



Biosurfactants in the sustainable eradication of SARS COV-2 from the environmental surfaces

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Received: 2 August 2021 / Accepted: 19 August 2022 / Published online: 11 September 2022
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Abstract

The COVID-19 outbreak has brought the world, at least, to one consensus that cleanliness is unavoidable under all circumstances. Hands are the main body part to interact with the environment and thus are prone to receive, initiate and propagate the chain of infection. Hand hygiene has, therefore, been most emphasized by experts to interrupt the spread of infection. Various harsh chemicals like synthetic surfactants and alcoholic preparations have been in practice to eradicate and disinfect the germs. This choice may be unsafe and cause a subsequent chain of adversities. Thereby, biosurfactants have been proposed as sustainable, non-toxic and safe surface cleaners cum disinfectants under a wide range of physiological and environmental conditions. The amphiphilic micellar behavior of biosurfactants makes them promising candidates as hygienic surface cleaners and therapeutic carriers. We overview the possibilities of using biosurfactants in different ways against microbial pathogens, in general, and the SARS COV-2, in specific.

Keywords Coronavirus · COVID-19 · Biosurfactant · SARS COV-2

Introduction

The pandemic COVID-19 has infected so about 0.261 billion people of the world and killed worth 6.512 million of them, as of September 9, 2022 (Worldometer 2022). Despite this shocking data, the reported cases have been far less in number than the actual ones, i.e., maybe just 6% or still lower (Bommer and Vollmer 2020). The reasons for this misreporting might be based on certain medical, financial, social and strategic grounds. The medical reasons for limited reports might be mild symptoms, sometimes no symptoms of the infection, limited testing facilities with several countries and the self-healing nature of infection in particularly in the mild

cases which constituted more than 80% of the total cases (Verity et al. 2020).

The COVID-19 pandemic has altogether changed the social and cleaning practices worldwide. Due to fearful pandemic situations and in hustle and bustle preventive measures, the eco-friendly protocols and sensible selection of materials have largely been avoided. It is generally believed that the person-to-person transmission of the COVID-19 virus (SARS COV-2) occurs through mucosal routes either by inhaling the viral-laden respiratory droplets or touching the viral-contaminated surfaces including unhygienic hands. The SARS COV-2 could stay viable on different surfaces for several days (van Doremalen et al. 2020). This indicates that a person may be infected after touching some virally contaminated objects. The World Health Organization (WHO), thus, recommends proper handwash and sanitation practices particularly in public places (Fathizadeh et al. 2020). The chain of SARS COV-2 infection is illustrated in Fig. 1.

In a race to beat the COVID-19 outbreak, diverse prevention and protection measures have been coined. We summarize the possible hazardous effects of the blind use of chemical surfactants and disinfectants and propose alternative biological surfactant routes to combat the current COVID-19 infection. There has been scarce focus on this topic which justifies extensive future research

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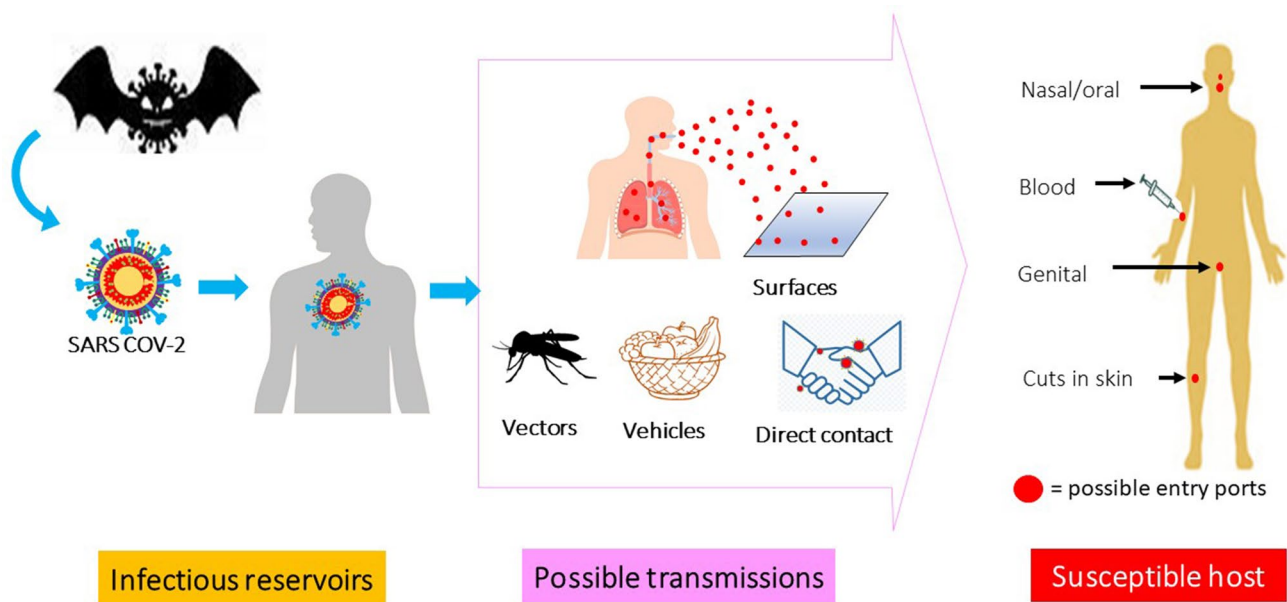


Fig. 1 Chain of SARS COV-2 infection

opportunities in this area. Currently, alcohols and other chemical disinfectants have been in practice to clean the hands and the contaminated surfaces which due to their toxicity and persistent nature deteriorate not only the environment but also the hand's skin, if used in sanitizers and cleaning formulations. Thereby, we outline some alternative approaches for the application of biosurfactants for sustainable eradication of coronavirus and other fetal microbes from the environmental and hand surfaces. The overall layout of the study is illustrated in Fig. 2.

