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ANALYSIS OF THE EXISTING METHODS AND SPECIFIC FEATURES OF DRYING SHIITAKE MUSHROOMS

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Abstract. The paper reviews and analyses the advantages and disadvantages of the existing technologies of drying shiitake mushrooms, which are a valuable source of bioactive polysaccharides, vitamins, antioxidants, etc. The findings presented in the paper show how various drying methods and their thermotechnological operating parameters affect the mechanostructural properties, chemical composition, content of aromatic substances and other compounds of mushrooms. It has been demonstrated that the traditional convection drying of shiitake in the temperature range 50–60°C allows maximum preservation of phenolic compounds, organic acids, nucleotides, sulphuric aromatic substances, and enhances the unique aroma of the mushroom. Radiation drying has such advantages as lower shrinkage of dried shiitake mushrooms, a higher coefficient of rehydration and higher hardness, and the drying time reduced by 66% compared with freeze-drying. Vacuum drying makes it possible to obtain high quality products, but significantly increases the duration of the process and reduces the content of aromatics. Radiation drying combined with hot air allows obtaining a dry form of shiitake rich in protein and bioactive polysaccharides and having high physicochemical properties, and reduces the duration of the process by 37.5% compared with convection drying. Spray drying of shiitake mushrooms is highly practical economically and allows organising industrial manufacture of high-quality dry mushroom powder in large volumes. It is characteristic of this drying method that its temperature effect on the product is slight, which makes it possible to preserve thermolabile bioactive substances. When using spray drying, it is advisable to add dextrin additives. This improves the structuring and moisture-conducting properties of the suspensions and their thermal stability, and helps preserve the unique aroma of shiitake mushrooms due to encapsulation of aromatic compounds. Studying the effect of various drying methods on the physicochemical properties of shiitake will lead to improving the existing technological processes and will make it possible to obtain products with desired properties.

Key words: shiitake mushroom, convection drying, radiation drying, vacuum freeze-drying, spray drying.

Introduction. Formulation of the problem

The leading role of healthy nutrition has been been becoming more and more evident in recent years, as it is one of the most important factors ensuring a full and active lifestyle. This led to the interest and active demand for so-called superfoods – plant-based products with a high concentration of beneficial nutrients. It can be fish, fermented milk products, vegetables, berries, nuts, leafy greens, algae, etc. These types of food include mushrooms. Due to the content of B and D vitamins and other bioactive substances, mushrooms have powerful antioxidant and nutritional properties, and promote breakdown of glycogen and fats. Fibre in their composition helps to improve digestion, detoxes the organism, and activates weight lost [1,2].

Delicacy mushrooms from the countries of Southeast Asia (reishi, tree ear, shiitake) have a specific composition and properties and have been used for thousands of years in traditional oriental medicine to restore the body's defences. The agaric basidiomycete shiitake (*Lentinula edodes*) is considered to be a real "elixir of life": it is a natural balanced complex of unique bioactive substances with pronounced oncostatic, immunomodulatory, hepatoprotective, and antiviral effects [3-6]. The well-known polyscharide lentinan isolated from the fruiting body of shiitake gently stimulates the human immune system, eritadenine (lentinacin) can normalise blood pressure, and the complex of polyphenols, vitamins, macro- and microelements exhibits antioxidant activity, has an anti-inflammatory effect, and helps to lower cholesterol [7-10].

At the present stage, the world production of mushrooms is growing every year. Market experts believe that the demand for fresh and processed mushrooms will grow in the years to come by at least 6–8% annually. Today's mushroom cultivation technologies make it possible to obtain 80–100 kg/year of the product in terms of dry protein from 1 hectare of a mushroom plantation. According to Fortune Business Insights, global mushroom consumption is expected to reach 20.84 million tons by 2026. The largest production volume (about 70%) is that of champignons (*Agaricus bisporus*). Cultivation of wood-destroying shiitake (*Lentinula edodes*) and oyster mushrooms (*Pleurotus ostreatus*) is also a promising direction [11,12].

China is the world leader in cultivating all types of industrial mushrooms. Its share in the world production of cultivated mushrooms is almost 37% (that of the United States is 25%, of France 10%, of Italy 6.8%). This branch of economy is developing rapidly in Poland [13,14]. In the world, mushroom production is a whole industry that not only grows mushrooms but processes them, too. Mushroom products are supplied to consumers in various forms: fresh, frozen, tinned, freeze-dried mushrooms. In Japan, China, South Korea, the USA, etc., various types of cultivated mushrooms, besides being used in the food industry, are valuable raw materials in the production of bioactive and medicinal substances, broad-spectrum drugs with curative and prophylactic effects. For example, in China, they are the basis of more than 500 medicines and dietary supplements [12].

The share of industrial production of medicinal shiitake mushrooms is growing especially fast. This edible basidiomycete is the undisputed leader in the countries of Southeast Asia. Its annual production is currently about 600 thousand tons. In the world, shiitake is the second most produced mushroom (the first being champignons) due to its high nutritional value, excellent taste and a wide range of medicinal properties. Among other things, it helps in the treatment of immunodeficiency, cancers and cardiovascular diseases: hypertension, coronary heart disease, atherosclerosis, consequences of heart attacks and strokes, other diseases. Japan has been the largest producer of shiitake for many years, followed by China and Korea. In the USA and Canada it began being grown in the early 70s, and in Europe, about 10–15 years ago. The increasing popularity of shiitake is confirmed by the fact that its global production over the past 40 years has grown more than 30 times [13,15].

In recent years, the industrial mushroom cultivation in Ukraine has also been developing intensively. This is one of the most dynamic and promising sectors of Ukrainian agriculture characterised by significant growth rates (25–30% per year). Mushroom production in Ukraine is mainly focused on the domestic market, and 90% of the market of cultivated mushrooms is held by champignons. The annual production of exotic mushrooms (shiitake, agrocybe, eryngi) is about 120 tons. In Ukraine, edible basidiomycetes, including shiitake, are cultivated and processed by Fungoterra LLC, Esmash LLC, Niko Agro Holding LLC, etc. The demand for their products is increasing, and, given the rapid development of industrial mushroom cultivation in the world, it has significant potential [16–18]. Unfortunately, the annual consumption of mushrooms and mushroom products in our country only averages 1.5 kg per capita, while in China, this figure is 5 kg/year, in France 3.1 kg/year, in Great Britain 2.7 kg/year, and in the USA 2.2 kg/year. Mushroom imports in Ukraine will exceed exports until the home market is fully provided with domestic products [19–23].

Cultivated mushrooms belong to perishables. To develop the further manufacture of mushroom products and increase their consumer and commercial appeal in the domestic and foreign markets, it is a task of current importance to create and improve integrated zero-waste technologies of processing mushrooms. Shiitake differs from other species in that it has a rich chemical composition with a variety of medicinal and health-improving effects. However, most modern methods of processing these mushrooms only focus on isolating pharmacologically active substances, which, as a rule, are components of a polysaccharide complex. This is accompanied by losing a significant part of the mushroom's unique biologically valuable potential. That is why it is so topical a task, both scientific and technical, to develop new modern technologies that will allow complex zero-waste processing of the fruiting body of the shiitake mushroom, taking into account its unique composition and properties.

The food industry widely uses various methods of drying mushrooms to increase significantly their shelf life, improve storage and transportation conditions, and to preserve the nutritional and biological value of finished products with certain aromatic and taste properties. New properties of a food product that form in the course of drying are due to significant changes in the composition of raw materials as a result of chemical and biochemical reactions [24,25].

To solve the problem of creating a technology of complex processing of shiitake mushrooms without losing their bioactive substances, it is important to analyse the existing traditional and alternative drying methods and modes and their effect on the chemical composition and physicochemical properties of the mushroom. Establishing the main advantages and disadvantages of each of them will allow choosing and scientifically substantiating the most practical method of processing shiitake to create a modern high-performance technology of products in their dried form.

