AGRICULTURAL MICROBIOLOGY / REVIEW ARTICLE

DOI: 10.1590/1808-1657000502017

Biosurfactant production by fungi as a sustainable alternative

Produção de biossurfactantes por fungos como uma alternativa sustentável

Artemisia Carla Santos da Silva[1], Patrícia Nunes dos Santos[1], Thayse Alves Lima e Silva[1], Rosileide Fontenele Silva Andrade[1], Galba Maria Campos-Takaki[1]*

ABSTRACT: A wide variety of bacteria is far more exploited than fungi as biosurfactants (BS) or bioemulsifiers (BE), using renewable sources. BS are considered to be environmentally safe and offer advantages over synthetic surfactants. However, the BS yield depends largely on the metabolic pathways of the microorganisms and the nutritional medium. The production of BS or BE uses several cultural conditions, in which a small change in carbon and nitrogen sources affects the quantity of BS or BE produced. The type and quantity of microbial BS or BE produced depend mainly on the producer organism, and factors such as carbon and nitrogen sources, trace elements, temperature and aeration. The diversity of BS or BE makes it interesting to apply them in the pharmaceutical and cosmetics industries, agriculture, public health, food processes, detergents, when treating oily residues, environmental pollution control and bioremediation. Thus, this paper reviews and addresses the biotechnological potential of yeasts and filamentous fungi for producing, characterizing and applying BS or BE.

KEYWORDS: surface active compounds; agroindustrial substrates; fungi; amphiphilic molecules.

RESUMO: Uma grande variedade de espécies bacterianas é bem mais explorada que os fungos como agentes biossurfactantes (BS) ou bioemulsificantes (BE), usando fontes renováveis. Os BS são considerados ecologicamente seguros e oferecem vantagens sobre os surfactantes sintéticos. Entretanto o rendimento de BS depende grandemente das vias metabólicas dos micro-organismos e do meio nutricional. A produção de BS ou BE utiliza várias condições culturais, em que uma pequena alteração nas fontes de carbono e nitrogênio afeta a produção de BS. O tipo e a quantidade de BS ou BE microbianos produzidos dependem principalmente do organismo produtor e de fatores como fontes de carbono e nitrogênio, oligoelementos, temperatura e aeração. A diversidade de BS ou BE torna-os interessantes para aplicação nos campos farmacêutico, cosmético, da agricultura, da saúde pública, em processos alimentares, detergentes, no tratamento de resíduos oleosos, no controle de poluição ambiental e na biorremediação. Assim, a presente revisão aborda o potencial biotecnológico de leveduras e fungos filamentosos para produção, caracterização e aplicações de BS ou BE .

PALAVRAS-CHAVE: compostos de superfícies ativas; substratos agroindustriais; fungos; moléculas anfifílicas.

[1]Núcleo de Pesquisas em Ciências Ambientais e Biotecnologia, Faculdade de Ciências Biológicas, Universidade Católica de Pernambuco – Recife (PE), Brazil
*Corresponding author: galba_takaki@yahoo.com.br
Received on: 06/06/2017. Accepted on: 03/23/2018

INTRODUCTION

Surfactants are chemical compounds, characterized by the presence of amphipathic molecules consisting of hydrophobic and hydrophilic moieties, which are partitioned preferentially at the interface between fluid phases with different degrees of polarity and hydrogen bonds. Thus, they reduce surface and interfacial tension, and form microemulsions, in which hydrocarbons can solubilize. The polar portion (head) may be ionic (cationic or anionic), nonionic and amphoteric, while the apolar portion often consists of hydrocarbons and can be solubilized in water (CALVO et al., 2009). Therefore, biosurfactants (BS) or bioemulsifiers (BE) are considered the most versatile chemical groups of amphipathic molecules possessing hydrophobic and hydrophilic domains used in various industrial processes. As they have to compete in the market, however, it is essential to produce BS or BE that are eco-friendly and to do so economically (DESAI; BANAT, 1997; PRADHAN, 2017; BHATTACHARYA et al., 2017).

BS and BE are amphipathic compounds produced by various microorganisms, and have unique properties, *e.g.*, they are lipophilic and hydrophilic. Their extremities have opposing polarities, represented by an apolar and a polar head. BS or BE accumulate in the air-water and oil-water interfaces and surface (MUTHUSAMY et al., 2008). The main properties of these compounds are: they reduce surface and interfacial tensions; they have hydrophilicity actions; they are ecologically correct and non-toxic; they retain their functionality under extreme conditions of pH and temperature, stability, wettability and dispersion (KOSARIC, 2001). In this context, the large chemical diversity and diverse properties demonstrate that BS can be applied across a wide range of activities, such as biodegradation, emulsification, de-emulsification, and solubilization. They can be produced from renewable sources, and they both remain effective under extreme conditions of pH, salinity and temperature. The BS and BE were more advantageous than the chemical surfactants The microbial BS produced in cold habitats provide a perspective on the most promising future applications (BANAT et al., 2000; PERFUMO et al., 2018).

The BS or BE are classified according to their chemical composition, molecular weight, physicochemical properties, mode of action and microbial origin. For example, those of low molecular weight are fatty acids, glycolipids, cyclic and acyclic lipopeptides, and those of high molecular weight are polysaccharides amphipathic, proteins, lipopolysaccharides, lipoproteins, polymeric and vesicles and microbial cells with surfactant activity, which are classified as particulate biosurfactants. Thus, low molecular weight BS are efficient at reducing surface and interfacial tensions, while high molecular weight BE are more effective in stabilizing oil-in-water emulsions (CALVO et al., 2009; DESAI; BANAT, 1997; RAJESH et al., 2017).

In the present study, it was found that BS or BE were produced by bacteria (KOMA et al., 2001; KREPSKY et al., 2007; RAJESH et al., 2017; BOUASSIDA et al., 2018), followed by yeasts (SARUBBO et al., 2001; 2006; 2007; VANCE-HARROP et al., 2003; AMARAL et al., 2008; KATEMAI, 2012), and rarely by filamentous fungi (BATRAKOV et al., 2001; 2003; KATEMAI et al., 2008; KIRAN et al., 2009; SILVA et al., 2014; 2015; PELE et al., 2018).

Natural BS or BE produced by bacteria have been exploited a lot — those produced by yeast a little less, while research studies on filamentous fungi are rare. However, the few filamentous fungi exploited have shown potential to produce BS or BE, with higher yields when compared to those from yeasts, but mainly when compared to those from bacteria (BHARDWAJ et al., 2013). Therefore, the release of high amounts of BS produced by filamentous fungi has been attributed to cell wall stiffness, as suggested by KIM et al. (2002; 2006).

Thus, this paper reviews and addresses the biotechnological potential of filamentous fungi for producing BS or BE, considering the high industrial potential of these organisms, as described by CASTIGLIONI et al. (2009), PELE et al. (2018), and SILVA et al. (2014). In addition, using filamentous fungi meets the demands of society for concerns about the environment to be taken into account. This is also reflected in the new legislation and prompts the search for products obtained via microbial, toxicity-free alternatives, rather than depending on commercial surfactants synthesized from petroleum.

Therefore, this paper generates perspectives on how to face the challenges, especially the need to increase knowledge about biochemical pathways of BS or BE production and to assess the biotechnological potential of fungi (yeasts and filamentous fungi) for producing BS or BE. They are a versatile alternative, and it includes the sustainable use of agricultural by-products in the search for new surfactants with wide applicability and which cost less to produce is included. Therefore, this paper indicates the main challenges and the need to increase knowledge about the biochemical pathways of BS production, associated with the biotechnological potential of yeasts and filamentous fungi.

Thus, a versatile and sustainable alternative is presented, considering the high enzymatic capacity of using agricultural and industrial by-products to produce new BS or BE, besides which molecules can be applied widely and reduce production costs. Table 1 shows the studies performed with yeasts, the genera and species most studied, as well as the class of BS, and which biosurfactant is synthesized.

