THE CONTENTS OF GANODERIC ACIDS IN MYCELIUM OF DIFFERENT GANODERMA SPECIES (GANODERMATACEAE) OBTAINED BY DIFFERENT METHODS OF CULTIVATION

Introduction. Ganoderma P. Karst. is a genus of polypore fungi, growing on different types of both conifers and deciduous trees. Species of Ganoderma are well-known for their medicinal effects, and in Asian countries they have been used in traditional medicine for over 2000 years [1]. It was discovered that not only fruit bodies, but also mycelium of fungi of this genus contain biologically active compounds [2]. Among them are polysaccharides, proteins, amino acids, cytokines and more than 150 different triterpenoids, including ganodermic acids [3, 4, 5]. According to the PubChem database, there are currently over 60 types of ganodermic acids [https://pubchem.ncbi.nlm.nih.gov]. Ganodermic acids show antitumor, antiviral (including HIV), anti-inflammatory, antihistamine activity [6, 7]. Such properties make these substances promising for medical and pharmaceutical applications. However, most of the global studies were focused on Ganoderma lucidum (Curtis) P. Karst. as a source of ganodermic acids, while other species have not been sufficiently studied [8]. Therefore, the study of ganodermic acids from different species and strains of Ganoderma and the effect of cultivation conditions on their amount in the fungal biomass is promising and necessary.

Material and methods. Strains from the IBK Mushroom Culture Collection of the M.G. Kholodny Institute of Botany, National Academy of Sciences of Ukraine were investigated. It has been shown that the submerged cultivation method is more efficient for the accumulation of ganodermic acids for five strains. In the mycelium of the strain G. sinense 2516 was the highest content of ganodermic acids – 25.2 ± 1.5 mg/g. The productivity (yield) of ganodermic acids synthesis is much higher with using the submerged culture cultivation method for mycelium of all used species and strains since the use of this method provides the accumulation of much more biomass in comparison with the static liquid cultivation method. The highest yield amount of ganodermic acids was in the mycelium of the G. tsugaee 2024 and G. tsugaee 2566 species, namely: 0.35 ± 0.019 and 0.36 ± 0.028 g/l. It was proved that the modified extraction method significantly reduces the extraction time of ganodermic acids. Extraction time is reduced from 14 to 2 days. For the G. sinense 2516 and G. tsugaee 2024 strains was determined content of the ganodermic acids and their yield in dynamics of grows in the submerged culture on 6, 8, 10, 12, 14, 16, 18 and 20 day of cultivation. The highest amount of ganodermic acids content was accumulated by the mycelium of the strain G. sinense 2516 – it was 26.4 ± 1.5 mg/g on the 14th day of cultivation. The highest yield of the ganodermic acids was in G. sinense 2516 on 14th day, and G. tsugaee 2024 mycelium on the 16th day of cultivation with the next numbers 0.6 ± 0.031, 0.62 ± 0.033 and 0.62 ± 0.027 g/l.

Keywords: Ganoderma, ganodermic acids, submerged cultivation, Ganoderma tsugaee, Ganoderma sinense.
The strains of G. tsugae 1848 and G. sinense 2516 contained 58% and 42.9% more GAs, respectively, when cultivated by submerged method, as compared to static liquid. Strains of G. resinaceum 2477, 2503, G. oregonense 2502 and G. carnosum 2502 produced approximately the same amount of GAs under static liquid and submerged cultivation conditions (the values are within statistical error limits). Mycelia of G. tsugae 2024, 2566, G. applanatum 1899, and G. lucidum 1904 grown by submerged cultivation had significantly higher amounts of GAs than those grown under static liquid conditions (Fig. 1). The highest level of GAs, 25.2 ± 1.5 mg/g, was found in the mycelium of G. sinense 2516, grown by submerged cultivation. As for the strain diversity of species, the GAs content of both strains of G. resinaceum was practically the same under both cultivation conditions. At the same time, G. tsugae strains had differences in the GAs content in the mycelium grown under static liquid conditions. Namely, the mycelium of G. tsugae strain 2566 accumulated 23.3% more GAs than G. tsugae 2024 and 56.7% more than G. tsugae 1848 (Fig. 1).