Drying a wet material is a complex thermophysical and technological process. The course and duration of drying depend on the chosen method, equipment, temperature and velocity of the drying agent, relative air humidity, size of the material's particles, etc. When manufacturing dried mushrooms, it is very important to carry out the drying process under conditions favourable for biochemical processes aimed at creating a product with high nutritional and biological properties, strong aroma, and pleasant taste. Scientists throughout the world study how oriental medicinal mushrooms affect the human body's protective function and how their processing tells on their chemical composition. Primarily, these are the Japanese researchers G. Chihara and J. Hamuro. The particular features of spray drying of mushrooms are studied by H. Shiga and H. Yoshii, by Israeli scientists of the University of Haifa (among them S. P. Wasser), by Russian scientists (E. Feofilova, T. Puchkova), by researchers from M. G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine (N. Bisko), and others.

The **purpose** of the paper is to study the current problems of the existing methods of drying the shiitake mushroom, their effect on the chemical composition, quality, and preservation of its bioactive components.

The **objective** of the research is to analyse scientific publications devoted to studying and solving the problem of creating industrial technologies of manufacturing nutritionally and biologically valuable high-quality products from shiitake mushrooms in dry form.

Analysis of recent research and publications

According to the theory of drying, a fresh mushroom containing up to 88–92% of moisture [26] is a capillary-porous colloidal body containing water in all forms of bonds: chemical, physicochemical, and physicomechanical. Chemically bound moisture is characterised by the highest energy of the bond with the material and can be removed from the material at high temperatures (above 120–200°C) [27], but, as a rule, this changes the molecular structure of the material. Physicochemically bound moisture, in turn, falls into adsorption and osmotic moisture. The group of physicomechanically bound moisture comprises the moisture of micro- and macrocapillaries and the moisture of wetting. Physicomechanical and osmotic moistures have weak energy of bonds and are free moisture by their properties. Adsorption moisture is water adsorbed on the outer and inner surfaces of colloidal particles. It is held by molecular forces and is bound moisture. The mechanism of material transport inside a solid phase is complex, because part of the moisture evaporates inside the material and travels to the surface in the form of liquid and vapour simultaneously due to the action of various forces. The share of the influence of the flows of phases and acting forces depends on many factors, both internal (associated with the structure of the material dried) and external (the operating parameters of the process and the properties of the drying agent). Besides, the ratio of flows and forces changes throughout the process [28]. In the course of drying, the physical, mechanostructural, and technological properties of the material change [29]. When studying the mushroom drying kinetics, the authors [30] note that the process is characterised mainly by the presence of the stage of decreasing velocity, which indicates the complexity of drying this material.

The choice of the method and thermotechnological parameters of drying, as well as the physicochemical effect during the preliminary preparation of raw materials, significantly affects the quality and composition of the dry product. When drying edible mushrooms, including shiitake, the types of drying most often used are: convection, by the exposure to energy fields (infrared rays, electric field of high and super high frequencies, acoustic field, electromagnetic field of low frequencies), vacuum, spray, freeze-drying, or their various combinations. Energy characteristics are an important criterion when choosing a drying method. When assessing the quality of a dry product, special attention is paid to determining the sensory and mechanostructural properties of the dried product, its ability to rehydrate, and its chemical composition, in particular, the content of volatile aromatic substances, about 150 of which are found in different mushroom species (aliphatic alcohols, ketones with 8 carbon atoms, etc.) [2].

The traditional method of drying mushrooms is *convection drying,* which is usually carried out at low temperatures (50–75°C) and at the velocity of the heat-carrying agent not less than 0.5 m/s. Depending on the type of the dryer and on how finely the raw materials have been comminuted, drying takes 3–4 hours to 5–6 hours [25]. For example, at the first stage, when the temperature of the heat-carrying agent is about 50°C, drying is carried out for 2 hours, then the temperature is raised to 70–80°C, and the material continues to dry for another 1.5–2 hours. At the third stage, the drying temperature is reduced to 50–55°C, and the mushrooms are dried for about 2 more hours. This drying method ensures the evaporation of 70–76% of water, the complete process of drying the mushroom takes 9–12 hours [31].

The authors [32,33], who studied the kinetics of hot air drying of mushroom caps in the temperature range 30–70°C, recommend using the upper temperature limit of no more than 50°C. A further increase in the temperature negatively affects the colour of the dried material and its rehydration capacity. However, in [34], it is noted that for the complete inactivation of fungal enzymes, the drying temperature is to be above 60°C, but to prevent the Maillard reaction and caramelisation, it should be below 70°C. With an increase in the temperature and drying rate, the samples were characterised by falling periods of the drying rate while there was no constant period of drying. This indicates the dominance of the diffusion process of moisture removal from the inside of the material to its surface [30,35].

Drying not only prolongs the shelf life of mushrooms, but also enhances their aroma and unique taste. Thus, with hot air drying at 50°C, it was noted that the stipes had a higher content of phenolic compounds, neutral sugars, nucleotides, amino and uronic acids than the caps did [36]. Y. Tian *et al.* [37] note that drying with hot air also increases the content of free amino acids and sulphur compounds of dried products. An increase in temperature to 60°C leads to a higher total content of organic acids and aromatics. The samples dried at 70°C showed the highest equivalent umami concentrations [38].

On the other hand, Guo *et al.* [39], on studying 6 variants of convection drying of the mushroom, argue that an improved chemical composition (g/100 g of dry matter: proteins – 20.75, fats – 2.32, total sugars – 32.06, dietary fibre – 30.46 moisture – 3.19, ash – 5.67, energy – 983.43 kJ), colour retention, and improved rehydration properties of shiitake can be achieved by the periodic method of drying at 55°C with different intervals between drying periods: 5 minutes every 55 minutes of drying during the first 5 hours, 10 minutes every 50 minutes for the next 7 hours, and 15 minutes every 45 minutes at the end of drying.

Convection drying of shiitake by the periodic method can be carried out at a low temperature at the beginning of drying, with its further increase, and vice versa, too: the material can be dried first at high temperatures, followed by the final drying at lower temperatures [40]. Thus, in the method [41], to prevent darkening during hot air drying, shiitake is pre-soaked in 0.05–0.1% sodium bisulphite solution ($NaHSO_3$) for 5–10 minutes. Next, the sliced mushrooms are dried at 30°C with a gradual temperature increase (2°C/h) to T=50°C. The total duration of the process is 12–13 hours. At the end of drying, the mushrooms are heated to T=60°C and kept at this temperature for 1 hour to enhance the aroma. This method of drying allows achieving the moisture content most favourable for storage (6–8%), and dried shiitake mushrooms are characterised by an increased amount of 5-ribonucleotides involved in aroma formation [42]. As a comparison, vegetables contain 1–10 mol of 5-nucleotides/100 g of fresh product, and button mushrooms about 50 mol of 5-nucleotides/100 g of fresh mushroom, while shiitake contain 182–235 mol/100 g of fresh mushroom. Another component that forms the pleasant taste of shiitake extract is 5'-guanidylic acid, the content of which increases during the breakdown of ribonucleic acids under the action of ribonuclease at 60–70°C [41].

To increase the content of aromatic substances due to the thermal activation of specific enzymes (gamma-glutamyltransferase and hyaluronidase), other authors first carry out preliminary convection drying of shiitake with air for 30 minutes, gradually increasing the temperature from 45°C to 75°C, which is followed by drying for 4.5 hours at a temperature lowered to 45°C (or at T=60°C for 4 hours). During the entire pre-drying process, the activity of these enzymes remains high, which contributes to the formation of aromatics and a higher content of sulphur compounds and formaldehyde. The mushroom particles dried at these thermotechnological parameters are harder and have a higher coefficient of rehydration, but a lower degree of shrinkage and darkening [40].