It is observed that most yeasts of the genus *Candida* are the most investigated among different types of BS or BE that have the potential to be produced economically. It is possible that the broader use of yeast to produce these substances with great success is related mainly to its GRAS status (generally considered as safe). Microorganisms that have a GRAS status do not present a risk of inducing toxicity and pathogenic reactions (FONTES et al., 2008). In addition, the versatility of the metabolic pathways of yeast, especially *Yarrowia lipolytica*, and the perfect stage of *Candida lipolytica*, both yeasts considered to have unconventional metabolism, is highlighted in view of its growth in a wide variety of substrates with different chemical natures to produce BS and/or in bioremediation (HUA et al., 2003; LANCIOTTI et al., 2005; AMARAL et al., 2010; CAMPOS-TAKAKI et al., 2010; RUFINO et al., 2014; AGHAJANI et al., 2018).

It should be noted that filamentous fungi (Table 2) are less exploited than yeasts, due to their slower growth. However, they are excellent producers of BS or BE, as well as emulsifiers, with stable emulsions, and have an excellent capacity to reduce stress. Moreover, they promote the dispersion of hydrophobic compounds, which enables them to be applied in different sectors (SILVA et al., 2014; SOUZA AF et al., 2016; SOUZA PM et al., 2016; 2017b; PELE et al., 2018).

Table 1. Types of biosurfactants or bioemulsifiers produced by yeasts according to the classification.

Biosurfactant	Microorganism	References
Glycolipids	*Candida bombicola*	Solaiman et al. (2004)
	Candida bombicola	Roelants et al. (2013)
	Candida bogoriensis	Kitamoto et al. (2001)
	Candida sphaerica UCP0995	Sobrinho et al. (2008)
	Candida glabrata	Andrade et al. (2015)
	Candida ishiwadae	Thanomsub et al. (2004)
	Candida batistae	Konishi et al. (2008)
	Pseudozima fusifornata	Morita et al. (2007)
	Wickerhamomyces anomalus CCMA 0358	Souza KST et al. (2017)
Sophorolipids	*Pseudozyma aphidis*	Rau et al. (2005)
	Candida bombicola	Casas; Ochoa (1999)
	Candida bombicola	Cavalero; Cooper (2003)
	Torulopsis petrophilum	Cooper; Paddock (1983)
	Candida (Torulopsis) apicola	Hommel et al. (1994)
	Candida bogoriensis	Tulloch et al. (1968)
	Candida antarctica	Kim et al. (2002)
	Pseudozyma rugulosa	Fukuoka et al. (2007a; 2007b)
	Candida sp. *SY16*	Kim et al. (2006)
	Kurtzmanomyces sp.	Kakugawa et al. (2002)
Complex Carbohydrates/protein/lipids	*Candida lipolytica* UCP0988	Sarubbo et al. (2007)
	Candida lipolytica IA1055	Sarubbo et al. (2001)
	Yarrowia lipolytica NCIM 3589	Zinjarde et al. (1997)
	Debaryomyces polymorphus	Singh; Desai (1989)
	Candida tropicalis	Singh; Desai (1989)
	Candida ingens	Amézcua-Vega et al. (2007)
	Candida utilis	Shepherd et al. (1995)
	Candida valida	Shepherd et al. (1995)
	Candida boleticota	Mossa et al. (2006)
Complex Carbohydrate /protein	*Candida lipolytica* ATCC8662	Cirigliano; Carman (1984; 1985)
	Saccharomyces cerevisiae	Cameron et al. (1988); Bahia et al. (2018)
	Kluyveromyces marxianus	Lukondeh et al. (2003)
	Candida utilis	Sheperd et al. (1995)
	Candida ingens	Amézcua-Vega et al. (2007)
	Rhodotorula glutinis	Yoon; Rhee (1983)
Lipopeptide	Candida glabrata	Morita et al. (2007)

Source: adapted from: Amaral et al. (2008; 2010); Campos-Takaki et al. (2010); Katemai (2012); Bhardwaj et al. (2013).

Influence of physico-chemical parameters on the production of biosurfactants or bioemulsifiers

The BS or BE synthesis may be spontaneous or induced by the presence of lipophilic compounds, temperature variations, pH, agitation speed, stress and low concentrations of the nitrogen source. Probably the main source for synthesis of BS or BE is the carbohydrate in the culture medium. The flow of this source regulates both the glycolytic and lipogenic pathways that act to form the hydrophilic portion (head) and the lipid part (tail), depending on the nature of the substrates (SYLDATK; WAGNER 1987; FONTES et al., 2008; 2012) (Fig. 1). However, the carbon sources that influence the production of BS or BE by different strains of microorganisms have been the subject of several studies. Although the production of BS or BE occurs in the presence of water-soluble carbon sources, such as sugars, several studies show that the highest BS or BE production is obtained when hydrophobic substrates are added (KALYANI et al., 2014).

It is observed in Figure 1 that, when a hydrocarbon is used as a carbon source, microbial metabolism mainly uses the lipolytic pathway and gluconeogenesis (formation of glucose from precursors other than hexoses) that can be used in the production of fatty acids or saccharides. Thus, the production of saccharides is activated by the gluconeogenesis pathway. Oxidation of fatty acids occurs via β-oxidation with the formation of acetyl coenzyme A (acetyl-CoA) or propionyl coenzyme A (propionyl-CoA), in the case of odd-chain fatty acids. From the formation of acetyl-CoA, the reactions involved in the synthesis of polysaccharide precursors, such as glucose 6-phosphate, are essentially the inverse of those involved in glycolysis. However, the reactions catalyzed by pyruvate kinase and phosphofructokinase-1 are irreversible; therefore, other enzymes, which are unique to gluconeogenesis, are required to bypass such reactions. The main reactions are shown in Figure 2, until the formation of glucose 6-phosphate, as the main precursor of the polysaccharides, disaccharides to be formed to produce the hydrophilic portion of the glycolipids (SYLDATK; WAGNER, 1987; OCHSNER et al., 1994; FONTES et al., 2008; 2012).

The biosynthesis of the emulsifier can take place in the synthesis of the head — hydrophilic portion (carbohydrate) and the hydrophobic part (lipids), whereas the lipid chain length will depend on the carbonic substrate present in the medium (Fig. 2). The authors described in this study that the carbohydrate and lipid syntheses depend on the chemical nature of the substrates used (SYLDATK; WAGNER, 1987; FONTES et al., 2008; 2012).

The effective cost of biosurfactant or bioemulsifier productions

The literature affirms the economic stand point of BS or BE is not yet competitive with the synthetic surfactants obtained from petroleum (RUFINO et al., 2011).

Table 3 describes the renewable substrates used to BS or BE productions. However, the use of these biomolecules BS and BE is limited since the cost of production is high, and the production potential is low (PACWA-PLOCINICZAK et al., 2011; LUNA et al., 2009; 2013).

In order to raise the productivity of BS or BE, several investigations described the successful of these active molecules production depends on the use of renewable substrates from biotechnological processes, as it cuts total costs by around 50%. Despite of that, the purification process is considering another obstacle to producing these compounds from microbial origin (BANAT et al., 2010; 2014; ROCHA E SILVA et al., 2014).

BS or BE are considered extracellular secondary metabolites or associated with the cell membrane, the structure of which depends on the ratio of carbon and nitrogen sources. In this case, the BS or BE can be replaced by synthetic surfactants if the cost of the raw material reduces the cost of production (SILVA et al., 2014; ROCHA E SILVA et al., 2014).

Methods of extraction and characterization of biosurfactants or emulsifiers

The methods for extracting BS are variable and depend on the structure and chemical composition of the BS (MUTHUSAMY

Table 2. Types of biosurfactants or bioemulsifiers produced by filamentous fungi.

