THE ROLE OF *SACCHAROMYCES* GENUS AND THEIR METABOLITES IN BIOSYNTHESIS OF NANOPARTICLES

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Biological methods of nanoparticle synthesis are environmentally friendly, as well as simple, fast, and cost-effective. Among the various biological systems that can be used for the biosynthesis of nanoparticles, yeast of the genus Saccharomyces has several advantages, since these microorganisms and their metabolites are completely safe for humans, animals, and the environment. In addition, yeast synthesize a large number of biologically active compounds (proteins, enzymes, amino acids, organic acids, vitamins), which can participate in the biosynthesis and stabilization of nanoparticles. When using yeast, both intracellular and extracellular nanoparticle biosynthesis is possible. And, taking into account that yeasts are facultative anaerobes, it is possible to realize the biosynthesis of nanoparticles both in oxic and anoxic conditions. To date, the biosynthesis of various nanoparticles using yeast of the genus Saccharomyces has been investigated. These are nanoparticles of precious metals (gold, silver, platinum, palladium), characterized by antibacterial, antifungal, antiviral, and antitumor properties. The possibility of nanoparticles' usage in the food industry, medicine, agriculture, and energy was shown. The biosynthesis of nanoparticles of metal oxides using Saccharomycetes is also being investigated - nanoparticles of oxides of silver, zinc, antimony, manganese, iron, selenium, silicon dioxide, and titanium. The biosynthesis of nanoparticles of binary chalcogenides (sulfide of selenium, zinc, cadmium) using Saccharomyces cerevisiae is studied. Such nanoparticles have better biological and electrochemical properties compared to their monocomponent counterparts due to faster electrochemical kinetics and higher electronic conductivity. There are different approaches when using yeast for the biosynthesis of nanoparticles. In particular, biomass, culture liquid, supernatant, and cell-free aqueous extract can be used. At the same time, the parameters of biosynthesis differ: temperature, pH, mixing, and duration. Depending on the choice of technique, nanoparticles of different shapes and sizes can be obtained, and they will also differ in their physicochemical and biological properties.

Keywords: nanoparticles, biosynthesis, Saccharomycetes, yeast

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Introduction

Traditional methods of nanoparticle synthesis, specifically chemical and physical methods, are long, time-consuming and based on the use of toxic compounds that subsequently pollute the environment (Joudeh et al. 2022). Biological methods of nanoparticles synthesis are environmentally friendly, as well as simple, fast and cost-effective (Chopra et al., 2022). Nowadays, various biological systems can be used for the biosynthesis of nanoparticles - plants, archaea, viruses, bacteria, fungi, and yeast. At the same time, their biomolecules act as reducing agents and stabilizers during the

biosynthesis of nanoparticles (Arul et al., 2024; Mustapha et al., 2022; Saravanan et al., 2021). Among various biological objects, yeast has a number of advantages when used for the biosynthesis of nanoparticles. These microorganisms and their metabolites are completely safe for humans, animals and the environment. In addition, yeast synthesize a large number of biologically active compounds (proteins, enzymes, amino acids, organic acids, vitamins) that can participate in the biosynthesis and stabilization of nanoparticles (Skalickova, Baron, & Sochor, 2017). Saccharomyces have highly active enzymes which perform wide range of biochemical reaction, including redox reactions. Saccharomycetes are widely used in food production and form a type of production waste applicable for nanoparticles synthesis. That is why methods of nanoparticle biosynthesis using Saccharomyces yeast are actively being researched (Ammar et al., 2021; Asghari-Paskiabi et al., 2019; Kthiri et al., 2021; Mulyani et al., 2021; Ranjani et al., 2022; Zamani et al., 2020). The use of yeast biomass for the production of nanoparticles involves the entire potential of the cell's biochemical systems. At the same time, metal ions are toxic to yeast, which in many cases imposes certain restrictions on the planning of the biosynthesis process.

Therefore, the purpose of this review is the analysis of scientific publications and the generalization of experimental research data related to the parameters and mechanisms of nanoparticle biosynthesis using *Saccharomyces* yeast.