Hands—infection and hygiene carriers

The skin, being the largest organ of the body, comprises between $17\pm 2\%$ of the body's weight. It has a surface coverage of 1.8 m^2 . The skin is composed of the following two primary layers: the outer—called as epidermis ($50\text{--}100\ \mu\text{m}$) and the inner being dermis ($1\text{--}2\text{ mm}$). Both protect the body from the environment and any transient infectious organisms. Accordingly, the skin of our hands constantly interacts with the environment and thus may carry different types of pollutants and pathogenic microbes. The contaminated hands, either gloved or ungloved, could be vehicles for the spread of certain viruses, bacteria and toxins (Chang et al. 2020). Thus, the single best way to prevent the spread of disease is handwashing as the skin of our hands is the first line of defense against a microbial attack on the human body. The washing of hands with plain soap although may remove transient microbes, yet, aids the body in reloading the resident bacteria on the skin.

On the other hand, handwashing with an antiseptic soap may kill or remove both resident and transient microbes leaving the hands at more risk by making it easier for transient bacteria to re-flourish (Hor et al. 2016).

The commercially available sanitizers usually contain ethanol, isopropanol, chlorine compounds, formaldehyde, hydrogen peroxide, etc. Amongst them, most are considered toxic to human body organs and biological systems. For instance, formaldehyde causes severe skin burns and eye damage and is toxic as well as carcinogenic. The alcohols, being highly inflammable, when applied as a disinfectant on hot surfaces, electronic devices or near sparks (may be electrical) could catch fire. The hypochlorite solutions, although effective antimicrobial agents, yet are strong irritants to skin, eyes, airways and mucus membranes, particularly, on prolonged usage and exposure. Once washed off, such toxic disinfectants contaminate the water bodies. The spraying with hypochlorite solutions deteriorates the landscapes and the surfaces of infrastructures. The choice of conventional disinfectants for the said purposes must be reconsidered as they not only destroy the environment but also affect flora and fauna, and kill useful microorganisms present in the biosphere, supporting life, e.g., denitrifying bacteria. If blended in detergent formulations, they may cause dangerous chemical impacts, particularly under the sun, thus polluting the air and causing local suffocation or even causalities (Mukhopadhyay 2011). A comparison of synthetic and bio-based surface cleaners is given in Fig. 3.

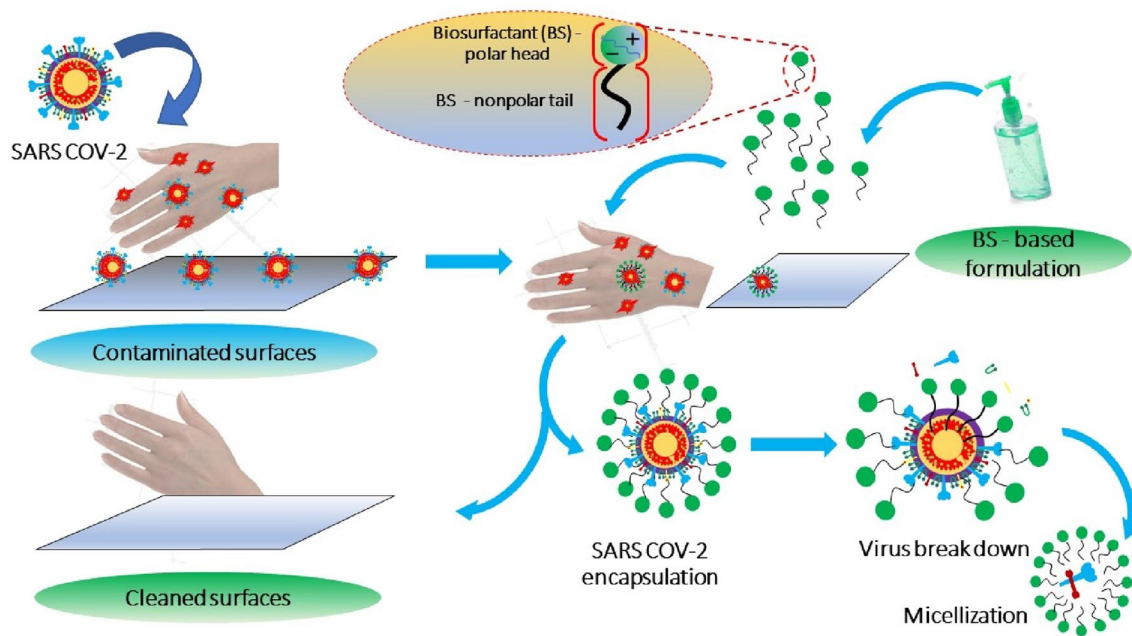


Fig. 2 The layout of the study

Alcohol intoxication—the conventional component of sanitizers

Alcohol, usually as 60–70 (% v/v) of the sanitizer's recipe, expresses excellent antibacterial activity against broad-spectrum bacteria, several fungal species and viruses like HIV by disrupting their RNA strands, thus preventing any replications. Alcohol, although, an effective germicide, is yet highly toxic to human skin. The toxicity of alcohol is accepted worldwide, but still, alternative recipes have not been widely employed. For instance, prolonged and extensive use of alcohol-based disinfectants may cause discoloration and damage the skin and sometimes darken its outlook. Alcohol exposure may also cause behavioral, cardiac, gastrointestinal, pulmonary, neurological and metabolic effects in the human body (Vonghia et al. 2008). In the present context, the major life-threatening consequence of acute alcohol intoxication is respiratory depression and pneumonia (Happel et al. 2006). Ahmed-Lecheheb et al. (2012) undertook the serious issue of ethanol intoxication via dermal and pulmonary absorption by healthcare workers (HCWs) using alcohol-based hand rubs (ABHRs) in their workplaces. The traces of alcohol absorbed from ABHRs could be detected in the blood. The absorbed alcohol diffuses into human body tissues and is mainly metabolized in the liver, with its traces being detectable in the kidneys, muscles, lungs, intestine and possibly the brain. Ethanol in the body oxidizes to acetaldehyde and then converts to acetate (Kramer et al. 2007). The traces of alcohol and its derivatives had also been found after the application of alcohol-containing preparations to