Biosurfactant	Microorganism	Reference
Lipopeptide	*Penicillium chrysogenum* SNP5	Gautam et al. (2014)
Glycolipid	*Aspergillus niger*	Kannahi; Sherley (2012)
Complex Carbohydrate/protein/lipid	*Cunninghamella echinulata*	Silva et al. (2014)
*Not identified	*Fusarium* sp.	Qazi et al. (2014)
	Fusarium, *Penicillium* and *Trichoderma*	Castillo-Méndez et al. (2017)
	Aspergillus spp.	Cavalcanti et al. (2017)
	Aspergillus niger	Silva et al. (2015)
	Aspergillus fumigatus	Castiglioni et al. (2009)
	Rhizopus arrhizus	Pele et al. (2018)

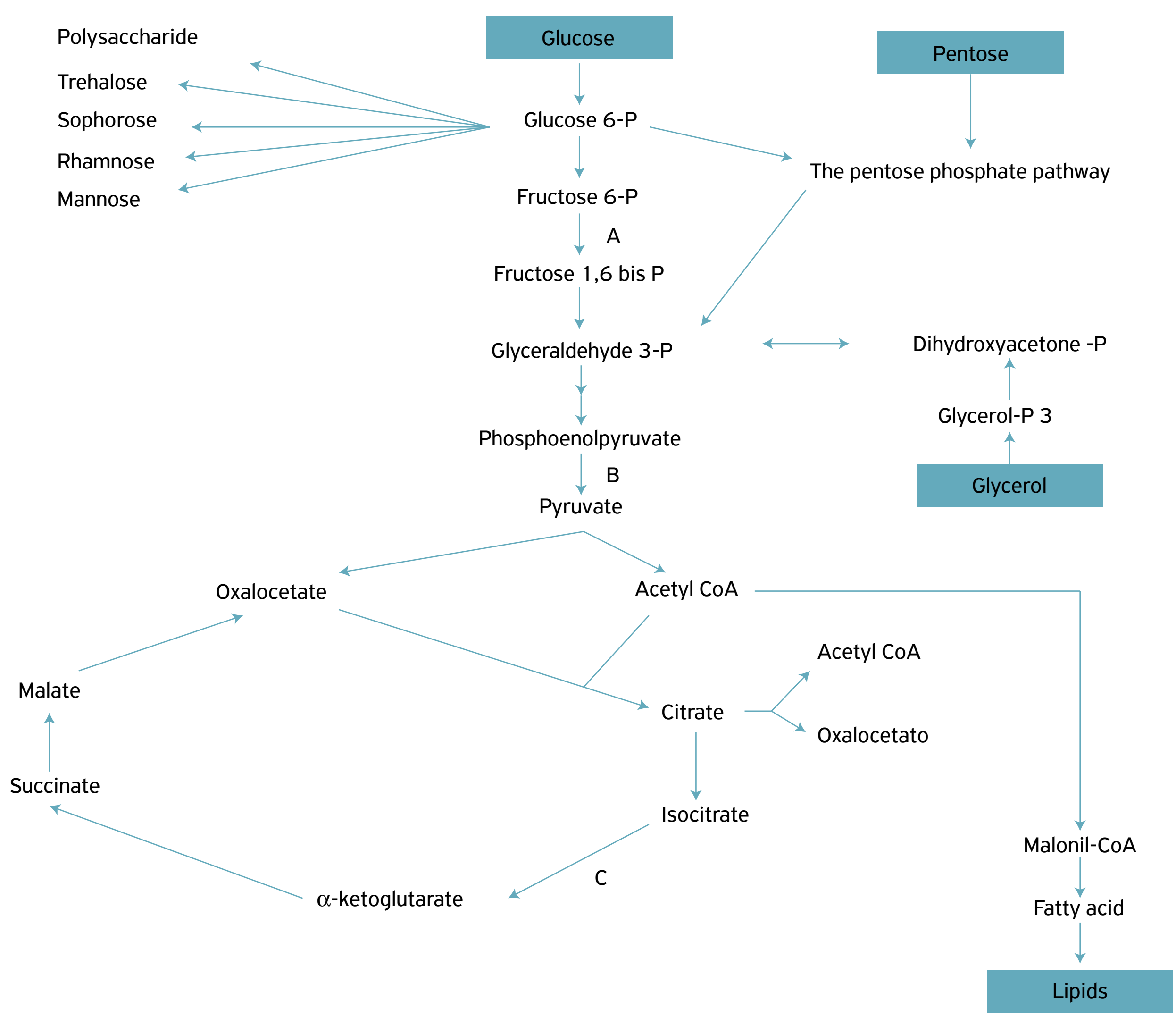
et al., 2008), as shown in Table 4. The most used methods are precipitation (acidic, ammonium sulphate) and extraction with organic solvents (methanol, chloroform, ethanol and their associations) (LUNA et al, 2009, 2013; CHEN, 2012; LIMA et al., 2017).

Precipitation is the most cited technique in the literature, and acidification, using hydrochloric acid (HCL), is common for extracting crude BS. This method consists of acidifying the cell free metabolic liquid to a pH 2–3 value. Another method to isolate BS is using ammonium sulphate precipitation, which follows a protocol similar to that one of acid precipitation, with the differential of the need for sample dialysis to remove salt in the final process (ANTUNES et al., 2013). Organic solvents such as ethanol and acetone are also commonly used to extract BS and are still a method that favors the reuse of solvents (SILVA et al., 2014). On the other hand, extraction with organic solvents favors the high yield of biosurfactants. However, it is a time-consuming and costly process (MUTHUSAMY et al., 2008; ANDRADE et al., 2015).

The main methods to characterize surfactants, according to LIMA et al. (2017), feature:

- the ability to reduce surface and interfacial tension due to the formation of a molecular film;
- the ability to form stable macro and microemulsions of hydrocarbons in water or water in hydrocarbons;
- the formation of micelles;
- their antimicrobial properties.

Some authors describe the most important properties evaluated in the search for new and powerful BS for industrial application, for example: being able to reduce surface and interfacial tension, a critical micellar concentration (CMC), the ability to form emulsions and to maintain the stability of them (MUTHUSAMY et al., 2008; PACWA-PLOCINICZAK, et al., 2011; JAMAL et al., 2012).



Acetyl-CoA: acetyl coenzyme A; Malonil-CoA: malonil coenzyme A.

Figure 1. Intermediate metabolism related to the production of biosurfactant or bioemulsifier, using hydrophilic and hydrophobic sources as substrates, according to Fontes et al. (2008).