Noble metals

Nowadays, nanoparticles of noble metals (gold, silver, platinum, palladium) are actively attracting the attention of scientists due to their unique physical, chemical and biological properties. They are used in various industries, in particular in the food industry, noble metal nanoparticles can be used in packaging materials to prevent the growth of pathogenic microorganisms in food products. Metal nanoparticles can also be used in water disinfection. There are studies on their use in agriculture as antifungal and antibacterial agents, pesticides, and soil bioremediation agents. Noble metal nanoparticles can be used in medicine as antibacterial, antifungal, antiviral, and antitumor compounds. The possibilities of their use for the diagnosis of various diseases are also being investigated (Koul al., 2021). Currently, research is being conducted on the biosynthesis of noble metals nanoparticles using saccharomycetes (Table 1). Accordingly, the synthesis of platinum nanoparticles (PtNPs) was implemented using *Saccharomyces boulardii* biomass. The optimal biosynthesis process parameters were determined: according to absorption in the UV spectrum, the synthesis with the highest biomass concentration of 500 mg/ml, at a temperature of 35°C, pH value of 7 and a concentration of 0.5 M of hydrogen hexachloroplatinate (IV) (H_2PtCl_6) was the most productive. The synthesis of nanoparticles was performed intracellularly (Borse al., 2015).

Studies related to the biosynthesis of palladium nanoparticles (PdNPs) using Saccharomyces cerevisiae yeast biomass have been conducted. Biosynthesized palladium nanoparticles with a face-centered cubic crystal lattice structure were characterized by photocatalytic activity (Sriramulu, & Sumathi, 2018). A cell-free extract of *Saccharomyces cerevisiae* was used for the biosynthesis of gold nanoparticles (AuNPs). The researchers studied the influence of the synthesis medium pH on the properties of AuNPs: it was found that with an increase in pH, the size of nanoparticles decreases and the proportion of triangular nanoparticles among other shapes increases (Yang et al., 2017). In one of the works, the supernatant of *Saccharomyces cerevisiae* KCCM:11293 is used for the synthesis of silver and gold nanoparticles at different pH values. The optimal pH values for the gold

nanoparticles synthesis ranged from 4 to 6, and for silver nanoparticles - from 6 to 10 (Lim et al. 2011).

Table 1. Yeast of the genus *Saccharomyces* for noble metals nanoparticles biosynthesis

Saccharomycetes	Nanoparticles biosynthesis conditions	Nanoparticles, their form and size	Source
Saccharomyces boulardii	Biomass, 0.5 mM $H_2PtCl_6 \times H_2O$ 35°C, 200 rpm, 72 h	PtNPs, spherical, 90 nm	Borse et al., 2015
Saccharomyces cerevisiae	Biomass, 1 mM $Pd(CH_3COO)_2$, room temperatre, static conditions, 24 h	PdNPs, spherical, triangular, hexagonal; 32 nm	Sriramulu, & Sumathi, 2018
Saccharomyces cerevisiae NBRC 2044	Biomass, 1.25 mM $HAuCl_4$, pH 7, anaerobic conditions	AuNPs, spherical, 10-20 nm	Saitoh et al., 2018
Saccharomyces cerevisiae	Cell-free extract, 2.5 mM $HAuCl_4$, 35°C, 5 h	AuNPs, triangular, hexagonal	Yang et al., 2017
Saccharomyces sp. BDU-XR1	Biomass, 0.01 mM $AgNO_3$, 30°C, 13 days	AgNPs, spherical, 8-17 nm	Jafarov et al., 2017
Saccharomyces cerevisiae PTCC 5052	Culture liquid, 2 mM $AgNO_3$, pH 7, 150 rpm, 25°C, 24 h	AgNPs, spherical, 5-20 nm	Niknejad et al., 2015
Saccharomyces cerevisiae BY4741	Supernatant, 1 mM $AgNO_3$, room temperature, 24 h	AgNPs, spherical, 2-12 nm	Kthiri et al., 2021
Saccharomyces uvarum HA-NY3	Supernatant, 2 mM $AgNO_3$, 150 rpm, 30°C, 72 h	AgNPs, round and cubic, 12.4 nm	Ammar et al., 2021
Saccharomyces cerevisiae M 437	Cell-free extract, 1 mM $AgNO_3$, 45°C, 72 h	AgNPs, spherical	Skrotska et al., 2021
Saccharomyces cerevisiae	Yeast extract, 25 mM $AgNO_3$	AgNPs, spherical, 10-60 nm	Sowbarnika et al., 2018
Saccharomyces cerevisiae ATCC-204661	Yeast β-glucan, 0.01 M $AgNO_3$, 150 rpm, 90°C, 350 min	AgNPs, spherical, 2.5-9 nm	Elnagar et al., 2021

