Vol. 36, No. 03, pp. 374-382/Junio 2023

ISSN-E 1995-9516
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http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v36i03.16460

Improving the efficiency of management decision-making: developing a simulation model of a cultivated mushroom farm

Mejora de la eficacia de la toma de decisiones de gestión: desarrollo de un modelo de simulación de una explotación de champiñones cultivados

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(recibido/received: 25-febrero-2023; aceptado/accepted: 19-mayo-2023)

ABSTRACT

Industrial production of edible mushrooms is now regarded as an independent agricultural industry not dependent on the seasonality of work inherent in most agricultural operations. Since agricultural production is characterized by high consumption of resources, cultivation and harvesting of mushroom produce are carried out by means of specialized technical and technological equipment, allowing one to provide the necessary microclimate conditions. These issues can be solved by using intensive technological resource-saving processes, which provide a sufficient level of production profitability. In this regard, there is a need to develop an economic-mathematical model able to simulate the process of the enterprise as an example. The study aims to develop a simulation model of a mushroom farm to improve the effectiveness of management decisions. The study employs the AnyLogic simulation instrument to create a model and test its accuracy with the cultivation of *Pleurotus ostreatus* oyster mushrooms. The authors develop a model of a farm for growing cultivated mushrooms and describe the created model, the algorithm of its operation, and the created interface. This model gives an idea about the optimal conditions for the cultivation of mushrooms and can be used for decision-making in techno-management complexes.

Keywords: cultivated mushrooms, mushroom farm, simulation model, technological process, anylogic instrumental environment.

RESUMEN

La producción industrial de setas comestibles se considera actualmente una industria agrícola independiente que no depende de la estacionalidad del trabajo inherente a la mayoría de las explotaciones agrícolas. Dado que la producción agrícola se caracteriza por un elevado consumo de recursos, el cultivo y la recolección de los productos del champiñón se llevan a cabo mediante equipos técnicos y tecnológicos especializados, que permiten proporcionar las condiciones microclimáticas necesarias. Estas cuestiones pueden resolverse utilizando procesos tecnológicos intensivos que ahorren recursos y proporcionen un nivel suficiente de rentabilidad de la producción. En este sentido, es necesario desarrollar un modelo económico-matemático capaz de simular el proceso de la empresa como ejemplo. El estudio pretende desarrollar un modelo de simulación de una explotación de champiñones para mejorar la eficacia de las decisiones de gestión. El estudio emplea el instrumento de simulación AnyLogic para crear un modelo y comprobar su precisión con el cultivo de setas ostra Pleurotus ostreatus. Los autores desarrollan el modelo de una granja de cultivo de setas y describen el modelo creado, el algoritmo de su funcionamiento y la interfaz creada. Este modelo da una idea de las condiciones óptimas para el cultivo de setas y puede utilizarse para la toma de decisiones en complejos de tecno-gestión.

Palabras claves: cultivo de setas, explotación de setas, modelo de simulación, proceso tecnológico, entorno instrumental anylogic.

1. INTRODUCTION

Cultivated mushrooms in the Russian Federation according to Government Resolution No. 458 are considered outdoor and indoor vegetables (Government of the Russian Federation, 2006). Over the past decade, industrial mushroom production has become an actively developing area of agriculture (Lazareva et al., 2011; Sysuev et al., 2018). For example, in 2021 the production volume of cultivated mushrooms in Russia increased by more than 16% and exceeded 100 thousand tons (Ministry of Agriculture of the Russian Federation, 2022). The growth of industry production in recent years has been mainly due to an increase in domestic competition. For further development of the market for cultivated mushrooms and increased efficiency of mushroom production and competitiveness in the near future, there is a need for transition to a new technological level of production system driven, in particular, by the use of innovative technologies of compost production and the cultivation and collection of the fruiting bodies of cultivated mushrooms.

Currently, there is a large body of scientific research on simulation modeling of production processes in agriculture. These models have been created for specific crops such as potatoes (Borodychev et al., 2020), wheat (Khudiakova, Klochkova, 2015), cotton (Reddy et al., 1997), etc., as well as their complexes (Iakushev et al., 2020; Li et al., 2012). There are several studies devoted to simulation modeling in animal husbandry, including the simulation of the number of livestock (Kuznetsov, 2018; Solianik, Solianik, 2020) and production at pig farms (Girutskii et al., 2022). Computer simulation models can also be employed to estimate the total allowable catch of fish (Menshutkin, Egorova, 2015) and the growth and development of mollusks (Vasechkina, Kazankova, 2014).

