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MICROBIAL SURFACE-ACTIVE SUBSTANCES AS ANTIADHESIVE AGENTS

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The literature data of recent years about capacity of biosurfactants synthesized by bacteria (*Pseudomonas, Lactobacillus, Bacillus*) and fungi (*Candida, Trichosporon, Saccharomyces*) not only to avert the adhesion of microorganisms on the different materials, but also to destroy formed biofilms on them were presented. The perspective of biosurfactants to prevent pathogens colonization on biotic and abiotic surfaces, that is known, can be a reason of cause and spread of infectious diseases was discussed. The data of our researches about antiadhesive properties of biosurfactants synthesized by *Acinetobacter calcoaceticus* IMV B-7241, *Nocardia vaccinii* IMV B-7405 and *Rhodococcus erythropolis* IMV Ac-5017 were presented.

Key words: surface-active substances of microbial origin, microbial adhesion, biofilm disruption.

Surfactants synthesized by microorganisms (MS) are widely used in different branches of industry. The applying of microbial surfactants in biology and medicine as an alternative to synthetic disinfectants or drugs is promising due to their antimicrobial and antiadhesive properties.

MS are amphiphilous compounds that lower the surface and interfacial tension in liquids. Due to the advantages of MS over their synthetic analogues (biodegradability, lack of toxicity, stability of physicochemical properties in a wide range of temperatures and pH), as well as their unique biological properties, these substances keep attracting more and more interest [1]. Thus MS have already been tried and shown promise in petroleum production and mining, in chemical and food industries, in agriculture, and in nature-friendly technologies for environmental remediation [2].

In 2011, a review of practical applying of MS for biology and medicine [3] analyzed their antimicrobial (antiviral, antibacterial and antifungal) and anti-adhesive activities, as well as the possibility of using these products of microbial synthesis for therapeutic purposes. In 2014, Mulligan et al. published a monograph [4] summarizing the information on microbial biosurfactants, including their anti-adhesive properties.

Since 1990s, microbial biosurfactants have been massively studied as alternatives for the preparations that disrupt biofilms on various materials used in medicine and in food industry. Microorganisms colonizing surfaces are known to be a fairly dangerous phenomenon, resulting in spoilage of food and facilitating the spread of infectious diseases. Many studies proved the possibility of using inorganic (for example, silver [5]) and other chemical substances (ellagic acid, esculetin, fisetin [6]) to prevent adhesion, antibiotics and bacteriophage therapy [7] to fight various infections. However, emergence of resistance of microorganisms to antibiotics and other biocides, and the high costs of methods of adhesion prevention and biofilm disruption stimulated the search of new substances with necessary properties.

Compared to accepted anti-adhesive agents, MS have a range of advantages [1–4]:

– they do not pollute the environment, since they are biodegradable;

– they do not induce allergic reactions, because are non-toxic;;

– because they are can be used in various environmental conditions due to stable physicochemical properties;

– their highly specific mechanisms of action prevent the emergence of resistant microorganisms.

The aim of this review is to summarize the current reports on anti-adhesive potential of biosurfactants, synthesized by different groups of microorganisms, and on their ability to disrupt biofilms on abiotic and biotic surfaces.

Anti-adhesive properties of surfactants synthesized by bacteria of Pseudomonas genus

Rhamnolipids. First reports of these surfactants come from as early as 1940-es [8]. The rhamnolipids consist of one or two rhamnose molecules bound to one, two (seldom three) molecules of hydroxyaliphatic acids. Depending on the number of the carbohydrate molecules and fatty acids they are usually classified as mono-rhamno-mono-lipids, mono-rhamno-di-lipids, di-rhamno-mono-lipids and di-rhamno-di-lipids. Over 60 homologues of rhamnolipids are synthesized by bacteria of *Pseudomonas genus* (*Pseudomonas chlororaphis, Pseudomonas alcaligenes, Pseudomonas putida, Pseudomonas stutzeri,* etc.), yet the main producers are strains of *Pseudomonas aeruginosa* [4, 9–11].

Despite the long history of research, biological properties of rhamnolipids started not that long ago. Thus, in 2001, Abalos et al. found the antifungal action of seven homologues of rhamnolipids of *P. aeruginosa* AT10, which in low concentrations (16–32 μg/ml) inhibited the growth of *Aspergillus, Penicillium* and *Aureobasidium* fungi, as well as the phytopathogenic *Botrytis* and *Rhizoctonia* [12]. In 2003, antimicrobial action of rhamnolipids of *P. aeruginosa* 47T2 NCBIM 40044 was published [13]. Thus, minimal inhibitory concentrations (MIC) of these surfactants against some bacteria of genera *Serratia*, *Enterobacter*, *Klebsiella*, and *Staphylococcus* were 0.5–32 μg/ml. Studies [12, 13] inspired the following research directed at the possibility of using microbial surfactants as antimicrobial agents [14–16]. After several years (in 2005) it was established that besides the antimicrobial action, rhamnolipids of *P. aeruginosa* PAO1 alsopossess anti-adhesive properties [17]. It was found that the surfactants prevented biofilm formation by *Bordetella bronchiseptica* TK-4 on glass and silicon surfaces. Data on antimicrobial and anti-adhesive action of surfactants produced by *Pseudomonas* representatives are summarized in reviews [10, 11, 18]. We provide results which were not included in those works.

The effect of rhamnolipids on attachment of microorganisms to various surfaces. Rodrigues et al. [19] studied anti-adhesive properties of rhamnolipids of *P. aeruginosa* DS10-129 and established that the number of the attached bacterial (*Staphylococcus epidermidis* GB 9/6, *Staphylococcus aureus* GB 2/1, *Streptococcus salivarius* GB 24/9, *Rothia dentocariosa* GBJ 52/2B) and yeast (*Candida tropicalis* GB 9/9, *Candida albicans* GBJ 13/4A, *C. tropicalis* GB 9/9) cells decreased to 40 and 30% respectively if the silicon was pretreated by a surfactant preparation at 4 mg/ml. Also, Janek et al. [20] demonstrated the influence of di-rhamnolipids and phosphatidylethanolamines synthesized by *Pseudomonas putida* BD2 on the attachment of microorganisms to polystirol, which is the material of most medical prostheses. Surfactant preparations were obtained by extracting the supernatant of cultural liquid of *P. putida* BD2 with ethyl acetate. As test cultures, bacteria *Escherichia coli* ATCC 10536, *E. coli* 17-2, *Enterococcus faecalis* ATCC 29212, *E. faecalis* JA/3, *Enterococcus hirae* ATCC 10541, *S. epidermidis* KCTC 1917, *Proteus mirabilis* ATCC 21100 and yeasts *C. albicans* ATCC 20231, *C. albicans* SC5314, isolated from Wrocław hospitals were used. If the polystirol was pretreated with di-rhamnolipids (0.5 mg/ml), the amount of the attached bacterial and yeast cells decreased to 21–57 and 10–11%, respectively. Phosphatidylethanolamines were less efficient anti-adhesive agents: their presence inhibited the adhesion of bacteria and yeasts only to 77 and 21%, respectively [20]. The authors of [21] established the efficiency of using rhamnolipids of *P. aeruginosa* LCD12 to prevent the attachment of cells of *Bacillus subtilis* RI6, *E. coli* PJ3, *S. aureus* FD5, *S. epidermidis* LK8 to a polystirol surface. Adhesion of test cultures was 50–80% if the wells of microplate were pre-treated with surfactant of LCD12 strain at the concentration of 8–64 μg/ml [21].

