Waste-free fungi production in the Russian Federation

N L Devochkina¹, M I Ivanova¹, R D Nurmetov¹ and L G Dugunieva¹

¹Federal Scientific Vegetable Center, 14, Selectionnaya str., VNISSOK, Odintsovo district, 143072, Moscow region, Russian Federation

E-mail: vniioh@yandex.ru

Abstract. Due to their pleasant taste, high protein levels, and tonic and medicinal value, fungi are clearly one of the world’s largest untapped resources of nutritious and delicious food for humanity. Different types of fungi have different abilities to use substrates. This depends on the specific enzymes secreted by the individual fungus. Commercially cultivated fungi show different abilities to use different lignocellulolytic substances as a substrate for growth and formation of fruit bodies. Fungi growing fits perfectly into the production line with such branches of agriculture as crop production and animal husbandry, as in its technological process it uses raw materials that are waste from these branches of agricultural production, disposes of them and gets a cost-effective output of food-valuable and environmentally friendly products.

1. Introduction

The world and domestic experience of agricultural production has shown that organic fertilizers have a decisive influence on increasing soil fertility. Their value is determined by a complex positive impact on all factors of soil fertility [1]. The trend towards organic farming, i.e. farming with the use of a minimum amount of chemical fertilizers, is currently only being formed in domestic practice, while this practice has been particularly active abroad since the early 2000s. For example, large areas of land are used for organic agriculture in Europe – 5.1 million ha, in North America – 1.5 million ha, in Latin America – 4.7 million ha, in Australia – 10.6 million ha [2]. In Russia, the land area under organic production is 0.4% (164,449 ha). At the same time, one of the leaders in the production of granular organic fertilizers is the United States. In 2015, there were more than 1,400 large specialized organic processing plants in the United States, and more than 500,000 farms switched to the biological farming system [3].

Chicken (broiler) manure is a valuable organic fertilizer, which contains the necessary amount of nutrients for the soil and plants [4]. However, the realities of doing business in domestic agriculture demonstrate the lack of opportunities for farmers to sell poultry excrement in full. Violation of poultry farming technology leads to the occurrence of large masses of organic matter, which are irrationally disposed of, violating the ecology of the environment.

Fresh bird droppings retain up to 30 percent of the not digested food, which does not allow it to be used as a fertilizer due to the longtime of natural development of microorganisms, the quantity and quality of which is not enough for the rapid decomposition of organic matter into available forms of plant nutrition.

In this regard, the processing of manure into safe organic fertilizers or its use in closed technological processes is an urgent need in modern agriculture in Russia [5,6]. In this regard, the expansion of the production of mushrooms, the sector of the fungi industry that uses waste of poultry
and grain production for the preparation of substrates, may have a positive value [7]. The developed technologies of controlled fermentation of substrates for fungi cultivation with full provision of technological equipment make it possible to obtain a high-quality substrate standardized for the main agrochemical indicators for growing fungi, and after the end of the growing process to have up to 40% of the spent substrate as a practically sterile highly concentrated organic material with a high nitrogen content in protein form [8, 9].

The deficit of the organic fertilizer market in the Russian Federation is equal to 300 thousand tons per year. At the same time, the market of organic fertilizers in Russia, according to scientists’ forecasts, may grow significantly [10].

Russia is increasing fungi production at a record pace [11]. After the Russian market was protected from cheap European products, fungi production in Russia began to grow rapidly, this was facilitated by the adoption of the state program for the development of the industry and the measures of state support developed by the Government of the Russian Federation. According to the Federal Customs Service, the annual import of fungi products is at the level of 67.5 to 100 thousand tons. Two-thirds of import deliveries were to two countries – Poland and Lithuania, which export to Russia more than 20 thousand tons of ready-made substrate for the mushroom culture and fresh fungi products [12]. National fungi complexes have been put into operation: a fungi production plant [the first stage of the project is 4 thousand tons/year, the company “Fungi rainbow” in the Kursk region], a little earlier a plant was opened in Krasnodar [the company “Russian fungus”, capacity - 6 thousand tons], in the Tula region - the company “Agrogrib” with the prospect of producing up to 25 thousand tons of fungi. The implementation of the initial stages has begun in the Moscow, Kaluga regions, and Tatarstan, and it is also possible to start construction of a fungi-growing complex in the Nizhny Novgorod region”.