There are several scientific publications devoted to various issues of production process automation in processing agro-industrial enterprises, such as optimal management of soil water regime in irrigation (Melikhova et al., 2019; Ovchinnikov et al., 2018), modeling of logistic systems of agricultural enterprises (Ovchinnikova, 2008; Savva, 2013), and optimization of business process structure (Khudiakova, Blakitnaia, 2013).

P. Qin et al. (2023) consider the main methods of extracting active substances from the residues of edible mushrooms. The spent mushroom substrate becomes a useful resource for biogas production, thereby being fully integrated into the circle of resource reuse for energy production (Pérez-Chávezet al., 2019). D. Tian et al. (2021) determine the main factors influencing the behavior of edible mushroom producers in the implementation of mushroom pulp processing technologies and build an agent-based model for simulating the behavior of farmers in the adoption of a particular technology.

Thus, it can be concluded that the artificial cultivation of mushrooms contributes to solving the problem of processing the wastes of woodworking and agricultural production and obtaining useful environmentally friendly products with a high content of plant protein as a result.

However, despite the significant body of work on simulation modeling devoted to improving the efficiency of agricultural production, including mushroom production, there are no studies on the issues of modeling the production of edible mushrooms.

Proper design and management of the production processes of an organization, including those associated with the production of cultivated mushrooms, requires the consideration of a large number of factors describing constantly varying conditions (Blednykh et al., 2014; Didmanidze et al., 2018). We suggest that the optimal method for solving such problems is the use of simulation modeling, which provides an opportunity for assessing both quantitative and qualitative results of modeling the object under study in the changed conditions.

Simulation modeling is an experiment on a valid digital representation of any system. Unlike physical modeling, simulation modeling is based on computer technology using algorithms and equations. A simulation model can be analyzed in dynamics as well as viewed in 2D or 3D animation (AnyLogic, n.d.).

In this light, **the purpose of the present study** is to develop a simulation model for the production of cultivated mushrooms (using oyster mushrooms as an example).

2. METHODS

Nowadays, researchers use a wide range of simulation systems, including GPSS, iThink, AGNES, Actor Pigrim, Extendsim, ARIS Platform, SILA Union, and Scilab (Levina, 2017; Riazanova, Veresokin, 2020; Zharov, 2021).

The study of simulation systems suggests that they vary in technical capabilities, the feasibility of support from the system provider, and the possibility of multi-criteria optimization.

To create a simulation model of a mushroom-growing farm, we employed the Anylogic simulation modeling tool as the software. The greatest advantage of this system is the ability to combine a variety of modeling styles, such as methods of system dynamics and discrete-event and agent-based modeling, and hence display the diversity and heterogeneity of reality systems. In addition, Anylogic provides an extensive set of options for visualizing the built model in 2D and 3D formats, accelerating development with industry-specific libraries, etc.

As an example of the approbation of the simulation model for cultivated mushroom farming, we use oyster mushrooms (*Pleurotus ostreatus*). This species is chosen because of its popularity in commercial cultivation and its ability to grow on various substrates.

The system of mushroom cultivation involves the organizational and technological structure of production whose foundation is the technology provided with an appropriate list of cultivation facilities for basic and auxiliary purposes, technological service systems, and management and control of technological processes.

Using the oyster mushroom as an example has enabled us to create a realistic production process and assess the efficiency of the model. The results of the study provide valuable information about the optimization of mushroom production and the development of sustainable agricultural production methods.

The simulation model of an oyster mushroom farm is developed in the Anylogic multi-approach simulation environment.

3. RESULTS AND DISCUSSION

The simulation of an oyster mushroom farm is created to determine the chain of production operations ensuring optimal economic and technical parameters. The model was designed based on the following technological production scheme (Fig. 1) (Nabokikh, 2010; Petrova, 2007).

