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Article

Effects of Silver Nanoparticles on the Red Microalga *Porphyridium purpureum* CNMN-AR-02, Cultivated on Two Nutrient Media

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Abstract: The purpose of this study was to examine the influence of 10 and 20 nm nanoparticles (AgNPs) on the growth and biochemical composition of microalga *Porphyridium purpureum* CNMN-AR-02 in two media which differ by the total amount of mineral salts (MM1 with 33.02 g/L and MM2 with 21.65 g/L). Spectrophotometric methods were used to estimate the amount of biomass and its biochemical composition. This study provides evidence of both stimulatory and inhibitory effects of AgNPs on different parameters depending on the concentration, size, and composition of the nutrient medium. In relation to the mineral medium, AgNPs exhibited various effects on the content of proteins (an increase up to 20.5% in MM2 and a decrease up to 36.8% in MM1), carbohydrates (a decrease up to 35.8% in MM1 and 39.6% in MM2), phycobiliproteins (an increase up to 15.7% in MM2 and 56.8% in MM1), lipids (an increase up to 197% in MM1 and no changes found in MM2), antioxidant activity (a decrease in both media). The composition of the cultivation medium has been revealed as one of the factors influencing the involvement of nanoparticles in the biosynthetic activity of microalgae.

Keywords: *Porphyridium purpureum*; silver nanoparticles; nutrient media; biomass; biochemical composition; antioxidant activity; malondialdehyde content

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1. Introduction

Interest in the use of microalga *Porphyridium purpureum* (formerly *Porphyridium cruentum*) (Rhodophyta) as a biotechnological object is steadily increasing, as it represents a valuable source of substances with pronounced biological effects, such as phycobiliproteins, carbohydrates, especially sulfated polysaccharides and lipids, which contain appreciable quantities of polyunsaturated fatty acids [1–5]. Being a marine species, microalga is cultivated under industrial conditions in media with high mineral salt content, and this involves both high production costs and negative environmental impacts due to the excessive discharge of saline wastewater. At the same time, it has been shown that under the conditions of a short biotechnological cycle, *Porphyridium purpureum* culture can provide the same technological advantages in terms of the quantity and quality of biomass, using various media with different mineral nutrient content, with a significantly lower mineral salt content [6,7].

Another aspect of improving *Porphyridium purpureum* cultivation technologies lies in the application of various procedures to stimulate biomass growth and direct biomass composition. In the context of applying stimulants to produce higher amounts of biomass with a valuable and predictable biochemical content, nanoparticles of various natures are increasingly being explored from this perspective [8,9]. For example, nanoparticles of Mg, Al, Zn, Cu, Pb, Ag, Fe, Fe_3O_4 are used as effective stimulants to enhance lipid synthesis in microalgae for biofuel production purposes [10–12]. However, this effect is more often a result of the stress caused by high concentrations of these nanoparticles. At the current stage, the greatest successes in the study of the interactions between nanoparticles and microalgae pertain to elucidating these entities' toxicity mechanisms, with the metabolic pathways involved in the response reactions being highlighted [13]. At the same time, by applying low concentrations of nanoparticles, it is possible to accelerate the growth rate of microalgae, improve nutrient absorption, stimulate biomass production, and optimize the synthesis of bio-products of interest, such as proteins, carbohydrates, pigments, and lipids [8,14,15]. The remarkable bioavailability of nanoparticles supports the idea that they could represent more efficient sources of trace elements compared to their macroscopic forms, thereby contributing to improve vital functions [16].

Silver nanoparticles (AgNPs) are among the most actively used in various fields, such as the food industry, agriculture, textile industry, medical industry, and phycobiotechnologies, including for the valorization of *Porphyridium purpureum* biomass [8,11,17–19]. Thus, AgNPs are used as stimulants for biosynthetic activity, primarily lipids, the content of which can increase in microalgal biomass by 3–8 times [15,18]. Studies have shown the stimulating action of AgNPs on other biosynthetic processes such as carbohydrate production [8].

Modeling the cultivation conditions of microalgae growth in relation to the characteristics of nanoparticles, such as type, size, coating, and concentration, creates new opportunities to enhance the yield of biologically active substances [18,20]. In this context, the study of the influence characteristics of silver nanoparticles on microalga *Porphyridium purpureum* CNMN-AR-02 is of particular interest. The potential positive effects of silver nanoparticles can be amplified through the additional benefits offered by the possibility of applying a medium with a reduced content of mineral salts. Moreover, under such nutritional conditions, the effects of the nanoparticles can be significantly altered both in terms of magnitude and the direction of this effect.

Thus, the purpose of this study was to highlight the effects of two-dimensional nanoparticles—10 and 20 nm—applied in concentrations from 0.01 to 10.0 μM to the culture of *Porphyridium purpureum* CNMN-AR-02 on two mineral media characterized by different total salt content.

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