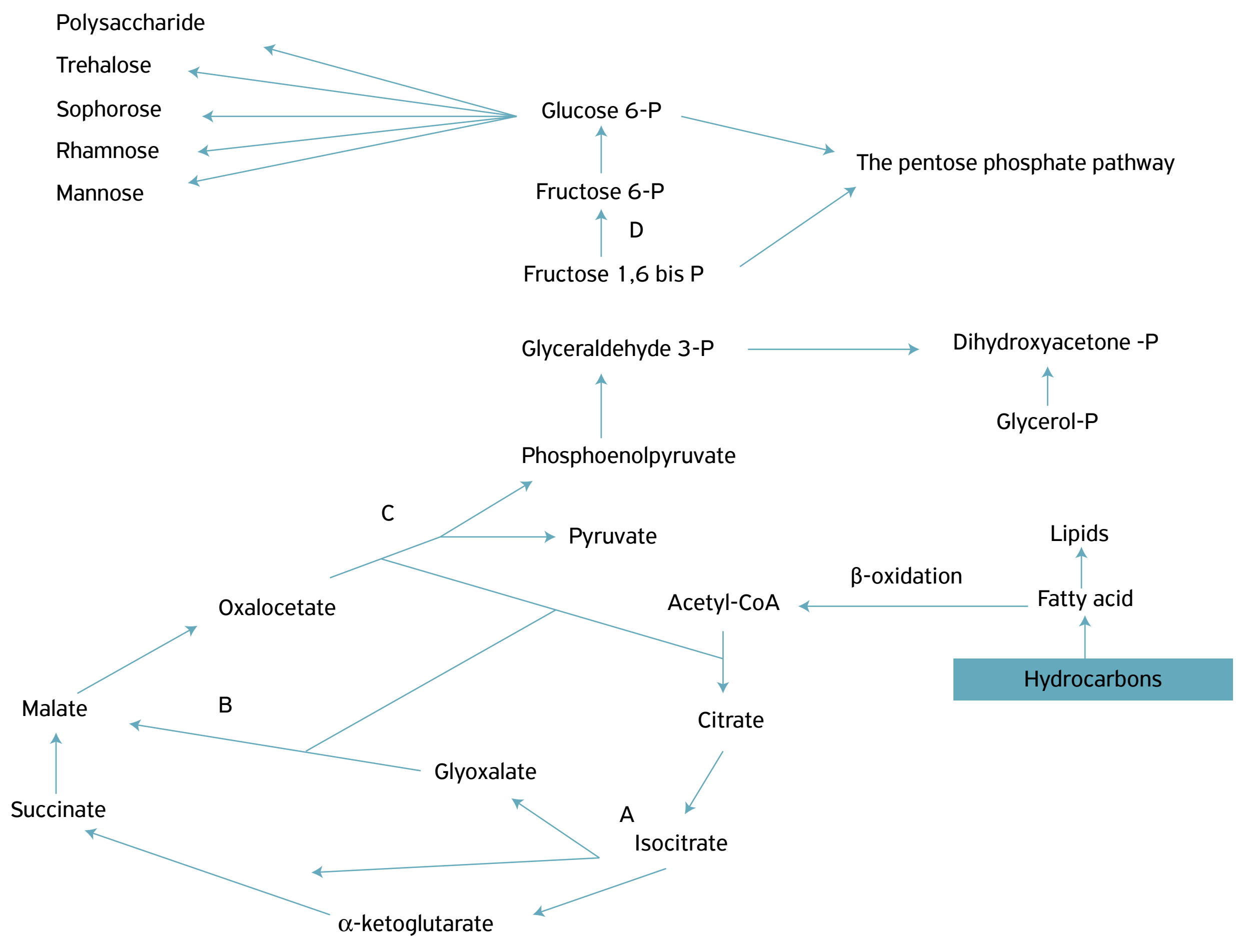


Figure 2. Intermediate metabolism related to the production of biosurfactant or bioemulsifier using hydrocarbons as substrates, according to Fontes et al. (2008).

Table 3. Renewable substrates as renewable sources for biosurfactant or bioemulsifier productions by yeasts or filamentous fungi.

Microorganism	Renewable substrates	Reference
Candida lipolytica	Canola oil/glucose	Sarubbo et al. (2007)
Candida lipolytica	Industrial hydrophobic waste	Rufino et al. (2014)
Candida lipolytica	Molasses	Karatay; Dönmez (2010)
Candida lipolytica	Waste soybean oil and corn steep liquor	Souza PM et al. (2016)
Candida sphaerica	Groundnut oil	Sobrinho et al. (2008)
Cryptococcus curvatus	Acetate	Gong et al. (2015)
Candida utilis	Corn oil	Shepherd et al. (1995)
Candida glabrata	Cotton seed oil/glucose	Sarubbo et al. (2006)
Candida glabrata	Corn steep liquor and whey	Lima et al. (2016; 2017)
Candida glabrata	Corn steep liquor, whey and cassava waste water	Silva et al. (2017)
Yarrowia lipolytica	Industrial glycerol	Papanikolaou et al. (2002)
Yarrowia lipolytica	Crude glycerin and cashew apple juice	Fontes et al. (2012)
Rhodotorula glutinis	Crude glycerol/Tween 20	Saenge et al. (2011)
Rhodotorula graminis	Corn steep solids/yeast extract	Galafassi et al.(2012)
Ustilago maydis	Crude glycerol	Liu et al. (2011)
Penicillium chrysogenum SNP5	Wheat bran, grease waste	Gautam et al. (2014)
Cunninghamella echinulata UCP	Soybean waste oil and corn steep liquor	Silva et al. (2014)
Cunninghamella phaeosphora UCP1303	Post-fry soybean oil and corn steep liquor	Lins et al. (2017)
Cunninghamella bertholletiae	Waste soy oil and corn steep liquor	Souza PM et al. (2017)
Fusarium sp.	Sucrose and yeast extract	Qazi et al. (2014)
Aspergillus fumigatus	Glycerol on solid state fermentation	Castiglioni et al. (2009)
Rhizopus arrhizus	Soybean post-frying oil/sodium glutamate	Pele et al. (2018)

Applications of biosurfactants

The surface-active compounds produced by microorganisms have the potential to be applied, based on their functional properties, which include: emulsification, separation, wetting, solubilization, demulsification, inhibition of corrosion, and reduction of liquid viscosity and of surface tension. Thus, biosurfactants divide the interface between fluids with different degrees of polarity and hydrogen bonds such as air/water or oil/interfacial water. Therefore, due to these properties, biosurfactants are able to diminish the surface and interfacial tension and to form microemulsions, in which the hydrocarbons can be solubilized in water, or water emulsions can be formed using hydrocarbons. Therefore, BS of fungal origin have wide application and can be used in several industrial sectors that use chemical surfactants. Such industries include: petroleum, pharmaceuticals, cosmetics, agriculture with regard to formulating herbicides and pesticides, and the production of personal hygiene products and food processing, as described by NITSCHKE; PASTORE (2002), confirmed by the literature (Table 1), and presented in Table 5 (BANAT et al., 2000; BHARDWAJ et al., 2013; LIMA et al., 2016; 2017; SOUZA AF et al., 2016; SOUZA KST et al., 2017; AGHAJANI et al., 2018).

CONCLUSION

BS synthesized by yeast are the most studied, while there are not many studies on BS production by filamentous fungi. However, microorganisms isolated from soils, mangrove sediments and contaminated areas demonstrate excellent production potential, as well as the metabolic ability to use renewable substrates to produce high value surfactants and BE.

The components of culture media, especially carbon sources, for the production of BS are divided into three categories: carbohydrates, hydrocarbons and vegetable oils. BS can be extracted, recovered and characterized by simple and low cost techniques. Therefore, using BS produced by fungi from renewable sources becomes a versatile and sustainable alternative that should be encouraged, in view of society's demands for ecologically safe products obtained through green technologies.

ACKNOWLEDGMENTS

The authors thank National Council of Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico — CNPq), Foundation of Support to the Science and Technology of Pernambuco (Fundação de Amparo à Ciência e Tecnologia de Pernambuco — FACEPE), and Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior — CAPES), for financial support and the fellowships for the training of human resources.

Table 5. Functions and applications of biosurfactants.

Functions	Fields of applications
Emulsification and dispersants	Cosmetics, paints, bioremediation, oils and food
Solubilizer	Pharmaceutical and hygiene products
Wetting and penetrating agents	Pharmaceutical, textile and paint products
Detergents	Cleaning products, agriculture
Foaming agent	Hygiene products, cosmetics and flotation of ores
Thickening agents	Paints and food
Metal sequestrants	Mining
Vesicle formers	Cosmetics and drug delivery system
Microbial grow factor	Treatment of oily residues
Demulsifiers	Waste treatment, oil recovery
Viscosity reducers	Transportation in pipelines, pipelines
Dispersants	Coal-water, lime-water mixtures
Fungicide	Biological control of phytopathogens
Recovery agent	Tertiary oil recovery (MEOR)

MEOR: microbial enhanced oil recovery.
Source: Nitschke; Pastore (2002).

Table 4. Extraction methods related to the properties of biosurfactants

Extraction methods	Properties	Vantages
Acid precipitation	Insoluble in low pH	Low cost, recuperation of crude biosurfactant
Precipitation with ammonium sulphate	Higher content of protein	Eficient for polymeric biosurfactant
Precipitation with ethanol/acetone	Soluble in organic solvent	Eficient for polymeric biosurfactant
Extraction with organic solvent	Soluble in organic solvent	Recuperation of crude biosurfactant, partial purification

REFERENCES

AGHAJANI, M.; RAHIMPOUR, A.; AMANI, H.; TAHERZADEH, M.J. Rhamnolipid as new bio-agent for cleaning of ultrafiltration membrane fouled by whey. *Engineering in Life Science*, v.18, n.5, p.272-280, 2018. DOI:10.1002/elsc.201700070

AMARAL, P.F.F.; DA SILVA, J.M.; LEHOCKY, M.; BARROS-TIMMONS, A.M.V.; COELHO, M.A.Z.; MARRUCHO, I.M.; COUTINHO, J.A.P. Production and characterization of a bioemulsifier from Yarrowia lipolytica. *Process Biochemistry*, v.41, n.8, p.1894-1898, 2006. DOI: 10.1155/2010/821306

AMARAL, P.F.; COELHO, M.A.; MARRUCHO, I.M.; COUTINHO, J.A. Biosurfactants from yeasts: characteristics, production and application. *Advances in Experimental Medicine and Biology*, v.672, p.236-249, 2010. DOI: 10.1007/978-1-4419-5979-9_18

AMÉZCUA-VEGA, C.; POGGI-VARALDO, H.M.; ESPARZA-GARCÍA, F.; RÍOS-LEAL, E.; RODRÍGUEZ-VÁZQUEZ, R. Effect of culture conditions on fatty acids composition of a biosurfactant produced by *Candida ingens* and changes of surface tension of culture media. *Bioresource Technology*, v.98, n.1, p.237-240, 2007. DOI: 10.1016/j.biortech.2005.11.025

ANDRADE, R.F.S.; ANTUNES, A.A.; LIMA, R.A.; ARAÚJO, H.W.C.; RESENDE-STOIANOFF, M.A.; FRANCO, L.O.; CAMPOS-TAKAKI, G.M. Enhanced Production of a Glycolipid Biosurfactant produced by *Candida glabrata* UCP/WFCC1556 for Application in Dispersion and Removal of Petroderivatives. *International Journal of Current Microbiology and Applied Sciences*, v.4, n.7, p.563-576, 2015.

