High-tech production of edible mushrooms on an industrial basis in the Russian Federation

N P Mishurov¹, V G Selivanov¹, N L Devochkina² and A A Rubtsov²

¹ Russian Research Institute of Information and Feasibility Study on Engineering Support of Agribusiness, the Federal State Budgetary Scientific Institution (Rosinformagrotekh FSBSI), 60, Lesnaya Str., Pravdinsky Township, Moscow Region, 141261 the Russian Federation
² Federal Scientific Center of Vegetable Growing, 14, Selektzionnaya Street, VNIISSOK village, Odintsovo urban district, Moscow Region, 143080 the Russian Federation

E-mail: fgnu@mail.ru

Abstract. The prospective development of industrial mushroom growing in the Russian Federation is assessed. Industrial mushroom growing is considered as the production of environmentally friendly products with a high content of food protein balanced in the content of the amino acid complex. Mushroom growing is an extremely capital-intensive, knowledge-intensive and labor-intensive agricultural production. General trends in the construction and establishment of new enterprises of the industry in the Russian Federation are determined based on the analysis of world trends in the development of industrial mushroom growing. Up-to-date approaches to technical and technological solutions prevailing in the world industrial mushroom growing are analyzed. An innovative organizational and technological system allows reaching a new level of labor productivity and ensuring high economic efficiency of production and achieving self-sufficiency of the population of the Russian Federation with mushroom products being 80% rich in protein [1].

1. Introduction

Industrial mushroom growing in the Russian Federation is currently actively developing. The industry is of great importance for supplying the population of the country with fresh and environmentally friendly cultivated mushrooms containing complete protein, vitamins and minerals. The production is not seasonal; it is carried out in specialized cultivation facilities all year round [1-2]. It is highly efficient in terms of intensive use of production areas and sizes of cultivation facilities. In order to meet the needs of the Russian population for mushroom products at the lowest European standards of 1 kg annually per capita, it is necessary to produce about 150,000 metric tons of mushrooms. However in reality, the Russian Federation produced only 0.5 to 0.6 kg annually per capita in 2020 [3]. A quantitative breakthrough in the mushroom industry took place in 2017. It has been marked, first of all, by the introduction in Russia of three large production facilities, these are Mushroom Rainbow in Kursk, Tander and Russian Mushroom in the Krasnodar Territory. Powerful promising projects are being performed in the Tula Region (Agrogrib LLC), the declared design capacity of the production facilities of which is 25,000 metric tons of mushrooms annually; in the Krasnodar Territory (Green Line greenhouse facilities) with a planned capacity of 10,500 metric tons annually; in the Penza
Region (Mushroom Company LLC) with a design capacity of 5,000 tons annually. According to the Greenhouses of Russia Association, the forecast of the total production size will be 85,000 metric tons of mushrooms per year in 2020, while taking into account the actual production output [4]. Such opportunities have opened up in our country thanks to the strong support of the government, which has taken measures to stimulate the development of the industry. The most important point was the fruitful cooperation with Christiaens group (Netherlands), an OEM that supplies equipment for mushroom growing [5].

2. Materials and methods
When conducting research in the field of prospects for the development of domestic mushroom growing and determining its importance in the production of food protein for the population of the Russian Federation on the introduction of up-to-date innovative technology and equipment currently used in real world production, the following methods were used:

- Economic and statistical method;
- Systemic and comparative analysis method;
- Method of mathematical modeling and planning [6-7].

The study is based on the collection and analysis of information and statistical data from the Federal State Statistics Service, FAO (Food and Agriculture Organization of the United Nations), which possesses reliable information in the field of world production of various types of food, and from Greenhouses of Russia, a Republican Production and Scientific Association. The paper evaluates the development trends of the world industrial mushroom growing and the state of domestic mushroom growing. The analysis of commercial offers of the world's leading suppliers of process equipment for mushroom growing is provided. The research was performed in three stages: stage 1 is an analytical review of the world production of mushroom products; stage 2 is a study of the organizational foundations of the world production of mushroom products, an assessment of the market for industrial equipment and mechanization means, and the most effective environmentally friendly production systems; stage 3 is an assessment of the state of Russian mushroom growing and elaboration of recommendations for the implementation of technology and equipment, as well as organizational and process production systems.