The role of rhamnolipids in biofilm destruction. The research of the last years is notable for having not only established not only the anti-adhesive properties of rhamnolipids but also their role in biofilm destruction on medical materials. Since *S. aureus* cause various infectious diseases, Gomesa and Nitschke [22] studied the effect of rhamnolipids of *P. aeruginosa* S5 on the destruction of biofilm of this pathogen. Experiments showed that as soon as two hours later, rhamnolipids caused biofilm destruction by 40–55% (depending on the surfactant concentration), and after twelve hours exposure, by 70–80%. In [21], Das et al. showed that rhamnolipids of *P. aeruginosa* LCD12 were able not only to prevent the attachment of *S. aureus* FD5,

S. epidermidis LK8, *B. subtilis* RI6, *E. coli* PJ3 cells to polystirol surface, but to destroy biofilms formed by the test cultures on the material. Thus, in the presence of surfactant of LCD12 strain (8–64 μg/ml) the biofilms of the test cultures were destroyed by 35–50%. A collective of scientists [23] studied the ability of rhamnolipids of *P. aeruginosa* HG3 to destroy the biofilm of yeast *Yarrowia lipolytica* NCIM 3589. Their contribution is rather important since it had been established that *Y. lipolytica* is an opportunistic microorganism, able to cause invasive candidiasis in patients who are fed parenterally [24]. Thus, Dusane et al. [23] showed that an hour after the biofilm on a polystirol surface was treated with preparations of P. aeruginosa HG3 surfactants (3.0–100 mg/ml) the degree of its destruction was 40–50%, and after three hours, in the presence of 6–12 mg/ml rhamnolipids it reached 75%. Singh et al. studied the ability of di-rhamnolipids of *P. aeruginosa* DSVP20 to destroy the structure formed by yeast *C. albicans* GH103 on polystirol [25]. Before that [26], it was established that these microorganisms easily colonize surfaces of prostheses (larynx, knee, heart valves), implants (especially breast), endotracheal tubes, leading to the infection spreading throughout the organism. In the experiment they used a solution of the surfactant, obtained by extracting it from the supernatant of the cultural liquid of *P. aeruginosa* DSVP20 with ethyl acetate. The efficiency of the destruction process for the biofilm of *C. albicans* GH103 in the wells of a microplate depended on the concentration of di-rhamnolipids (0.04–5.0 mg/ml) and exposure [25]. Thus, experiments showed that 50–60% yeast cells remained in the biofilm on polystirol surface two hours after treatment with surfactant (0.16–0.62 mg/ml) produced by DSVP20 strain. However, at higher concentrations of *P. aeruginosa* DSVP20 surfactant, after twelve hours the biofilm was practically totally destroyed (Table 1). Turbhekar et al. [27] established the ability of *P. aeruginosa* RT rhamnolipids to destroy the biofilm of *C. albicans* BT107. A single hour after the surface was treated with the surfactant preparation, the degree of destruction of BT107 strain biofilm on the polystirol surface was, on average, 52%, and after three hours of exposure at the surfactant concentration of 25–100 mg/ml it reached 70%.

An overview of data on anti-adhesive properties of rhamnolipids, synthesized by

Table 1. **Destruction of *C. albicans* GH103 biofilm on polystirol surface in the presence of *P. aeruginosa* DSVP20 di-rhamnolipids [25]**

Surfactant concentration, mg/ml	Exposure, hours	Biofilm degradation, (%)
0.16	2	50
0.31	2	55
0.62	2	60
1.25	12	65
2.5	12	70
5.0	12	90

oorganisms of *Pseudomonas* genus and their role in biofilm destruction on medical materials are shown in Table 2.

Lipopeptides. In early 1990-es [28] it was established that bacteria of *Pseudomonas* genus are able to produce not only rhamnolipids, but also lipopeptides. Lipopeptides consist of a lipid part connected with a short linear or cyclical oligopeptide. They differ by the length and composition of the lipid residue, the type, number and configuration of the amino acids in the peptide [4, 29]. The [4] and [29] provide the generalized information about the lipopeptide producers among the bacteria of *Pseudomonas*, pathways of surfactant synthesis, their antimicrobial and antifungal properties, practical use. However, these reviews mostly lack info on the anti-adhesive properties of lipopeptides of the bacteria of *Pseudomonas* genus. Until quite recently, anti-adhesive properties were studied only for glycolipids of *Pseudomonas* sp., but in 2010, Raaijmakers et al. [30] established that lipopeptides viscosin and massetolide A, synthesized by *P. fuorescens* HT7, disrupted the process of plastic surface colonization by *P. aeruginosa* PAO1. Unfortunately, the article doesn't state at which concentration they applied the lipopeptides.

In 2012, a study showed isolation from Swalbard archipelago of a strain *P. fluorescens* BD5, able to synthesize pseudofactin II (cyclical lipopeptide). Janek et al. [31] extracted pseudofactin II with ethyl acetate from the cultural liquid of *P. fluorescens* BD5. The scientists conducted a number of experiments which showed that the lipopeptide, produced by strain BD5, prevents the attachment of *E. coli* FR47, *E. faecalis* UD35, *E. hirae* KB73, *S. epidermidis* DS41, *P. mirabilis* GD87 and *C. albicans* HU34 to various surfaces (glass, polystirol, silicon). Pretreating polystirol plates with pseudofactin II (0.5 mg/ml)

Table 2. **Effect of rhamnolipids on the adhesion of microorganisms and biofilm destruction**