The authors (Patent 2034488 RU) have developed a two-stage convective method of drying mushrooms involving rolling of their particles between drying periods. According to this method, crushed mushroom plates, 6–18 mm thick, are dried on a belt dryer at 70–90°C and at the air rate 1.3–1.5 m/s for 1.5–1.8 hours till the moisture content is 12–20%. Then the dried mushroom plates are flattened by rolling and dried in a convective dryer at T=50–75°C, with the same rate of the heat-carrying agent as at the first stage, for 0.6–1.5 hours to the final moisture content 4–8%. Then the dried material is ground into particles sized no more than 3 mm. These parameters and sequence of stages not only allow reducing the loss of raw materials during grinding, drying, and rolling, but also prevent the burning of the product's particles and loss of bioactive substances.

In [43], it is experimentally established that the temperature 55°C is optimal for convection drying of shiitake, since it ensures the shortest time of the process and the highest content of β-glucan. On the other hand, the researchers [36] note that when drying shiitake mushrooms with hot air, there is a decrease in their hydrophilic properties and ability to rehydration, they become dark in colour and form a hard texture.

Thus, the main advantage of the traditional convective method of drying mushrooms is the simplicity and availability of equipment. However, significant losses of bioactive substances and deterioration in the product's quality due to prolonged exposure to rather high temperatures are its disadvantages. Besides, this drying method is characterised by increased specific energy consumption and takes significant time. To obtain a dried mushroom with the final moisture content 4–5%, the drying of the material can last up to 10–12 hours. For intensive energy transfer from the heat-carrying agent to the material, it is necessary to move large volumes of air in the dryer. The large temperature potential of emissions and their large volumes lead to significant energy losses with the waste heat carrier. According to some authors, more than half of the energy expended is lost in convective dryers.

Infrared drying. Today, to dry mushrooms and other plant raw materials, infrared energy is widely used [25,44]. The equipment includes conveyor-type tunnel belt dryers or multifunctional infrared drying ovens. The main advantage of this type of drying is rapid removal of moisture and rather low temperatures of the process (up to 60°C). These temperature conditions make it possible to preserve almost completely the bioactive substances, vitamins, natural colour, taste, and aroma of dried products. The faster drying of plant materials is explained by the fact that infrared waves only affect the water molecules in the material. The radiant heat flux partially penetrates the capillary-porous bodies up to 20 mm in depth and is absorbed almost completely, but it is especially effective for drying thin layers of material (up to 5–7 mm). This process is characterised by high values of the heat exchange coefficient, and a unit of the surface of a raw material receives much more heat in a unit of time than it does with the convection drying method. The reduced duration and capital costs of infrared drying can make its prime cost lower than that of convection drying, which makes it more promising. However, a disadvantage of this drying is the high consumption of specific power, which is the main obstacle to its widespread industrial implementation.

Technologically, infrared drying of mushroom raw materials occurs due to radiation of infrared waves with the length λ=0.76–15 microns, with the power of the heaters N=1–75 kW. A product, cut into plates sized up to 60 mm, is laid out in one layer. The drying temperature is t = 40–60°C, the distance from the radiation source is up to 14 cm, with 2 kg/m^2 of the material loaded. Researchers suggest the following rational conditions for drying shiitake mushrooms using infrared radiation: the middle wavelength range (λ=2.4–3.0 μm), the heating temperature t=60°C, and the air velocity 1.4 m/s [45]. Hermetically sealed packaging allows extending the shelf life and preserving the quality characteristics of dry mushrooms. For better drying, preliminary thermal preparation of mushroom raw materials is used, for example, blanching or roasting (Patent 83002 UA), or the energy of infrared radiation can be combined with other drying methods [46]. There are results of research into convection drying of cultured oyster mushrooms that was combined with drying using infrared rays, both light and dark, from infrared emitters of various powers. The optimal power of the dark heating elements was found to be 1.5 kW and that of the light ones 2 kW at the specific load 4.4 kg/m^2. The optimal air rate is 5.5 m/s, and the distance from an IR emitter to the material to be dried is 12 cm. Under these conditions, the oyster mushroom retains the highest contents of protein (24.2% and 24.0% respectively) and nitrogen (3.9% and 3.4% respectively) [47].

Thus, the method of infrared drying of mushroom raw materials allows quickly removing moisture at low temperatures, preserving valuable bioactive substances and compounds, and obtaining the finished mushroom product with high organoleptic characteristics. However, this method is still problematic, since it is characterised by low productivity and high specific energy consumption. Besides, due to the specific features of absorption of infrared radiation, only the surface layers of the material are dried, which makes it difficult to remove moisture from the inner layers.

Another mushrooms drying technique is the use of *super high frequency (microwave) radiation*, when the material is heated mostly from the inside, unlike infrared radiation, which heats the object from the outside to the inside [48, 49]. Electromagnetic waves of the microwave range (λ=0.001–1 m, ν=2.45–2.46 GHz, power P=0.5–1 kW) deeply penetrate the material to be dried. This ensures heating the material more uniformly throughout the entire volume, thus significantly accelerating the drying process. Due to the high drying rate, mushrooms retain their beneficial properties, natural taste, colour, and aroma. Microwave drying is several times more productive than the convection method is (Patent 2035844 RU). This drying method has disadvantages, though: the moisture that evaporates from the material settles on the walls of the working chamber, which leads to its heating. So, additional ventilation is needed, and the product has to be constantly turned over, which increases the drying time. Besides, this method does not allow drying mushrooms till a required dry matter content is achieved. Therefore, microwave radiation, too, is often used in combination with other mushroom drying methods. There is a method of drying mushrooms in a microwave oven, followed by convection drying. First, part of the moisture is removed from the material in a microwave oven at a temperature not exceeding 95°C. This lasts 5–40 minutes until the final weight of the product is 30–90% of the initial one. Then, the drying of the partially dehydrated product is completed by the convection method (Patent 2063691 RU, Patent 2035844 RU).

For long-time storage of products, with the maximum preservation of their properties (taste, colour, odour) and bioactivity, the food and pharmaceutical industries also use *vacuum drying*. There are two methods: vacuum drying at an elevated temperature of the product (cold vacuum drying) and vacuum drying at a sub-zero temperature (vacuum freeze-drying), when water turns into the gaseous state at temperatures below the boiling point. The method is used for products high in bioactive substances that are sensitive to high temperatures.

Cold vacuum drying consists in dehydration at a subatmospheric pressure, but above the triple point of water. The source of heat can be infrared heating lamps, microwave generators, or heating surfaces. Drying processes in vacuum are similar to those taking place during convection or infrared drying. Reduced pressure contributes to the more intensive evaporation of moisture from the product due to an increase in the mass transfer coefficient, which, to a first approximation, is inversely proportional to the pressure. The drying temperature of vegetable raw materials approximately corresponds to that of saturation or the boiling point of water at a given pressure in the drying chamber of the apparatus. An important technological advantage of vacuum dryers, as compared with hot air dryers, is intensive drying at low temperatures. This is a crucial factor in preserving of bioactive substances of plant materials otherwise lost under the influence of high temperatures. The air-tightness of the drying chamber prevents the raw materials from contamination by dust present in the working environment. Besides, during vacuum drying, there is but very little oxygen in the environment. This is important for raw materials with the technical conditions of drying that do not allow its presence.

The work [50] determined the equilibrium moisture content in shiitake caps dried in a vacuum dryer (0.2 bar) at 50, 55, and 60°C with a heat pump as the source of heat. It was found that with an increase in the relative humidity from 20 to 75%, the equilibrium moisture content of the mushrooms being dried increased, respectively, from 0.2 to 0.45 g/g of dry matter. The authors also note that drying the mushrooms at temperatures below 50°C leads to its microbiological deterioration.

In the method described in Patent 2133094 RU, chopped mushrooms are placed on trays in a layer of up to 40 mm and dried in a chamber at 60–70°C in a vacuum, the value of which is cyclically changed in the range 0–0.04 MPa. When the moisture level reaches 14%, the drying process is stopped, the mushrooms are packed in an airtight container, and the water obtained during drying is collected for its further processing. This drying method allows obtaining a product of high quality.