the skin (Leeper et al. 2000). A study demonstrated the effect of repeated exposure of various chemical disinfectants on the epithelial tissues. The resultant brownish lesions exhibited local thickening and hardening of the skin. The glutaraldehyde immersion assay could be used to indicate marked dermal tissue destruction after disinfecting with the alcohol-based formulations (Hess et al. 1991). However, to minimize such side effects, hypoallergenic moisturizers had been recommended to apply on the hands' skin after washing to prevent any hand eczema and skin dryness (Yan et al. 2020). Thereby, rational hand-hygiene measures are desirable along with proper use of protective gloves and moisturizers for the HCWs, in the frontline against COVID-19. Table 1 expresses the standard test methods to evaluate the performance of test hand cleaner formulations. They must be comprehensively performed while choosing the desirable ingredients for the hand cleaning formulations.

Surfactant-based cleaners: in practice

Cleaning usually refers to eradicating pathogens, pectins, dirt and contaminants from the affected surfaces. It does not essentially kill the pathogens, but rather may just strip them off. On the other hand, a disinfectant kills the pathogens but may necessarily not remove their cell biomasses which may revive under other suitable conditions. Thus, in surface cleaner formulations, surfactants and disinfectants are usually both added to achieve the required features. They play multiple roles as surface and interfacial tension reductants,

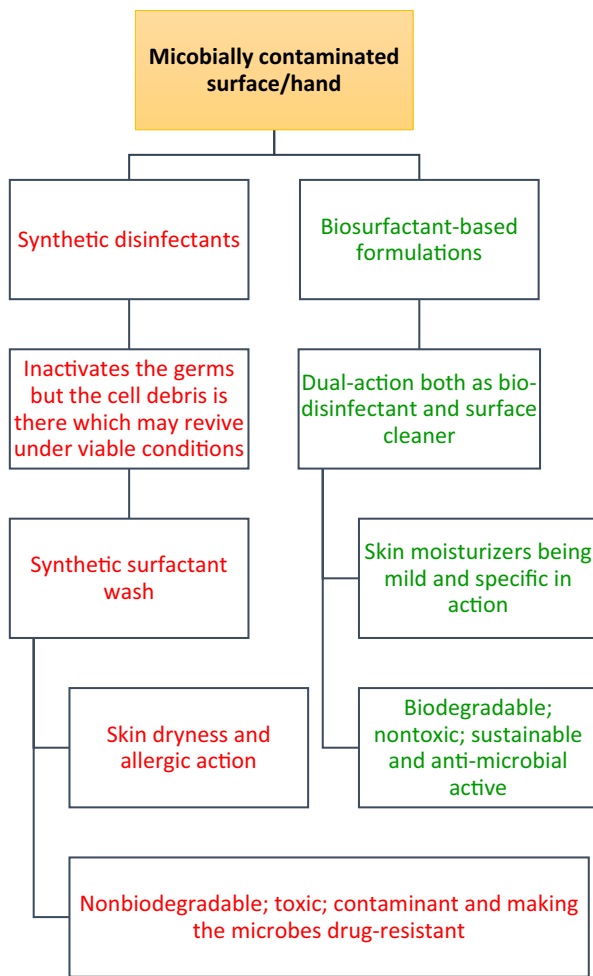


Fig. 3 Comparison of synthetic and bio-based surface cleaners

emulsifiers, dispersants, stabilizers, detergents, micellizers (Santos et al. 2017). The surfactants typically account for 15–40% of net detergent formulation (Yangxin et al. 2008). When dissolved in aqueous media, the amphipathic surfactant molecules tend to concentrate at the surface and at the interface in the case of immiscible liquids by lowering surface and interfacial energy barriers, respectively. Once the surfaces or interfaces are saturated with them, they tend to orient at subsurface to form spherical micelles exposing their hydrophilic moieties outward in the case of oil-in-water systems and reverse micelles with lipophilic ends oriented outward in the case of water-in-oil systems (Raza et al. 2010).

The toxicity and non-biodegradability of synthetic detergents have been well declared but they have still extensively been practiced at domestic and industrial levels (Lourith et al. 2009). Moreover, the incorporation of synthetic antibacterial agents into soaps and cleaning agents makes the germs more resistant; this aspect has also been ignored in the preparation of such products. It has been documented

Table 1 Standard assays to access the performance of a test handwash formulation

Method code	Title	Description
ASTM E1115	“Evaluation of surgical hand scrub formulations”	This test method is designed to measure the reduction in bacterial flora on the skin and to assess the cumulative antimicrobial activity after repetitive exposures
ASTM E1174	“Evaluation of the effectiveness of health care personnel or consumer handwash formulations”	The protocol is designed to evaluate the performance of hand rub formulations in eradicating the bacteria from experimentally contaminated hand surfaces
ASTM E1838	“Determining the virus-eliminating effectiveness of hygienic handwash and handrub agents using the fingerpads of adults”	It measures the reduction in the level of the viable virus after exposure to the test formulations—time-based measurements
ASTM E2011	“Evaluation of hygienic handwash and handrub formulations for virus-eliminating activity using the entire hand”	Herein, “the entire surface of both hands is contaminated with the test virus and the test handwash formulation is applied to them. The surface of both hands is eluted and the eluates are assayed for the viable virus.”
ASTM E2752	“Standard guide for evaluation of residual effectiveness of antibacterial personal cleansing products”	“The procedure is used to evaluate personal cleansing products containing antibacterial ingredients that are intended to reduce the number of organisms on intact skin. It also may be used to demonstrate the effect of residual antibacterial activity through inhibiting the proliferation of bacteria on the skin after contact.”
ISO 10993	“Biological evaluation of medical devices—Part 1: Evaluation and testing within a risk management process”	“The biological evaluation of a medical device (or a material component of such) should be conducted within the framework of a risk management process.”