ANTUNES, A.A.; ARAÚJO, H.W.C.; ALVES DA SILVA, C.A.; ALBUQUERQUE, C.D.C.; CAMPOS-TAKAKI, G.M. Biosurfactant production by *Chromobacterium violaceum* ATCC 12472 using corn steep liquor and corn post-frying oil as nutrientes. *Arquivos do Instituto Biológico*, v.80, n.3, p.334-341, 2013. DOI: 10.1590/S1808-16572013000300011

BAHIA, F.M.; DE ALMEIDA, G.C.; DE ANDRADE, L.P.; CAMPOS, C.G.; QUEIROZ, L.R.; DA SILVA, R.L.V.; ABDELNUR, P.V.; CORRÊA, J.R.; BETTIGA, M.; PARACHIN, N.S. Rhamnolipids production from sucrose by engineered *Saccharomyces cerevisiae*. *Scientific Reports*, v.8, p.1-10, 2018. DOI: 10.1038/s41598-018-21230-2

BANAT, I.M.; MAKKAR, R.S.; CAMEOTRA, S.S. Potential commercial applications of microbial surfactants. *Applied Microbiology Biotechnology*, v.53, n.5, p.495-508, 2000.

BANAT, I.M.; FRANZETTI, A.; GANDOLFI, I.; BESTETTI, G.; MARTINOTTI, M.G.; FRACCHIA, L.; SMYTH, T.J.; MARCHANT, R. Microbial biosurfactants production, applications and future potential. *Applied Microbiology Biotechnology*, v.87, p.427-444, 2010. DOI: 10.1007/s00253-010-2589-0.

BANAT, I.M.; SATPUTE, S.K.; CAMEOTRA, S.S.; PATIL, R.; NYAYANIT, N.V. Cost effective technologies and renewable substrates for biosurfactants' production. *Frontiers in Microbiology*, v.5, p.697, 2014. DOI: 10.3389/fmicb.2014.00697

BATRAKOV, S.G.; KONOVA, I.V.; SHEICHENKO, V.I.; GALANINA, L.A. Glycolipids of the filamentous fungus Absidia corymbifera F-295. *Chemistry and Physics of Lipids*, v.123, n.2, p.157-164, 2003. Available from: https://www.eurekamag.info/research/010/721/010721278.php. Accessed on: Apr. 03 2017.

BHARDWAJ, G.; CAMEOTRA, S.S.; CHOPRA, H.K. Biosurfactants from fungi: a review – *Petroleum & Environmental Biotechnology*, v.4, n.6, p.1-6, 2013. DOI:10.4172/2157-7463.1000160

BHATTACHARYA, B.; GHOSH, T.K.; DAS, N. Application of bio-surfactants in cosmetics and pharmaceutical industry. *Scholars Academic Journal Pharmacy*, v.6, n.7, p.320-329, 2017. DOI:10.3390/ijms150712523

BOUASSIDA, M.; GHAZALA, I.; ELLOUZE-CHAABOUNI, S.; GHRIBI, D. Improved Biosurfactant production by *Bacillus subtilis* SPB1 mutant obtained by random mutagenesis and its application in enhanced oil recovery in a sand system. Journal Microbiology Biotechnology, v.28, n.1, p.95-104, 2018. DOI: 10.4014/jmb.1701.01033

CALVO, C.; MANZANERA, M.; SILVA-CASTRO, G.A.; UAD, I.; GONZÁLEZ-LÓPEZ, J. Application of bioemulsifiers in soil oil bioremediation processes. Future prospects. *Science of the Total Environment*, v.407, n.12, p.3634-3640, 2009. DOI: 10.1016/j.scitotenv.2008.07.008

CAMERON, D.R.; COOPER, D.G.; NEUFELD, R.J. The mannoprotein of *Saccharomyces cerevisiae* is an effective bioemulsifier. *Applied Environmental Microbiology*, v.54, n.6, p.1420-1425, 1988.

CAMPOS-TAKAKI, G.M.; SARUBBO, L.A.; ALBUQUERQUE, C.D. Environmentally friendly biosurfactants produced by yeasts. *Advances in Experimental Medicine and Biology*, v.672, p.250-260, 2010.

CASAS, J.; OCHOA, F.G. Sophorolipid production by *Candida bombicola*: medium composition and culture methods. *Journal of Bioscience and Bioengineering*, v.88, n.5, p. 488-494, 1999. DOI: 10.1016/S1389-1723(00)87664-1

CASTIGLIONI, L.G; BERTOLIN, T.E; COSTA, J.A. Produção de biossurfactantes por *Aspergillus fumigatus* utilizando resíduos agroindustriais como substrato. *Química Nova*, v.32, n.2, p.292-295, 2009. DOI: 10.1590/S0100-40422009000200005.

CASTILLO-MÉNDEZ, L.; PRIETO-CORREA, E.; JIMÉNEZ-JUNCA, C. Identification of fungi isolated from banana rachis and characterization of their surface activity. *Applied Microbiology*, v.64, n.3, p.246-251, 2017. DOI: 10.1111/lam.12712.

CAVALCANTI, R.M.F.; SILVA, D.P.D.S.; PAZ, M.C.F.; QUEIROZ, J.C.F. Screening, production and characterization of biosurfactants from Caatinga's filamentous fungi. *International Journal Pharmaceutical Science Invention*, v.6, n.5, p.23-28, 2017.

CAVALERO, D.A.; COOPER, D.G. The effect of medium composition on the structure and physical state of sophorolipids produced by *Candida bombicola* ATCC 22214. *Journal of Biotechnology*, v.103, n.1, p.31-41, 2003. DOI: 10.1016/S0168-1656(03)00067-1

CHEN, J.; HUANG, P.T.; ZHANG, K.Y.; DING, F.R. Isolation of biosurfactant producers, optimization and properties of biosurfactant produced by *Acinetobacter* sp. from petroleum-contaminated soil. *Journal of Applied Microbiology*, v.112, n.4, p.660-671, 2012. DOI: 10.1111/j.1365-2672.2012.05242.x

CIRIGLIANO, M.C.; CARMAN, G.M. Isolation of a bioemulsifier from *Candida lipolytica*. *Applied Environmental Microbiology*, v.48, n.4, p.747-750, 1984.

CIRIGLIANO, M.C.; CARMAN, G.M. Purification and characterization of liposan, a bioemulsifier from *Candida lipolytica*. *Applied Environmental Microbiology*, v.50, n.4, p.846-850, 1985.

COOPER, D.G.; PADDOCK, D.A. *Torulopsis petrophilum* and Surface Activity. *Applied Environmental Microbiology*, v.46, n.6, p. 1426-1429, 1983.

DESAI, J.D.; BANAT, M. Microbial production of surfactants and their commercial potential. *Microbiology and Molecular Biology Reviews*, v.61, n.1, p.47-64, 1997.

