The characteristics of actinomyces strptomyces griseorubiginosus 83 – the effective biosorbent of silver

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Abstract. The bacteria bound about the same amount of silver at the time of inoculation and when added after 24 hours Fourier transform infrared spectroscopy (FT-IR) and measurements of the ζ- potential showed that several groups, mainly carboxy groups are involved in the binding and biotransformation of silver cations. Also, volatile organic compounds profiling for L. lactis, demonstrated the presence of many compounds in the free space of bacteria, which were typical products of bacterial metabolism. Finally, it can be stated that the combination of various instrumental methods used has opened up new possibilities for the interpretation of physicochemical phenomena occurring at the interface between bacteria-bacteria and bacteria-metals- bacteria. The ability of the biomass of cultures of various taxonomic groups to sorb metals is used both for purification of wastewater from metals and in the additional separation of valuable and environmentally significant metals from various wastes. In this work 48 strains of actinomycetes were isolated from various samples of desert soils of Uzbekistan under agricultural crops. As a result of screening, a strain of Streptomyces sp. 83, efficiently absorbs silver from solutions. The morphological-cultural and physiological-biochemical characteristics of the selected

1 Introduction

Currently, biotechnology is rapidly developing, based on the use of various processes of activity of microorganisms. In particular, the ability of the biomass of cultures of various taxonomic groups to sorb metals is used both for purification of wastewater from metals and in the additional separation of valuable and environmentally significant metals from various wastes [1, 2].

Industrial wastewater is known to contain heavy metals from metallization, mining, smelting, battery manufacturing, leather processing plants, oil refining, dye, pesticide, pigment and the printing and photographic industries [1-3].

The biosorption of various heavy metals, for example, cadmium, silver, lead, nickel, etc. using microorganisms such as fungi, algae or bacteria, has been studied by various groups

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[4-7]. The problem of biosorption of heavy and noble metals is important both environmental and economic point of view. Extraction of precious metal from wastewater from silver processing plants and biosorption of Cu^{2+}, Zn^{2+} and Ni^{2+} ions from galvanic waste are a cheap alternative to the use of traditional sorbents- ion exchange resins and activated carbons. One of the perspective directions to increase the efficiency of silver extraction processes from complex composition solutions is the use of microbial biomass-waste from the medical industry [8].

At present, the physicochemical foundations of the biosorption extraction of silver have not been sufficiently studied; many questions remain in determining the mechanism of sorption, the behavior of biosorbents in real production conditions.

In this regard, Bezrukova Zh.N [9] conducted research on the development of a high-performance and economical technology for extracting silver from industrial solutions using a new sorptions material from cheap and widely available wastes of the microbiological industry and biosorbents based on them was an urgent task.

In [10], the phenomenon of absorption of silver cations by two types of bacteria isolated from dairy products is considered. The mechanism of sorption of silver cations by bacteria *Lactococcus lactis and Lactobacillus casei* has been investigated inductively coupled plasma mass spectrometry was used to determine the concentration of silver sorbed by bacteria (ICP-MS). Changes in the ultrastructure of *Lactococcus lactis* and *Lactobacillus casei* cells after treatment with silver cations were studied using transmission electron microscopy. Molecular spectroscopy methods were used to describe the sorption mechanism, namely Fourier transform infrared spectroscopy (FT-IR) and matrix laser desorption/ ionization mass spectrometry (MALDESI). In addition, the analysis of volatile organic compounds (VOCs) isolated from bacterial cells was performed. It was shown that the studied lactic acid bacteria -- *L. Lactis* and *L. casei,* had the ability to absorb silver cations. This was due to the cell surface of the bacterial strain assessed using TEM -studies [1-9].

Changes in the spectra obtained by profiling MALDI-TOF MS of whole bacterial cells using different concentrations of silver are demonstrated.