elsewhere that the monolayer of detergent on the surface of glassware is still present there even after several washes. Thereby, extensive hand and skin washing with soaps may also be hazardous for dry and affected skins. According to WHO, about 900 million people worldwide suffer from various skin related diseases, annually; for instance, eczema, being an inflammatory skin disease, is more common in children and affects about 20% of the population at any stage of life (Asher et al. 2006) and the synthetic detergents further intensify the adversity. The frequent handwashing with water and soap leads to possible potential skin damages (Cavanagh et al. 2020), which may provide a channel of entry for SARS COV-2 like viruses into the body. Whereas the human skin is a vulnerable reservoir of SARS COV-2 virus as the angiotensin-converting enzyme 2 (ACE2) being abundantly present in blood vessels in the epidermal tissues, hair follicles, and the eccrine gland acts as SARS COV-2 receptor (Hamming et al. 2004). To prevent any toxicity and hazards caused by the surface cleaners, both surfactants and disinfectants could be eco-friendly. Thereby, the public is concerned about the toxic impact of synthetic surfactants and the researchers are digging out some alternative eco-friendly ways. One option may be the biosurfactants due to their biodegradable nature.

Biosurfactants—an alternative surface cleaner

Biosurfactants are secondary metabolites produced by certain microbes including bacteria, fungi and yeasts under suitable physiological, nutrient and environmental conditions (Perfumo et al. 2017). They contain versatile features including biological origin, eco-friendly and biodegradable nature, low toxicity, specificity and excellent surface-active and biological properties. They are comparable with synthetic surfactants in terms of reducing the surface and interfacial tensions of the liquid systems. These properties enable them as potential candidates for diverse environmental and biomedical applications like in personal hygienic protection, drug delivery systems, anti-viral facemasks and so on (Smith et al. 2020). They have shown promising results in various fields of science and technology including bioremediation, flotation and cosmetic and detergent formulations (Khubaib et al. 2021).

The biosurfactants also being amphipathic structures comprise both hydrophilic and lipophilic moieties of natural origin; the former may be a peptide chain, amino acid, poly- or oligosaccharide(s), whereas the latter may be a lipid or a saturated or unsaturated/hydroxyl fatty acid/hydrocarbon chain(s) (Raza et al. 2010). The biosurfactants are classified as glycolipids, phospholipids, lipoproteins or lipopeptides, polysaccharide-lipid complexes or even surface-active microbial surfaces. (Vijayakumar and Varatharajan 2015).

Commercially, they are made by large-scale fermentation on oil, sugar or a combination of the two as carbon sources. Due to their antimicrobial, antiadhesive and antibiofilm properties, biosurfactants could be impregnated on textile-based surgical facemasks (Chakhalian et al. 2020). The surface-cleaning action of a biosurfactant is illustrated in Fig. 4.

Among surface-active properties, surface and interfacial tension reduction are the key parameters; besides, critical micelle concentration (CMC) is the minimum surfactant concentration required to achieve reduced surface tension and to initiate the micellization. The lower molecular mass biosurfactants exhibit better surface-active properties, whereas the higher molecular mass biosurfactants express better emulsification and stabilization properties, which are highly desirable features in surface cleaners (Nitschke et al. 2007). During detergency, the biosurfactants due to their amphipathic structures permit attachment simultaneously to hydrophobic cell surfaces and polar solvents like water. Once eradicated from the affected surface, the germs and contaminants are entrapped in the micelles of surfactants and thus removed from the contaminated surfaces (Smith et al. 2020). For instance, an anionic surfactant (e.g., rhamnolipids) when is applied to a surface, the hydrophobic part the biosurfactant could attach to the lipophilic constituents of the microbial surfaces, whereas the hydrophilic part of biosurfactant may surround the water molecules in the media. This results in the encapsulation of microbial species or their dead biomass, eradicated from the contaminated surfaces. This encapsulation cum micellization behaviour of the biosurfactants enables them behave as effective surface cleaners.

Biosurfactants as antiviral agent

There are some well-documented reports available that highlight the potential effects of surface-active compounds on virus activity with special reference to disinfecting them (Lombardi et al. 2008; Falk 2019). The biosurfactants express adequate antimicrobial, anti-biofilm, anti-inflammatory and therapeutic abilities against many pathogens (Naughton et al. 2019; Shu et al. 2021). We undertake their possible role as antiviral agents, particularly, being strategic partners to prevent the spread of COVID-19 infection. Certain biosurfactants could express their ability to disrupt viral membranes and inactivate them (Shah et al. 2005). For instance, in handwashing formulations, the hydrophilic end of biosurfactants may interact with the hydroxyl groups of the glycoproteins on the coronavirus and break down it from the lipid layer (Jin et al. 2021).