3. Results
Upgrading of domestic mushroom growing is currently the main task that requires a quick and qualified solution. An increase in the production of mushroom products and in its efficiency is possible due to the construction of new state-of-the-art growing mushroom facilities. The conditions for the transition to market relations in the agricultural sector require the improvement of organizational forms and methods of work. The production of mushroom products based on the up-to-date organization model is attractive for investment in the implementation of new construction, since it allows actually intensifying more than 1.5 times the process for mushroom production, thereby ensuring a return on investment within 5 years [8]. In addition, it is environmentally friendly throughout the entire production process starting from the substrate preparation through the end of the harvest, since it uses agricultural as waste renewable natural organic resources, such as cereal straw and waste from poultry and livestock, in the form of raw materials for the preparation of nutrient substrates necessary for growing mushrooms [9]. Most of the countries, where champignons (Agaricus) takes the lead in the mushroom industry, has introduced a process of three-phase preparation of the substrate and established specialized compost enterprises, which centrally produce high-quality compost for growing mushrooms [10]. Compost enterprises perform the processes of preliminary preparation of the initial components and their fermentation, heat treatment and germination of the mycelium of the fungus ‘in bulk’. For these purposes, hoppers equipped with ventilated floors and dedicated tunnels are used. The processes are fully mechanized and automated.
and are separated from the production facilities, which directly grow the fungal fruits. The nutritious substrate enters the mushroom after processing with steam in the tunnels, where it is freed from infectious substances, pests and diseases. The cultivation cycle is reduced to 6 weeks, 8.6 revolutions of the crop are performed annually with 1.8 time increase in production output (from 135 kg / m$^2$ to 258 kg / m$^2$) (table 1). The turnover of the culture in the growing chamber after the end of the harvest is completed with the operation of thermal treatment of the fully substrate loaded chamber with steam at a temperature of 70 °C for 6 to 8 hours. The remaining mycelium in the substrate enriches it with protein nitrogen, and after the champignon culture turnover, the substrate itself is a good organic fertilizer free from sources of infections.

**Table 1.** Comparative assessment of mushroom cultivation systems by process indicator.

| Indicator                                      | Growing system |
|-----------------------------------------------|----------------|
|                                               | Dual-zone      | Three-zone    |
| Specific substrate consumption per 1 m$^2$ after heat treatment (kg) | 85             | 100           |
| Planned yield, (kg / m$^2$)                    | 25             | 30            |
| Annual production output: (kg / m$^2$)         |                |               |
|                                               | 135            | 243           |
|                                               | 1,350          | 2,430         |
| Estimated cost of 1 kg of mushrooms (at 2020 prices) (rubles / kg) | 110            | 90            |
| Break-even level at an average annual selling price of 140 rubles / kg (%) | 30             | 56            |

The introduction of innovative process for the three-phase substrate preparation has a number of significant advantages over previously used processes:

- Reduction of energy intensity of production per unit of production;
- Increase in labor productivity due to complete mechanization and automation of labor-intensive processes (procurement of raw materials, their mixing and moistening, moving from one process area to another, handling in production facilities, etc.);
- High efficiency of combating diseases and pests of cultivated champignons due to the treatment of the substrate mass with steam (a protection process without the use of pesticides);
- Optimization of the water-air regime (microclimate) in all production facilities based on the use of effective ventilation equipment and control of air parameters using programming and computer control;
- Possibility of standardizing the process for preparing the substrate through the use of starting materials showing accurate agrochemical indicators;
- Ability to standardize the final product;
- Significant improvement of working conditions for employees of the plant for the preparation of champignon substrate.