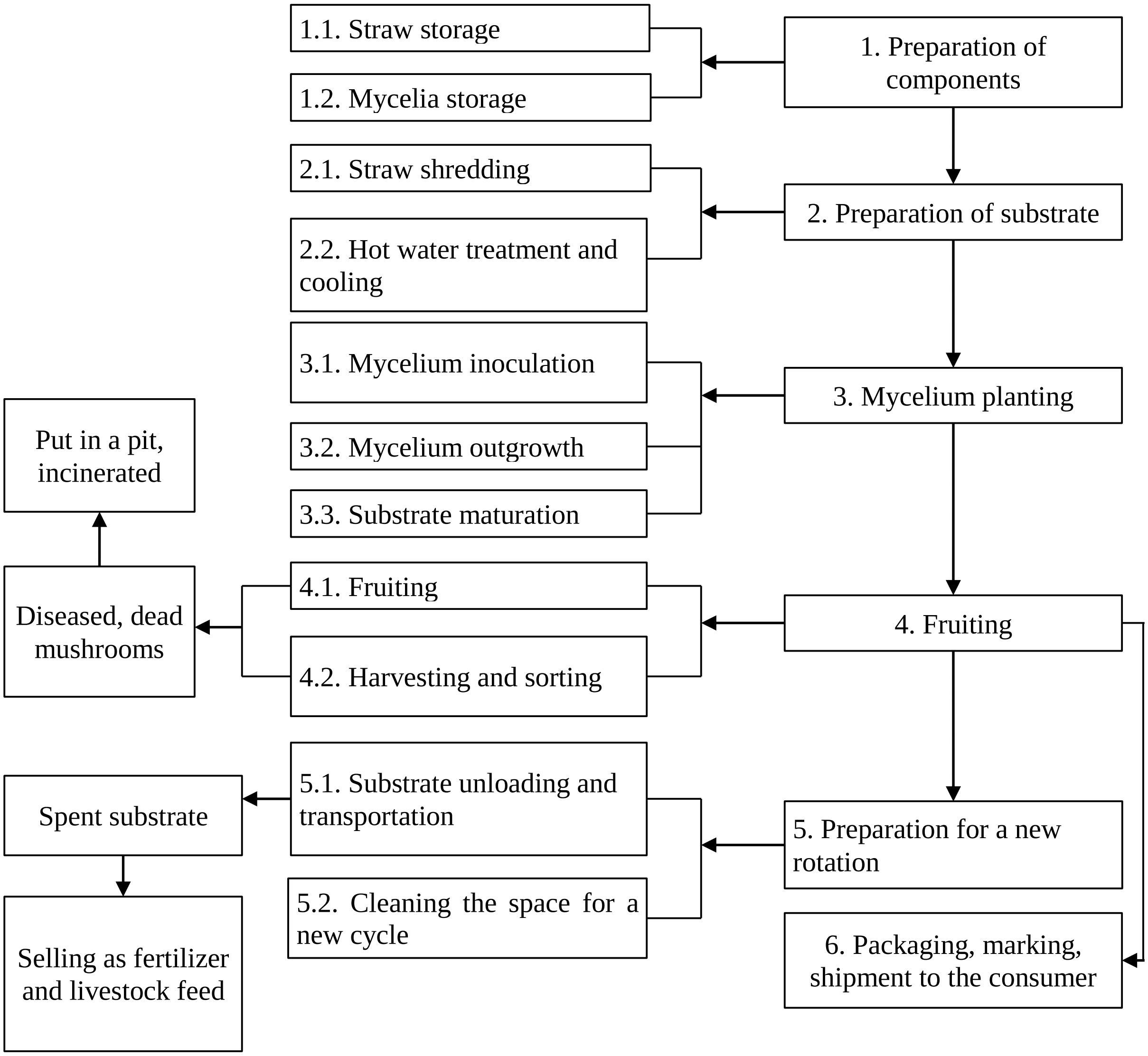

Figure 1. Technological scheme of oyster mushroom production.

The substrate workshop is divided into separate functional zones (Table 1) in which the operations of grinding and loading raw materials, mixing substrate components, steaming and moistening the substrate with cooling to the required temperature, and inoculation and molding of substrate blocks are performed sequentially.

Table 1. Substrate shop work zones.