It had been documented that the bioactive peptides, also being biosurfactants, have a surface activity that could inactivate the enveloped viruses. The lipopeptide vaccines, like surfactants, are also amphiphilic structures consisting of

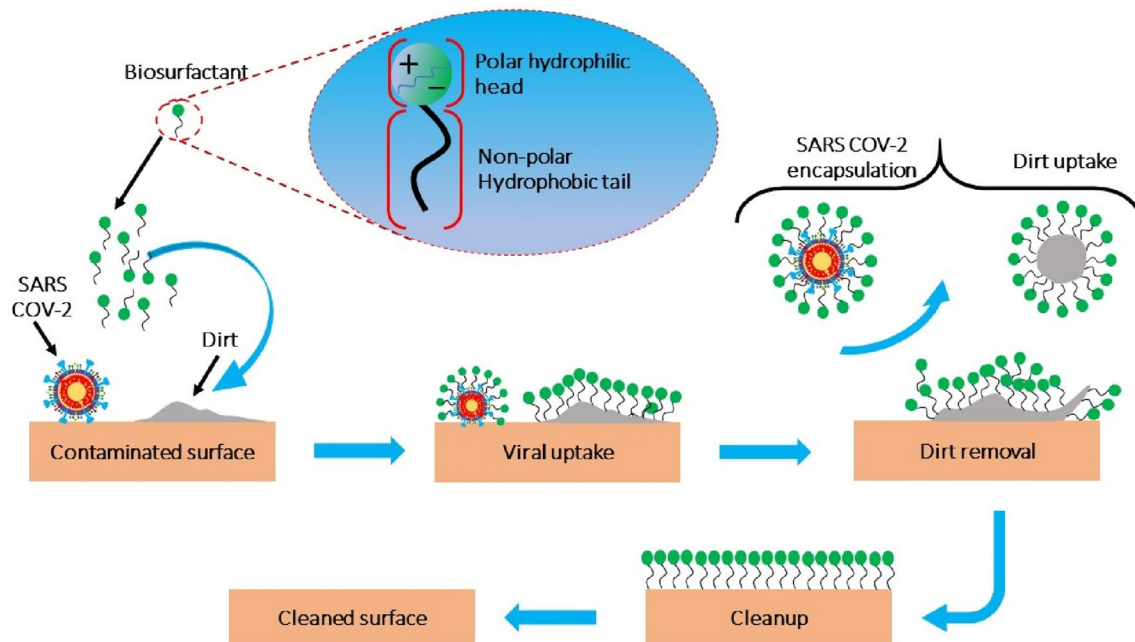


Fig. 4 The surface cleaning action of a biosurfactant

epitopes as hydrophilic ends and the fatty acid chains as the lipophilic moieties. Such amphiphilic vaccines could induce virus-specific cytotoxic T-lymphocytes against the influenza nucleoprotein epitopes (Deres et al. 1989) and the HIV-1 (Loleit et al. 1996). Likewise, sophorolipid—a glycolipid surfactant, produced in yeasts, could express good biological properties like immunomodulators, anti-inflammatory and improved sepsis survival on animal trials (Borsanyiova et al. 2016). On acetylizing the sophorose head groups, it could exhibit enhanced activity against the herpes virus and HIV (Gudiña et al. 2013). The biosurfactants, eventually, could find value-added applications in a wide range of industrial and medical processes (Randhawa and Rahman 2014).

Fortunately, some glycolipid surfactants like rhamnolipids, sophorolipids and mannosylerythritol lipids are now commercially employed in cleaning formulations by various companies worldwide (Singh et al. 2019). They are mild on the skin and hence could safely be used for hygienic hand wash and surface cleaning formulations. The performance of rhamnolipid-comprising detergent formulations is analogous to their commercial counterparts (Khubaib et al. 2021). Thus, they may fulfill the pre-requirements for coronavirus-related applications. Table 2 lists the commercial companies either producing biosurfactants or using them in eco-friendly preparation of surface-cleaners. In some surfactants, acetyl groups, as hydrophilic moieties, cause the antiviral activity (Borsanyiova et al. 2016).

Case of rhamnolipids: as antiviral agents

Rhamnolipids are one of the most extensively studied biosurfactants amongst glycolipids. They exhibit outstanding properties including non-toxic nature, high biodegradability, and antibacterial and antiviral activities. The structures of rhamnolipids can be divided into two main moieties, a hydrophilic head containing rhamnose sugar (also called glycon) and a lipid (also called aglycon) part. The hydrophilic moiety consists of mono- and/or di-rhamnose molecule that is normally bonded together by a strong 1,2-glycosidic linkage. The lipid part is hydrophobic and comprises fatty acid chain(s) of variable lengths C_8 - C_{24} (Raza et al. 2014). *Pseudomonas aeruginosa*, a Gram-negative bacterium, is the most predominant species known to produce rhamnolipids. Owing to their eco-friendly nature, rhamnolipids have been utilized in various applications such as dispersants, stabilizers, emulsifiers, bactericides, fungicides, and foaming and wetting agents (Khubaib et al. 2021; Lopez-Prieto et al. 2019; Mujumdar et al. 2019).

If we look into the structure of enveloped viruses, like herpesviruses, coronaviruses, and influenza viruses, they have double-stranded DNA enclosed in the protein capsid that is further wrapped in a lipid bilayer envelope (Remichkova et al. 2008). The SARS COV-2 is also an enveloped positive-sense RNA virus (Abo-Zeid et al. 2020; Andersen et al. 2020). The SARS COV-2 assembly comprises four types of structural proteins viz. spikes, membrane, nucleocapsid, and envelop proteins. The viral

