.     | Plagiomnium sp. (Plate 2: Figure 11) | Bicyclohumulenone, plagiochline A, plagiochline,plagiochline B, menthanemonoterpenoids,triterpenoidal saponins, riccardins A and B, sacullatal |
| 33.     | Platymnium riparioides | Phenolics |
| 34.     | Polytrichastrum alpinum | Benzonaphthoxanthenones (Ohioensins F and G) |
| 35.     | Polytrichum formosum | Phenolics |
| 36.     | Porella platysphylla | Custunolide, isoremanthin, 3-β-hydroxycostunolidecinnamolide |
| 37.     | Rhodobryum roseum | Prevents lipid peroxidation and augments antioxidants |
|   | Species                              | Compounds                                      |
|---|--------------------------------------|------------------------------------------------|
| 1 | Radula complanata                    | Bibenzyl, 3-methoxy bibenzyl, 2-terpinine ethylbenzene |
| 2 | Rhodobryum giganteum                 | Triterpenoidalsaponins, p-hydroxycinnamic acid, 7-8-dihydroxycoumarin |
| 3 | Riccardia sp. (Plate 2: Figure 12)   | Bicycloumenlenone, plagiochiline A, plagiochilde, plagiochilal B, menthanem onoterpenoids, triterpenoidal saponins, riccardins A and B, sacullatal |
| 4 | Sanonia uncinata                     | Antioxidant enzymes                            |
| 5 | Scapania parvitexa                   | Subulatin                                      |
| 6 | Sphagnum magellanicum                | Phenolics                                      |
| 7 | Thuidium tamariscinum                | Phenolics, terpenoids                          |
| 8 | Wiesnerella denudata                 | Tulpinolide, costunolide, zaluzanin C & D, 2α acetoxy-zaluzalin |

Plate 1

**Figures 1-6:** 1. Chiloscyphus polyanthus; 2. Conocephalum conicum; 3. Diplophyllum albicans; 4. Dumortiera hirsuta; 5. Frullania tamarisci; 6. Marchantia polymorpha.
3. Conclusion

Due to their unique thallus organization, phytoconstituents and defense responses, bryophytes have all the potential to be used in efficacious remedies to prevent and cure viral infections. These plants not only have antiviral activities but also provide natural antioxidants. Since they exist everywhere except the oceans, and can grow without any special need hence, readily available with low cost and can be used without any harmful effects on the human body. Therefore, in future they can be used as main reservoir of beneficial phytoconstituents to make natural pharmaceuticals and nutraceuticals with therapeutic utility against the viral infections.

Figures 7-12: 7. Mnium sp.; 8. Pallavicinia lyelli; 9. Philonotis fontana; 10. Plagiochila sp.; 11. Plagiomniuni sp.; 12. Riccardia sp.
The antioxidants which are naturally present in these plants have great potential to boost the immunity of human beings against a range of viruses, including COVID-19 by quenching the free radicals to protect the health status of cells. Increasing occurrences of viral diseases demand the use of natural therapeutic antioxidants as consistent dietary complements for provided improved and effective healthcare. Earlier, the focus of the scientists was on the angiosperms but now there is need to explore the bryophytes second largest group of plants for the natural healthcare systems. Since nothing is created on this planet either without the need or with no benefit to human kind therefore these plants with rich storage of useful biomolecules can also offer a more competent resource of many phytoconstituents that could be used for innovative medication.

Acknowledgements

The author is grateful to Professor Ina Aditya Shastri, Vice-Chancellor, Banasthali Vidyapith for his encouragement and support.

Conflict of interest

The author declares that there are no conflicts of interest relevant to this article.

References

Abdel-Shafi, S.; Hussein, Y.; Lashin, G. and Abdel-Monaem, A. (2017). An evaluation of the antibacterial and antiviral activities of some bryophytes. Egyptian Journal of Microbiology, 52(1):63-86.

Adhikari, S.P.; Meng, S.; Wu, Y.J.; Mao, Y.P.; Ye, R.X.; Wang, Q.Z.; Sun, C.; Sylvia, S.; Rozelle, S.; Raat, H. and Zhou, H. (2020). Epidemiology, causes, clinical manifestation and diagnosis, prevention and control of coronavirus disease (COVID-19) during the early outbreak period: A scoping review. Infectious Diseases of Poverty, 9(1):1-12. doi.org/10.1186/s40249-020-00646-x

Alam, A. (2012). Some Indian bryophytes known for their biologically active compounds. International Journal of Applied Biology and Pharmaceutical Technology, 3(2):239-246.

Alam, A. and Sharma, Y. (2015). Horticultural importance of bryophytes: A review. International Journal of Horticulture, 5(19):1-9. doi:10.5376/ijh.2015.05.0019

Alam, A.; Dwivedi, A. and Emmanuel, I. (2019). Resurrection plants: Imperative resources in developing strategies to drought and desiccation pressure. Plant Sci. Today, 6(3):333-341.