ICP-MS analysis proved that *L. Casei* bacteria can grow in a medium of silver cations and that these bacteria can bind more of this element if it was added during inoculation. In the case of *L. Lactis,* this relationship was not observed.

The bacteria bound about the same amount of silver at the time of inoculation and when added after 24 hours Fourier transform infrared spectroscopy (FT-IR) and measurements of the ζ- potential showed that several groups, mainly carboxy groups are involved in the binding and biotransformation of silver cations. Also, volatile organic compounds profiling for *L. lactis,* demonstrated the presence of many compounds in the free space of bacteria, which were typical products of bacterial metabolism. Finally, it can be stated that the combination of various instrumental methods used has opened up new possibilities for the interpretation of physicochemical phenomena occurring at the interface between bacteria-bacteria and bacteria-metals- bacteria.

Biosorption, a process defined as the sorption or complexation of dissolved metals based on the chemical activity of microbial biomass or materials obtained from biological sources, is used for metal removal and recovery technology [11-15].

The first component in contact with the metal is the bacterial cell wall. The presence of functional groups in the cell wall, including carboxyl, phosphonate, amine and hydroxyl, plays a vital role in biosorption [12-16].

In general, gram-positive microorganisms have a greater sorption capacity, due to their thick layer of peptidoglycan, which contains a large amount of substances of sorption [13]. Biosorption involves the removal of heavy metals into non-living biomass by passive binding from an aqueous solution; thus, the process is metabolically independent. Unlike

biosorption, bioaccumulation is an active process based on living cells, in which the metabolic activity of living organisms is required to remove metals [14]. The advantages of using biosorption together with bioaccumulation are the potential for onsite secondary contamination that does not result from bioremediation and cost-effectiveness.

A number of factors affect biosorption; pH, temperature, dosage of biosorbent, ionic strength, size of biosorbent and initial concentration of solute [15]. When choosing biomass, the main factor should be their availability and cheapness. The original biomass can be obtained from industrial waste, for example, biotechnological industries, from the natural environment, or easily grown under certain conditions [16-19].

Recently, much attention has been paid to biosorption processes for the removal of heavy metals from the aquatic environment. Thus, it is Karavaiko G.I. et al. [17] found that the choice for biosorption is a serious problem for the development of cheaper and more efficient technologies. Studies on the biosorption of metals by actinomycetes are relatively few. Actinobacteria are directly involved in stimulating plant growth by stimulating hormones and improving the absorption of nutrients by plants. Actinobacteria have also been reported to reduce biotic stress in plants. The biomass of actinobacteria is considered an efficient, environmentally friendly and economical potential candidate for the biosorption of heavy metals, since they have the ability to produce secondary metabolites and enzymes – the main factors necessary for resistance to environmental stress.

They are reported to have metal detoxifying abilities such as soil acidification and the production of substances that promote the mobilization of metals and are considered a bio-tool for phytoremediation [18].

Metals (loids) play a dual biological role as micronutrients and stress agents. Certain geochemical and natural processes can cause their release into the environment, although most of the sites contaminated with metals have arisen as a result of anthropogenic activities. Actinobacteria include high GC bacteria that inhabit a wide range of terrestrial and aquatic ecological niches, where they play an important role in the processing or transformation of organic and inorganic substances. Metal (loid) tolerance and / or resistance of some members of this type depends on mechanisms such as biosorption and extracellular sequestration by siderophores and extracellular polymeric substances (EPS), bioaccumulation, biotransformation and metal outflow processes, which generally contribute to the maintenance of the metal, homeostasis. Considering the potential for bioremediation of metals (loids) by actinobacteria, the development of bioremediation strategies for the restoration of a metal- contaminated environment has received scientific and economic interest.

Moreover, the ability of actinobacteria to produce nanoscale materials with interesting physicochemical and biological properties underscores the technological value of these biotic approaches. Taking these prerequisites into account, this review summarizes the strategies used by actinobacteria to combat the toxicity of metals (loids), and their undoubted role in the fields of bioremediation as well as bio nanotechnology [19].