Table 2 List of companies employing biosurfactants in cleaning formulations

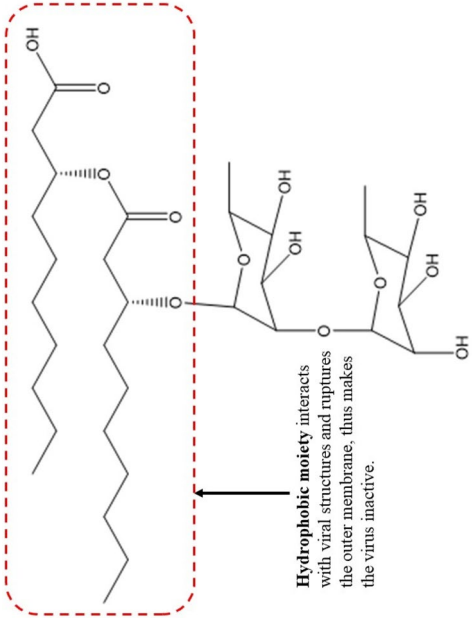
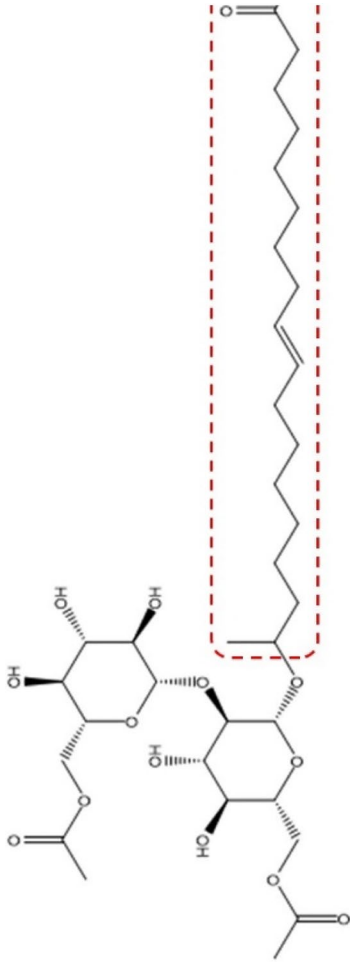
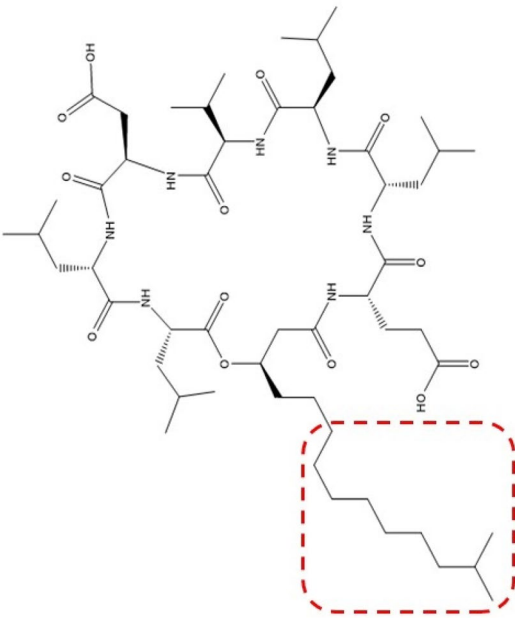
Company/ Website	Biosurfactant(s) employed	Role	Product(s)
TeeGene (UK) https://www.teege.co.uk	<ul style="list-style-type: none"> - Lipopeptide - Rhamnolipids 	<ul style="list-style-type: none"> - Emulsifier - Stabilizer 	From cosmetics to bio-pharmaceuticals
<p>Representative biosurfactants' structures (Dotted boundary covers the lipophilic moiety which is the most active part of biosurfactant to rupture the viral bilayer)</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p>Hydrophobic moiety interacts with viral structures and ruptures the outer membrane, thus makes the virus inactive.</p> </div> </div>			
Evonik (German) https://corporate.evonik.com/en	<ul style="list-style-type: none"> - Sophorolipid - Rhamnolipids - Lipopeptide 	<ul style="list-style-type: none"> Skin conditioner, refatting agent, moisturizer and surface cleaner Surface cleaner 	Shampoo, shower gel and household cleaners
Saraya (Japan) https://saraya.world	Sophorolipid	Surface cleaner	Detergent and cosmetics
<p>Rhamnolipid</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p>Sophorolipid</p> </div> </div>			

Table 2 (continued)

Company/ Website	Biosurfactant(s) employed	Role	Product(s)	Representative biosurfactants' structures (Dotted boundary covers the lipophilic moiety which is the most active part of biosurfactant to rapture the viral bilayer)
Ecover (Belgium) https://www.ecover.com	Sophorolipid	Surface cleaner	Household cleaners	 <p style="text-align: center;">Lipopeptide</p>
Henkel (Germany) https://www.henkel.com/company	Not disclosed the biosurfactant type	Surface cleaner	Laundry, dishwashing and cleaning products	
BASF (Germany) www.care-chemicals.basf.com	– Lipopeptide – Rhamnolipids	Emulsifier and surface cleaner	Personal care	
Unilever (UK) https://www.unilever.com	– Lipopeptide – Rhamnolipid	Foaming and surface cleaning agent	Green cleaning ingredient	
Jeneil Biotech, Inc. (USA) https://www.jeneilbiotech.com/biosurfactants	Rhamnolipid	Surface active, emulsification and antimicrobial agents	Green ingredient for personal care products, bioremediation, agriculture and antimicrobial applications	