Surfactant producers	Surfactant concentration, mg/ml	Test cultures	Studied material	Adhesion/ destruction (%)	Source
Anti-adhesive properties					
P. aeruginosa PAO1	–	*B. bronchiseptica* ТК-4	Glass, silicon	–	[17]
P. aeruginosa DS10-129	4	*S. epidermidis* GB 9/6, *S. salivarius* GB 24/9, *S. aureus* GB 2/1, *R. dentocariosa* GBJ 52/2B; *C. tropicalis* GB 9/9, *C. albicans* GBJ 13/4A, *C. tropicalis* GB 9/9	Silicon	30–40	[19]
P. putida BD2	0.5	*E. coli* ATCC10536, *E. coli* 17-2, *E. faecalis* ATCC 29212, *E. faecalis* JA/3, *E. hirae* ATCC 10541, *S. epidermidis* KCTC 1917, *P. mirabilis* ATCC 21100	Polystirol	21–57	[20]
		C. albicans ATCC20231, *C. albicans* SC5314		10–11	
P. aeruginosa LCD12	0.008–0.064	*B. subtilis* RI6, *E. coli* PJ3, *S. aureus* FD5, *S. epidermidis* LK8	Polystirol	50–80	[21]
Biofilm destruction					
P. aeruginosa S5	2.5–10.0	*S. aureus* ATCC 25923	Polystirol	70–80	[22]
P. aeruginosa LCD12	0.008–0.064	*B. subtilis* RI6, *E. coli* PJ3, *S. aureus* FD5, *S. epidermidis* LK8	Polystirol	35–50	[21]
P. aeruginosa HG3	6–12	*Y. lipolytica* NCIM 3589	Polystirol	75	[23]
P. aeruginosa DSVP20	1.25–5.0	*C. albicans* GH103	Polystirol	65–90	[25]
P. aeruginosa RT	25–100	*C. albicans* BT107	Polystirol	70	[27]

Note: – not reported.

inhibited adhesion of bacteria and yeast by 36–90 and 92–99%; silicon ones — by 18–37 and 8–9%, respectively. Adhesion of cells to glass did not exceed 26–70% for all studied bacteriae and yeast [31]. Therefore, each year brings more and more information on the surfactants of the bacteriae of *Pseudomonas* not only as efficient anti-adhesive agents to prevent microbes colonizing various surfaces [10, 11, 17–21], but as compounds able to destroy biofilms formed on abiotic and biotic materials [21–23, 25, 27]. However, rhamnolipids are still the most studied, since about lipopeptides we have to date only single reports. If surfaces of different materials (glass, silicon, polystirol) are treated with rhamnolipid preparations (0.008–4 mg/ml), microorganism adhesion decrease more than by 50%. Rhamnolipids (1.25–100 mg/ml) are also able to practically utterly destroy biofilms formed on polystirol.

Bacteria of Bacillus genus as producers of lipopeptides with anti-adhesive properties

Of the most studied lipopeptide producers, one can name the genus *Bacillus*, in particular strains of *B. subtilis*. These lipopeptides are divided into three families of cyclical compounds: surfactin, iturin and fengicin, differing by the position, length and isomers of fatty acids in their molecules [4, 29, 34]. The ability of *B. subtilis* AMS-H2O-1 to synthesize surfactin was first established in 1968 [32], and in 1977 *B. subtilis* DS-104 was found to produce iturin [33]. The reports [29, 34] and [4] provide summaries on most producers of lipopeptides, cultivation conditions and media, and practical applications. The first reports on the antimicrobial action of *B. subtilis* OKB105 surfactin go back to 1997. Vollenbroich et al. showed that the lipopeptide of OKB105 strain (0.032 mg/ml) could inhibit the growth of *Mycoplasma hyorhinis* and *Mycoplasma orale*,

able to cause infectious diseases of the urinary tract [35, 36].

In 2001, the surfactin produced by *B. subtilis* HT73 was for the first time shown to prevent attaching *Salmonella enterica* SJW1103 cells to polystirol and silicon [37]. It was established that the lipopeptide (5–50 μg/ml) lowered the number of the test culture cells attached to polystirol surface by 60–85%. These authors also established the efficiency of using the lipopeptide of the strain HT73 (100 μg/ml) for the total destruction of the biofilms of *S. enterica* SJW1103, *E. coli* TH5, *P. mirabilis* GI7 on urethral catheters. The data on biologic properties of the lipopeptides of bacteria *Bacillus* genus are given in [29, 34]. Let us consider the results on anti-adhesive properties which were not included in those reviews.

The effect of lipopeptides on the attachment of microorganisms to different surfaces

Zeraik and Nitschke [38] found the ability of surfactin, synthesized by *B. subtilis* LB5a, to prevent attaching to polystirol cells of *S. aureus* ATCC 25923, *Listeria monocytogenes* ATCC 19112 and *Micrococcus luteus* ATCC 4698 surface. Lipopeptide (10 mg/ml) of the strain LB5a decreased adhesion of the studied cells by 63–66%. The authors compared the efficiency of using surfactin of *B. subtilis* LB5a (10 mg/ml) and rhamnolipids of *P. aeruginosa* LB1 (40 mg/ml) as anti-adhesive preparations. Studies showed that lipopeptides of strain LB5a are more efficient anti-adhesive agents: adhesion of bacteria to the polystirol surface when treated with the rhamnolipids of strain LB1 was 2–3 times higher, then in the presence of surfactin.

Rivardo et al. [39] described the effect of lipopeptides, synthesized by *B. subtilis* V19T21 and *Bacillus licheniformis* V9T14, on the attachment of *S. aureus* ATCC 29213, *E. coli* CFT073, *P. aeruginosa* PA14 and *S. epidermis* TI23 to polyvinyl chloride, which is used for primary packing of medical preparations. Adhesion of *E. coli* CFT073 was efficiently reduced after treatment by surfactant preparation of strain V9T14 (2.6 μg/ml): number of attached cells did not exceed 7%. However, lipopeptide of B. licheniformis V9T14 did not prevent the colonization of surface by other test cultures (*S. aureus* ATCC 29213, *P. aeruginosa* PA14, *S. epidermis* TI23). The authors established that the surfactants of *B. subtilis* V19T21 (5–25 μg/ml) showed anti-adhesive activity against a wider range of bacteria than those of *B. licheniformis* V9T14: thus, after the surfaces were treated with superficially active substances of strain V19T21, the number of *E. coli* CFT073 cells attached to polyvinyl chloride surface, as well as cells of *S. aureus* ATCC 29213, *P. aeruginosa* PA14 and *S. epidermis* TI23, did not exceed 10%. The ability of strain *Bacillus cereus* NK1 to synthesize lipopeptides with expressed surface activity has also been investigated [40]. The authors found that these surfactants are able to prevent formation of biofilms of *P. aeruginosa* HP1 and *S. epidermidis* PI5 on plastic. At 15 mg/ml, the preparations of surfactants inhibited by 55–65% adhesion on abiotic surface both *P. aeruginosa* HP1 and *S. epidermidis* PI5. In the study [41] they showed that lipopeptides of *B. subtilis* AC7 are efficient against the formation of biofilm of *C. albicans* OD1. Thus, if the silicon surface of the urethral catheters was treated with preparations of surfactants of AC7 (20–200 μg/ml), the number of adherent cells of *C. albicans* OD1 dropped by more than 70%.