FONTES, G.C.; AMARAL, P.F.F.E.; COELHO, M.A.Z. Produção de biossurfactante por levedura. *Química Nova*, v.40, p.316-323, 2008. DOI: 10.1590/S0100-40422008000800033

FONTES, G.C.; RAMOS, N.M.; AMARA, P.F.F.; NELE, M.; COELHO, M.A.Z. Renewable resources for biosurfactant production by *Yarrowia lipolytica*. *Brazilian Journal of Chemical Engineering*, v.29, n.3, p.483-493, 2012. DOI: 10.1590/S0104-66322012000300005

FUKUOKA, T.; MORITA, T.; KONISH, M.; IMURA, T.; KITAMOTO, T. Characterization of new glycolipid biosurfactants, tri-acylated mannosylerythritol lipids, produced by *Pseudozyma* yeasts. *Biotechnology Letters*, v.29, n.7, p.1111-1118, 2007a. DOI: 10.1007/s10529-007-9363-0

FUKUOKA, T.; MORITA, T.; KONISH, M.; IMURA, T.; KITAMOTO, T. Structural characterization and surface-active properties of a new glycolipid biosurfactant, mono-acylated mannosylerythritol lipid, produced from glucose by *Pseudozyma antarctica*. *Applied Microbiology Biotechnology*, v.76, p.810-810, 2007b. DOI: 10.1007/s00253-007-1051-4

GALAFASSI, S.; CUCCHETTI, D.; PIZZA, F., FRANZOSI, G.; BIANCHI, D.; COMPAGNO, C. Lipid production for second generation biodiesel by the oleaginous yeast *Rhodotorula graminis*. *Bioresource Technology*, v.111, p.398-403, 2012. DOI: 10.1016/j.biortech.2012.02.004

GAUTAM, G.; MISHRA, V.; VERMA, P.; PANDEY, A.K.; NEGI, S. A Cost Effective Strategy for Production of Bio-surfactant from Locally Isolated *Penicillium chrysogenum* SNP5 and its Applications. *Journal of Bioprocessing and Biotechniques*, v.4, n.6, p.1-7, 2014. DOI: 10.4172/2155-9821.1000177

GONG, Z.; SHEN, H.; ZHOU, W.; WANG, Y.; YANG, X.; ZHAO, Z.K. Efficient conversion of acetate into lipids by the oleaginous yeast Cryptococcus curvatus. *Biotechnology Biofuels*, v.8, p.1, 2015.

HOMMEL, R.K.; WEBER, L.; WEISS, A.; HIMMELREICH, U.; RILKE, O.; KLEBER, H.-P. Production of sophorose lipid by *Candida* (*Torulopsis*) *apicola* grown on glucose. *Journal of Biotechnology*, v.33, n.2, p.147-155, 1994. DOI: 10.1016/0168-1656(94)90107-4

HUA, Z.; CHEN, J.; LUN, S.; WANG, X. Influence of biosurfactants produced by Candida antarctica on surface properties of microorganism and biodegradation of n-alkanes. *Water Research*, v.37, n.17, p.4143-4150, 2003. DOI: 10.1016/S0043-1354(03)00380-4

JAMAL, P.; NAWAWI, W.; NAWAWI, W.M.F.W.; ALAM, Z. Optimum medium components for biosurfactant production by *Klebsiella pneumoniae* WMF02 utilizing sludge palm oil as a substrate. *Australian Journal of Basic and Applied Sciences*, v.6, n.1, p.100-108, 2012.

KAKUGAWA, K.; TAMAI, M.; IMAMURA, K.; MIYAMOTO, K.; MIYOSHI, S.; MORINAGA, Y.; SUZUKI, O.; MIYAKAWA, T. Isolation of yeast *Kurtzmanomyces* sp. I-11, novel producer of mannosylerythritol lipid. *Bioscience Biotechnology Biochemistry*, v.66, n.1, p.188-191, 2002. DOI: 10.1271/bbb.66.188

KALYANI, A.L.T.; SIREESHA, G.N.; SANKAR, G.G.G.; PRABHAKAR, T. Isolation of bio-surfactant producing actinomycetes from terrestrial and marine soils. *International Journal of Pharmaceutical Sciences and Research*, v.5, n.9, p.4015, 2014. DOI: 10.13040/IJPSR.0975-8232.5(9).4015-22

KANNAHI, M.; SHERLEY, M. Biosurfactant production by *Pseudomonas putida* and *Aspergillus Níger* from oil contaminated site. *International Journal Chemical and Pharmaceutical Sciences*, v.3, n.4, p.37-43, 2012.

KATEMAI, W. Biosurfactants from Yeasts: characteristics, production and application. *Walailak Journal of Science and Technology*, v.9, n.1, p.1-8, 2012.

KATEMAI, W.; MANEERAT, S.; KAWAI, F.; KANZAKI, H.; NITODA, T.; H-KITTIKUN, A. Purification and characterization of a biosurfactant produced by *Issatchenkia orientalis* SR4. *The Journal of General and Applied Microbiology*, v.54, n.1, p.79-82, 2008.

KARATAY, S.E.; DÖNMEZ, G. Improving the lipid accumulation properties of the yeast cells for biodiesel production using molasses. *Bioresource Technology*, v.101, p.7988-7990, 2010. DOI: 10.1016/j.biortech.2010.05.054.

KIM, H.S.; JEON, J.W.; KIM, B.H.; AHN, C.Y.; OH, H.M.; YOON, B.D. Extracellular production of a glycolipid biosurfactant, mannosylerythritol lipid, by *Candida* sp. SY16 using fed-batch fermentation. *Applied Microbiology Biotechnology*, v.70, n.4, p.391-396, 2006. DOI: 10.1007/s00253-005-0092-9

KIM, H.-S.; JEON, J.-W.; KIM, S.-B.; OH, H.-M.; KWON, T.-J.; YOON, B.-D. Surface and physico-chemical properties of a glycolipid biosurfactant, mannosyl erythritol lipid, from *Candida antarctica*. *Biotechnology Letters*, v.24, n.19, p.1637-1641, 2002.

KIRAN, G.S.; HEMA, T.A.; GANDHIMATHI, R.; SELVIN, J.; THOMAS, T.A.; RAVJI, T.R.; NATARAJASEENIVASAN K. Optimization and production of a biosurfactant from the sponge-associated marine fungus *Aspergillus ustus* MSF3. *Colloids and Surfaces B: Biointerfaces*, v.73, n.2, p.250-256, 2009. DOI: 10.1016/j.colsurfb.2009.05.025.

KITAMOTO, D.; IKEGAMI, T.; SUZUKI, G.T.; SASAKI, A.; TAKEYAMA, Y.; IDEMOTO, Y.; KOURA, N.; YANAGISHITA, H. Microbial conversion of n-alkanes into glycolipid biosurfactants, mannosylerythritol lipids, by *Pseudozyma* (*Candida antarctica*). *Biotechnology Letters*, v.23, n.20, p. 1709-1714, 2001.

KOMA, D.; HASUMI, F.; YAMAMOTO, E.; OHTA, T.; CHUNG, S.Y.; KUBO, M. Biodegradation of long-chain n-paraffins from waste oil of car engine by *Acinetobacter* sp. *Journal of Bioscience and Bioengineering*, v.91, n.1, p.94-96, 2001. DOI: 10.1016/S1389-1723(01)80120-1

KONISHI, M.; FUKUOKA, T.; MORITA, T.; IMURA, T.; KITAMOTO, D. Production of new types of sophorolipids by *Candida batistae*. *Journal of Oleo Science*, v.57, n.6, p.359-369, 2008. DOI: 10.5650/jos.57.359

KOSARIC, N. Biosurfactants and Their Application for Soil Bioremediation. *Food Technology and Biotechnology*, v.39, n.4, p.295-304, 2001.