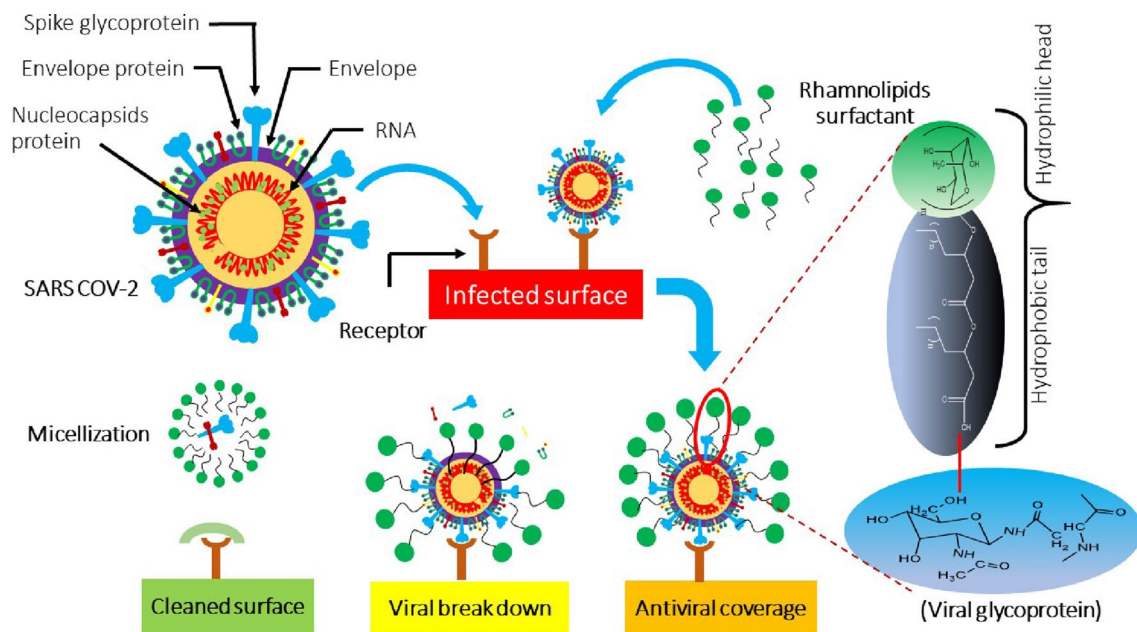


Fig. 5 Anti-viral action of rhamnolipid surfactant

spike's glycoproteins contain hydroxyl groups on their carbohydrate congener helping their attachment with different hydrophilic surfaces and the respiratory aerosols (Raza et al. 2021). The spike glycoproteins are also involved in the attachment of the virus to the receptors found in the host cell and thus the infection gets started.

Rhamnolipids have been reported as antiviral agents against different enveloped viruses including bovine coronavirus, herpes simplex viruses (HSV1 and HSV2) and SARS COV-2. This could be attributed to the interaction of lipid parts of rhamnolipids with the outer lipid membrane of the enveloped viruses which may induce some structural damages in the glycoproteins present there (Remichkova et al. 2008). The lipid bilayer envelopes in the SARS COV-2 are systematically targeted by the amphipathic rhamnolipid molecules thus deactivating them (Jin et al. 2021).

The affinity of the lipophilic tail with virus phospholipid bilayer facilitates the surfactants like rhamnolipid to penetrate easily through the membrane. This interaction, consequently, brings some changes in structural conformation of virus envelope or phospholipid bilayer membrane, thus unzipping it. Such interactions between rhamnolipid and virus envelop have a detrimental effect on the structural integrity of the virus. So, if the virus loses the integrity of its envelope, in general, and the spike proteins, in specific, it becomes unable to bind to the receptors on the host cells and cause any infectivity (Das 2020). Based on the available literature, a mechanism has been proposed for antiviral activity by rhamnolipid surfactant against the SARS-CoV-2 as shown in Fig. 5. However, research on applications of

rhamnolipid as antiviral agents is in its infancy and needs to be further developed.

The origin, nature, chain length, hydrophilic-lipophilic balance (HLB), polar and any additional functional groups attached to the lipophilic moieties on the biosurfactant may determine their mode of interaction with and penetration into the lipid bilayer. For instance, the biosurfactants with $HLB > 10$ tend to form micelles in the oil-in-water systems, whereas with $HLB < 8$, they align themselves as the reverse micelles in the water-in-oil systems. The lipid bilayers are 3D micellar arrangements in some layer-on-layer patterns with their lipophilic ends forming the surface of the virus. In the lipid bilayers, there occur cone-shaped lipids at a highly curved outer convex face, whereas the inner concave occupies some more wedge-shaped lipids. On the other hand, the stressed regions may even adopt a locally non-bilayer structure. Thereby, the lipophilic moieties of rhamnolipids, having the affinity with the lipophilic cage of the virus, may penetrate into micellar network of bilayers thus disrupting that into tiny segments which are then encapsulated by rhamnolipid micelles in the aqueous media. Therein, the rhamnolipids expose their polar moieties as shells and lipophilic moieties tended towards the core; thus the disrupted lipophilic segments of the viral bilayers and the spike proteins are encapsulated in the micelles and disposed off (Vollenbroich et al. 1997). Thus the contaminated surface becomes free of virus and its inactive segments. This ultimately inactivates the virus before its adsorption or penetration into the skin (Kracht et al. 1999). The rhamnolipids thus may be considered in handwashing and surface-cleaning