At the same time, the gross harvest of mushrooms increased by about 30% and oyster mushrooms – by 20%. If this trend continues in the following years, which is quite possible to count on, the volume of fungi production in Russia in 2019 will be about 35 thousand tons. The annual growth rate will be an impressive 25.5%. The Russian fungi industry has not developed at such a rapid pace yet. The structure of fungi production is still dominated by mushrooms. Their share in the total gross collection is approximately 73%. Oyster mushrooms account for about 27% of the gross harvest. The total production of fungi should reach 140 thousand tons by 2020[13]. At the same time, the annual consumption of basic resources in accordance with technological standards for the production of fungi will be: ready-made substrate that has passed full-scale fermentation and is ready for fruiting – 470 thousand tons per year; winter wheat straw – 275 thousand tons; chicken manure – 200 thousand tons. The spent substrate – waste of fungi production will amount to 188 thousand tons.

2. Materials and methods
The research is based on the use of well-known technological methods for determining the metabolic processes in the compostable mass of the substrate, the development of standards for the use of the main components [14]. Methods of statistical evaluation of substrate production and economic analysis in industrial fungi growing are applied. Technical and economic indicators of individual production cycles in the general technological process of production of fruit bodies of edible fungi produced in the Russian Federation are developed and evaluated [15]. The result of this work is to determine the needs of the fungi industry in the use of renewable organic resources when reaching the volume of production of fresh fruit bodies of fungi in the specified volumes of 140 thousand tons per year, as well as to calculate the volume of organic waste received at the end of the process of growing fungi products. In our research, the quality indicators of the spent substrate were determined, its biochemical and agrochemical analysis was carried out, which confirms its suitability as a highly effective organic fertilizer [16].

3. Results
In a number of European countries, enterprises have been established for the centralized production of a substrate for the cultivation of mushrooms and other types of fungi. The substrate is the most
important product of the fungi growing industry and is supplied to a wide range of consumers - fungi producers [17].

In Russia, organic fertilizers are applied only at 7.5% of the total fertilized area. The volume of organic fertilizer exports from Russia in 2014 amounted to 876 tons, which is 116% higher than in 2012. The growth in exports of organic fertilizers indicates that in foreign countries, fertilizers of this type are gaining popularity as the most environmentally friendly. The import of organic fertilizers to the domestic market continues to be relatively high. Thus, according to 2015 data, the import amounted to 22 thousand tons. The study of the capacity of foreign markets showed that the leader in the consumption of organic fertilizers is the UAE (United Arab Emirates), Uzbekistan, and Tajikistan, which indicates a high potential for selling organic fertilizers to the territory of these countries (table 1) [18, 19]

Table 1. Actual capacity of the organic fertilizer market abroad, 2015.

| Region      | Actual capacity of the market, thousand tons |
|-------------|---------------------------------------------|
| UAE         | 32081.25                                    |
| Kazakhstan  | 85244.63                                    |
| Mongolia    | 24695.04                                    |
| Tajikistan  | 50482.00                                    |
| Uzbekistan  | 896720.00                                   |