No.	Work zones	Equipment
1	Straw chopping	Straw chopper (capacity from 1 t of straw per hour) Pneumatic conveyor Substrate machine SM-8 Steam generator from 50 to 100 kg/h (EPG-75)
2	Mechanical room	Water tank of 2-3 m^3 Technologist's room with automated process control system
3	Clean zone	Conveyor with receiving hopper and leveler Block molder

		Scales Punching machine Filtered air supply and overpressure unit Container for mycelium preparation Device to cut the film for blocks Film sleeve rolls
4	Sanitary pass to the clean zone	UV irradiators Hangers for dirty clothes Hangers for clean clothes Water shower or air blower
5	Tambour or airlock corridor	Cooling chamber for mycelium for one month of operation (10-20 m^3)

Importantly, if the substrate room and the incubation chambers are in the same room, there should be an airlock corridor or tambour room between them that is washed and disinfected before the finished substrate is fed in. Such an airlock prevents contamination from the incubation chambers into the clean area, even if the clean area fan is switched off.

The logical model of the enterprise was built using the flow modeling library and process modeling library (Dokumentatsiia Anylogic, n.d.; Boev, 2016).

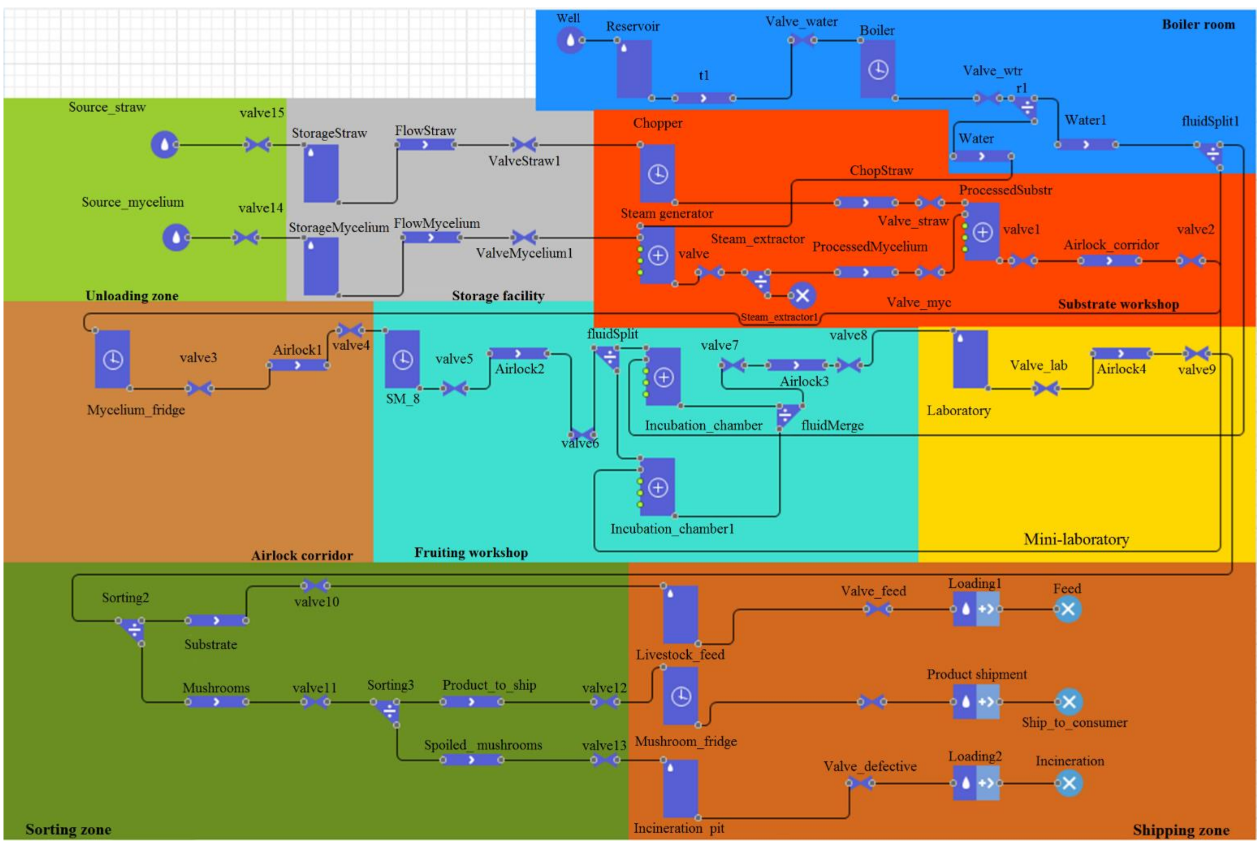

Figure 2. Logic diagram of the simulation model.