Consequently, new methods are needed to provide environmentally friendly and highly selective technology. Streptomyces, with their unique growth characteristics, the ability to form spores and mycelium and relatively rapid colonization of substrates, act as suitable agents for bioremediation of metals and organic compounds in contaminated soil and water. In this case, various mechanisms can be used in the reduction of metals in the environment, such as sorption by exopolymers, precipitation, biosorption and bioaccumulation. The conducted studies of the potential of biosorption and bioaccumulation of streptomyces can be used as basis for further development in this area. Streptomyces are of interest for their ability to survive in a metal contaminated environment through the production of a wide rage of metal ion chelators such as siderophores, which provide protection against the negative effects of heavy metals or specific absorption for specialized metabolic processes.

Many strains also have an equally important characteristic of resistance to high concentrations of heavy metals [20]. Despite the fact that the ability of living microbes to adsorb metals from aqueous solutions has been studied since the 18 th century, living or non-living microorganisms have only been used as adsorbents to remove toxic materials from aqueous solutions over the past three decades [15].

In soils with a high content of heavy metals, the species of diversity of streptomyces from the pigmented sections and of the *Cinereus, Chromogenes, Helvolo-Flavus Flavus, Roseus, Ruber* series, as well as streptomyces from the *Imperfectus* section (species with the absence of aerial mycelium) increases.

The soils of the residential zone and garden plots, on the contrary, as well as for natural soils of the humid zone, are characterized by the predominance of streptomyces of the species *Albus, Cinereus, Achromogenes* [17].

In this regard, the main goal of this work is to isolate and search for effective strains of actinomycetes that adsorb silver ions from dilute aqueous solutions, to establish their species identity.

2 Materials and methods

The objects of the research were 48 local strains of actinomycetes, isolates according to the generally accepted method [4-7]. To isolate pure cultures of microorganisms from the soil, we used traditional methods of sowing on solid nutrient media [18-20] of the following composition:

starch-casein(g/l):

starch – 10.0 (or glycerin – 10,0); casein – 0.3; KNO_3 – 2.0; NaCl – 2.0; K_2HPO_4 – 2.0; $MgSO_4 \cdot 7H_2O$ – 0.05; $CaCO_3$ – 0.02; $FeSO_4 \cdot 7H_2O$ – 0.01; pH 7,2-7,4; agar – 20,0;

glycerin-arginine agar (g/l):

glycerin – 12.5; arginine – 1.0; NaCl – 1.0; K_2HPO_4 – 1.0; $MgSO_4 \cdot 7H_2O$ – 0.5; $FeSO_4 \cdot 6H_2O$ – 0.01; $CuSO_4 \cdot 5H_2O$ – 0.001; $FeSO_4 \cdot 7H_2O$ – 0.001; $MnSO_4 \cdot H_2O$ – 0.001; pH 7.4; agar – 20.0;

The study of silver sorption was carried out as follows. The biomass of actinomycetes was obtained by submerged cultivation in liquid starch- ammonia medium (g/l: $NaNO_3$ – 1,0; $MgSO_4$ – 1.0; K_2HPO_4 – 1.0; starch – 10.0; pH=7.2) on a rocking chair (180 revolution /min) for 6 days at a temperature of 28 ^oC. The resulting biomass was separated from the culture liquid by filtration, washed repeatedly with sterile distilled water and if necessary, the biomass was stored in sterile Petri dishes in a freezer.

To study the biosorption of silver, a sample of biomass in an amount of 1 g was introduced into a flask with 25 ml of $AgNO_3$ solution with a silver concentration of 50 mg/l.

The sorption process was carried out with stirring on a rocking chair at 180-200 revolution /min at a temperature of 28-30^o C for 15 minutes. Then the contents of the flask were centrifuged and the residual silver content in the supernatant liquid was determined by instrumental neutron activation and atomic adsorption methods [9-14]. The amount of silver sorbed on the biomass determined from the difference between its initial amount and the amount remaining in the solution after adsorption.