The use of modern nano-and biotechnologies of fermentation and granulation allows processing bird droppings into granulated organic fertilizers that increase the yield of vegetables in the open ground by 20-30%. The cost is 2-3 times lower. The size of the granules allows applying fertilizer to the soil simultaneously with sowing, using existing equipment, and the soil fertility increases for up to 3 years. The production of biohumus is also effective, based on the processing of fungal waste substrate with the use of California worm. It is produced from the waste of the substrate after the cultivation of fungi. It has a high demand in the world and can be exported. One of the largest consumers of biohumus on the world market is the United Arab Emirates and Saudi Arabia, which use biohumus in national projects to transform the environment (turning sandy deserts into flowering oases). Therefore, the world prices for biohumus are dictated by the Arab countries (their only requirement is not to produce compost based on pig manure). The demand for high-quality organic fertilizers in the world is extremely high and continues to grow, according to experts, by 20-30% annually, because environmentally friendly food remains a large deficit. In addition, in Russia, this market is very far from being saturated. Only Russian gardeners (without taking into account the needs of the agricultural industry) need more than 2 million tons of biohumus annually. Biohumus is effective in solving a number of tasks for agricultural producers: reducing the cost of fertilizers (chemical fertilizers and pesticides are more expensive); improving the quality and shelf life of vegetables; production of environmentally friendly agricultural products; reducing the incidence of plant diseases. The calculated values of only the substrates used in the production cycle are about 188 thousand tons [20, 21]. The presented calculation is based on the study of the substrate metabolism processes that take place from the moment of mixing the initial materials to the end of harvesting the fungi fruit bodies. It shows the potential for high yield and the final yield of the spent substrate at the end of the crop rotation when using intensive multi-zone technology for growing the main fungi cultures: mushrooms and oyster mushrooms (table 2).

Table 2. Substrate mass loss during preparation and growing of mushroom fruit bodies (2015-2018) depending on the growing system.

| Indicators                     | Two zone system | Three zone system |
|-------------------------------|----------------|-----------------|
| Phase Ph1, 14 days, %         | 32-35          | 32-35           |
| Phase Ph2, 7-10 days, %       | 25-30          | 25-28           |
| Phase Ph3, 35/25 days, %      | 29-35          | 8-10            |
| Phase of fruiting and picking up mushroom, 35/14 days, % | 50-55 | 28-30 |
Specific consumption of the substrate & Total substrate mass loss, kg/m² & 75 & 90 & 50 & 40 & 5.6 & 8.6

To produce the volumes of fresh fruit bodies of fungi specified as indicators of the state program (140 thousand tons per year), it will be necessary to produce 470 thousand tons of phase 3 substrate in accordance with the introduction of a three-zone intensive cultivation system. The planned yield is 30 kg/m² per crop rotation. The yield of the spent substrate will be 188 thousand tons per year with a number of positive properties that allow it to be used as a concentrated organic fertilizer for both open and protected soil. In technological terms, after the culture turnover, the substrate is subjected to steam heat treatment at a temperature of +70°C (table 3).

Table 3. Physical and chemical indicators of the spent substrate (2015-2018).

| Indicator | Standard |
|-----------|----------|
| Appearance | loose in structure product with strongly decomposed components: straws, sawdust, other cellulose-containing materials, with an admixture of cover material, peat, interspersed with white mycellial hyphae of edible mushrooms |
| Color | from light brown to dark brown, almost black |
| Smell | humus, fungal substrate, peat mixture |
| pH of the medium (acidity of the water extract) | 5.5 – 6.8 |
| Mass fraction of moisture, W, % | 30 - 50 |
| Mass fraction of total nitrogen, N, % | 0.6 – 2.9 |
| Mass fraction of total phosphorus, P, at least,% | 0.6 |
| Mass fraction of total potassium, K, at least,% | 0.5 |
| Mass fraction of organic matter, % | 66 - 70 |
| Ratio of C:N | 6 -25 |
| Volume weight, g/cm³ | 0.9 -2.15 |
| Nutrient content, % of dry matter: | 0.3 – 1.0 |
| - mobile potassium (K2O) | 0.15 – 0.4 |
| - mobile phosphorus (P2O5) | 0.3 – 0.8 |
| - ammonia nitrogen (NH4)+ | 0.5 – 2.0 |
| - exchange calcium (CaO) |