In 2013, Ajesh et al. [42] isolated strain *B. cereus* AK1, capable of synthesizing a lipopeptide which by its chemical composition was different from surfactin and iturin. It was proposed to be called kannurin. The authors managed to find the ability of kannurin (0.25–512 μg/ml) to prevent the attachment of yeasts *C. albicans* LK3 and *Cryptococcus neoformans* BM8 to silicon surface. Thus, when the material was treated with surfactant preparations (2–64 μg/ml), the adhesion of test cultures reduced by 25–75%.

The role of lipopeptides in the destruction of biofilms

Recent years showed increasing attention the researchers pay to the search of new lipopeptide surfactants capable not only of biofilm formation prevention but also of destroying those already established on medical materials, since microorganisms in their structure there are resistant practically to all known antimicrobial preparations [43]. Sriram et al. [40] studied the ability of lipopeptides of *B. cereus* NK1 to destroy formed biofilms of *P. aeruginosa* HP1 and *S. epidermidis* PI5 on polystirol surface. Experiments showed that as soon as two hours later, lipopeptides (5.0–15.0 mg/ml) disrupted the biofilm on average by 25–55% (Table 3).

The highest level of *P. aeruginosa* HP1 and *S. epidermidis* PI5 biofilm destruction (54–58%) was reached by using maximal (15 mg/ml) of the studied concentrations of surfactant preparations. Song et al. showed

Table 3. **The destruction of *P. aeruginosa* HP1 and *S. epidermidis* PI5 biofilms after treatment of polystirol surfaces with *B. cereus* NK1 lipopeptides [40]**

Surfactant concentration, mg/ml	Biofilm destruction, %	
	P. aeruginosa HP1	*S. epidermidis* PI5
0.1	2.5 ± 0.2	2.56 ± 0.3
0.2	2.63 ± 0.15	3.56 ± 0.5
0.4	4.5 ± 0.26	5.33 ± 0.5
0.8	7.56 ± 0.2	9.43 ± 0.5
1.6	13.5 ± 0.3	12.5 ± 0.6
5.0	22.7 ± 0.52	26.46 ± 0.4
10.0	31.76 ± 0.35	33.35 ± 0.12
15.0	54.21 ± 0.04	57.52 ± 0.55

that lipopeptides of *B. amyloliquefaciens* GH7 (25–75 μg/ml) are able to destroy, on polystirol surfaces, formed biofilms of the fungi *Metschnikowia bicuspidata* 2E00088, *C. tropicalis* 2E00879, *Y. lipolytica* 2E00856 and *Saccharomyces cerevisiae* 2E01006: the level of disruption was 35–50% [44]. The report inspired Rautela et al. [45], who studied the ability of lipopeptides of *B. amyloliquefaciens* AR2 to disrupt already formed on polystirol biofilms of the yeasts *C. albicans* (MTCC 1637, MTCC 4748 and MTCC 183). After three hours of treating the surface with lipopeptides of *B. amyloliquefaciens* AR2 (1–6 mg/ml) they observed destruction of biofilms on it. The most efficient (up to 80%) was the process of biofilm destruction by surfactants at the concentration of 6 mg/ml. The researchers found that if the polystirol surface was treated with lipopeptides at lower concentration (1–4 mg/ml), the exposure necessary to destroy the biofilm, was longer (6–12 hours). Table 4 summarizes data on anti-adhesive properties of lipopeptides of representatives of the genus *Bacillus* and their role in the destruction of biofilms on medical materials. Therefore, data prove the efficiency of using lipopeptides of the genus *Bacillus* as anti-adhesive agents [35–45]. If the surfaces were treated with preparations of lipopeptides (0.002–15.0 mg/ml), microbe adhesion decreased by more than 60%. The experiments showed that lipopeptides (0.025–15.0 mg/ml) are also able to practically utterly (80–90%) destroy biofilms formed on polystirol.

Surfactants of Lactobacillus genus bacteria as anti-adhesive agents

Data on surfactants, synthesized by representatives of the genus *Lactobacillus*, are scarce. Initial research appeared in 1990-es [46, 47]. In 1993, Blomberg et al. [46] found the ability of bacteria of the genus *Lactobacillus* (*Lactobacillus crispatus* 152, *Lactobacillus fermentum* 104R, *Lactobacillus murinus* C39 and others) to produce substances, able to prevent adhesion of cells of *E. coli* K88. In time (1996), it was established that these substances have high content of proteins, polysaccharides, phosphates. Nowadays, there is still next to nothing on the chemical composition of the surfactants synthesized by bacteria of the genus *Lactobacillus* [47–49]. The established ability of *L. fermentum* B54 and *Lactobacillus acidophilus* RC14 to produce surfactants which at 20 mg/ml prevented adhesion of *E. faecalis* 1131 on glass surfaces: after 4 hours, the amount of adherent cells did not exceed 30–33% [47]. Studying biological properties of surface-active substances of the representatives of the genus *Lactobacillus* is an urgent task, since they are the most suitable anti-adhesive agents for medicine due to lack of pathogenicity. Unfortunately, by now there are but few single data points suggesting the ability of these surfactants to prevent microbial colonization of various surfaces. Below we give an overview of latest years' research on anti-adhesive potential of surfactants synthesized by bacteria of the genus *Lactobacillus*.