The biosynthesis of silver nanoparticles was realized using the supernatant of *Saccharomyces cerevisiae*, which were isolated from grape juice. Researchers synthesized AgNPs at different pH values – from 4 to 6. It was found that silver nanoparticles exhibit antibacterial properties against *Escherichia coli* and *Staphylococcus aureus*, while nanoparticles synthesized at pH 6 inhibit the growth of microorganisms better than those synthesized at pH 4 (Badhusha & Mohideen, 2016).

Another example of the study of biogenic silver nanoparticles, which were obtained using the supernatant of Saccharomyces cerevisiae BY4741, includes the study of the biosynthesis of AgNPs in a static magnetic field. According to the results of the experiment, nanoparticles obtained in a static artificial magnetic field of 250 mT had smaller sizes (2-12 nm) than those synthesized without such

conditions, that is, in the earth's magnetic field (11-25 nm at 0.075 mT). Biogenic AgNPs were characterized by antibacterial activity. Minimum inhibitory concentration and minimum bactericidal concentration against *Escherichia coli* were 25 μg/ml and 70 μg/ml, respectively. Against *Staphylococcus aureus* these values were 15 μg/ml and 50 μg/ml, respectively (Kthiri et al., 2021).

The biosynthesis of silver nanoparticles using a cell-free extract of *Saccharomyces cerevisiae* was studied. The extract that was obtained from cells that were at the initial stage of the stationary phase of growth provided the highest efficiency of AgNPs synthesis compared to other samples of cell-free extract that were obtained from cells in other phases of growth. When increasing the concentration of silver from 1 to 5 mM, the researchers did not observe a significant increase in the concentration of nanoparticles, which can be explained by the toxicity of silver ions at concentrations higher than 1 mM. At synthesis temperatures higher than 40 °C, a decrease in the concentration of AgNPs was observed, which was attributed by the researchers to the denaturation of proteins involved in the synthesis and stabilization of the nanoparticles. The concentration of the synthesized silver nanoparticles also increased when pH shifted towards alkaline values, however considerable aggregation of the nanoparticles was observed. Synthesized AgNPs have anticancer activity: in concentrations from 10 to 100 μg/ml of AgNPs, the inhibitory activity against MCF-7 cells was about 80%, while for silver salts this indicator was less than 40%. The IC_{50} value for silver nanoparticles was 10 μg/ml (Kaler al., 2013).

Silver chloride nanoparticles (AgClNPs) were synthesized using a cell-free extract of *Saccharomyces cerevisiae*. They were spherical in shape and 9-51 nm in size. Antimycobacterial activity of AgClNPs against *Mycobacterium tuberculosis* and *Mycobacterium smegmatis* was investigated. Synthesized AgClNPs were analyzed using FTIR analysis: according to the results of the study, peak shifts of primary amines were recorded in nanoparticle samples, which, according to the researchers, indicates the involvement of this functional group in the synthesis of nanoparticles (Sivaraj al., 2020).

Regarding the mechanisms of biosynthesis of noble metals nanoparticles, it was shown that amide and hydroxyl groups of protein molecules take part in the reduction of platinum ions, as well as in the formation and stabilization of platinum nanoparticles (Borse, 2015; Eramabadi, 2020). Amide, methyl, methylene, and hydroxyl groups of biomolecules contained in the yeast supernatant participate in the biosynthesis of palladium nanoparticles (Gayda et al., 2019). When using biomass for the biosynthesis of PdNPs, hydroxyl, carboxyl and amino groups of biomolecules localized on the surface of cells participate in the adsorption and reduction of palladium ions and play an important role in the synthesis of nanoparticles (Chen et al., 2021).

When using yeast biomass for the biosynthesis of AuNPs, it was established that gold ions (Au^{3+}) are reduced (Au^0) with the participation of specific biomolecules on the cell surface or in cytoplasm. Next, nanoparticles are formed and stabilized with the participation of other biomolecules, whereafter AuNPs are released from the cell into the environment. At the same time, amide, carboxyl, and hydroxyl groups of proteins can take part in the reduction of gold and the formation of nanoparticles (Qu et al., 2018). It was also established that NADH participates in the reduction of Au^{3+} to Au^0, but it does not participate in the stabilization of already formed nanoparticles (Kumar et al. 2011). It was shown that the biosynthesis of AuNPs can be carried out without the participation of active enzymes, especially when using cell-free extracts (Krishnan al., 2021).