The logic model (Fig. 2) simulates the process of cultivated mushroom production. The process begins with the supply of raw materials, the amount of which can be regulated as needed and depending on the capacity of storage facilities. Valves are installed for the convenience of raw material supply flows. The incoming raw materials are sent for storage to storage facilities, the straw storage area, and the mycelium storage room and then to the substrate shop for further processing.

The water needed for production is assumed to be taken from the well, and a water tank is needed as well. After that, the water passes through a pipe to the boiler to heat some of the rooms and provide the facility with hot water.

From the boiler, water is supplied to the splitter for the operation of the steam generator and maintenance, as well as irrigation of the incubation chambers. It is envisaged that the company uses two incubation chambers, so the water flow is divided into two. A boiler room is provided for the convenience of housing all the elements.

In the substrate workshop, the primary processing of raw materials takes place, the straw is fed for chopping. In the meantime, the mycelium is processed in a steam generator, and then the raw material passes through a valve to the splitter. Here, the raw material necessary for planting is separated from the water accumulated after the heat treatment. Excess moisture goes to the steam removal unit and then is excluded from the model. The remaining raw material goes via a pipe through a valve and enters the block for raw material mixing. At the same time, the crushed raw material also enters the mixing tank via a pipe, and thus the mycelium is sown into the substrate.

After that, the substrate is considered ready for incubation and sent to the airlock corridor compartment. In the airlock corridor, there is a refrigerator for the finished substrate with a capacity for one batch to be supplied to the incubation chamber. After cooling, the ready substrate is transported through the airlock sleeve to the fruiting workshop. All raw material from the gateway corridor goes to the fruiting workshop into the substrate machine for repeated heat treatment and formation of substrate blocks. Then, the shaped and treated substrate blocks are transported to the incubation chambers.

The prepared substrate is kept in incubation chambers until the full maturation of mushrooms. A water supply line is connected to the incubation chambers for cleaning and watering the substrate. The cultivated mushrooms from every incubation chamber are combined into one stream and sent to the laboratory through the airlock corridor and valves. The laboratory analyzes the harvest, identifies infected and diseased mushrooms, takes samples, and then the entire harvest is sent for sorting.

In the sorting zone, the entire input stream is first divided into two parts, thereby separating the harvest from the substrate. Then the two output streams go on their way through the pipes with all the processed substrate sent to the tank for cattle feed, and the finished product stream transported for further sorting, where the mushrooms ready for sale are separated from the contaminated and spoiled ones. Then all the sorted components are forwarded to the shipment area.

The shipment zone is the final stage of production where spoiled mushrooms are incinerated and the harvest and substrate are sent to consumers. A refrigerator is provided for storing the finished product.

The constructed model for monitoring the main economic indicators of the enterprise can be supplemented with various graphs and blocks to collect statistics, for example, on the mass of incoming raw materials, straw, mycelium, the volume of mushrooms sold, rejected goods, processed substrate sold for cattle feed, water used, income, costs, and profit of the enterprise. The model can also be optimized by, for example, using different incubation chamber modes.

4. CONCLUSION

The developed animated model simulating the line of production of cultivated oyster mushrooms provides information on the state of all processes of the considered technological chain at specific points in time that is easily perceivable and available for further analysis.

The considered prototype of production is a visual example of the use of computer simulation modeling tools for studying problems and making appropriate decisions in techno-management complexes, including providing an opportunity to analyze the development of events in case of abnormal situations. The described model can serve as an example of a mushroom farm operation, setting the necessary parameters of production processes.

The created simulation model can be used to carry out various experiments on variations in the farm operation parameters included in the model, which will allow, if necessary, to choose production process characteristics suitable for a particular producer for its most effective management.

REFERENCES

AnyLogic. (n.d.). Imitatsionnoe modelirovanie – Instrument imitatsionnogo modelirovaniia Anylogic [Simulation modeling - Anylogic simulation modeling tool]. Retrieved from https://www.anylogic.ru/use-of-simulation/

Blednykh, V.V., Siniavskii, I.V., Svechnikov, P.G. (2014). Proektirovanie tekhnologicheskikh protsessov v rastenievodstve [Designing technological processes in crop production]. Bulletin of the Chelyabinsk State Agro-Engineering Academy, 70, 219-223.

Boev, V.D. (2016). Modelirovanie v Anylogic [Modeling in Anylogic]. St. Petersburg: VAS, 412 p.