Vacuum drying of mushrooms is used in the production of powdered food concentrates such as soups, sauces, meat products, vegetables, herbal extracts, juices, thickeners or flavourings and spices. Chopped mushrooms are slowly boiled in their natural juice for 30 minutes, then a 40% starch suspension is added in the ratio 1:0.2–0.5 respectively, and they are dried in a vacuum at 25–30°C for 2 hours and at 50–55°C for another 2–3 hours till the moisture content is 10% (Patent 2129810 UA). In the course of drying, dissolved low-molecular flavouring and aroma-forming substances are adsorbed on starch fractions, which results in a finished product with pronounced aromatic and taste properties.

The authors [51] studied the physicochemical parameters of the quality of shiitake samples vacuum-dried in the temperature range 46–74°C, with a reduced pressure of 20–580 mbar, simulated this process using the response surface methodology, and established the optimal conditions to be 57°C and the pressure p=100 mbar.

However, according to [52], although periodic vacuum-pulse drying of mushrooms crushed to 5–10 mm at 55°C, with a periodic decrease in the pressure from atmospheric to 100 Pa for 30 s and its subsequent increase to atmospheric for 100 s, improves their adsorption and microbiological parameters, this, nevertheless, decreases the content of volatile and aroma-forming components in edible mushrooms. In comparison with mushrooms dried with hot air, this parameter is lower by 45–55%.

In general, due to the complexity of the drying process and the high cost of equipment, the vacuum drying method is not widely used.

The high quality of dried mushrooms is provided by *freeze-drying*: the frozen material is dried in a fixed bed under a deep vacuum. During this process, moisture passes into vapour, bypassing the liquid phase. Although this method is expensive and requires complex apparatus, the cost of equipment and operation can be justified by the excellent quality characteristics of the dried mushrooms: retention of the primary structure and shape, high porosity, low bulk density, high rehydration properties, etc. [38].

Drying is done in a batchwise manner. During the process, the temperature conditions change: from a temperature below the freezing point of the mixture (to remove surface moisture) to low above-zero temperatures for additional drying of the material and removal of bound moisture. As a result, a lyophilised mass is formed, which follows the shape of the container in which the drying is carried out. Very often, the lyophilisate is highly hygroscopic, so it must be quickly packaged in a moisture-proof container. Energy is supplied by conduction (heat transfer from the shelf on which the material is located) or radiation (heat supply from the heated upper shelf to the material). There are installations in which additional energy is supplied by means of installed infrared and microwave emitters [53].

According to one of the freeze-drying methods, blanched mushrooms are fed for freezing into a vacuum chamber where the pressure is continuously decreased. This results in intensive evaporation of moisture (up to 10–15%) and cooling of the mushrooms to the temperature of water crystallisation. Next, the raw material is quickly frozen to minus 15–18°C, preventing the formation of crystals that lead to undesirable cell destruction and irreversible changes in proteins, and the ice is evaporated by vacuum treatment (133.3–13.3 Pa or 1–0.1 mm Hg). The freezing stage has a decisive influence on the quality of the final product, so, to ensure high quality of the dried product, it is necessary to create a uniformly distributed fine-crystalline structure of ice in the material. Under these conditions, the structure of the mushroom does not change, since cooling is quick and even, which excludes the formation of large ice crystals. The subsequent sublimation of the frozen material is carried out in the reverse temperature mode: the temperature of the product is increased from the lowest value achieved during freezing to 1°C, thus removing more than 50% of moisture. After that, the material is finally dried at about 30°C. When the residual unfrozen moisture evaporates, the drying rate decreases and the product's temperature rises continuously. The drying of mushrooms is completed when their moisture content is no more than 6–8% [54].

The advantages of the freeze-drying method are the high quality of the finished mushroom product, retention of the colour, taste, and composition, and quick recovery. However, this drying method has its drawbacks, which include the periodicity, duration and high energy consumption, the complexity, strict requirements for the equipment, and high hygroscopicity of the dried material. The main reason why freeze-drying is so costly is that the process occurring at sub-zero temperatures is less intensive, the motive force of the process is lower than it is during thermal drying. There are a number of ways to intensify the process, and, consequently, to reduce the drying time: carrying out the process in a vacuum under conditions of active hydrodynamics, combination with radiation drying, etc. [55].

In [56], the authors considered *different drying methods*: freeze-drying (FD), far-infrared radiation drying (FIRD), heat pump drying (HPD), hot air drying (HAD), and hot-air-combined controlled instant pressure drop drying (DIC). These methods were compared for their effect on the drying efficiency and quality characteristics of dried shiitake mushrooms. In comparison with the HPD, HAD, and DIC, the FIRD shiitake mushroom had a better appearance, lower shrinkage and hardness, and higher rehydration ratio (7.55). These values were close to those of the FD sample. Besides, the FD and FIRD samples were found to be significantly higher in protein (2.47 mg/g and 2.30 mg/g respectively) and in polysaccharides (1.79 mg/g and 1.39 mg/g respectively). Using FIRD reduced the drying time by 66.25%, as compared with FD, and resulted in the highest content of aroma-forming components, most of which were specific sulphides (24.59%). Thus, the shiitake mushroom dried by the FIRD method had the best quality characteristics among the products dried by the five drying methods.

Combined methods of mushroom drying. Quite a number of papers focus on studying how the mechanostructural properties of food products are determined by various drying methods and by their combinations that can intensify the process and shorten the drying time [57-60]. The combination of radiation drying with hot air results in the shortest drying time, while convection combined with radio frequency energy allows achieving the best colour and preserving the nutrient of a mushroom. Under the conditions tested, convection drying with infrared radiation in the medium wavelength range provides the minimal shrinkage (maximum rehydration) and lower hardness upon rehydration [61].

The paper [62] studies how mid-infrared drying (MIRD) applied before or after freeze-drying (FD) of shiitake mushrooms shortens the drying time, enhances the rehydration, and allows better preserving the aroma compounds and colour. Combination of FD (for 4 h) with following MIRD saves 48% of time, as compared with FD, and keeps the product's quality at an acceptable level. The MIRD–FD combination was found to be inferior to FD–MIRD, since the former tended to produce products with a collapsed surface layer and poor rehydration capability.

In [63], shiitake mushrooms were dehydrated by two different drying methods: microwave-vacuum drying (MVD) and microwave-vacuum combined with infrared drying (MVD+IR). MVD was carried out at the microwave powers 56, 143, 209, and 267 W under the absolute pressures 18.66, 29.32, 39.99, and 50.65 kPa, whereas in MVD+IR, infrared radiation was added at 100 and 200 W. It was found that the drying rate increased with lower absolute pressures, higher microwave power, and higher infrared power. The preferable drying conditions, with respect to the product's quality parameters (colour, rehydration ratio, texture of rehydrated mushrooms) and energy consumption, were MVD+IR drying with the microwave power 267 W, absolute pressure 18.66 kPa, and infrared power 200 W. The study [51], also confirms that shiitake can be vacuum-dried at 57°C and 100 mbar.

The authors [61] present their findings on how the drying characteristics and key quality parameters of shiitake (*Lentinula edodes*) are determined by the three hybrid drying technologies applied at 60°C: mid-infrared-assisted convection drying (MIRCD), hot air coupled with radio frequency drying (HCRFD), and hot air coupled with microwave drying (HCMD). For comparison, the standard drying technique using hot air was also tested. The results showed that hot air coupled with microwave drying gave the shortest drying time. Mid-infrared-assisted convection and hot air coupled with radio frequency drying showed better colour attributes and nutrient retention. Mid-infrared-assisted convection drying yielded minimal shrinkage (maximal rehydration) and lower hardness upon rehydration [61].