All strains, except G. oregonense 2560, had a significant advantage in the productivity of GAs synthesis by mycelium when grown under submerged cultivation conditions (Fig. 2). This is due to the fact that most species and strains accumulate significantly higher amounts of biomass in submerged culture, which was described in our previous study [11]. The highest productivity of GAs synthesis ≈ 0.35 g/l was in G. tsugae 2024 and 2566 strains grown in submerged culture, with the difference between them being in the range of statistical error (Fig. 2). Also the highest yield of endopolysaccharides synthesis was in mycelium of G. tsugae 2024, that was demonstrated in our previous experiment [11]. These results are due to the fact that strain G. tsugae 2024 accumulated the highest level of biomass, than other strains. Based on the results of this part of the study, strains of G. sinense 2516 (with the highest GAs content) and G. tsugae 2024 (with the highest biomass accumulation and productivity of GAs synthesis) in submerged culture were selected for further research. The application of the modified method of GAs extraction allowed to significantly reduce the total time of GAs extraction without loss of substance in comparison with the classical method. Therefore, in our further research a modified method was used.
As the diagram in Fig. 3 shows, the mycelium GAs content of G. tsugae 2024 and G. sinense 2516 strains increased gradually from the 6th day to a peak on the 14th day of cultivation, and after that, it began to decline. On the 6th day of cultivation, the amount of GAs in mycelium of both species was almost equal, and increased significantly already on the 8th day of cultivation, by 56.5% and 63.3% in G. tsugae 2024 and G. sinense 2516, respectively. In all other days there was a gradual increase in the content of GAs, with a dominant strain of G. sinense 2516. On the 14th day, the GAs content in the mycelium of both strains reached its maximum, while in G. tsugae 2024 this parameter was 9% lower than for G. sinense 2516. After that the trend of higher content of GAs was maintained in G. sinense 2516 (Fig. 3) in addition, on the 16th, 18th, and 20th day of cultivation, the content of GAs in G. sinense 2516 mycelium varied within the statistical error and was lower than that on the 14th day of cultivation. On the 16th day of cultivation, the GAs content in mycelium of G. tsugae 2024 was as high as on the 14th day of cultivation, but decreased and remained almost unchanged on the 18th and 20th days of cultivation.

Data analysis in Fig. 4 indicates that both studied strains, G. tsugae 2024 and G. sinense 2516 showed extremely low yield of GAs synthesis on the 6th day of cultivation. This is related both to the small amount of biomass and the low level of GAs. On the 8th day of cultivation, the yield of GAs synthesis by both strains increased remarkably, although in G. sinense 2516 this value was almost twice as high as in G. tsugae 2024. However, on the 10th, 12th, and 14th days this parameter was almost the same for each of the strains (the values lied within the statistical error limits). The peak of productivity in G. sinense 2516 occurred on the 14th day and gradually decreased up to the 20th day of cultivation, which was related to the reduction of biomass and GAs content. The difference between the yield of G. sinense 2516 on the 14th and 6th days of cultivation (the highest and lowest value) was 98% (Fig. 4). For the mycelium of G. tsugae 2024, the peak of productivity occurred on the 16th day of cultivation, but on the 14th, 18th, and 20 days of cultivation the value varied within the statistical error, which was associated with an increase in the biomass accumulation of the mycelium of this strain. The difference between the synthesis productivity of G. tsugae 2024 on the 14th and 6th days of cultivation (the highest and lowest value) was also 98% (Fig. 4).
Analysis of literature data on the content and productivity of GAs in the mycelium of different species and strains of the genus Ganoderma, including the impact of different cultivation conditions shows that the majority of researchers used strains of G. lucidum in their studies [14].

Fang and Zhong report GAs content of 18.6 mg/g and GAs synthesis yield of 0.267 g/l under submerged cultivation conditions for G. lucidum [12], which is 29.5% and 57.1% lower, respectively than similar parameters in the highest results, what we got in our study. GAs content of G. sinense 2516 is 26.4 mg/g, and productivity of G. tsugae 2024 is 0.623 g/l. In another study, Zhang and Tang [13] published the results on the positive effect of light exposure on G. lucidum mycelium in submerged culture and GAs content was 31 mg/g, which is 14.8% more than the same parameter in our experiment, but the productivity was 0.466 g/l [13], which is 25% lower than the maximum value in our study. According to Tang et al. [15], the GAs content and productivity were higher, but they were using a bioreactor for G. lucidum cultivation. The two-stage cultivation method in flasks allowed to obtain very high values for the specified parameters, GAs content was 44.7 g/l, and the productivity of GAs synthesis was 1.427 g/l in mycelium of G. lucidum [16], which was 50% and 56.3% higher than the maximum values obtained in our study.

Wei et al. [8] in their study screened different species for GAs content and optimized cultivation conditions for the selected G. lucidum strain. As a result, after selecting the optimal nutrient medium and using 300 l bioreactor, the values of 20 mg/g on the GAs content and productivity of 0.677 g/l were obtained. Therefore, the highest GAs content of G. sinense 2516 strain we used in the study was 24.2% higher than that of the above researchers, but the maximum yield what we got was 7% lower. It should be noted that the cultivation time in our study was 5 days longer. It was, because using a bioreactor is better way to cultivate mycelium biomass then the Erlenmeyer’s flasks with laboratory shaker.

Based on the results of the experiment, it is advisable to consider strains G. tsugae 2024 and G. sinense 2516 from the IBK Mushroom Culture Collection of the M.G. Kholodny Institute of Botany NASU as promising producers of valuable biologically active substances – ganoderic acids.

Conclusion. It was found that the submerged cultivation method has an advantage over the static cultivation method in terms of GAs accumulation parameter for 5 out of 10 studied strains and species (for 2 strains of G. tsugae, G. sinense 2516 as well as G. lucidum 1904 and G. applanatum 1899).

It was proved that the submerged cultivation method has a significant advantage over the static cultivation in terms of GAs synthesis productivity for all strains and species used in the study, except G. oregonense 2560. It was established that our modified method of GAs extraction allows to significantly reduce the total time of their extraction from mycelium.