4. Summary
Fungi cultivation includes a wide range of technologies. The choice of these technologies depends on the cultivated species, substrates, available capital, and so on. Organic solid waste is a type of biomass that is generated annually as a result of agriculture, forestry, and food processing. They consist mainly of three components: cellulose, hemicellulose, and lignin. Waste lignocellulose biomass is a potential raw substrate for growing edible fungi. Due to its active development, the fungi industry can make a significant contribution to the development of organic farming. However, further improvements in the production of existing cultivated species should be considered, including year-round cultivation of “seasonal” species and improved quality control.
5. References
[1] Novikov M N, Khokhlov V I, Ryabkov V V 1989 Bird droppings – valuable organic fertilizer. M.: Rosagropromizdat 80
[2] Kudryakov V G, Mironchuk V A, Esayan S A 2015 State regulation of organic agriculture: the basics and features of European and American legislation (Polythematic network electronic scientific journal of Kuban State Agrarian University) 105 505-522
[3] Kharitonov S A 2011 Organic agriculture as an innovative direction in agricultural development (Agrarian Russia) 2 54-56
[4] Litvinov S S, Nurmetov R D, Devochkina N L, Rogova N D, Konkova N A 2011 Prospects for the development of vegetable and fungi growing in the Russian Federation (Potatoes and vegetables) 56
[5] Ilin D Yu 2018 Possibilities of bioconversion of poultry waste (Sursky Bulletin) 33 3-8
[6] Devochkina N L 2004 Improvement of the complete technological process of cultivation of mushrooms (Achievements of Science and Technology of the Agro-Industrial Complex) 8 14.
[7] Devochkina N L, Alekseeva K L, Nurmetov R D 2016 Innovative technology of three-phase preparation of substrate for cultivation of mushrooms (Greenhouses of Russia) 3 70-74
[8] Devochkina N L, Alekseeva K L, Nurmetov R D 2017 Industrial cultivation of edible fungi as an element of closed technological processes in agricultural production (Greenhouses of Russia) 3 47-50
[9] Nurmetov R D, Popov G F, Devochkin L A 1982 Machines and equipment for growing fungi (System of machines for complex mechanization of agricultural production for 1981-1990 - Moscow: CRDIRPB) 598-602
[10] Gorchakov Ya V 2004 Development trends and market aspects of world organic agriculture Barnaul: “Az Buka” 256
[11] Soldatenko A V, Devochkina N L, Razin A F, Razin O A, Nurmetov R Dzh 2018 Industrial fungi growing as an innovative direction of economic activity in the agricultural sector of the Russian Federation (Vegetables of Russia) 3 89-92
[12] Muravyov A Yu 2015 Conception of the development of Russian fungi farming for the period 2015-2020. Moscow, Association “Greenhouses of Russia” 41
[13] Muravyov A Yu, Afanasyev V I 2016 State and prospects of development of fungi farming in Russia (Greenhouses of Russia) 3 18-21
[14] STD AIC 1. 10yu09. 0002-04. Norms of technological design of complexes for growing mushrooms (2004)
[15] Devochkina N L, Selivanov V G 2014 Innovation technologies and technical means for the production of fungi in protected ground M FSBSE “Rosinformagrotech” 136
[16] Devochkina N L 2004 Agrotechnological substantiation of industrial cultivation of mushrooms: autoref. diss... of Doctor of Agricultural Sciences M ARRIVG, 46
[17] Devochkina N L 2001 Modern principles of industrial fungi farming organization (Scientific works of ARRIVG. Vegetable growing: status, problems, prospects) 1 428–432.
[18] Organic fertilizer market in Russia - 2019. Indicators and forecasts. E-document of TEBIZGroup. order@tebiz.ru
[19] Gorshkov D V 2004 Market of environmentally friendly products: foreign experience and prospects of Russia (Marketing in Russia and abroad) 6 15-29
[20] Devochkina N L, Litvinov S S 2004 Economic efficiency of fungi-growing enterprises (Economics of agricultural and processing enterprises) 918-21
[21] Ivanov A I, Grishin G E, Ilin D Yu 2012 Ecological and economic efficiency of using waste from fungi production in crop production (Niva of the Volga region) 324 93-96