Considering the mechanisms of biosynthesis of silver nanoparticles using a cell-free aqueous yeast extract, the formation of silver nanoparticles begins with the reduction of Ag^+ ions to Ag^0 by

compounds contained in the extract itself, including amino acids, vitamins, and carbohydrates (Shu et al., 2020). Another mechanism of AgNPs biosynthesis using yeast is due to NADH-dependent nitrate reductase. It was found that the reduction of silver ions occurs with the help of electron transfer from NADH. After that, stabilization of AgNPs occurs due to biomolecules present in the reaction mixture (Shabbir & Mohammad, 2018).

Metal oxides

Scientists are investigating the role of yeast cells in the biosynthesis of metal oxides nanoparticles (Table 2). When investigating the biosynthesis of antimony oxide nanoparticles with a face-centered cubic lattice, the authors hypothesize that membrane-bound oxidoreductases, which exhibit oxidase activity in acidic pH, are involved in the formation of nanoparticles in *Saccharomyces cerevisiae* cells, while membrane-bound quinones accelerate the reaction due to their own tautomerism, ensuring the formation of molecular oxygen (Jha al., 2009).

The biosynthesis of silicon dioxide nanoparticles using the culture liquid of *Saccharomyces cerevisiae* PTCC 5269 was studied. The biosynthesized nanoparticles effectively changed the rheological properties of oil, which can be successfully used in oil production and oil refining (Zamani et al. 2020).

The possibility of biosynthesis of titanium dioxide nanoparticles (TiO_2NPs) using the supernatant of *Saccharomyces cerevisiae* MTCC 463 was shown. The researchers studied the antimicrobial activity of the synthesized nanoparticles when using various bacteria and fungi. Antibacterial activity was detected on models of gram-positive and gram-negative bacteria at concentrations of nanoparticles from 80 to 140 μg/ml. Antifungal activity was expressed much less: it was almost zero for the genera *Aspergillus* and *Mucor*, although it was at a level equivalent to antibacterial activity for the genus *Rhizopus* and yeast. The researchers also tested the photocatalytic activity on organic dyes: in white light, degradation was observed at the level of 24%, while in UV light - at the level of 38% (Hallis Nisar, & Kanimozhi, 2016).

In the work devoted to the optimization of the biosynthesis of zinc oxide nanoparticles (ZnONPs), researchers obtain nanoparticles with a hexagonal crystal structure using the supernatant of *Saccharomyces cerevisiae* A18 and explain the mechanism of biosynthesis by the reaction between zinc ions and hydroxyl groups of amino acids, as well as the activity of reductase enzymes, which are synthesized by yeast cells (Mulyani et al. 2021). Zinc oxide nanoparticles have antimicrobial properties. Mohamed & Kadium prepared ZnONPs using *Saccharomyces boulardii* yeast supernatant. The antimicrobial activity of biogenic zinc oxide nanoparticles at a concentration of 200 μg/ml was confirmed against *Proteus mirabilis* and *Pseudomonas aeruginosa*. The researchers attribute the existing antibacterial activity to the property of zinc oxide nanoparticles to promote the formation of reactive oxygen species that damage the cell membrane of bacteria, which leads to disruption of its structural and barrier functions. The anti-biofilm effect of zinc oxide nanoparticles was also investigated: using the example of *Proteus mirabilis* and *Staphylococcus aureus*, the researchers have shown that at a concentration of 64 μg/ml nanoparticles inhibited the formation of biofilms by 50%, and when the concentration of nanoparticles increased to 1024 μg/ml - by 97%. Interesting results occured in the study of the antioxidant properties of zinc oxide nanoparticles: at a concentration of 1 mg/ml, the nanoparticles neutralized more than 73% of 2,2-diphenyl-1-picrylhydrazyl radicals. Researchers explain the mechanism of nanoparticle biosynthesis by the presence of reductase enzymes in the supernatant (Mohamed & Kadium, 2022). The antitumor effect

of biogenic ZnONPs has been discovered. Anticancer activity of zinc oxide nanoparticles against MCF-7 (breast adenocarcinoma) cells was expressed in a significant decrease in the number of viable cells: up to 40% of viable cells after treatment with 25 μg/ml ZnONPs and up to 10% of viable cells after treatment with 100 μg/ml ZnONPs (Motazedi al., 2020).