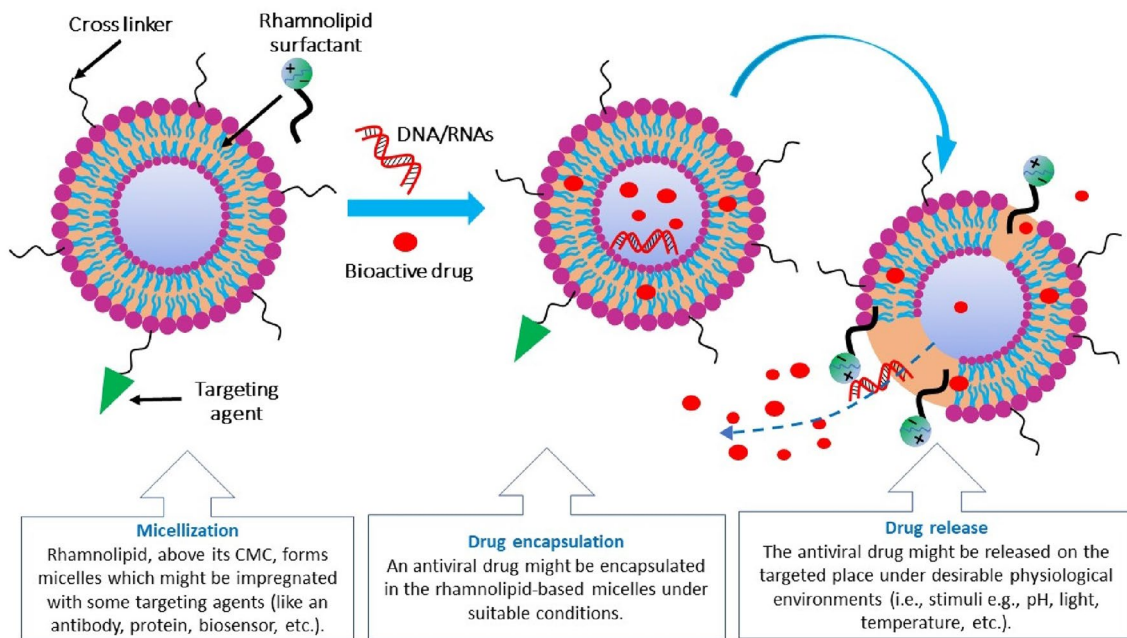


Fig. 6 Antiviral drug encapsulation and release with a biosurfactant

formulations to prevent the spread of the virus and in diagnostic applications (Rehman et al. 2015).

Rhamnolipids: as antiviral drug carrier

The rhamnolipids, due to their amphipathic structures, form different morphologies like lamellar sheets, fibers, micelles and liposomes depending on certain chemo-physical conditions above CMC. The micellar behavior of biosurfactants could be significant in indirectly targeting the coronavirus in capturing it, thus inactivating it and for drug and vaccine delivery applications (Sandeep and Rajasree 2017). The liposomes, for instance, are self-assembled spherical vesicles comprising of one or two lipid bilayer that surrounds the aqueous compartment. They are well known as efficient drug delivery vehicles. They can enclose and solubilize the hydrophobic/hydrophilic drugs in a dispersed phase to form microemulsions. The biosurfactant-based micelles could again be used as liposomes to deliver the drugs and vaccines to the infection site and release them, accordingly (Nakanishi et al. 2009).

The use of rhamnolipid for making microemulsions is an excellent choice owing to its non-toxic nature. The ability of biosurfactant like rhamnolipid to form micelles makes it an ideal candidate to form the stable liposome for drug delivery to the specific target. The physicochemical properties of rhamnolipid would protect the drug and enhance the liposome stability inside the biological system. Furthermore, the solubility of the biosurfactant could significantly enhance the bioavailability of the drug soon after it has been

administered (Omkar et al. 2020). The use of rhamnolipid would act as a double sword providing safe delivery to the target site and also exhibiting the intrinsic antiviral activities. A schematic illustration of antiviral drug encapsulation and release with a biosurfactant is given in Fig. 6.

The glycolipid surfactants could also be employed to enhance the stability of antimicrobial nanostructures (e.g., of silver, ZnO, chitosan etc.) by reducing the interfacial tension and facilitating nanoemulsion formation (Kasture et al. 2008). This would improve the chemo-physical as well as biological properties of biosurfactant-mediated nanoemulsions for effective antioxidant, antimicrobial and anti-biofilm effects (Rehman et al. 2015). Joanna et al. (2018) reported enhanced antimicrobial activity of the silver nanoparticles (SNPs) stabilized by rhamnolipid as a capping agent. This might be due to more availability of the rhamnolipid-mediated SNPs in the physiological environment to disrupt the microbial DNA in an effective manner (Bidyarani et al. 2020).

Another study reported the use of rhamnolipids mediated nano-micelles as an antiviral agent against SARS COV-2 (Bakkar et al. 2021). The researchers found good interaction of rhamnolipids with the active sites of various enzymes of SARS COV-2 that are responsible for its replications. Such studies pave the path for the utility of rhamnolipid as an efficient molecule in a fight against SARS COV-2 and may be considered as a future perspective. Thus, rhamnolipid can be an excellent alternative to alcohol for hand sanitizers and surface cleaners.

Conclusions

The COVID-19 pandemic has badly hit human life on Earth. It has compelled people to revisit their health-related habits and reconstruct social and environmental livelihood patterns. We are trying to learn to live with this deadly virus. The biosurfactants due to their excellent surface-active and emulsification properties could be used for multi-purposes in food, pharmaceutical, cosmetic and detergent formulations. In the present context, the biosurfactants due to their effective surface-active, emulsifying, antiviral, therapeutic and anti-inflammatory properties could be a sustainable solution to combat the COVID-19 infection in diverse ways. For instance, they may significant constituents in in surface cleaning, hand sanitizing and disinfecting formulations. This would be accomplished in an eco-friendly and less-toxic way. The biosurfactants by using their amphiphilic structures may easily interact with the SARS COV-2's lipid bilayer and destroy the viral genome—thus facilitating the eradication of the virus. Likewise, their emulsification and micellization properties enable them to encapsulate and deliver the drug and vaccines in an intelligent way. Consequently, if the coronaviruses were natural entities, they should be handled naturally lest the virus would ultimately be beaten but may leave for us the biosphere not worth living.

Author contributions ZAR: conceptualization, writing—original draft, review and editing. QS: conceptualization and formal analysis. AR: validation. MT: resources and formal analysis. AA: visualization.

Declarations

Conflict of interest “The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.”

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