The paper [64] evaluated the influence of different drying methods on the aroma and sensory profile of the shiitake mushroom. The drying methods tested were: convection drying (CD), freeze-drying (FD), vacuum-microwave drying (VMD), and a combination of convective pre-drying and vacuum-microwave finish-drying (CPD-VMFD). The volatile composition of fresh and dried shiitake mushrooms was analysed and showed the presence of 71 volatile compounds, most of them present in all dried samples but with quantitative variation. The major volatile compounds in fresh shiitake were 1-octen-3-ol (20.2%), 2-octanone (20.7%), 1,2,4-trithiolane (9.8%), and 1,2,3,5,6-pentathiepane (8.2%). Drying of shiitake mushrooms caused significant losses of C_8 compounds and cyclic sulphur compounds. Samples dried by CD at 80°C for 120 min had the highest contents of total volatiles (1594 μg per 100 g^{-1}) and cyclic sulphur compounds (126 μg per 100 g^{-1}), and the highest intensity of most of the sensory attributes: inner colour (7.0), fresh shiitake flavour (6.7), and sponginess (6.2). The best dehydration methods resulting in the highest total concentrations of volatile compounds and the highest sensory attributes were FD and CD at 80°C. Similar data were obtained in [65]. In particular, dimethyl disulphide, dimethyltrisulphide, 1,2,4-trithiolane ($C_2H_4S_3$), 1,2,4,6-tetratiepane ($C_3H_6S_4$), and 1,2,3,4,5,6-hexathiepan (CH_2S_6) were identified as the main sulphur-containing metabolites in dried shiitake mushrooms. Dry shiitake was irradiated with doses of 5 and 10 kGy. The total volatile compounds were decreased by more than 50%, including sulphur-containing compounds [66].

The purpose of the study [67] was to conduct comparative analyses on drying kinetics, colour, rehydration ratio, polysaccharide content, and aromatic components composition of shitake mushrooms dried by using hot air drying, infrared drying, and intermittent microwave-assisted hot air drying. Intermittent microwave-assisted drying resulted in greatly reduced drying time and higher drying rate in comparison with the other methods. The highest polysaccharide content (240.28 mg/100 g) was achieved with microwave-assisted drying used. Shitake mushrooms treated with hot air showed the greatest amount of sulphuric aromatic compounds (7.7%) and the highest rehydration ability, and differed less in the colour of their caps.

The practical importance of drying shiitake using infrared radiation in combination with hot air was confirmed in [68]. The purpose of this research was to study the effect of thermal and non-thermal drying on the drying kinetics and physicochemical properties of the final product. The results showed that shiitake mushroom treated with non-thermal drying (vacuum freeze-drying) had an attractive colour, low shrinkage, and uniform honeycomb structure. However, the drying time was the longest, and the method did not lead to the formation of shiitake mushroom aroma. On the contrary, the thermal-dried shiitake mushrooms had an attractive fragrance. Unlike hot air convection drying (HAD), infrared hot air convection drying (IRHAD) shortened the drying time by 37.5% and led to the highest oxidation resistance, the highest polysaccharide content, and the least colour change of the dried sample.

Analysis of the results has shown that the lowest and highest energy consumption levels when drying mushroom slices were associated with microwave and vacuum dryers respectively. The use of vacuum in combination with microwave drying increased energy consumption, as compared with microwave drying. The combination of hot air with infrared drying reduced energy consumption, compared with infrared drying alone. Using a combined microwave-vacuum dryer reduced the drying time and, consequently, the energy consumption, compared with vacuum drying. Thus, the lowest energy consumption was observed when drying mushroom slices with infrared radiation in combination with hot air. But combined drying leads to more stages of processing and more complicated production technology.

Spray drying is often used to produce mushroom powders and granular products. Spray drying makes it possible to develop significantly the interfacial surface and obtain a significant increase in the evaporation surface. This allows achieving intensive mass and heat exchange between the product and the drying agent and increasing the general energy efficiency of the process. Mushroom solutions, emulsions, suspensions, or pastes are sprayed into the drying chamber and, upon contact with the hot drying agent (air or flue gas), are dehydrated in quite a short time. Spray drying is applied to materials that cannot be mechanically dehydrated, are highly thermosensitive (thus, cannot be exposed to high temperatures too long), and contain particles that can agglomerate. The process takes place under very mild conditions, that is why even unstable substances are well preserved and easily rehydrated. This type of drying makes it possible to obtain dry powder products with the required structural, dispersive, and taste characteristics, which are not inferior in quality to products obtained by freeze-drying. Spray dryers are widely used due to their versatility and the ability to dry almost any liquid. There is a whole range of spray dryers of various capacities [69]. During drying by this method, the air is filtered, heated, and enters the feeding device located in the upper part of the apparatus. From there, it is fed into the chamber and forms a rotational air flow in it. At the same time as the air is supplied, an aqueous suspension is dispersed in the drying chamber by means of centrifugal discs or pneumatic or mechanical nozzles. When air interacts with finely dispersed particles of the solution, moisture evaporates. High intensity of moisture evaporation is achieved due to the dispersed distribution of the material in the working chamber, through which the heated air moves, while the specific evaporation surface becomes so large that the drying process ends very quickly (up to about 15–30 s). The sprayed particles turn into powder. Under the action of gravity, part of the already dry product falls to the bottom of the chamber and is removed from its lower part. The other part of the dewatered substance is transported by the air flow to the cyclone separator, from where it is unloaded. By regulating the flow of hot air, it is possible to reduce or increase the rate of moisture evaporation. The output gases are expelled from the apparatus after the smallest particles have been removed in a wet scrubber. This way is the most effective for obtaining finely dispersed free-flowing powder or granules. The specific character of the process allows obtaining a high-quality product due to the high intensity of heat and mass transfer between the material and the heat carrying gas. The transfer is determined by the degree of dispersion of the wet material, the temperature of the heat carrier, and the hydrodynamic characteristics of the apparatus [55].

Besides whole shiitake mushrooms, their individual parts or extracts can be processed, too. A number of publications and patents describe methods of obtaining mushroom powder from extracts of the fruiting body, or mycelium (JPH07313089A, JP5856655A). The fruiting body (mycelium) of a mushroom is extracted with water or a water–ethanol mixture with the concentration up to 50% at 10–60°C for 15–30 minutes. The resulting extract is quickly heated to 60–100°C in a heat exchanger, cooled, and filtered until transparent. Then the extract is dried by spraying at the air temperature 150–180°C at the entrance to the drying chamber and 70–90°C at the exit from it. The dried powder product has high taste qualities, contains a lot of physiologically active substances, and is more stable when stored. It was determined [70,71] that heat treatment of a liquid mushroom extract led to the accumulation of the sulphur-containing aroma-forming substance lenthionin, but it did not affect the content of other aromatic substances in the dried powder.

At the stage of preliminary preparation for obtaining extracts and suspensions, the drying conditions of shiitake are improved by using hydromechanical methods of dispersion and homogenisation. For this purpose, mechanical dispersers, high pressure homogenisers, colloid mills, and pulsation devices are used [72]. In (CN101617808A), a method of producing granular mushroom condiment from shiitake mushrooms is described. The technology involves washing mushrooms, boiling them at 95°C for 2 minutes, grinding at the mushroom to water mass ratio 1:2 using a meat mincer or colloid mill until puree is formed, homogenisation under high pressure to destroy the cell walls in the mushrooms, concentration till achieving the dry matter content 30–40%, spray drying, adding flavouring components (sodium glutamate, maltodextrin, sodium chloride, egg yolk powder, yeast extract, disodium-5-ribonucleotide), granulating, and drying in a vacuum chamber at the temperature of the heat-carrying agent 55–60°C till the final moisture content is 5%. The finished condiment is characterised by an enhanced fresh aroma of meadow and straw mushrooms and has a mild taste.