The effect of surface-active substances on the adhesion of microorganisms to various surfaces

As the authors of [48] report, the surfactants of *Lactobacillus paracasei* ssp. *paracasei* A20 are able to prevent adhesion of some microorganisms to plastic. So, if plastic was treated with surfactant preparations (3–50 mg/ml), the amount of adherent cells of *E. coli* E-8 and *P. aeruginosa* L-7 was 11 and 21%,

Table 4. **The effect of the lipopeptides of the genus *Bacillus* on microbial adhesion and biofilm destruction**

Surfactant producers	Surfactant concentration, mg/ml	Test cultures	Material under study	Adhesion/ destruction (%)	Source
Anti-adhesive properties					
B. subtilis HT73	0.005–0.05	*S. enterica* SJW1103	Polystirol, silicon	60–85	[37]
B. subtilis LB5a	10	*S. aureus* ATCC 25923, *L. monocytogenes* ATCC 19112, *M. luteus* ATCC 4698	Polystirol	63–66	[38]
B. subtilis V19T21	0.005–0.025	*S. aureus* ATCC 29213, *E. coli* CFT073, *P. aeruginosa* PA14, *S. epidermis* TI23	Polyvinyl chloride	10	[39]
B. licheniformis V9T14	0.0026	*E. coli* CFT073	Polyvinyl chloride	7	[39]
B. cereus NK1	15	*P. aeruginosa* HP1, *S. epidermidis* PI5	Plastic	35–45	[40]
B. subtilis AC7	0.02–0.2	*C. albicans* OD1	Silicon	30	[41]
B. cereus AK1	0.002–0.064	*C. albicans* LK3, *C. neoformans* BM8	Silicon	25–75	[42]
Biofilm destruction					
B. subtilis HT73	0.1	*S. enterica* SJW1103, *E. coli* TH5, *P. mirabilis* GI7	Polystirol	~ 90	[37]
B. cereus NK1	5–15	*P. aeruginosa* HP1, *S. epidermidis* PI5	Polystirol	23–58	[40]
B. amyloliquefaciens GH7	0.025–0.075	*M. bicuspidata* 2E00088, *C. tropicalis* 2E00879, *Y. lipolytica* 2E00856, *S. cerevisiae* 2E01006	Polystirol	35–50	[44]
B. amyloliquefaciens AR2	1–6	*C. albicans* (MTCC 1637, MTCC 4748, MTCC 183)	Polystirol	80	[45]

respectively. However, adhesion of *S. aureus* H-3, *S. epidermidis* R-7, *Streptococcus sanguis* 12 and *Streptococcus agalactiae* K-9 was much higher (67–76%). The amount of adherent cells of the yeast *C. albicans* E-7 and the fungus *Trichophyton mentagrophytes* K-5 reached 75–80%. Brzozowski et al. [49] studied the anti-adhesive potential of surfactants of strains *L. rhamnosus* CCM 1825 and *Lactobacillus fermenti* 126. The studies used surfactants at the concentrations of 2.0–12.5 mg/ml, and treatment led to the decrease in adhesion of *E. coli* 22, *P. aeruginosa* W2 and *K. pneumoniae* 2 on polystirol surface. Surfactants of strain CCM 1825 were more efficient and decreased the test cultures' adhesion by 43–56% after 5 hours after treatment, while in the presence of surfactants of strain 126 the number of adherent cells of the microorganisms was higher and reached 67%. A study [50] established the efficiency of using surfactants of *Lactobacillus jensenii* GJ107 and *L. rhamnosus* FD45 to prevent adhesion of *E. coli* RT347, *S. aureus* EI171 and *Acinetobacter baumannii* BV230 on polystirol surface. Surfactants (50 mg/ml) of both strains of *Lactobacillus* efficiently (by 85%) decreased adhesion of *A. baumannii* BV230 and *E. coli* RT347. It should be noted that for maximal adhesion of *S. aureus* EI171 cells, a lower (25 mg/ml) concentration of surfactants of strains GJ107 and FD45 is needed; under the treatment, adhesion doesn't exceed 10% [50]. Fracchia et al. [51] studied the ability of surfactants synthesized by *Lactobacillus* sp. CV8LAC, to prevent the attachment of two strains of *C. albicans* (CA-2894 and DSMZ 11225) to polystirol surface. They used surfactant solutions of different concentrations (2.5–78 μg/ml), obtained be extraction with a mixture of ethyl acetate and methanol (4:1) of the supernatant of the cultural liquid of *Lactobacillus* sp. CV8LAC. The maximal decrease in adhesion (by 82%) of *C. albicans* CA-2894 was observed if the surfactant were used at concentration of 25 μg/ml. If the surfactant concentration was further raised to 62.5 μg/ml, there was practically no change in adhesion. Meanwhile, adhesion of cells of another strain, *C. albicans* DSMZ 11225, was 19% if the researchers used a much lower concentration (10 μg/ml) of *Lactobacillus* sp. CV8LAC surfactant [51]. The

Table 5. **Effect of biosurfactants of Lactobacillus genus bacteria on the adhesion of the microorganisms and the biofilm destruction**

Surfactant producers	Surfactant concentration, mg/ml	Test cultures	Material under study	Adhesion/ destruction (%)	Source
Antiadhesive properties					
L. fermentum B54	20	*E. faecalis* 1131	Glass	30	[47]
L. acidophilus RC14	20	*E. faecalis* 1131	Glass	33	[47]
L. paracasei A20	3–50	*E. coli* E-8, *P. aeruginosa* L-7	Plastic	11–21	[48]
		S. aureus H-3, *S. epidermidis* R-7, *S. sanguis* 12, *S. agalactiae* K-9		67–76	
		C. albicans E-7, *T. mentagrophytes* K-5		75–80	
L. rhamnosus CCM 1825	2.0–12.5	*E. coli* 22, *P. aeruginosa* W2, *K. pneumoniae* 2	Polystirol	43–56	[49]
L. fermenti 126	2.0–12.5	*E. coli* 22, *P. aeruginosa* W2, *K. pneumoniae* 2	Polystirol	67	[49]
L. jensenii GJ107	25–50	*E. coli* RT347, *S. aureus* EI171, *A. baumannii* BV230	Polystirol	10–15	[50]
L. rhamnosus FD45	25–50	*E. coli* RT347, *S. aureus* EI171, *A. baumannii* BV230	Polystirol	10–15	[50]
Lactobacillus sp. CV8LAC	0.0025–0.078	*C. albicans* CA-2894, *C. albicans* DSMZ 1225	Polystirol	16–19	[51]
L. acidophilus GF4	0.001–0.01	*P. mirabilis* FKJ347	Silicon	20–30	[52]
Biofilm destruction					
L. acidophilus GF4	0.006	*P. mirabilis* FKJ347	Polystirol	50	[52]
Lactobacillus sp. CV8LAC	0.8	*P. aeruginosa* HP1, *S. epidermidis* PI5	Polystirol	70	[51]
L. acidophilus ATCC 4356	0.1	*C. albicans* SDC284	Polystirol	55	[54]

authors of [52] established that it was possible to prevent colonization of FKJ347 urethral catheters by *Proteus mirabilis*, if the catheters were treated with surfactants of strain *L. acidophilus* GF4. The experiments showed that if the surfactant was used at a much lower concentration of 1–10 μg/ml, the number of the adherent cells was as low as 20–30%.