Borodychev, V.V., Dobrachev, Iu.P., Buber, A.A., Menshikova, S.A. (2020). Faktornyi analiz dannykh po urozhainosti rannego kartofelia v polevom opyte i obrabotka rezultatov imitatsionnogo modelirovaniia [Factor analysis of early potato yield data in a field experiment and processing of simulation results]. Izvestia of the Lower Volga Agro-University Complex, 2(58), 404-419.

Didmanidze, O.N., Andreev, O.P., Zhurilin, A.N. (2018). Proektirovanie proizvodstvennykh protsessov v rastenievodstve s ispolzovaniem kompiuternykh tekhnologii [Designing production processes in crop production using computer technology]. Moscow: "UMTS "TRIADA", LLC, 150 p.

Dokumentatsiia Anylogic [Anylogic documentation]. (n.d.). Biblioteka modelirovaniia protsessov [Process modeling library]. Retrieved from https://anylogic.help/ru/library-reference-guides/process-modeling-library/index.html

Girutskii, I.I., Maryshev, V.F., Zhur, A.A. (2022). Imitatsionnoe modelirovanie otkorma svinei [Simulation modeling of pig fattening]. Mechanization and Electrification of Agriculture, 2(44), 27-33.

Government of the Russian Federation. (2006). Resolution of the Government of the Russian Federation of July 25, 2006 No. 458 “On the classification of types of products as agricultural products and primary processing products made from agricultural raw materials of our own production”. Retrieved from http://government.ru/docs/all/56955/

Iakushev, V.P., Iakushev, V.V., Badenko, V.L., Matveenko, D.A., Chesnokov, Iu.V. (2020). Operativnoe i dolgosrochnoe prognozirovanie produktivnosti posevov na osnove massovykh raschetov imitatsionnoi modeli agroekosistemy v geoinformatsionnoi srede (obzor) [Operative and long-term forecasting of crop productivity based on mass calculations of the agroecosystem simulation model in geoinformation environment (review)]. Agricultural Biology, 3, 451-467.

Khudiakova, E.V., Blakitnaia, N.A. (2013). Imitatsionnoe modelirovanie sistem massovogo obsluzhivaniia v srede AnyLogic kak metod sovershenstvovaniia biznes-protsessov na predpriiatii APK [Simulation modeling of mass service systems in the AnyLogic environment as a method to improve business processes in the agroindustrial complex]. Agricultural Engineering, 2, 65-68.

Khudiakova, E.V., Klochkova, K.V. (2015). Optimizatsiia tekhniko-ekonomicheskikh parametrov organizatsii protsessa uborki zernovykh kultur na osnove imitatsionnogo modelirovaniia [Optimization of technical and economic parameters of the process of grain harvesting based on simulation modeling]. Agroengineering, 5(69), 60-64.

Kuznetsov, V.M. (2018). Issledovanie INSILICO rasshirennogo vosproizvodstva pri zakrytom razvedenii molochnogo skota [INSILICO study of extended reproduction in closed dairy cattle breeding]. Problems of Productive Animal Biology, 3, 54-86.

Lazareva, T.G., Aleksandrova, E.G., Makushina, T.N., Vlasova, N.I., Lipatova, N.N. (2021). Otsenka i perspektivy razvitiia promyshlennogo gribovodstva v Rossii [Assessment and prospects for the development of industrial mushroom farming in Russia]. The Eurasian Scientific Journal, 2, 1-11. Retrieved from https://esj.today/PDF/25ECVN221.pdf (in Russian, English).

Levina, A.P. (2017). Obzor metoda imitatsionnogo modelirovaniia [A review of the simulation modeling method]. Modern Technics and Technologies, 5(69), 30.

Li, X., Wang, J., Yu, J. (2012). Computer simulation in plant breeding. Advances in Agronomy, 116, 219-264.

Melikhova, E.V., Rogachev, A.F., Skiter, N.N. (2019). Information system and database for simulation of irrigated crop growing. Studies in Computational Intelligence, 826, 1185-1191.

Menshutkin, V.V., Egorova, N.A. (2015). Primenenie imitatsionnogo modelirovaniia pri otsenke obshchego dopustimogo ulova [Application of simulation modeling in estimating total allowable catch]. Problems of Fisheries, 3, 367- 375.