Asakawa, M. (2004). Chemosystematics of the hepaticae. Phytochemistry, 65:623-669.

Asakawa, Y. and Ludwiczuk, A. (2018). Chemical constituents of bryophytes: Structures and biological activity. Journal of Natural Products, 81:641-660. doi:10.1021/acs.jnatprod.6b01046.

Asakawa, Y.; Ludwiczuk, A. and Nagashima, F. (2013). Chemical constituents of bryophytes: Bio and chemical diversity, biological activity, and chemosystematics. In: Progress in the Chemistry of Organic Natural Products. Wiens: Springer; pp:796.

Aslanbaba, B.; Yilmaz, S.; Tonguç, Y.; Özyurt, D. and Özyurt, B.D. (2017). Total phenol content and antioxidant activity of mosses from Yeniçe forest (Ilda mountain). Journal of Scientific Perspectives. 1(1):1-12.

Bhattarai, H.D.; Pandel, B.; Lee, H.K.; Oh, H. and Yim, J.H. (2009). In vitro antioxidant capacities of two benzaphenoxane oxanthones: Ohioensins F and G, isolated from the Antarctic moss Polytrichastrum umalpinum. Zeitschrift für Natur. für schung. 64(3-4):197-200.

Bhattarai, H.D.; Pandel, B.; Lee, H.S.; Lee, Y.K. and Yim, J.H. (2008). Antioxidant activity of Sanionia umalpinum, a polar moss species from King George Island, Antarctica. Phytotherapy Research, 22:1635-1639.

Casadevall, A. (2008). Evolution of intracellular pathogens. Annual Review in Microbiology, 62:19-33. doi: 10.1146/annurev.micro.61.080070.093305

Castro, L. and Freeman, B.A. (2001). Reactive oxygen species in human health and disease. Nutrition, 17:163-165.

Chandra, S.; Chandra, D.; Barb, A.; Pankaj, Pandey, R.K. and Sharma, L.P. (2016). Bryophytes: Hoard of remedies, an ethnomedicinal review. Journal of Traditional and Complementary Medicines, 7(1):94-98. doi:10.1016/j.jtcme.2016.01.007

Chaudhary, B.L. and Kumac, P. (2011). Antibacterial activity and preliminary phytochemical screening of Epiphytic Moss Stressiv Phylum Li gulatum Jaeg. International Journal of Pharma, and Biosciences, 2:1-4.

Dey, A. and De, J.N. (2012). Antioxidative potential of bryophytes stress tolerance and commercial perspectives: A review. Pharmacologia, 3:151-159.

Friedrich, S.; Maier, U.H. and Deus-Neumann, B. (1999). Biosynthesis of cyclic bis (bienzyls) in Marchantia polymorpha. Phytochemistry, 50:589-598.

Gaftori, D. and Chaturvedi, P. (2019). Bryophytes: A potential source of antioxidants. Intech. Open. doi.org/10.5772/intechopen.84587.

Glime, J.M. and Saenza, D.K. (1991). Uses of Bryophytes. New Delhi: Today and Tomorrow’s Printers and Publishers; p:1-100.

Gokbulut, A.; Satilmis, B; Butcioğlu, K.; Cetin, B. and Sarcer, E. (2012). Antioxidant activity and luteolin content of Marchantia polymorpha L. Turkish Journal of Biology, 36:381-385.

Goldsmith, C.S. and Miller, S.E. (2009). Modern uses of electron microscopy for detection of viruses. Clinical Microbiology Reviews, 22(4):552-563. doi:10.1128/CMR.00027-09

Gordon, D.E.; Jiang, G.M.; Bonhaddou, M.; Xu, J.; Obernier, K.; O’Meara, M.J.; Guo, J.Z.; Swaney, D.L.; Tummino, T.A.; Huttonhain, R. and Kaake, R. (2020). A SARS-CoV-2-Human Protein-Protein Interaction Map Reveals Drug Targets and Potential Drug-Repurposing. bioRxiv. doi.org/10.1101/2020.03.22.002386

Greeshma, G.M. and Murugan K. (2012). Comparison of antimicrobial potentiality of the purified Terpenoids from two moss species Thuidium tamariscellum (C. muel.) Bosch. and Sande-Lac and Brachythecium buchananii (Hook). A. Jaegr. Journal of Analytical and Pharmaceutical Research, 7(5):530-538.

Helms, J.B.; Kaloyanova, D.V.; Strating, J.R.; van Helmond, J.J.; van der Schaaf, H.M.; Telens, A.G.; van Kuppeveld, F.J. and Brouwers, J.F. (2015). Targeting of the hydrophobic metabolome by pathogens. Traffic, 16(5), pp.439-460. doi: 10.1111/tra.12280.

Hillhouse, B.J. (2003). Screening of bi flavonoid compounds and British Columbian bryophytes for antiviral activity against Potato Virus X. MS. C, Faculty of Graduate Studies, British Columbia University.