The role of surface-active substances in biofilm destruction

One of the problems of bladder catheterization in medical practice is the organ's easy colonizability by microorganisms which are able to cause infectious diseases. One of the pathogens is *P. mirabilis*, which is able to hydrolyze urine using its own urease [53]. A consequence of this is the sedimentation of magnesium phosphate and calcium phosphate on the inside of the catheter, which blocks the urine flow from the bladder. Conglomerates of cells and salts are formed, which later on leads to biofilm formation. Abd Ulkareem Ali [52] studied the efficiency of using preparations of surfactants of strain *L. acidophilus* GF4 to destroy the biofilm of *P. mirabilis*, formed on urethral catheters, and to prevent the formation of a new one. The first round of experiments established that 45 clinical isolates of the bacteria (94% of the studied) formed biofilms. Later experiments showed that surfactants of *L. acidophilus* GF4 (6 μg/ml) caused 50% destruction of *P. mirabilis* FKJ347 biofilm, formed on plate wells. In [51] they showed that the surfactants, synthesized by *Lactobacillus* sp. CV8LAC, at the concentration of 17.5–800 μg/ml destroyed on polystirol surface the biofilm of *C. albicans* CA-2894 and *C. albicans* DSMZ 11225. It was found that at the concentration of 800 μg/ml, the degree of the destruction of yeast biofilm reached 70%. These are the first studies which

show that surfactants of *L. acidophilus* showed high ability to disrupt the structure of biofilms on biotic surface.

A continuation of the work by Fracchia et al. [51] was the study by Simone et al. [54], which established the ability of surfactants (10–1 000 mkg/ml) of *L. acidophilus* ATCC 4356 to destroy biofilms of the yeast *Candida*. At the concentration of the surfactant of 100 μg/ml they observed the destruction of the biofilm *C. albicans* SDC284 by 55%. Generalized data on anti-adhesive properties of the surfactants, synthesized by representatives of the genus *Lactobacillus*, and their role in the destruction of biofilms are presented in Table 5. Analysis shows that using surfactants, synthesized by bacteria of the genus *Lactobacillus* as anti-adhesive agents and to destroy biofilms is efficient [46–54]. Treating abiotic and biotic materials with surfactants (0.003–50.0 mg/ml) was accompanied by decrease of adhesion of microorganisms to 30–80%. However, currently there are only single reports of the anti-adhesive properties of the surfactants of the bacteriae of the genus *Lactobacillus*.

Fungi as producers of surfactants with anti-adhesive properties

In the beginning of the XXI century, there was a marked increase in the research of surfactants produced by organisms belonging to the genera *Candida* and *Pseudozyma*. It is explained by the ability of fungi to produce, on cheap substrates, substantially higher concentrations of surfactants compared to bacteria, which is economically profitable [55]. In 1970–80-ies, *Candida bogoriensis* FT6-1 was first found to synthesize sophorolipids, which contain disaccharide sophorose, linked by glycosidic bond to the penultimate atom of the carbon chain of the fatty acid C16–C19, however the research of biological properties of fungal surfactants started later [56–58]. In 2001, Golubev et al. [57] showed that glycolipids of *Pseudozyma fusiformata* VKM Y-282 have an antifungal activity [57]. By their chemical composition these glycolipids are mannosyl erythritol lipids, which as the basic structure have 4-O-β-D-mannopyranosyl meso-erythritol, linked with fatty acid and/or acetyl groups. In their further studies, the authors established the ability of glycolipids of the strain VKM Y-282 to inhibit the growth of fungi of the genera *Cryptococcus, Filobasidiella, Candida* and *Saccharomyces* at low concentrations (0.13–1.6 mg/ml) [58]. First studies of the anti-adhesive properties of fungi occurred in 2011 [59, 60]. Luna et al. [59] found the ability of sophorolipid lunasan, synthesized by *Candida sphaerica* UCP0995, at 10 mg/ml to lower adhesion to plastic of the bacteria of the genus *Lactobacillus* (*Lactobacillus casei* G43 — by 90%, *Lactobacillus reuteri* 104R — 55%), *Staphylococcus* (*S. aureus* S27 — 90%, *S. epidermidis* GB — 22%), *Streptococcus* (*Streptococcus oralis* J22 — 91%, *Streptococcus mutans* HG985 — 50%) and *P. aeruginosa* CS34 — by 90%. An influential article of Rufino et al. [60], shows anti-adhesive properties of rufisan — a sophorolipid produced by *C. lipolytica* UCP0988. If polystirol surface is treated with a preparation of the surfactant of the strain UCP 0988 at the concentration of 0.75 mg/l, the number of adherent cells of *Streptococcus agalactiae* LNM103, *L. casei* G43, *S. mutans* NS27 and *S. aureus* H75 are 80–90%; *Streptococcus sanguis* 12, *S. oralis* J22 and *S. mutans* HG985 — 60–75%, and *P. aeruginosa* P351 — 49%. Under conditions of increased concentration of rufisan (12 mg/l), decreased (by 20–50%) adhesion of the cells of *E. coli* NH471, *S. epidermidis* B41 and *C. albicans* TP31 has also been observed. The articles [11, 61–63] provide an overview of data on surfactant producers among fungi, optimal conditions of their biosynthesis and their biological properties. Let us review the data on anti-adhesives which were left out of these reviews.

The influence of fungal surfactants on microorganism adhesion to various surfaces

Padmapriya and Suganthi [64] established the ability of surfactants synthesized by *C. tropicalis* CTY 25H and *C. albicans* FGY 25H to prevent attachment of cells of *P. aeruginosa* JC92, *K. pneumoniae* GH107, *E. coli* ATCC 20743, *P. mirabilis* PJ502, *S. aureus* ATCC 25923, *C. albicans* HY103 and bacteriae belonging to genera *Citrobacter* and *Bacillus*, isolated from hospitals of Coimbatore (India), to urethral catheters. The surfactants were obtained by twice extracting supernatant of the cultural liquid of *C. tropicalis* CTY 25H and *C. albicans* FGY 25H with dichloromethane. According to the data of infrared spectroscopy, these surfactants contain alkenes, hydroxyl, carbonyl, aromatic nitro- and amino residues. More efficient for prevention of test cultures' adhesion were surfactants of *C. tropicalis* CTY 25H (0.1–1.0 mg/ml): if the catheters were treated so, the number of adherent cells of *P. aeruginosa* JC92, *K. pneumoniae* GH107 and *E. coli* ATCC 20743 was 50–60%, *P. mirabilis* PJ502 and *S. aureus* ATCC 25923 — 15–20%, *C. albicans* HY103, and of bacteria of the

genera *Citrobacter* and *Bacillus* — 5–12%. Using surfactant preparations of *C. albicans* FGY 25H (0.2–1.5 mg/ml) lead to higher cell adhesion (15–90%). The authors of [65] studied the ability of the surfactants of *Trichosporon montevideense* CLOA72 to prevent adhesion of yeast *C. albicans* CC to plastic. Thus, under treatment with surfactant (4–16 mg/ml), the amount of test culture cells adherent to plastic was as low as 10–25%. The authors showed that using lower (0.5–2.5 mg/ml) concentrations of surfactants of *T. montevideense* CLOA72 is less efficient: the adhesion of *C. albicans* CC cells reached 95%. They note that surfactants synthesized by *T. montevideense* CLOA72 are glycolipids but their chemical composition isn't stated.