Ministry of Agriculture of the Russian Federation. (2022). Proizvodstvo kultiviruemykh gribov v 2021 godu vyroslo na 16% [Cultivated mushroom production in 2021 increased by 16%]. Retrieved from https://mcx.gov.ru/press-service/news/proizvodstvo-kultiviruemykh-gribov-v-2021-godu-vyroslo-na-16/

Nabokikh, A.A. (2010). Problemy spetsializatsii i kontsentratsii v upravlenii rynkom kultiviruemykh gribov [Problems of specialization and concentration in the management of the market for cultivated mushrooms]. Regional Economics: Theory and Practice, 41, 40-43.

Ovchinnikov, A.S., Bocharnikov, V.S., Fomin, S.D., Bocharnikova, O.V., Vorontsova, E.S., Borodychev, V.V., Lytov, M.N. (2018). Optimum control model of soil water regime under irrigation. Bulgarian Journal of Agricultural Science, 24(5), 909-913.

Ovchinnikova, L.A. (2008). Multiagentnoe imitatsionnoe modelirovanie logisticheskoi sistemy pererabatyvaiushchego predpriiatiia APK [Multi-agent simulation modeling of the logistics system of agro-industrial complex processing enterprises]: Summary of a candidate dissertation in technical sciences. Moscow State University of Applied Biotechnology, Moscow, Russia, 24 p.

Pérez-Chávez, A.M., Mayer, L., Albertóa, E. (2019). Mushroom cultivation and biogas production: A sustainable reuse of organic resources. Energy for Sustainable Development, 50, 50-60.

Petrova, L.A. (2007). Tekhnologii vyrashchivaniia veshenki kultiviruemoi [Technologies of growing cultivated oyster mushrooms]. Food Industry, 11, 58.

Qin, P., Li, T., Liu, C., Liang, Y., Sun, H., Chai, Y., Gong, X., Wu, Z. (2023). Extraction and utilization of active substances from edible fungi substrate and residue: A review. Food Chemistry, 398, 133872.

Reddy, K.R., Hodges, H.F., McKinion, J.M. (1997). Crop modeling and applications: A cotton example. Advances in Agronomy, 59, 225-290.

Riazanova, A.V., Veresokin, M.M. (2020). Obzor programmnykh produktov dlia imitatsionnogo modelirovaniia dorozhnogo dvizheniia [Review of software products for simulation modeling of traffic]. Dalnii Vostok: Problemy razvitiia arkhitekturno-stroitelnogo kompleksa, 1, 177-179.

Savva, T.Iu. (2013). Avtomatizatsiia formirovaniia proizvodstvennykh raspisanii na predpriiatiiakh po pererabotke plodoovoshchnogo syria [Automation of manufacturing schedules at fruit and vegetable processing enterprises]: Summary of a candidate dissertation in technical sciences. State University - Educational, Research and Production Complex, Orel, Russia, 16 p.

Solianik, S.V., Solianik, V.V. (2020). Vychislitelnaia metodologiia predproektnogo modelirovaniia oborota stada i imitatsionnogo rascheta dvizheniia pogolovia funktsioniruiushchego svinovodcheskogo predpriiatiia [Computer methodology for pre-project simulation of herd turnover and simulation calculation of herd at functioning pig breeding enterprise]. Zootechnical Science of Belarus, 5(2), 319-334.

Sysuev, V.A., Shirokikh, I.G., Shirokikh, A.A., Yui, L. (2018). Griby kak kultura selskokhoziaistvennogo proizvodstva [Mushrooms as a culture of agricultural production]. Agricultural Science Euro-North-East, 1(62), 4-10.

Tian, D., Zhang, M., Zhao, A., Wang, B., Shi, J., Feng, J. (2021). Agent-based modeling and simulation of edible fungi growers' adoption behavior towards fungal chaff recycling technology. Agricultural Systems, 190, 103138.

Vasechkina, E.F., Kazankova, I.I. (2014). Matematicheskoe modelirovanie rosta i razvitiia midii Mytilis galloprovincialis na iskusstvennom substrate [Mathematical modeling of the growth and development of Mytilis galloprovincialis mussel on artificial substrate]. Oceanology, 54(6), 1-9.

Zharov, M.V. (2021). Obzor programmnykh sredstv imitatsionnogo modelirovaniia dlia issledovaniia tekhnologii i proizvodstv mashinostroeniia [Review of simulation modeling software for the study of mechanical engineering technologies and productions]. Bulletin PNRPU. Mechanical Engineering, Materials Science, 4, 85-92.