Table 2. Usage of saccharomycetes for metal oxides nanoparticles biosynthesis

Saccharomycetes	Nanoparticles biosynthesis conditions	Nanoparticles, their form and size	Source
Silver oxide nanoparticles			
Saccharomyces cerevisiae A12	Supernatant, 0.1 M $AgNO_3$, 180 rpm, 24 h	Spherical, 9-85 nm	Eddy et al. 2021
Zinc oxide nanoparticles			
Saccharomyces cerevisiae A18	Supernatant, 0.3 M $Zn(CH_3COO)_2$, room temperature, 180 rpm	Spherical, 32 nm	Mulyani et al. 2021
Saccharomyces boulardii	Supernatant, 1 mM $Zn(CH_3COO)_2$	Spherical, 24 nm	Mohamed, & Kadium, 2022
Saccharomyces cerevisiae	Supernatant, 0.01 – 0.1 mM $Zn(CH_3COO)_2$, 30°C, 24 h	Spherical, 20 – 30 nm	Motazedi al., 2020
Saccharomyces cerevisiae	Baking yeast extract, 2 mM $Zn(CH_3COO)_2$, 50°C, 12 h	Spherical, 13 – 20 nm	El-Khawaga et al. 2023
Antimony oxide nanoparticles			
Saccharomyces cerevisiae	Biomass, 0.025 M $SbCl_3$, 60°C, 10 – 20 h	Spherical, 2 – 10 nm	Jha al., 2009
Manganese oxide nanoparticles			
Saccharomyces cerevisiae ATCC 24858	Supernatant or yeast extract, 1 mM $KMnO_4$, 10 min	Hexagonal, spherical, 34.4 nm	Salunke et al. 2015
Ferric oxide nanoparticles			
Saccharomyces cerevisiae	Biomass, 100 mM $FeSO_4 \times 7H_2O$, 1 mM $FeCl_3$, 30°C, 120 rpm, 48-72 h	Spherical, 155.7 nm	Ranjani et al. 2022
Silicon dioxide nanoparticles			
Saccharomyces cerevisiae PTCC 5269	Culture liquid, 0.1, 0.2, 0.5 M Na_2SiO_3	Mostly spherical, 40 – 70 nm	Zamani et al. 2020
Titanium dioxide nanoparticles			
Saccharomyces cerevisiae MTCC 463	Supernatant, 0.05 g TiO_2, 60°C, 10 – 20 min	Hexagonal, 100 nm	Hallis Nisar, & Kanimozhi, 2016

Binary chalcogenides

The biosynthesis of zinc sulfide nanoparticles (ZnS-NPs) was realized using *Saccharomyces cerevisiae* MTCC 2918 cells (Table 3). The researchers confirmed the intracellular synthesis of nanoparticles with a face-centered cubic crystal lattice. At the same time, it was noted that before biosynthesis, the toxic effect on yeast cells of the precursor - zinc sulfate in concentrations up to 10 mM, was tested. Zinc sulfate was found to be non-toxic to yeast cells, which was explained by the important role of zinc ions in yeast cells. The maximum rate of biosynthesis of nanoparticles was achieved at a concentration of 0.5 mM zinc sulfate and a concentration of yeast biomass of 1%. The researchers also noted that the highest rate of synthesis of nanoparticles is achieved in the culture at the stage of exponential growth. The final concentration of zinc sulfide nanoparticles in the culture fluid was 1.86 mM (Mala, & Rose, 2014).

The work related to the intracellular biosynthesis of selenium sulfide nanoparticles (SeS-NPs) using the yeast *Saccharomyces cerevisiae* PTCC 5052 showed their antifungal activity against *Aspergillus flavus*, *Aspergillus fumigatus*, *Alternaria alternata*, *Trichophyton rubrum*, *Microsporum canis* and *Candida krusei*: minimum inhibitory concentration (MIC) of nanoparticles was 1.25 mg/ml (Asghari-Paskiabi al., 2019).