When determining the metal concentration by the instrumental neutron activation method, the test solutions in an amount of 0.1ml of the corresponding solution were applied to strips of ash-free filter paper, which were then carefully dried and packed in polyethylene and aluminum bags and placed in a special container for irradiation in an atomic reactor. Samples for determining the silver content were irradiated for 20 hours with the total flow of a nuclear reactor, with a density of 5.1 x 10^{13} n/sm^{-2} $^{c.}$ After

irradiation, the samples were kept for 6-7 days to reduce the activity of ^{24}Na radionuclide formed from packaging aluminum by the reaction: $^{27}Al(n,)^{24}Na$

The silver content was determined by the line 657,7 KEV of radionuclide 110 mAg (half-life $T_{1/2}$ = 255.0 days). Depending on the silver content of the sample, the error in determining the relative root-mean- square error was 0.01 to 0.1

The concentration of metal was also determined by atomic adsorption on a Perkin-Elmer 3100 device (Germany) at a wavelength of 328.1 nm in an air-acetylene flame. To study the morphological structure of the selected streptomyces, an active biosorbent of silver, the culture was grown in Petri dishes on oatmeal (oat flour 20 g, water – 1l, pH = 7.4) starch-ammonia and starved agar (agar – 20 g, water - 11), the most favourable for sporulation.

The type of spore was determined in mature cultures on the 7 th day of growth. For this, a piece of agar mycelium was placed on a glass slide, cutting off all excess agar with a razor and viewed in an «OlympusBX-41» light microscope (Japan) at a magnification of 320-400 times.

The surface of the spores was studied using a «JEM-100B» electron microscope without fixation at a magnification of 8 thousand and 10 thousand times.

The preparations were prepared by the method of prints on the pharmaceutical film.

Cultural traits were judged by the color of the aerial and substrate mycelium and the presence of soluble and melanoid pigments [23] during growth on mineral agar-1 (g/l: starch-20, K_2HPO_4 - 0.5. $MgSO_4$ – 0.5. KNO_3 - 1. NaCl – 0.5. $FeSO_4$ - 0.01. pH 7.2-7.4). sucrose-nitrate agar (med. Czapek. g/l: sucrose – 30; $NaNO_3$ – 2.0; KH_2PO_4 – 1.0; KCl – 0.5; $MgSO_4$ – 0.5 $FeSO_4$ – 0.01; pH = 7.2) and oat agar. The color of the aerial, substrate (VM and SM) actinomycete mycelium and the presence of pigments were determined using the Bondartsev color scale [15-17] under daylylight on a clear day on the 7th, 14 th, and 21st days of culture growth.

The presence of soluble pigment (RP) was determined on C-5 medium 5 (g/l: K_2HPO_4 – 3.0; NaCl – 0.2; $MgCO_3$ – 0.3; KNO_3. - 1.0; $CaCO_3$ – 0.6; pH = 6.8 – 7.0). the formation of pigments (MP) – on peptone- yeast agar containing iron citrate. (g/l: peptone – 10. yeast extract-1, iron citrate -0.5, pH= 7.0) on the 2-4 th day of growth. For complete characterization, the antagonistic properties and physiological and biochemical characteristics of the selected streptomyces strain were checked.

The antagonistic properties of actinomycetes were studied by the method of agar blocks [15-17]. In order to study the physiological and biochemical properties, actinomycetes were sown on a colored row. The sources of carbon were: glucose, sucrose, d- fructose, l-arabinose, xylose, i-inositol, d-mannitol, rhamnose, raffinose. The observation was carried out on 10-16 days. Proteolytic activity was judged by the liquefaction of gelatin by microorganisms. To reveal this ability, the organism under study was planted on Giss medium with gelatin (peptone – 10 g, NaCl-5 g, water – 11, pH = 7.0).