The adopted process for the production of the phase III substrate excludes the possibility of harmful emissions entering the atmosphere and water sources. The preparation of the substrate and the moistening of the raw materials are performed using a closed water recycling system. All effluents from production facilities and corridors are collected through filters into tanks and reused to moisten the substrate. To neutralize gaseous metabolic products, in particular, ammonia released in phases I and II of substrate preparation, a dedicated filter is provided at the substrate production plant, which neutralizes the ammonia contained in the air. At the same time, ammonia-free air is discharged into the surrounding atmosphere from the production premises.
To prepare the substrate, the use of chemicals permitted for use in mushroom growing in accordance with the State catalog of pesticides and agrochemicals permitted for use on the territory of the Russian Federation is restrictedly allowed as protective agents [11].

A multi-zone process for the production of champignons has been introduced at all newly built facilities in the Russian Federation. Most of the facilities operate based on a full process cycle having three main production departments, such as a substrate preparation shop, a champignon growing shop, and a coating material preparation shop.

Multi-zone process is the basis of an up-to-date organizational and technological system for the production of mushrooms, not only champignons (*Agaricus*), but also oysters (*Pleurotus ostreatus*) and shiitake (*Lentinula edodes*).

Thus, the production output during the transition to a new organizational and technological system of production increases from 1,350 metric tons of fungal fruits to 2,430 metric tons per hectare of production area, i.e. 1.8 times.

In connection with the new construction of up-to-date mushroom growing facilities and the introduction of the latest technology, the growth rates of domestic mushroom growing have changed significantly (table 2).

### Table 2. Growth rates of mushroom production in the Russian Federation in 2010-2020 (‘000 metric tons).

| Year | *Agaricus* | *Pleurotus ostreatus* | *Lentinula edodes* | Total | Total gain |
|------|------------|-----------------------|-------------------|-------|------------|
| 2010 | 6,420      | 1,213                 |                   | 7,633 | –          |
| 2011 | 6,792      | 1,240                 |                   | 8,032 | 399        |
| 2012 | 7,300      | 1,800                 |                   | 9,100 | 1,068      |
| 2013 | 7,110      | 2,237                 |                   | 9,347 | 247        |
| 2014 | 8,349      | 2,751                 |                   | 11,100| 835        |
| 2015 | 7,048      | 2,770                 | 24                | 9,842 | –1,258     |
| 2016 | 9,900      | 3,475                 | 84                | 12,459| 2,617      |
| 2017 | 12,300     | 1,800                 | 85                | 18,100| 5,641      |
| 2018 | 21,500     | 3,500                 | 92                | 25,000| 6,900      |
| 2019 | 52,230     | 3,770                 | 100               | 56,000| 11,000     |
| 2020 | 80,900     | 4,100                 | 100               | 85,000| 29,000     |

The structure of the Russian market for fresh cultivated mushrooms has changed significantly in connection with the sanctions introduced by the Government of the Russian Federation in 2014 to restrict the import of mushroom products from Poland and other European countries, and a number of other countries (table 3) [12].

### Table 3. Structure of the Russian market of fresh cultivated mushrooms in the Russian Federation in 2017-2020 (‘000 metric tons).

| Year | Domestic production | Import | Total |
|------|---------------------|--------|-------|
| 2017 | 18.1                | 27.0   | 45.1  |
| 2018 | 26.0                | 26.0   | 52.0  |
| 2019 | 56.0                | 25.0   | 81.0  |
| 2020 | 85.0                | 20.0   | 105.0 |

We should note that industrial mushroom growing in the Russian Federation is accruing mainly due to the construction of industrial facilities for growing mushrooms. Based on the statistical data obtained (table 4), we can say with confidence that the Russian Federation will reach the level of 135,000 to 140,000 metric tons of fresh mushroom production in the near future, thereby taking a place in the first seven champignon producing countries (table 4).
Table 4. World ranking of countries in terms of cultivated mushroom production (2020).