A specific feature of an aqueous suspension made from shiitake when used as an object for spray drying is its abnormally high viscosity [73]. This is due to the peculiarities of the morphological structure of these mushrooms and their chemical composition (a lot of high-molecular-weight water-insoluble polysaccharides with sorption properties). Their presence complicates feeding the material into the drying chamber, and when an aqueous suspension is sprayed, the conditions for the formation of a spherical shape of droplets and their uniform dispersion are impaired. This leads to uneven drying, deposition of the wet product on the walls of the drying chamber, and the low quality of dry powder. The following structuring additives improve the drying conditions: mono- and disaccharides, starch, gelatine, sodium bicarbonate, microcrystalline cellulose, methylcellulose, dextrins, etc. [72]. In [70,71], it was found that aromatics are most effectively preserved by introducing such substances as malto- or cyclodextrin. When treating mushroom extracts or suspensions with branched cyclodextrin, the components are included in the clathrate cavity. Due to the structure formation, the quality properties of dry powder are improved, the stability and activity of the components during storage are increased, and the product becomes more functional.

One of the ways to process shiitake mushrooms is to obtain dry powders of protein hydrolysates for functional nutrition. In [74], enzymatic hydrolysis of shiitake mushroom powder was carried out with 15% (g/g) papain (activity 4600 NF/mg) at 65°C and pH 7.0 for 18 hours. The resulting hydrolysate was spray-dried and freeze-dried. Comparison of these two drying methods showed that the dry hydrolysates obtained differed in their composition, physicochemical properties, antioxidant activity, and organoleptic characteristics. It has been proved that the drying process affects the concentration of free amino acids and physiologically active peptides, causing a specific off-flavour. Free amino acids, especially aspartic and glutamic acids, alanine, leucine, lysine, tyrosine and phenylalanine, can be the main components that affect the taste of dry mushroom hydrolysates. The taste of the sample was improved by the addition of 30% maltodexdrin. The results showed that using spray drying was preferable. The powder thus obtained was high in protein, low in moisture, and had better organoleptic properties. Besides, the spray-dried sample had low water activity values and a higher solubility index.

Thus, the use of spray drying makes it possible to organise industrial manufacture of high-quality dry mushroom powder with a high content of bioactive substances and a good rehydration capacity. The method is efficient, has an insignificant temperature effect on the product during dehydration, and allows drying thermolabile solutions. It can be used to obtain new nanostructured materials. The disadvantages of spray drying are its complexity and high cost of equipment.

Conclusion

The analysis of a number of publications and patents has shown considerable interest in the use of various drying methods when processing shiitake mushrooms to obtain high quality characteristics of the dry product and preserve unique bioactive substances. Researchers pay much attention to the energy efficiency of drying technologies.

The drying method and thermotechnological operating parameters of the process greatly affect the quality and properties of the dry mushroom product obtained. Thus, convection drying of mushrooms in the temperature range 50–60°C allows the maximum preservation of compounds of phenolic nature, organic acids, and nucleotides, and enhances the unique aroma of the mushroom. The advantages of infrared drying are lower shrinkage, lower hardness, and higher rehydration rates, and the drying time is shorter by 66% than it is with freeze-drying. Vacuum drying of shiitake results in a significant decrease in the content of flavouring substances, namely, by 45–55% compared with convection drying. Spray drying is highly economical and efficient and makes it possible to organise the industrial manufacture of high-quality dry mushroom powder in large volumes. The specific feature of spray drying is but a slight temperature effect on the product during dehydration, which allows drying thermolabile solutions high in bioactive substances and obtaining a product with a high rehydration rate. The use of structuring additives helps to preserve the unique aroma of the mushrooms due to encapsulation of odorous compounds. The method can be used to obtain new nanostructured materials. Combining various drying methods makes it possible to obtain mushroom powder with desired physicochemical properties.

Research and improvement of various methods of drying mushrooms will increase the energy efficiency of the process, allow their complex processing, result in maximum preservation of the nutritional and biological value of raw materials, and make it possible to obtain high-quality products with long shelf life.

References:

1. Patel S, Goyal A. Recent developments in mushrooms as anti-cancer therapeutics: a review. 3Biotech. 2012;2(1):1-15. DOI: https://doi.org/10.1007/s13205-011-0036-2
2. Wasser SP, redactor. Biologicheskie osobennosti lekarstvennyih makromitsetov v kulture Kiev: Alterpres; 2012. T.1.
3. Wasser SP. Medicinal mushroom science: current perspectives, advances, evidences, and challenges. Biomedical Journal. 2014;37:345-356. DOI: https://doi.org/10.4103/2319-4170.138318
4. Nisar J, Mustafa I, Anwar H, Sohail MU, Hussain G, Ullah MI, et al. Shiitake Culinary-Medicinal Mushroom, Lentinus edodes (Agaricomycetes): A Species with Antioxidant, Immunomodulatory, and Hepatoprotective Activities in Hypercholesterolemic Rats. International Journal of Medical Mushrooms. 2017;19(11):981-990. DOI: https://doi.org/10.1615/IntJMedMushrooms.2017024504
5. Rahman T, Choudhury MBK. Shiitake Mushroom: A Tool of Medicine. Review article. Bangladesh Journal of Medical Biochemistry. 2012;5(1):24-32. DOI: https://doi.org/10.3329/bjmb.v5i1.13428
6. Dai X, Stanilka J, Rowe CA, Esteves E, Nieves C, Spaiser SJ, et al. Consuming Lentinula edodes (Shiitake) Mushrooms Daily Improves Human Immunity: A Randomized Dietary Intervention in Healthy Young Adults. Journal of the American College of Nutrition. 2015;34(6):478-487. DOI: https://doi.org/10.1080/07315724.2014.950391
7. Wasser SP. Medicinal Mushroom Science: History, Current Status, Future Trends and Unsolved Problems. International Journal of Medical Mushrooms. 2010;12(1):1-16. DOI: https://doi.org/10.1615/IntJMedMushr.v12.i1.10
8. Sheng K, Wang C, Chen C, Kang M, Wang M, Liu K, et al. Recent advances in polysaccharides from Lentinus edodes (Berk.): Isolation, structures and bioactivities. Food Chemistry. 2021;358:129883. DOI: https://doi.org/10.1016/j.foodchem.2021.129883
9. Chien R-C, Yen M-T, Mau J-L. Antimicrobial and antitumor activities of chitosan from shiitake stipes, compared to commercial chitosan from crab shells. Carbohydrate Polymers. 2016;138:259-264. DOI: https://doi.org/10.1016/j.carbpol.2015.11.061
10. Wang J, Li W, Huang X, Liu Y, Li Q, Zheng Z, et al. A polysaccharide from Lentinus edodes inhibits human colon cancer cell proliferation and suppresses tumor growth in athymic nude mice. Oncotarget. 2017;8(1):610-623. DOI: https://doi.org/10.18632/oncotarget.13481
11. Fortune business insights. [Internet]. 2021 Jun [cited 2021 Jan 20]. Available from: https://www.fortunebusinessinsights.com/industry-reports/mushroom-market-100197
12. Vyrashchyvanye hrybov kak byznes. Moi byznes [Internet]. 2021 Jun [cited 2021 Jan 20]. Available from: https://moybiznes.org/vyraschivanie-gribov
13. YKTs APK. Sovremennoe sostoianye hrybov v myre [Internet]. 2021 Jan [cited 2021 Jan 23]. Available from: http://ikc.belapk.ru/upload/iblock/c81/c81e3db14af4c90e946b646b8a4fb99d.pdf
14. Market research future. [Internet]. 2021 Jun [cited 2021 Jan 15]. Available from: https://www.marketresearchfuture.com/reports/shiitake-mushroom-market-4731
15. Shyitake. Zahalni vidomosti. Ahrarnyi sektor Ukrainy. [Internet]. 2021 Apr [cited 2021 Mar 17]. Available from: http://agroua.net/plant/catalog/cg-50/c-130/info/cag-235/
16. Hrybnaia otrasl Ukrayny: osnovnye tsyfry. UMDIS Hrybnoe ynformatsyonnoe ahenstvo. [Internet]. 2021 May [cited 2021 May 13]. Available from: https://www.umdis.org/gribnaya-otrasl-ukrainy-osnovnye-cifry-16829/
17. Nesterenko N. Vyrobnytstvo i spozhyvannia kultyvovanykh hrybiv v Ukraini. Tovary i rynky. 2011;2:61-68.
18. Samyi tykhyi biznes. Internet-hazeta Ekonomika. [Internet]. 2021 Jun [cited 2021 Jun 14]. Available from: http://economica.com.ua/article/77705609.html
19. Ohliad rynku hrybiv Ukrainy. [Internet]. 2021 Feb [cited 2021 Feb 10]. Available from: https://www.marketing-ua.com/article/obzor-rynka-gribov-ukrainy/
20. Analiz rynku hrybiv za 2011-2015. [Internet]. 2021 May [cited 2021 May 10]. Available from: http://www.belferma.ru/assets/files/analiz_rynka_gribov_15.pdf
21. Webster J, Weber R. Introduction to Fungi. Edinburgh: Cambridge University Press; 2007. DOI: https://doi.org/10.1017/CBO9780511809026
22. Simakhina HO, Hoiko IYu. Vyrobnytstvo sukhoho hrybnoho napivfabrykatu dlia zbahachennia kharchovykh ratsioniv. Naukovi pratsi NUKhT. 2015;21(2):190-196
23. Ukrainske hrybivnytstvo: pohliad u maibutnie. [Internet]. 2021 Apr [cited 2021 Apr 20]. Available from: https://a7d.com.ua/novini/40360-ukrayinske-gribvnictvo-poglyad-u-maybutnye.html
24. Kudra T, Mujumdar AS. Advanced drying technologies. New York: Marcel Dekker; 2002.
25. Zhuk YuT. Konservyrovanye y khranenye hrybov (byokhymycheskye osnovy). Moskva: Lehkaia y pyshchevaia promyshlennost; 1982.
26. Coates PM, Paul MC, Blackman M, Blackman MR. Encyclopedia of Dietary Supplements. Boca Raton: CRC Press; 2004. DOI: https://doi.org/10.1201/b13959