The role of surface-active substances of fungi in the destruction of biofilms

We managed to find only a single report [66] describing the ability of surfactants of *S. cerevisiae* D1, D2 and D3 strains (0.1–1.0 mg/ml) to destroy bacterial and yeast biofilms on polystirol. It was established that the most efficient were the preparations of *S. cerevisiae* D3 surfactants (0.1–0.2 mg/ml), in the presence of which the observed destruction of *C. albicans* CA107 biofilm was by 10–20%. The surfactants of *S. cerevisiae* D3 at the concentration of 0.1 mg/ml caused the destruction of *B. subtilis* BT37 biofilm by 30%. A comparison of *S. cerevisiae* D3 surfactants with sodium dodecyl sulphate (SDS), which is widely used as a component of disinfectants, showed that at higher (up to 1.0 mg/ml) concentrations of SDS the biofilm of *C. albicans* CA107 is destructed by 30% and *B. subtilis* BT37 — by 40% [66]. There are, however, no data on the chemical composition of *S. cerevisiae* D3 surfactants. Therefore, the results support the notion that fungal surfactants (Table 6) are a fairly efficient agent preventing adhesion of microbial cells [59–65]. If materials were treated with surfactants (0.00075–16.0 mg/ml), adhesion of microorganisms did not, on average, exceed 40–90%. Currently, fungal surfactants are little researched as to their ability to destroy microbial biofilms.

Anti-adhesive potential of the surfactants of Acinetobacter calcoaceticus IMB B-7241, Nocardia vaccinni IMB B-7405 and Rhodococcus erythropolis IMB Ac-5017

Earlier, in the Department of Biotechnology and Microbiology of the National University of Food Technologies the oil-oxidizing bacteria were isolated from the oil polluted samples of soil, identified as *Rhodococcus erythropolis* EK-1, *Acinetobacter calcoaceticus* K-4 and *Nocardia vaccinii* K-8 [67] and registered in the Microorganisms Depositary of the Institute of Microbiology and Virology the National Academy of Sciences of Ukraine under the numbers IMV Ac-5017, IMV B-7241and IMV B-7405 respectively. We found they were able to produce surfactants on hydrophilic and hydrophobic substrates [68–70]. By their chemical nature surfactants of *R. erythropolis* IMV Ac-5017 are a complex of glyco-, phospho- and neutral lipids with compounds of polysaccharide-protein nature, surfactants of *A. calcoaceticus* IMV B-7241 and *N. vaccinii* IMV B-7405 are complexes of glyco-, amino- and neutral lipids. Glycolipids of all strains are represented by trehalosomycolates [11].

It was shown [71] that surfactants of strain *A. calcoaceticus* IMV B-7241, *N. vaccinii* IMV B-7405 and *R. erythropolis* IMV Ac-5017 at the concentrations of 0.003–0.12 mg/ml were able to decrease adhesion of some bacteriae (*E. coli* IEM-1, *B. subtilis* BT-2), yeast (*C. albicans* D-6) and micromycetes (*Aspergillus niger* P-3, *Fusarium culmorum* T-7) on abiotic (plastic, glass, tile, linoleum) and biotic (catheters, dental prostheses) surfaces by 75–90, 50–80 and 20–40%, respectively.

Later, the ability of the surfactants of *A. calcoaceticus* IMV B-7241, synthesized on ethanol, glycerol and *n*-hexadecane to destroy formed bacterial biofilms, was also studied. The data provided in Table 7 suggest that regardless of the nature of the carbon source (ethanol, glycerol, *n*-hexadecane) and the degree of purification (supernatant, surfactant solution), all surfactants at the concentrations of 0.04–1.28 mg/ml destroyed the biofilm of *S. aureus* BMC-1 by 21–88%, and the destruction increased with the increase in surfactant concentration. The highest degree of biofilm destruction of the *S. aureus* BMC-1 (88%) was obtained with 1.28 mg/ml solution of surfactant synthesized on *n*-hexadecane. At the concentration of 0.04 mg/ml we already observed destruction of the biofilm of the test culture by 54 and 58%, respectively. Further research showed that unlike of *S. aureus* BMC-1, biofilm of *B. subtilis* BT-2 and *E. coli* IEM-1 were more efficiently destroyed by surfactants (0.04–1.28 mg/ml) synthesized on ethanol. Thus, the maximal degree of biofilm destruction of test cultures after treatment with surfactant solution (1.28 mg/ml) was 86 and 53%, respectively. Surfactants synthesized by strain IMV B-7241 were more efficient

Table 6. **The effect of surfactants, produced by fungi, on adhesion of microorganisms and destruction of biofilms**

Surfactant producers	Surfactant concentration, mg/ml	Test cultures	Material under study	Adhesion/ destruction (%)	Source
Anti-adhesion properties					
C. sphaerica UCP0995	10	*L. casei* G43, *L. casei* VF59, *L. reuteri* 104R, *L. reuteri* ML1, *S. aureus* S27, *S. epidermidis* GB, *S. oralis* J22, *S. mutans* HG985, *P. aeruginosa* CS34	Plastic	10–80	[59]
C. lipolytica UCP 0988	0.00075–0.012	*S. agalactiae* LNM103, *L. casei* G43, *S. mutans* NS27, *S. aureus* H75	Polystirol	80–90	[60]
		S. sanguis 12, *S. oralis* J22, *S. mutans*		60–75	
		P. aeruginosa P351, *E. coli* NH471, *S. epidermidis* B41, *C. albicans* TP31		20–50	
C. tropicalis CTY 25H	0.1–1.0	*P. aeruginosa* JC92, *K. pneumoniae* GH107, *E. coli* ATCC 20743	Polystirol (urethral catheters)	50–60	[64]
		P. mirabilis PJ502, *S. aureus* ATCC		15–20	
		C. albicans HY103, genera *Citrobacter*, *Bacillus*		5–12	
C. albicans FGY 25H	0.2–1.5	*P. aeruginosa* JC92, *K. pneumoniae* GH107, *E. coli* ATCC 20743	Polystirol (urethral catheters)	65–90	[64]
		P. mirabilis PJ502, *S. aureus* ATCC		35–65	
		C. albicans HY103, genera *Citrobacter*, *Bacillus*		15–35	
T. montevideense CLOA72	4.0–16.0	*C. albicans* CC	Plastic	10–25	[65]
Biofilm destruction					
S. cerevisiae D3	0.1–0.2	*C. albicans* CA107, *B. subtilis* BT37	Polystirol	10–30	[66]

destructors of bacterial biofilms compared to rhamnolipids of *P. aeruginosa* LBI and surfactin of *B. subtilis* RT7 [72], which supports the possibility of using them as novel disinfectants to eliminate bacterial biofilms.