| Item | Country          | Output (MT) | Item | Country            | Output (MT) |
|------|------------------|-------------|------|--------------------|-------------|
| 1    | China            | 7,800,000   | 15   | Indonesia          | 40,900      |
| 2    | USA              | 420,000     | 16   | Turkey             | 40,200      |
| 3    | Italy            | 683,000     | 17   | Hungary            | 32,000      |
| 4    | Netherlands      | 300,000     | 18   | India              | 30,000      |
| 5    | Poland           | 260,140     | 19   | Belgium            | 29,450      |
| 6    | Spain            | 197,000     | 20   | Republic of Korea  | 26,200      |
| 7    | France           | 120,000     | 21   | Vietnam            | 24,000      |
| 8    | Great Britain    | 100,000     | 22   | South Africa       | 18,800      |
| 9    | Canada           | 100,000     | 23   | Lithuania          | 15,800      |
| 10   | Russian Federation| 85,000     | 24   | Ukraine            | 15,000      |
| 11   | Australia        | 75,000      | 25   | Romania            | 14,500      |
| 12   | Germany          | 72,000      | 26   | Portugal           | 12,000      |
| 13   | Ireland          | 70,000      | 27   | Taiwan             | 10,530      |
| 14   | Japan            | 65,600      | 28   | Cyprus             | 11,500      |

4. Discussion

In our opinion, the expansion of the cultivation of oyster mushrooms and other wood-destroying mushrooms at specialized facilities based on state-of-the-art processes and process equipment is a very promising area for this country. The total annual production of these species of mushrooms in the Russian Federation does not exceed 5,000 metric tons annually, which is 5 to 6% of the total production. At the same time, oyster mushroom is attracting more and more attention of domestic producers. This is due to the fact that oyster mushroom is one of the fastest growing fungal cultures being disease resistant, highly competitive with respect to pathogenic microflora, and capable of growing on a variety of lignocellulosic substrates. In the Russian Federation, there is sufficient resource provision for the cultivation of wood-destroying species (oyster mushrooms, eringi (Pleurotus eryngii), shiitake, winter mushroom (Flammulina velutipes), changeable agaric (Kuehneromyces mutabilis), etc.) and other exotic mushrooms, since many regions produce grain crops, sunflowers, there is an increase in the production of flax and industrial hemp, the waste from the production of which can be used in mushroom growing as raw materials for the substrate preparation. A process of sterile production of a substrate for the cultivation of these species of mushrooms based on flax shover, sunflower seed husks, cereal straw, and birch and oak sawdust has been developed and introduced into production [13]. The advantages of the group of wood-destroying fungi are their nutritional and medicinal value due to their powerful enzymatic apparatus and the content of acutely deficient microelements (selenium) and group B and PP vitamins [14].

The developed process and technological regulations are promising for the oyster mushroom closed production cycle that reuses, as substrate components for growing oyster mushroom fungal fruits, the coconut material, winter wheat straw and sunflower seed husks spent in protected ground after growing the main cucumber and tomato crops. The novelty of this technology lies in the fact that for the first time a closed-loop production system in greenhouses with the reuse of waste materials for the production of additional mushroom products has been proposed. The practical significance of the process is the reuse as a substrate component of waste coconut material after the turnover of the main crops in greenhouses, which makes it possible to reduce its cost by 13-15%. The use of a natural organic growth stimulator (Epin) when processing the substrate at the time of sowing the mycelium increases the yield of mushroom products by 27 to 30%, while reaching a yield of 350 kg from 1 metric ton of finished substrate [15]. A complete closed process cycle for the production of oyster mushroom fungal fruits provides a profitability of at least 100% while obtaining a net income from 1,000 m² of usable area of cultivation facilities in the amount of 1.26 million rubles [16].
5. Conclusion

Analysis of the state of the industrial mushroom growing in the Russian Federation shows that the potential for its development is significant [17]. The edible mushroom production sector in Russia has begun to develop rapidly. In a short period of time, Russian mushroom growing has moved from 22nd place (18,000 metric tons of mushrooms annually as of 2017) to 10th (85,000 metric tons of mushrooms annually as of 2020). This was facilitated by measures of governmental support provided for in the State Program for the Development of the Industry.