The liquefaction was noted visually. The assimilation of various nitrogen sources by microorganisms was studied on Czapek's medium, to which the following sources were added: NH_4Cl, citric-acid ammonium, asparagine, urea, in the amount of 3%. Control - Czapek medium without nitrogen. To determine the effect of microorganisms on milk, inoculation was performed on skim milk. In this case, the coagulation and peptonization of this substrate were taken into account. Fiber destructive capacity was studied on Hutchinson's medium (g/l: K_2HPO_4 – 1. $CaCl_2$ – 0.1. $MgSO_4$ – 0.3. NaCl -0.1. $NaNO_3$ -2.5. FeCl - 0.01). At the same time, the growth of the culture and the decomposition of a strip of filter paper were noted. Hydrolysis of starch was carried out by microorganisms that form amylase and use the products of starch hydrolysis as a source of carbon and energy. To reveal this ability, the following medium was used, g/l: peptone – 1, K_2HPO_4 – 0,5, soluble starch – 0.2, water–1, pH=6.8-7.0. Starch hydrolysis was detected in zone of

clarification of the medium along the stroke using Lugol's solution. The formation of hydrogen sulfide is characteristics of microorganisms that use sulfur-containing amino-acids in metabolic processes, for example, cysteines, cystine, methionine

This ability was revealed when growing microorganisms on Tresner's medium with hydrogen sulfide paper. The species belonging of the streptomyces strain was established using the actinomycete identification keys [18-20] and the Bergey bacteria identification key [16-19].

3 Results and discussion

Isolation and selection of the most effective actinomycetes – silver sorbents was carried out from samples of newly irrigated and rhizosphere soils of the Surkhandarya region under various agricultural crops (wheat, cotton, corn and alfalfa). In total, more than 60 enrichment cultures were isolated of which 48 strains of actinomycete were isolated into a pure culture.

The study of 48 strains of actinomycetes by their morphological and cultural properties-forms of spore- bearers, color of aerial and substrate mycelium, the presence of melanoid pigment made it possible to classify most of the cultures – 37 strains of the genus *Streptomyces.*

This confirms the known data that the most resistant adapted to unfavourable conditions are actinomycetes of the genus *Streptomyces,* which were isolated in the predominant number of samples compared to other genera.

The study of the ability of 37 strains of actinomycetes isolated in a pure culture showed that all tested strains sorb silver from a model solution containing 50mg/l of silver (Table 1).

Table 1. Biosorption of silver by actinomycetes

#	Microorgaisms	Residual content Ag, mg/l	Sorbed Ag, mg/l	Sorption Ag, %
1	Streptomyces sp. 141	15.3 ± 0.03	34.7	69.4
2	Streptomyces sp. 116	10.2 ± 0.25	39.8	79.6
3	Streptomyces sp. 138	10.7± 0.57	39.3	78.6
4	Streptomyces sp. 101	11.3± 0.03	38.7	70.6
5	Streptomyces sp. 3-3	15.5± 1.13	34.5	65.0
6	Streptomyces sp. 140	8.1±1.03	41.9	83.8
7	Streptomyces sp. 61	16.4±0.12	33.6	77.6
8	Streptomyces sp. 1	15.2±0.88	34.8	69.6
9	Streptomyces sp.4-15	8.0 ± 0.22	42.0	84.0
10	Streptomyces sp. 4-16	7.5±0.18	42.5	85.0
11	Streptomyces sp. 4-5	13.5±1.46	36.5	73.0
12	Streptomyces sp. 4-18	12.4±0.07	37.6	75.2
13	Streptomyces sp. 4-12	15.8± 1.4	34.2	68.4
14	Streptomyces sp. 7	23.8±0.29	26.2	52.4
15	Streptomyces sp. 8	17.2±0.37	32.8	65.6
16	Streptomyces sp. 49	7.0±0.11	43.0	86.0
17	Streptomyces sp. 14	8.4± 0.79	41.6	83.2
18	Streptomyces sp. 4-2	13.7± 1.12	36.7	72.6
19	Streptomyces sp. 30	21.5± 0.23	28.5	57.0
20	Streptomyces sp. 4-4	11.0± 0.35	39.0	78.0
21	Streptomyces sp.4-11	8.0±0.22	42.0	84.0