Table 3. Binary chalcogenides nanoparticles biosynthesis using *Saccharomyces cerevisiae*

Saccharomycetes	Nanoparticles biosynthesis conditions	Nanoparticles, their form and size	Source
Saccharomyces cerevisiae	Culture liquid, 0.25 M $CdCl_2$, H_2S aqueous solution, 60°C, 10 – 20 min	Cadmium sulfide nanoparticles, spherical, 3.57 nm	Prasad, & Jha, 2010
Saccharomyces cerevisiae MTCC 2918	Biomass (1%), 1 mM $ZnSO_4$, 25°C, 180 rpm	Zinc sulfide nanoparticles, spherical, 30 – 40 nm	Mala, & Rose, 2014
Saccharomyces cerevisiae PTCC 5052	Biomass, 1 mM Na_2O_3SSe, 35°C, 180 rpm, 18 h	Selenium sulfide nanoparticles, spherical, 5-7 nm	Asghari-Paskiabi et al., 2019

Other nanoparticles

Intracellular biosynthesis of selenium nanoparticles (SeNPs) using *Saccharomyces cerevisiae* was realized. The researchers discovered antioxidant properties in synthesized nanoparticles against 2,2-diphenyl-1-picrylhydrazyl radicals (Faramarzi al., 2020). Another study on the biosynthesis of SeNPs using *Saccharomyces cerevisiae* biomass showed that the biosynthesis of spherical nanoparticles (100 nm) occurs under anaerobic conditions. The presence of a protein shell on the surface of SeNPs was found, which may indicate the direct involvement of yeast proteins in the formation and stabilization of nanoparticles (Zhang al., 2012).

Intracellular biosynthesis of bimetallic cadmium-selenium nanoparticles (CdSeNPs) using yeast biomass was studied. The researchers showed that the productivity of the process depends on the concentration of tryptone in the nutrient medium for the cultivation of *Saccharomyces cerevisiae*:

biosynthesis was carried out at tryptone concentrations of 22.5, 25, 27.5 and 30 g/l. The highest productivity of nanoparticle synthesis was observed at a tryptone concentration of 25 g/l. The researchers assume that the negatively charged amino acids of tryptone act as centers of initiation of the synthesis of CdSeNPs, attracting positively charged cadmium ions. At the same time, higher concentrations of tryptone can inhibit the metabolic pathways involved in the synthesis of nanoparticles. The authors also claim that the tripeptide glutathione can play an important role in the biosynthesis of CdSeNPs, since the synthesis of CdSeNPs was significantly suppressed when the GSH1 and GSH2 genes, which encode γ-glutamylcysteine ligase and glutathione synthase, respectively, were deleted (Sur et al., 2019).

Chang et al. have shown the possibility of intracellular synthesis of barium carbonate nanoparticles using *Saccharomyces cerevisiae*. The researchers note that barium ions are able to infiltrate inside living cells, where they react with dissolved carbon dioxide, resulting in the formation of nanoparticles. At the same time, the intracellular enzymes dihydrolipoyl dehydrogenase, alcohol dehydrogenase type I and enolase take a direct part in the formation of nanoparticles (Chang et al., 2021).

Conclusions

Scientific publications, which highlight the results of research into the biosynthesis of nanoparticles using yeast of the genus *Saccharomyces*, demonstrate the fundamental possibility of synthesizing both mono- and binary nanoparticles. Most of the works have an applied direction and aim to study useful properties and potential use of nanoparticles in many areas of human activity: medicine, industry, technology, etc. At the same time, quite a few works are aimed at optimizing the biosynthesis process of nanoparticles and studying the mechanisms of their formation in detail. The most common explanation for the mechanism of nanoparticle biosynthesis using yeast is the activity of reductase enzymes and the formation of nanoparticle growth centers on charged groups of amino acids in proteins. It should be noted that among the scientific publications there are practically no studies on the biosynthesis of copper nanoparticles using yeast cells, although there are data on their biosynthesis with the use of plants, bacteria and fungi, both when using aqueous extracts and biomass, culture liquid and supernatant. Therefore, the biosynthesis of copper nanoparticles using yeast, in particular saccharomycetes, is a promising direction of scientific research. Further research are being planned with scope on controllable copper nanoparticles biosynthesis in Saccharomyces cerevisiae biomass and cell-free extract.

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Conflict of interest

The authors state no conflict of interest.

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