27. Lukin VD, Novoselskiy AV. Tsiklicheskiye adsorbtsionnye protsessy: Teoriya i raschet. Leningrad: Khimiya; 1989.
28. Lykov AV. Teoriia sushky. Moskva: Enerhiia; 1968.
29. Mujumdar AS. Handbook of Industrial Drying. Boca Raton: CRC Press; 2014. DOI: https://doi.org/10.1201/b17208
30. Wakchaure GC, Manikandan K, Mani I, Shirur M. Kinetics of Thin Layer Drying of Button Mushroom. Journal of Agricultural Engineering. 2010;47(4):41-46.
31. Biblioteka o hrybakh. [Internet]. 2021 Jun [cited 2021 Jun 11]. Available from: http://gribochek.su/books/item/f00/s00/z0000022/st011.shtml
32. Argyropoulos D, Mueller J. Convective drying and desorption isotherms of Shiitake (Lentinula edodes) mushroom. Chemistry.. [Internet]. 2013 Jun 20 [cited 2021 Jun 11]. Available from: https://opus.uni-hohenheim.de/volltexte/2013/782/pdf/Argyropoulos_2011c.pdf
33. Argyropoulos D, Alex R, Müller J. Equilibrium moisture contents of a medicinal herb (Melissa officinalis) and a medicinal mushroom (Lentinula edodes) determined by dynamic vapour sorption. Procedia Food Science. 2011;1:165-172. DOI: https://doi.org/10.1016/j.profoo.2011.09.026
34. Rhim JW, Lee JH. Drying kinetics of whole and sliced Shiitake mushrooms (Lentinus edodes). Food Science and Biotechnology. 2011;20(2):419-427. DOI: https://doi.org/10.1007/s10068-011-0059-9
35. Doymaz I. Drying Kinetics and Rehydration Characteristics of Convective Hot-Air Dried White Button Mushroom Slices. Journal of Chemistry. 2014;2014:p.8. DOI: https://doi.org/10.1155/2014/453175
36. Zhang M, Bhandari B, Fang Z. Handbook of drying of vegetables and vegetable products. Boca Raton: CRC Press; 2017. DOI: https://doi.org/10.4324/9781315152677
37. Tian Y, Zhao Y, Huang J, Zeng H, Zheng B, et al. Effects of different drying methods on the product quality and volatile compounds of whole shiitake mushrooms. Food Chemistry. 2016;197(A):714-722. DOI: https://doi.org/ 10.1016/j.foodchem.2015.11.029
38. Yang X, Zhang Y, Kong Y, Zhao J, Sun Y, Huang M. Comparative analysis of taste compounds in shiitake mushrooms processed by hot-air drying and freeze drying. International Journal of Food Properties. 2019;22(1):1100-1111. DOI: https://doi.org/10.1080/10942912.2019.1628777
39. Guo XH, Xia CY, Tan YR, Chen L, Ming J. Mathematical modeling and effect of various hot-air drying on mushroom (Lentinus edodes). Journal of Integrative Agriculture. 2014;13(1):207-216. DOI: https://doi: 10.1016/S2095-3119(13)60265-8
40. Xu L, Fang X, Wu W, Chen H, Mu H, Gao H. Effects of high-temperature pre-drying on the quality of air-dried shiitake mushrooms (Lentinula edodes). Food Chemistry. 2019;285:406-413. DOI: https://doi: 10.1016/j.foodchem.2019.01.179
41. Mujumdar AS. Handbook of industrial drying. Boca Raton: RC/Taylor and Francis; 2007. DOI: https://doi.org/10.1201/9781420017618
42. Wu BK. Encyclopedia of Food Science and Technology [Internet]. New York; 1992;3:1844-1848 [cited 2020 Dec 20]. Available from: https://books.google.com.ua/books?id=80TMBQAAQBAJ&pg=PA660&lpg=PA660&dq=handbook+arun+mujumdar+shiitake&source=bl&ots=lcr3X6VjNU&sig=ACfU3U1fzgKqe1YMJo_5BQnJ9KYAv-hRMQ&hl=ru&sa=X&ved=2ahUKEwiUq_7v7ZvxAhW0h_0HHSfmAEUQ6AEwDXoECBkQAw#v=onepage&q=handbook%20arun%20mujumdar%20shiitake&f=false
43. Timm TG, Pasko RZ, da Gama Campos CS, Helm CV, Tavares LBB. Drying process of Lentinula edodes: Influence of temperature on β-glucan content and adjustment of mathematical models. Agricultural Sciences. 2019;43:1-12. DOI: https://doi.org/10.1590/1413-7054201943025719
44. Kotova TY, Khanturhaiev AH, Kharaiev HY. Mikrovolnovyi vakuumnyi mietod sushky siedobnykh hribov. Pishchevaia promyshliennost. 2013;8:28-29.
45. Wang H. Mid-Infrared Drying Shiitake Mushrooms and Its Hybrid Study. Wuxi: Jiangnan University. 2014.
46. Salehi F, Kashaninejad M, Mahoonak AR, Ziaiifar AM Drying Of Button Mushroom By Infrared-Hot Air System. Iranian Journal Of Food Science And Technology. 2017;13(59):151-159.
47. Burlaka TV, Dubkovetskyi IV, Malezhyk IF. Doslidzhennia sushinnia kultyvovanykh hrybiv riznymy infrachervonymy vyprominiuvachamy. Naukovi pratsi ONAKhT. 2015;47(2):12-17.
48. Nekrutman SV. Sverkhbystraia kuliynariia ili SVCh-pech v vashem dome. Moskva: VO Ahropromizdat; 1988.
49. Tiepliashin VN, Chientsova LI, Nievzorov VN. Tekhnolohii i oborudovanie dlia sushky rastitielnoho syria. Krasnoiarsk; 2019.
50. Supakarn S, Theerakulpisut S, Artnaseaw A. Equilibrium Moisture Content and Thin Layer Drying Model of Shiitake Mushrooms Using a Vacuum Heat-pump Dryer. Chiang Mai University Journal of Natural Sciences. 2018;17(1):1-12. DOI: https://doi.org/10.12982/CMUJNS.2018.0001
51. Šumić Z, Horecki TA, Vidović S, Vladić J. Drying of shiitake mushrooms in a vacuum dryer and optimization of the process by response surface methodology (RSM). Journal of food measurement and characterization. 2016;10(3):425-433. DOI: https://doi.org/10.1007/s11694-016-9321-4
52. Shchiehlova IV, Vierieshchahin AL. Vliianie sposoba sushki na sostav lietuchikh komponientov hribov. Tekhnika i tekhnolohiia pishchevykh proizvodstv. 2010:1(16):21-25.
53. Kamovnikov BP, Malkov LS, Voskoboinikov VA. Vakuum-sublimatsionnaia sushka pishchevykh produktov. Osnovy tieorii, raschot i optimizatsiia. Moskva: Ahropromizdat; 1985.
54. Xu D, Wei L, Guangyue R, Wenchao L, Yunhong L. Comparative study on the effects and efficiencies of three sublimation drying methods for mushrooms. International Journal of Agricultural & Biological Engineering. 2015;8(1):91-97. DOI: https://doi.org/10.3965/j.ijabe.20150801.012
55. Mienshutina NV, Mishina YuV, Alves SV. Innovatsionnyie tiekhnolohii i oborudovanie farmatsevticheskoho proizvodstva. Moskva: BINOM; 2012.
56. Zhao Y, Bi J, Yi J, Jin X, Wu X, Zhou M. Evaluation of sensory, textural, and nutritional attributes of shiitake mushrooms (Lentinula edodes) as prepared by five types of drying methods. Journal of Food Process Engineering. 2019;42(4):e13029. DOI: https://doi.org/10.1111/jfpe.13029
57. Qi LL, Zhang M., Mujumdar A.S. Comparison of Drying Characteristics and Quality of Shiitake Mushrooms (Lentinus edodes) Using Different Drying Methods. Drying Technology: An International Journal. 2014;32(15):1751-1761. DOI: https://doi.org/10.1080/07373937.2014.929588
58. Burdo OG. Evolyutsiya sushilnyih ustanovok. Odessa: Poligraf; 2010.
59. Her JY, Kim MS, Kim MK, Lee KG. Development of a spray freeze-drying method for preparation of volatile shiitake mushroom (Lentinula edodes) powder. International Journal of Food Science and Technology. 2015;50(10):2222-2228. DOI: https://doi.org/10.1111/ijfs.12888
60. Motevali A, Minaei S, Khoshtaghaza MH, Amirnejat H. Comparison of energy consumption and specific energy requirements of different methods for drying mushroom slices. Energy. 2011;36(11):6433-6441. DOI: https://doi.org/10.1016/j.energy.2011.09.024