KREPSKY, N.I.; DA SILVA, F.S.I.; FONTANA, L.F.I.; CRAPEZ, M.A.C. Alternative methodology for isolation of biosurfactant-producing bacteria. *Brazilian Journal Biology*, v.67, n.1, p.117-124, 2007. DOI: 10.1590/S1519-69842007000100016

LANCIOTTI, R.; GIANOTTI, A.; BALDI, D.; ANGRISANI, R. SUZZI, G.; MASTROCOLA, D.; GUERZONI, M.E. Use of *Yarrowia lipolytica* strains for the treatment of olive mill wastewater. *Bioresource Technology*, v.96, n.3, p.317-322, 2005. DOI: 10.1016/j.biortech.2004.04.009

LIMA, J.M.S.; PEREIRA, J.O.; BATISTA, I.H.; COSTA NETO, P.Q.; DOS SANTOS, J.C.; ARAÚJO, S.P.; PANTOJA, M.C.; MOTA, A.J.; AZEVEDO, J.L. Potential biosurfactant producing endophytic and epiphytic fungi, isolated from macrophytes in the Negro River in Manaus, Amazonas, Brazil. *African Journal Biotechnology*, v.15, n.24, p.1217-1223, 2016. DOI: 10.5897/AJB2015.15131

LIMA, R.A.; RODRIGUEZ, D.M.; ANDRADE, R.F.S.; TAKAI, G.C. Production and characterization of biosurfactant isolated from *Candida glabrata* using renewable substrates. *African Journal of Microbiology Research*, v.11, n.6, p.237-244, 2017. DOI: 10.5897/AJMR2016.8341

LINS, A.B.; BIONE, A.P.; FONSECA, T.C.S.; SILVA, T.C.; ANDRADE, R.F.S.; CAMPOS-TAKAKI, G.M. Biosurfactant production by *Cunninghamella phaeosphora* UCP 1303 using controlled temperature through of arduino. *International Journal of Current Microbiology and Applied Sciences*, v.6, n.12, p.2708-2715, 2017. DOI: 10.20546/ijcmas.2017.612.314

LIU, Y.; KOH, C.M.J.; JI, L. Bioconversion of crude glycerol to glycolipids in Ustilago maydis. *Bioresource Technology*, v.102, n.4, p.3927-3933, 2011. DOI: 10.1016/j.biortech.2010.11.115

LUKONDEH, T.; ASHBOLT, N.J.; ROGERS, P.L. Evaluation of *Kluyveromyces marxianus* as a source of yeast autolysates. *Journal of Industrial Microbiology and Biotechnology*, v.30: 52–56. DOI 10.1007/s10295-002-0008-y.

LUNA, J.M.; SARUBBO, L.A.; CAMPOS-TAKAKI, G.M. A new biosurfactant produced by *Candida glabrata* UCP1002: characteristics of stability and application in oil recovery. *Brazilian Archives of Biology and Technology*, v.52, n.4, p.785-793, 2009. DOI: 10.1590/S1516-89132009000400000

LUNA, J.M.; RUFINO, R.D.; SARUBBO, L.A.; CAMPOS-TAKAKI, G.M. Characterisation, surface properties and biological activity of a biosurfactant produced from industrial waste by *Candida sphaerica* UCP0995 for application in the petroleum industry. *Colloids Surface and Interface B*, v.102, p.202-209, 2013. DOI: 10.1016/j.colsurfb.2012.08.008

MORITA, T.; KONISHI, M.; FUKUOKA, T.; IMURA, T.; KITAMOTO, H.K.; KITAMOTO, D. Characterization of the genus *Pseudozyma* by the formation of glycolipid biosurfactants, mannosylerythritol lipids. *FEMS Yeast Research*, v.7, n.2, p.286-292, 2007. DOI: 10.1111/j.1567-1364.2006.00154.x

MOSSA, T.A.A.; AHMED, G.M.; ABDEL-HAMID, S.M.S. Optimization of cultural conditions for biosurfactant production from Nocardia amarae. *Journal of Applied Sciences Research*, v.2, n.11, p.844-850, 2006.

MUTHUSAMY, K.; GOPALAKRISHNAN, S.; KOCHUPAPPY RAVI, T.; SIVACHIDAMBARAM, P. Biosurfactants: properties, commercial production and application. *Current Science*, v.94, n.6, 736-p.746, 2008.

NITSCHKE, M.; PASTORE, G.M. Biossurfactantes: propriedades e aplicações. *Química Nova*, São Paulo, v.25, n.5, p.772-776, 2002. DOI: 10.1590/S0100-40422002000500013

OCHSNER, U.A.; KOCH, A.K.; FIECHTER, A.; REISER, J. Isolation and characterization of a regulatory gene affecting rhamnolipid biosurfactant synthesis in *Pseudomonas aeruginosa*. *Journal of bacteriology*, v.176, n.7, p.2044-2054, 1994. DOI: 10.1128/jb.176.7.2044-2054.1994

PACWA-PLOCINICZAK, M.; PLAZA, G.A.; PIOTROWSKA SEGET, Z.; CAMEOTRA, S.S. Environmental applications of biosurfactants: Recent Advances. *International Journal of Molecular Sciences*, v.12, n.1, p.633-654, 2011. DOI: 10.3390/ijms12010633

PAPANIKOLAOU, S.; CHEVALOT, I.; KOMAITIS, M.; MARC, I.; AGGELIS, G. Single cell oil production by *Yarrowia lipolytica* growing on an industrial derivative of animal fat in batch cultures. *Applied. Microbiology Biotechnology*, v.58, p.308-312, 2002. DOI: 10.1007/s00253-001-0897-0

PELE, M.A.; MONTERO-RODRIGUEZ, D.; RIBEAUX, D.R.; SOUZA, A.F.; LUNA, M.A.C.; SANTIAGO, M.F.; ANDRADE, R.F.S.; SILVA, T.A.L.; SANTIAGO, A.L.C.M.A.; CAMPOS-TAKAK, G.M. Development and improved selected markers to biosurfactant and bioemulsifier production by *Rhizopus* strains isolated from Caatinga soil. *African Journal of Biotechnology*, v.17, n.6, p.150-157, 2018. DOI: 10.5897/AJB2017.16230

PERFUMO, A.; BANAT, I.M.; MARCHANT, R. Going Green and Cold: Biosurfactants from Low-Temperature Environments to Biotechnology Applications. *Trends in biotechnology*, v.36, n.3, p.277-289, 2018. DOI: 10.1016/j.tibtech.2017.10.016

PRADHAN, A.K. A bioactive microbial compound having various biotechnological activities: biosurfactant. *Journal Bacteriology and Infectious Diseases*, v.1, n.1,1-2, 2017.

QAZI, M.A.; KANWA, T.; JADOON, M.; AHMED, S.; FATIMA, N. Isolation and characterization of a biosurfactant-producing Fusarium sp. BS-8 from oil contaminated soil. *Biotechnology Progress*, v.30, n.5, p.1065-1075, 2014. DOI: 10.1002/btpr.1933.

RAJESH, M.; SAMUNDEESWARI, M.; ARCHANA, B. Isolation of Biosurfactant Producing Bacteria from Garbage Soil. *Journal Applied & Environmental Microbiology*, v.5, n.2, p. 74-78, 2017. DOI: 10.12691/jaem-5-2-3

RAU, U.; NGUYEN, L.A.; ROEPER, H.; KOCH, H.; LANG, S. Downstream processing of mannosylerythritol lipids produced by *Pseudozyma aphidis*. *European Journal of Lipid Science and Technology*, v.107, n.6, p.373-380, 2005. DOI: 10.1002/ejlt.200401122

ROCHA E SILVA, N.M.P.; RUFINO, R.D.; LUNA, J.M.; SANTOS, V.A.; SARUBBO, L.A. Screening of *Pseudomonas* species for biosurfactant production using low-cost substrates. *Biocatalise Agriculture Biotechnology*, v.3, p.132-139, 2014. DOI: 10.1016/j.bcab.2013.09.005

ROELANTS, S.L.; SAERENS, K.M.; DERYCKE, T.; LI, B.; LIN, Y.C.; VAN DE PEER, Y.; DE MAESENEIRE, S.L.; VAN BOGAERT, I.N.; SOETAERT, W. *Candida bombicola* as a platform organism for the production of tailor-made biomolecules. *Biotechnology of Bioengineering*, v.110, n.9, p. 2494-503, 2013. DOI: 10.1002/bit.24895

RUFINO, R.D.; LUNA, J.M.; CAMPOS-TAKAKI, G.M.; SARUBBO, L.A. Characterization and properties of the biosurfactant produced by *Candida lipolytica* UCP 0988. *Electronic Journal of Biotechnology*, v.17, n.1, 2014. DOI: 10.1016/j.ejbt.2013.12.006