The analyzed literature of the recent years concerning anti-adhesive properties of surfactants synthesized by various groups of microorganisms and their role in the destruction of bacterial biofilms on biotic and abiotic surfaces, demonstrated the possibility to use these products of microbial synthesis to develop novel efficient disinfectants. Comparative analysis of the well-known microbial surfactants is given in Table 8. These data show that microbial surfactants have their own advantages and disadvantages. A substantial advantage of microbial surfactants is the fact that synthesis of some of these compounds (rhamnolipids of the bacteria belonging to the genus *Pseudomonas*, sophorolipids of the yeast *Candida* and surfactants of *A. calcoaceticus* IMV B-7241) is possible on the waste of food industry (fried vegetable oil, soap stock) and biodiesel production (technical glycerol). Notably, most currently known microbial surfactants have high anti-adhesive properties towards a wide range of test cultures at fairly low concentrations. As to most disadvantages of microbial surfactants as anti-adhesive agents, eliminating them is only a question of time and optimization of bio-surfactant synthesis using both intensification of the production technologies and improvement of strains by genetic and metabolic engineering.

Table 7. **Effect of *A. calcoaceticus* IMV B-7241 surfactants synthesized on various substrates on the destruction of *S. aureus* BMC-1 biofilm**

Carbon source in medium	Preparations	Test culture biofilm destruction (%) after treatment with surfactant of certain concentration, mg/ml					
		0.04	0.08	0.16	0.32	0.64	1.28
Ethanol	Supernatant	21	25	27	31	38	42
	Surfactant solution	31	35	46	50	54	54
Glycerin	Supernatant	31	42	54	58	62	65
	Surfactant solution	42	50	54	56	58	62
n-Hexadecane	Supernatant	54	58	61	62	69	73
	Surfactant solution	58	65	67	69	73	88

Table 8. **Advantages and disadvantages of various microbial surfactants — potential anti-adhesive agents**

Surfactants	Producers	Peculiarities of production and using the surfactants		References
		Advantages	Disadvantages	
Rhamnolipids	Bacteria of the genus *Pseudomonas*	Synthesis on waste of food industry (oil-fat, alcohol, dairy); high surfactant content (1.5–50 g/l)	Producers are opportunistic pathogenic microorganisms	[4, 10, 11, 17, 19–21]
Lipopeptides	Bacteria of the genus *Pseudomonas*	Sufficiently low efficient concentration	Low concentrations of produced surfactants	[4, 9–31]
	Bacteria of the genus *Bacillus*	Efficient towards a wide spectrum of pathogenic microbes	Limited range of substrates for surfactant synthesis (mostly carbohydrates)	[4, 29, 34, 37–42]
Surfactants of lactic bacteria	Bacteria of the genus *Lactobacillus*	Lack of pathogenicity of the producers; high anti-adhesive potential of surfactants at low concentrations	Expensive media cultivation; low concentration of surfactants (20–100 mg/l)	[47–52]
Sophorolipids	Yeasts of the genus *Candida*	Synthesis on cheap substrates (fried vegetable oil, waste of vegetable oil production)	Low (<18%) yield of product from substrate; producers are opportunistic pathogens	[11, 59–65]
A complex of amino- and glycolipids	*Acinetobacter calcoaceticus* IMB B-7241	Synthesis on waste (fried vegetable oil, glycerol); high anti-adhesive potential at low surfactant concentrations	Low anti-adhesive potential towards fungi	[69, 70, 71]

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МІКРОБНІ ПОВЕРХНЕВО-АКТИВНІ РЕЧОВИНИ ЯК АНТИАДГЕЗИВНІ АГЕНТИ

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Наведено дані літератури останніх років щодо здатності поверхнево-активних речовин, синтезованих бактеріями (*Pseudomonas*, *Lactobacillus*, *Bacillus*) та грибами (*Candida*, *Trichosporon*, *Saccharomyces*), не лише запобігати адгезії мікроорганізмів на різних матеріалах, а й руйнувати утворені на них біоплівки. Обговорюється перспектива використання мікробних поверхнево-активних речовин для унеможливлення колонізації патогенами абіотичних і біотичних поверхонь, що є однією з причин виникнення і поширення інфекційних захворювань. Подано результати власних досліджень авторів стосовно антиадгезивних властивостей поверхнево-активних речовин, синтезованих *Acinetobacter calcoaceticus* IMB B-7241, *Nocardia vaccinii* IMB B-7405 та *Rhodococcus erythropolis* IMB Ac-5017.

Ключові слова: поверхнево-активні речовини мікробного походження, адгезія мікроорганізмів, руйнування біоплівки.

МИКРОБНЫЕ ПОВЕРХНОСТНО-АКТИВНЫЕ ВЕЩЕСТВА В КАЧЕСТВЕ АНТИАДГЕЗИВНЫХ АГЕНТОВ

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Приведены данные литературы последних лет о способности поверхностно-активных веществ, синтезированных бактериями (*Pseudomonas, Lactobacillus, Bacillus*) и грибами (*Candida, Trichosporon, Saccharomyces*), не только предотвращать адгезию микроорганизмов к различным материалам, но и разрушать образовавшиеся на них биопленки. Обсуждается возможность использования микробных поверхностно-активных веществ для предотвращения колонизации патогенами абиотических и биотических поверхностей, являющейся одной из причин возникновения и распространения инфекционных заболеваний. Приведены результаты собственных исследований авторов относительно антиадгезивных свойств поверхностно-активных веществ, синтезированных *Acinetobacter calcoaceticus* ИМВ B-7241, *Nocardia vaccinii* ИМВ B-7405 и *Rhodococcus erythropolis* ИМВ Ac-5017.

Ключевые слова: поверхностно-активные вещества микробного происхождения, адгезия микроорганизмов, разрушение биопленки.