22	Streptomyces sp. 4-8	26.5± 1.33	23.5	47.0
23	Streptomyces sp. 3-7	16.0± 0.46	34.0	68.0
24	Streptomyces sp.3-6	8.8±0.31	41.2	82.4
25	Streptomyces sp. 4-14	8.4± 0.79	41.6	71.6
26	Streptomyces sp. 4-3	14.7± 0.12	35.3	69.0
27	Streptomyces sp. 4-8a	16.0±0.54	34.0	68.0
28	Streptomyces sp. 67	4.8±0.15	45.2	90.4
29	Streptomyces sp. 88	13.2±0.07	36.8	77.4
30	Streptomyces sp. 80	11.2± 0.03	38.8	77.6
31	Streptomyces sp. 43	13.4± 0.47	36.6	73.2
32	Streptomyces sp. 96	12.0± 0.38	38.0	76.0
33	Streptomyces sp. 24	18.1± 0.49	31.9	63.8
34	Streptomyces sp. Мс 1	11.2± 0.03	38.8	77.6
35	Streptomyces sp. Мм 2	17.0± 1.44	33.0	660
36	Streptomyces sp. 247	21.8± 1.46	28.2	56.4
37	Streptomyces sp. 83	4.7± 0.8	45.3	90.6

Note: the obtained values of the residual Ag content significantly differ from those of the control variant

All cultures tested did not adapt to silver and their ability to absorb silver reflected their natural properties.

From the data in Table 1, it follows that the biomass of the tested actinomycetes sorbed from 39% to 90.6% silver from the solution.

The least activity of 47.0% was shown by the culture of *Streptomyces sp. 4-8*. The most effective were 10 streptomyces strains- 83. 67. 49. 4-15. 4-16. 4-11. 140. 14. 3-6. 82. the activity of which ranged from 80.2 to 90.6%. Biosorption of other cultures ranged from 52.4 - 79.6%. Of the 10 studied strains. the strain 83 had the highest activity. the biosorption of which was 90.6%. The strain sorbed 45.3 mg/l of silver from a model solution containing 50 mg/l of silver. In order to identify the selected active biosorbent, the morphological-cultural and physiological – biochemical properties were studied. This made it possible to establish the systematic position of this strain.

The most significant characteristics in the determination of actinomycetes is the color of the aerial and substrate mycelium, as well as the formation of soluble and melanoid pigments [19,20].

Morphological- cultural and physiological – biochemical features of the active biosorbent *Streptomyces sp. 83.* The culture forms straight, long, often branched spore-bearers with chains of spores (Fig. 1). Electron microscopic studies found that the spores of the studied actinomycete are oval, the surface of the spore membrane is smooth (Fig. 2). Colonies grow strongly into agar on all nutrient media.

On the Czapek medium on the 4^{th}-5^{th} day, growth is good**,** the colonies are folded with even edges, covered with whitish -lilac aerial mycelium, the substrate mycelium is brown, in the old culture from dark brown to black (Fig. 3). Soluble pigment on mineral agar-light purple, in the old culture- light brown.