Large domestic firms and companies are successfully operating on the mushroom market of the Russian Federation, such as Mushroom Rainbow LLC, Martin LLC, Agrogrib LLC, Russian mushroom LLC, April LLC and others, which have introduced the latest processes and innovative equipment. It is planned to launch enterprises for the centralized production of substrates for the cultivation of champignons and other species of mushrooms that are attractive to Russian consumers.

Work is underway in the field of scientific support to study and develop new agricultural practices that contribute to increasing the yield of cultivated mushrooms, the development of closed production processes, including the processing of fresh mushroom products, which provides high economic efficiency of production and return on investment [18].

References

[1] Muravyov A Yu and Efremov A A A concept for the development of Russian mushroom growing for 2015-2020 (Moscow: CJSC Interexpert) 42
[2] Devochkina N L, Nurmetov R D and Dolgikh L I 2012 Industrial cultivation as the basis for the development of mushroom growing in Russia. Greenhouses of Russia 3 39-43
[3] Soldatenko A V, Devochkina N L, Razin AmF, Razin OmA and Nurmetov R D 2018 Industrial mushroom growing as an innovative area of economic activity in the agricultural sector of the Russian Federation. Vegetables of Russia 3 89-92
[4] Zimenko A V 2020 Development of mushroom growing in Russia. Greenhouses of Russia 1 75-77
[5] Behrens V 1995 Guidelines for the Preparation of Industrial Feasibility Study (Moscow: AOZT Interexpert) 112
[6] Razin A F 2004 Modeling of innovative manufacture of competitive products. Bulletin of the Moscow Academy of Labor Market and Information Technologies 11 108-115
[7] Devochkina N L and Selivanov V G 2014 Innovative Technology and Technical Means for the Production of Mushrooms in Greenhouses (Guidelines) (Moscow: Rosinformagrotekh) 135
[8] Nurmetov R D and Devochkina N L 2010 Cultivation of Champignons and Oyster Mushrooms (Moscow: Russian Agricultural Academy) 67
[9] Devochkina N L, Alekseeva K L and Nurmetov R D 2016 Innovative process for three-phase preparation of a substrate for mushroom cultivation. Greenhouses of Russia 3 70-74
[10] Alekseeva K L 2002 Scientific Basis for Cultivation and Protection of Edible Mushrooms against Pests and Diseases (Moscow: PhD in Agriculture Thesis Author's abstract) 46
[11] Razin A F, Meshcheryakova R A, Devochkina N L and Razin O A 2020 The current state of mushroom growing in Russia and the risks (vulnerability) of the production of cultivated mushrooms. Economy of Agriculture of Russia 9 43-50
[12] Devochkina N L, Mukienko S V, Nurmetov R D and Pryanishnikova L N 2019 Innovative technology for the preparation of a substrate in sterile conditions for the cultivation of oyster mushrooms. Potatoes and vegetables 2 17-19
[13] Sychev P A 2003 Mushrooms and Mushroom Growing (Moscow: AST Publishing house, Donetsk Starker) 511
[14] Alekseeva K L and Churikova V V 2004 The use of Epin to stimulate the growth of an edible oyster mushroom. Reports of the Russian Academy of Agricultural Sciences 5 18-19
[15] Devochkina N L, Nurmetov R D and Razin O A 2017 Technology of growing oyster mushrooms in a closed production cycle. Vegetables of Russia 5 66-68
[16] Devochkina N L, Dugunieva L G, Razin A F, Ivanova M I and Nurmetov R D 2018 Investment attractiveness of industrial mushroom growing. *Economy of agriculture of Russia* **11** 52-59

[17] Devochkina N L, Alekseeva K L and Nurmetov R D 2017 Industrial cultivation of edible mushrooms as an element of closed processes in agricultural production. *Greenhouses of Russia* **3** 47-50