RUFINO, R.D.; LUNA, J.M.; SARUBBO, L.A.; RODRIGUES, L.R.M.; TEXEIRA, J.A.C.; CAMPOS-TAKAKI, G.M. Antimicrobial and anti-adhesive potential of a biosurfactant Rufisan produced by *Candida lipolytica* UCP 0988. *Colloids Surfurface and Inteface B*, v.84, p.1-5, 2011. DOI: 10.1016/j.colsurfb.2010.10.045

SAENGE, C.; CHEIRSILP, B.; SUKSAROGE, T.T; BOURTOOM, T. Potential use of oleaginous red yeast *Rhodotorula glutinis* for the bioconversion of crude glycerol from biodiesel plant to lipids and carotenoids. *Process Biochemistry*, v.46, p.210-218, 2011. DOI: 10.1016/j.procbio.2010.08.009

SARUBBO, L.A.; FARIAS, C.B.; CAMPOS-TAKAKI, G.M. Co-Utilization of Canola Oil and Glucose on the Production of a Surfactant by *Candida lipolytica*. *Current Microbiology*, v.54, n.1, p.68-73, 2007. DOI: 10.1007/s00284-006-0412-z

SARUBBO, L.A.; MARÇAL, M.C.; NEVES, M.L.C.; SILVA, M.P.C.; PORTO, A.L.F.; CAMPOS-TAKAKI, G.M. Bioemulsifier production in batch culture using glucose as carbon source by *Candida lipolytica*. *Applied Biochemistry Biotechnology*, v.95, n.1, p.59-67, 2001. DOI: 10.1385/ABAB:95:1:59

SARUBBO, L.A.; LUNA, J.M.; CAMPOS-TAKAKI, G.M. Production and stability studies of the bioemulsifier obtained from a new strain of *Candida glabrata* UCP 1002. *Electronic Journal of Biotechnology*, v.9, n.4, p.400-406, 2006. DOI: 10.4067/S0717-34582006000400008

SHEPERD, R.; ROCKEY, J.; SUTHERLAND, I.W.; ROLLER, S. Novel bioemulsifiers from microorganisms for use in foods. *Journal of Biotechnology*, v.40, n.3, p.207-217, 1995. DOI: 10.1016/0168-1656(95)00053-S

SILVA, N.R.A.; LUNA, M.A.; SANTIAGO, A.L.; FRANCO, L.O.; SILVA, G.K.; DE SOUZA, P.M.; OKADA, K.; ALBUQUERQUE, C.D.; DA SILVA, C.A.; CAMPOS-TAKAKI, G.M. Biosurfactant-and-Bioemulsifier Produced by a Promising *Cunninghamella echinulata* isolated from Caatinga Soil in the Northeast of Brazil. *International Journal of Molecular Sciences*, v.15, n.9, p. 15377-15395, 2014. DOI: 10.3390/ijms150915377.

SILVA, G.K.B.; NEGREIROS, J.M.; SILVA, N.R.A.; SILVA, T.A.L.E.; BARBOSA, R.N.; OLIVEIRA, N.T.; OKADA, K.; CAMPOS-TAKAKI, G.M. Characterization of *Aspergillus niger* isolated from Caatinga soil with potential of biosurfactant production. *In*: MÉNDEZ-VILAS, A. (Org.). *Industrial, Medical and Environmental Applications of Microorganisms Current Status and Trends*. Madrid: eBookstore, 2015. p.65-69. DOI: 10.3390/ijms150915377.

SINGH, M.; DESAI, J.D. Hydrocarbon emulsification by *Candida tropicalis* and *Debaryomyces polymorphus*. *Indian Journal of Experimental Biology*, v.27, n.3, p.224-226, 1989.

SOBRINHO, H.B.S.; RUFINO, R.D.; LUNA, J.M.; SALGUEIRO, A.A.; CAMPOS-TAKAKI, G.M.; LEITE, L.F.C.; SARUBBO, L.A. Utilization of two agroindustrial by-products for the production of a surfactant by *Candida sphaerica* UCP0995. *Process Biochemistry*, v.43, n.9, p.912-917, 2008. DOI: 10.1016/j.procbio.2008.04.013

SOLAIMAN, D.K.; ASHBY, R.D.; NUÑEZ, A.; FOGLIA, T.A. Production of sophorolipids by *Candida bombicola* grown on soy molasses as substrate. *Biotechnology Letters*, v.26, n.15, p.1241-1245, 2004. DOI: 10.1023/B:BILE.0000036605.80577.30

SOUZA, A.F.; RODRIGUEZ, D.M.; RIBEAUX, D.R.; LUNA, M.A.; LIMA E SILVA, T.; ANDRADE, R.F.; GUSMÃO, N.B.; CAMPOS-TAKAKI, G.M. Waste Soybean Oil and Corn Steep Liquor as Economic Substrates for Bioemulsifier and Biodiesel Production by *Candida lipolytica* UCP 0998. *International Journal of Molecular Science*, v.17, n.10, p.1608-1626, 2016. DOI: 10.3390%2Fijms17101608

SOUZA, K.S.T.; GUDIÑA, E.J.; AZEVEDO, Z.; FREITAS, V.; SCHWANA, R.F.; RODRIGUES, L.R.; DIAS, D.R.; TEIXEIRA, J.A. New glycolipid biosurfactants produced by the yeast strain *Wickerhamomyces anomalus* CCMA 0358. *Colloids and Surfaces B: Biointerfaces*, v.154, p.373-382, 2017. DOI: 10.1016/j.colsurfb.2017.03.041

SOUZA, P.M.; SILVA, T.A.L.; FREITAS-SILVA, M.C.; ANDRADE, R.F.S.; LIMA, M.A.B.; SILVA, P.H.; FONSECA, T.C.S.; CAMPOS-TAKAKI, G.M. Factorial Design based Medium Optimization for the Improved Production of Biosurfactant by *Mucor polymorphosphorus*. *International Journal of Current Microbiology and Applied*, v.5, n.11, p.898-905, 2016. DOI: 10.20546/ijcmas.2016.511.103

______. Production of Tensioactive Compound using Waste Soy Oil and Corn Steep Liquor by Mucoralean fungus *Cunninghamella bertolletiae*. *International Journal of Current Microbiology and Applied Science*, v.6, n.12, p.2728-2737, 2017. DOI: 10.20546/ijcmas.2017.612.316

SYLDATK, C.; WAGNER, F. Biosurfactants and Biotechnology, Marcel Dekker: New York, cap. 3, 1987.

THANOMSUB, B.; WATCHARACHAIPONG, T.; CHOTELERSAK, K.; ARUNRATTIYAKORN, P.; NITODA, T.; KANZAKI, H. Monoacylglycerols: glycolipid biosurfactants produced by a thermotolerant yeast, *Candida ishiwadae*. *Journal of Applied Microbiology*, v.96, n.3, p.588-592, 2004. DOI: 10.1111/j.1365-2672.2004.02202.x

TULLOCH, A.P.; SPENCER, J.F.T.; DEINEMA, M.H. A new hydroxy fatty acid sophoroside from *Candida bogoriensis*. *Canadian Journal of Chemistry*, v.46, n.3, p.345-348, 1968. DOI: 10.1139/v68-057

VANCE-HARROP, M.H.; GUSMÃO, N.B.; CAMPOS-TAKAKI, G.M. New bioemulsifiers produced by *Candida lipolytica* using D-glucose and babassu oil as carbon sources. *Brazilian Journal of Microbiology*, São Paulo, v.34, n.2, p. 120-123, 2003. DOI: 10.1590/S1517-83822003000200006

ZINJARDE, S.; CHINNATHAMBI, S.; LACHKE, A.H.; PANT, A. Isolation of an emulsifier from *Yarrowia lipolytica* NCIM 3589 using a modified mini isoelectric focusing unit. *Applied Microbiology*, v.24, n.2, p.117-121, 1997. DOI: 10.1046/j.1472-765X.1997.00355.x

YOON, S.H.; RHEE, J.S. Lipid from yeast fermentation: Effects of cultural conditions on lipid production and its characteristics of *Rhodotorula glutinis*. *Journal of the American Oil Chemists' Society*, v.60, n.7, p.1281-1286, 1983.