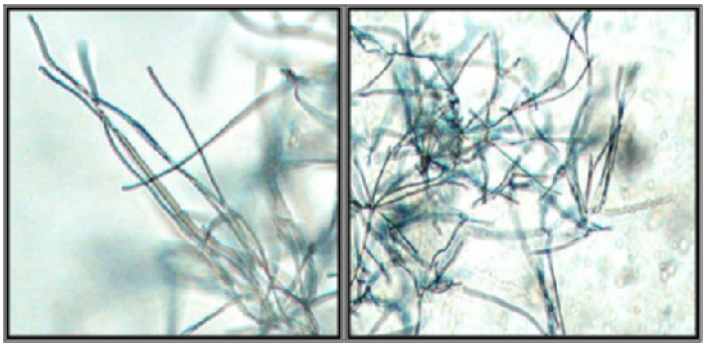

Fig. 1. Spore bearers Streptomyces sp 83 (magnification 320-400 times)

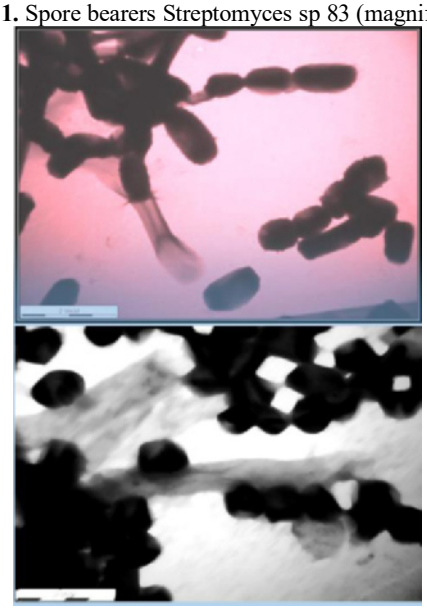

Fig. 2. Chains spore and spores of Streptomyces sp.83.

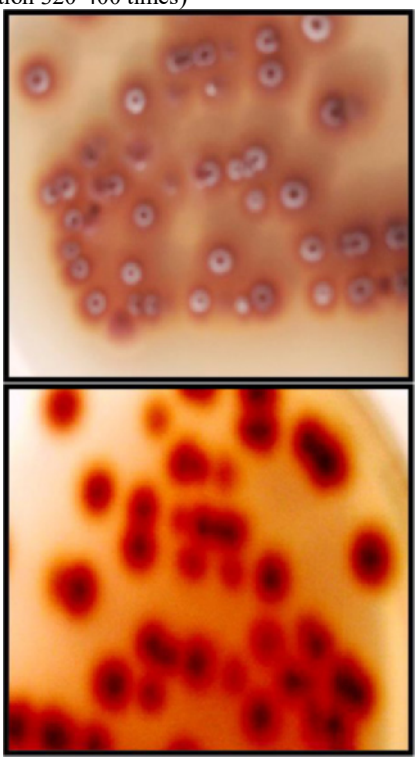

Fig. 3. Growth of Streptomyces sp.83 on Czapek's medium

On oat agar forms colonies of medium size, smooth with even edges, covered with a mealy, velvety, fluffy aerial mycelium of white color, brown substrate mycelium (Fig. 4).

On mineral agar-1 abundant growth, colonies with dark gray aerial mycelium and brown substrate mycelium (Fig. 5).

On organic agar C-5 forms aerial and substrate orange mycelium, soluble pigment does not synthesize (Fig. 6).

Strain 83 actively forms black melanoid pigment (Fig. 7).

The culture uses glucose, sucrose, fructose, arabinose, xylose, inositol, mannitol, rhamnose, raffinose as carbon sources. Actively hydrolyzes starch, does not destroy fiber.

The sources of nitrogen nutrition are corn extract, yeast auto lysate, peptone; it grows weakly in the presence of inorganic salts such as sodium nitrate ($NaNO_3$) and ammonium sulfate ($(NH_4)_2SO_4$).

It grows well on a medium with urea and aspartic acid, coagulates milk, does not grow on gelatin and on a medium with ammonium citrate.

The culture forms hydrogen sulfide(H_2S), antagonizes cocci, spore-bearing bacteria and fungi- *Micrococcus sp., Bac.subtilis, Bac. megaterium, Asp.violaceae tuscus, V. dahlia* (Fig. 8).