It was proved that the mycelium of the different strains of one specie (G. tsugae) could accumulate different number of GAs in the same conditions of cultivation.

References
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ВМІСТ ГАНДЕРОВИХ КИСЛОТ
У МІЦЕЛІ РІЗНИХ ВИДІВ РОДУ GANODERMA (GANODERMATACEAE), ОТРИМАНОМІ РІЗНИМИ СПОСОБАМИ КУЛЬТИВУВАННЯ

У ході досліджень перевірено вплив різних способів культивування на вміст ганодерових кислот 7 видів, 10 штамів грибів роду Ganoderma з Колекції культур шляхових грибів (ІВК) Інституту ботаніки імені М. Г. Холодного НАН України: Ganoderma applanatum 1899; Ganoderma cortinum 2502; Ganoderma lucidum 1904; Ganoderma resinaeform 2477, 2503; Ganoderma sinense 2516; Ganoderma tsugae 1848, 2024, 2566, Ganoderma oregonense 2560. Доведено, що для 5 видів глубинний спосіб культивування є ефективнішим для накопичення ганодерових кислот. Визначено, що найбільш вміст ганодерових кислот був у міцелі штаму G. sinense 2516 – 25,21±1,5 мг/мл. Продуктивність синтезу ганодерових кислот набагато вища за використання глубинного способу культивування для міцелі всіх видів і штамів, завдяки тому, що застосування вказаного способу забезпечує накопичення значно більшої кількості біомаси порівняно з методом поверхневого культивування. Найбільша продуктивність синтезу ганодерових кислот була отримана для міцелі штаму G. sinense 2516 і G. tsugae 2024 та G. tsugae 2566 зі значеннями 0,350±0,019 та 0,360±0,028 г/л. Доведено, що модифікований спосіб екстракції дозволяє значно скоротити час екстракції ганодерових кислот. Порівняно з класичним методом час екстракції зменшується із 14 до 2 хв. Перевірено вплив ганодерових кислот і продуктивність його синтезу для штамів G. sinense 2516 та G. tsugae 2024 в динаміці, вирощених у глубинній культурі, на 6, 8, 10, 12, 14, 16, 18 та 20 добу культивування. Найвишу кількість ганодерових кислот накопичувала міцеля штаму G. sinense 2516 – 26,43±1,5 мг/л на 14 добу культивування та G. sinense 2516 на 16 добу, і складала 0,610±0,031, 0,620±0,033 та 0,620±0,027 г/л відповідно.

Ключові слої: Ganoderma, ганодерові кислоти, глубинне культивування, Ganoderma tsugae, Ganoderma sinense.

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СОДЕРЖАННЯ ГАНДЕРОВИХ КИСЛОТ
В МІЦЕЛІ РІЗНИХ ВИДІВ РОДА GANODERMA (GANODERMATACEAE), ПОЛУЧЕНОМІ РІЗНИМИ СПОСОБАМИ КУЛЬТИВУВАННЯ

В ході проведеного ісследования было проведено вплив различных способов культивирования на содержание ганодерових кислот 7 видов, 10 штаммов грибов рода Ganoderma из коллекции культур шляховых грибов (ИВК) Института ботаники имени М. Г. Холодного НАН Украины: Ganoderma applanatum 1899; Ganoderma cortinum 2502; Ganoderma lucidum 1904; Ganoderma resinaeform 2477, 2503; Ganoderma sinense 2516; Ganoderma tsugae 1848, 2024, 2566, Ganoderma oregonense 2560. Доказано, что для 5 видов глубинный способ культивирования является эффективным для накопления ганодерових кислот. Определено, что наибольшее содержание ганодерових кислот было в мицелии штамма G. sinense 2516 – 25,21±1,5 мг/мл. Производительность синтеза ганодерових кислот гораздо выше при использовании глубинного способа культивирования для мицели этих видов и штаммов, благодаря тому, что использование указанного способа обеспечивает накопление значительного количества биомассы по сравнению с методом поверхностного культивирования. Наиболее производительная синтеза ганодеровных кислот получена для мицелиев видов G. tsugae 2024 и G. tsugae 2566 со значениями 0,350±0,019 и 0,360±0,028 г/л. Доказано, что модифицированный способ экстракции позволяет значительно сократить время экстракции ганодеровных кислот. По сравнению с классическим методом экстракции время уменьшается на 14 до 2 суток. Было проверено содержание ганодеровных кислот и производительность их синтеза для штаммов G. sinense 2516 и G. tsugae 2024 в динамике, в выращенных в глубинной культуре, на 6, 8, 10, 12, 14, 16, 18 и 20 сутки культивирования. Наибольшее количество ганодеровных кислот накапливал мицелий штамма G. sinense 2516 – 26,43±1,5 мг/л на 14 сутки культивирования. Наибольшая производительность синтеза ганодеровных кислот была 0,610±0,031, 0,620±0,033 и 0,620±0,027 г/л соответственно.

Ключевые слова: Ganoderma, ганодеровье кислоты, глубинное культивирование, Ganoderma tsugae, Ganoderma sinense.