Hirata, T.; Ashida, Y. and Mori, H. (2002). A 37-kDa peroxidase secreted from liverworts in response to chemical stress. Phytochemistry, 55:197-202.

Huang, C.; Wang, Y.; Li, X.; Ren, L.; Zhao, J.; Hu, Y.; Zhang, L.; Fan, G.; Xu, J.; Gu, X. and Cheng, Z. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. The Lancet, 395(10223):497-506. doi.org/10.1016/S0140-6736(20)30183-5
Khan, A.A. (2020). Role of Unani medicine in empowering national healthcare. Ann. Phytoimed., 9(2):1-5.

Koranda, M.; Kerschbaum, S.; Venek, W.; Zechmeister, H. and Richter, A. (2007). Physiological responses of bryophytes Thuidium tamariscinum and Holocarпус Splendens to increased nitrogen deposition. Annals of Botany, 99:161-169.

Krishnan, R. and Murugan K. (2013b). In vitro anticancer properties of flavonoids extracted from cell suspension culture of Marchantia linearis Lehm & Lindenb. (bryophyta) against SW 480 colon cancer cell lines. Indo American Journal of Pharmaceutical Research, 3:1427-1437

Krishnan, R. and Murugan, K. (2013a). Polyphenols from Marchantia polymorpha L. a bryophyta: A potential source as antioxidants. World Journal of Pharmacy and Pharmaceutical Sciences, 2:5182-5198.

Lamorde, M.; Tabuti, J.R.; Obua, C.; Kukunda-Byobona, C.; Lanyero, H.; Byakika-Kiwika, P.; Bhosa, G.S.; Luhega, A.; Ogwal-Okeng, J.; Ryan, M. and Waako, P. (2010). Medicinal plants used by traditional medicine practitioners for the treatment of HIV/AIDS and related conditions in Uganda. Journal of Ethnopharmacology, 130(1):43-53. doi.org/10.1016/j.jep.2010.04.004.

Lin, C.; Zhou, Q.; Li, Y.; Garner, L.; Watkins, S.P.; Carter, L.J.; Smoot, J.; Gregg, A.C.; Daniels, A.D.; Jervey, S. and Albaiu, D. (2020). Research and development on therapeutic agents and vaccines for COVID-19 and related Human Coronavirus Diseases. https://dx.doi.org/10.1021/ascentsci.0c00272

Lo, G. and Lin, D. (2012). SARS-like virus in the Middle East: A truly related coronavirus causing human diseases. Protein and cell, 3(11):803-805. doi:10.1007/s13238-012-2811-1

Mehrotra, N. (2020). Medicinal plants, aromatic herbs and spices as potent immunity defenders: Antiviral (COVID-19) perspectives. Ann. Phytoimed., 9(2):30-49. doi.org/10.21276/ap.2020.9.2.4.

Mohandas, G.G. and Kumarswamy, M. (2018). Antioxidant activities of Terpenoids from Thuidium tamariscinum (C. Muell.) Bosch. and Sande-Lac. A Moss. Pharmacognosy Journal, 10(4):645-649.

Montenegro, G.; Portaluppi, M.C.; Salas, F.A. and Diaz M.F. (2009). Biological properties of Chilean native moss Sphagnum magellanicum. Biological Research, 42(2):233-237.

Mugisha, M.K.; Asiimwe, S.; Namutebi, A.; Borgen-Karlson, A.K. and Kakudidi, E.K. (2014). Ethnobotanical study of indigenous knowledge on medicinal and nutritious plants used to manage opportunistic infections associated with HIV/AIDS in western Uganda. Journal of Ethnopharmacology, 158(1):194-202. doi.org/10.1016/j.jep.2014.05.012

Negi, K.; Tiwari, S.D. and Chaturvedi, P. (2018). Antibacterial activity of Marchantia applanata Radi pi sub sp. Grossi barba (Steph.) Bischl against Staphylococcus aureus. Indian Journal of Traditional Knowledge, 17(4):763-769.

Nymakuru, A.; Tabuti, J.R.; Lamorde, M.; Kato, B.; Sekagya, Y. and Aduna, P.R. (2017). Medicinal plants and traditional treatment practices used in the management of HIV/AIDS clients in Mpigi District, Uganda. Journal of Herbal Medicine, 7:51-58. doi.org/10.1016/j.jhermed.2016.10.001

Paciolla, C. and Tommasi, F. (2003). The ascobrate system in two bryophytes: Brachythecium aetinatum and Marchantia polymorpha. Biologia. Plantarum, 47:387-393.

Perlman, S. and Netland, J. (2009). Coronavirus post-SARS: Update on replication and pathogenesis. Nature Reviews Microbiology, 7(6): 439-450. doi.org/10.1038/nrmicro2147.
Afroz Alam (2021). Potential of bryophytes in prevention and medication of COVID-19. Ann. Phytomed., Volume10, Special Issue1 (COVID-19): S121-S129. http://dx.doi.org/10.21276/ap.covid19.2021.10.1.12