Fig. 4. Growth of Streptomyces sp.83 on oat agar

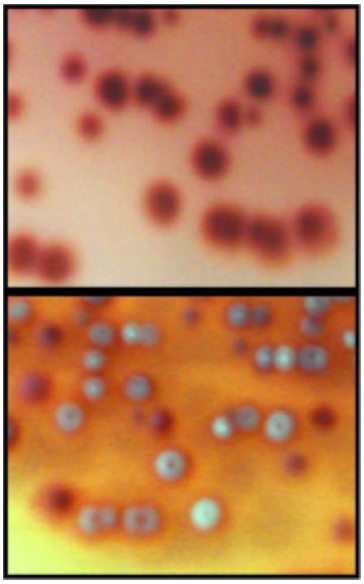

Fig. 5. Growth of Streptomyces sp.83 on mineral agar

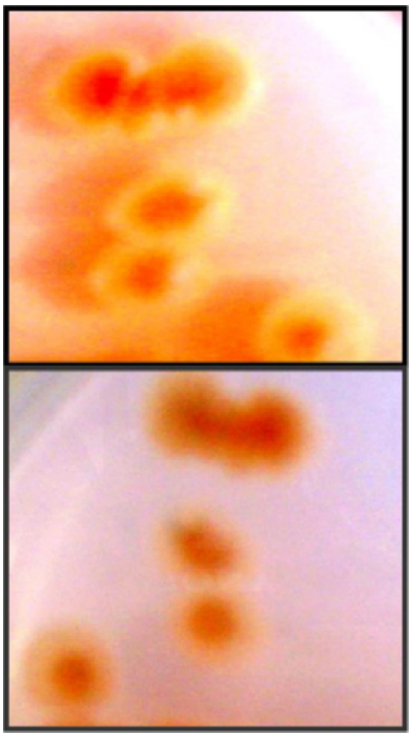

Fig. 6. Growth of Streptomyces sp.83 on organic agar C-5

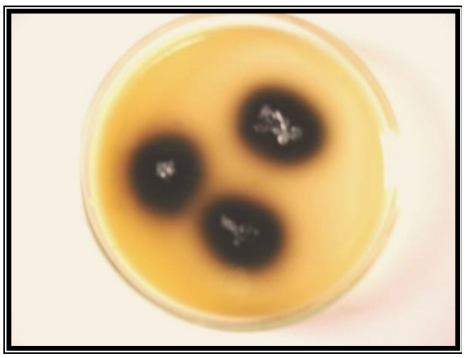

Fig. 7. Formation of melanoid pigment in Streptomyces sp.83

Fig. 8. Inhibition of the phytopathogen V. dahliae Culture of Streptomyces sp. 83

Based on the study of the totally of morphological, cultural, physiological and biochemical characteristics, the culture was identified as *Streptomyces griseorubiginosus 83.*Thus, as a result of studying the biosorption capacity of 37 isolated local strains streptomyces, an active strain of actinomycetes was selected, which showed the maximum ability-90.6%, which sorbed 45.3mg/l silver from a model solution containing 50 mg/l silver from solution.

The results of determining the systematic position of the effective silver biosorbent *Streptomyces sp. 83* showed that according to the totally of the studied morphological-cultural and physiological- biochemical properties of this strain the culture was assigned to the species *Streptomyces griseorubiginosus 83.*

4 Conclusions

From the above results, it can be concluded that actinomycetes, including s*treptomyces* are suitable agents for bioremediation methods and organic compounds from contaminated soils and wastewater due to their metabolic diversity, growth characteristics, ability to form spores, mycelium, and relatively fast accumulation in substrates. The presented data are the basis for the development of ecological biotechnology. The obtained research results can be used in environmental biotechnology for the treatment of wastewater from industrial enterprises, such as jewelry, photographic production, mining, and metallurgical.etc.

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