61. Wang H, Zhang M, Arun SM. Comparison of Three New Drying Methods for Drying Characteristics and Quality of Shiitake Mushroom (Lentinus edodes). An International Journal of Drying Technology. 2014;32(15):1791-1802. DOI: https://doi.org/10.1080/07373937.2014.947426
62. Wang Hc, Benu A, Zhang M Drying of shiitake mushroom by combining freeze-drying and mid-infrared radiation. Food and Bioproducts Processing. 2015;94:507-517. DOI: https://doi.org/10.1016/j.fbp.2014.07.008
63. Kantrong H, Tansakul A, Gauri S. Mittal Drying characteristics and quality of shiitake mushroom undergoing microwave-vacuum drying and microwave-vacuum combined with infrared drying. Journal of Food Science and Technology. 2014; 51(12):3594-3608. DOI: https://doi.org/10.1007/s13197-012-0888-4
64. Politowicz J, Lech K, Lipan L, Figiel A, Carbonell-Barrachina AA. Volatile composition and sensory profile of shiitake mushrooms as affected by drying method. Journal of Science of Food and Agriculture. 2018;98(4):1511-1521. DOI: https://doi.org/10.1002/jsfa.8622
65. Esser K, Hofrichter M. The mycota: a Comprehensive Treatise on Fungi as Experimental Systems for Basis and Applied Research. 2nd ed. Berlin: Springer; 2010. DOI: https://doi:10.1007/978-3-642-11458-8
66. Lai CL, Yang JS, Liu MS. Effects of gamma-irradiation on the flavour of dry shiitake (Lentinus edodes sing). Journal of Food and Agriculture. 1994;64(1):19-22. DOI: https://doi.org/10.1002/jsfa.2740640104
67. Wang Q, Li S, Han X, Ni Y, Zhao D, Hao J. Quality evaluation and drying kinetics of shitake mushrooms dried by hot air, infrared and intermittent microwave-assisted drying methods. Food science and technology. 2019;107:236-242. DOI: https://doi.org/10.1016/j.lwt.2019.03.020
68. Zhang J, Yagoub A ElG A, Sun Y, Mujumdar SA, Ma H, Zhou C. Role of thermal and non-thermal drying techniques on drying kinetics and the physicochemical properties of shiitake mushroom. Journal of the Science of Food and Agriculture. 2021. DOI: https://doi.org/10.1002/jsfa.11348
69. Dolinskiy AA, Maletskaya KD Raspyilitelnaya sushka. Teplotehnologii i oborudovanie dlya polucheniya poroshkovyih materialov. Kiev: Akademperiodika; 2015.
70. Shiga H, Yoshii H, Ohe H, Yasuda M, Furuta T, Kuwahara H, Ohkawara M, Linko P. Encapsulation of Shiitake (Lenthinus Edodes) Flavors by Spray Drying. Bioscience Biotechnology Biochemistry. 2004;68(1):66-71. DOI: https://doi.org/10.1271/bbb.68.66.
71. Yoshii H, Yasuda M, Furuta T, Kuwahara H, Ohkawar M. Retention of Cyclodextrin Complexed Shiitake (Lentinus edodes) Flavors with Spray Drying. Drying Technology: An International Journal. 2005;23(6):1205-1215. DOI: https://doi.org/10.1081/DRT-200059343
72. Sharkova NO, Turchyna TIa, Zhukotskyi EK, Dekusha HV. Mikrostrukturnyi analiz hrybnoi suspenzii na stadii pidhotovky do rozpyliuvalnoho sushinnia. Naukovi pratsi NUKhT. 2018;24(6):240-247. DOI: https://doi.org/10.24263/2225-2924-2018-24-6-29
73. Sharkova NO, Zhukotskyi EK, Dekusha HV, Kostianets LO. Doslidzhennia dynamichnoi viazkosti vodnoi suspenzii plodovoho tila hryba shyitake. Naukovi pratsi NUKhT. 2017;23(6):219-225. DOI: https://doi.org/ 10.24263/2225-2924-2017-23-6-28
74. Krittalak P, Panida B, Supaporn B, Nowwapan N, Takunrat T, Ubolwanna S. Effect of Drying Process on the Physicochemical Properties and Biological Activities of Enzymatic Protein Hydrolysate from Shiitake Mushroom (Lentinula edodes). Chiang Mai Journal of Science. 2018;45(2):762-773.

АНАЛІЗ ІСНУЮЧИХ СПОСОБІВ І ОСОБЛИВОСТЕЙ СУШІННЯ ГРИБА ШИЇТАКЕ

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Анотація. Статтю присвячено огляду та аналізу переваг та недоліків існуючих технологій сушіння плодового тіла базидіального гриба шиїтаке, який є цінним джерелом біологічно активних полісахаридів, вітамінів, антиоксидантів, тощо. Наведено загальні результати досліджень впливу різних способів сушіння та їхніх теплотехнологічних режимних параметрів на структурно-механічні властивості, хімічний склад, вміст ароматоутворювальних речовин та інших сполук. Показано, що при сушінні гриба шиїтаке традиційним конвективним способом в температурному діапазоні 50–60°С максимально зберігаються сполуки фенольної природи, органічні кислоти, нуклеотиди, сірчані ароматичні речовини та посилюється унікальний аромат гриба. Перевагою радіаційного сушіння є менший ступінь усадки висушеного гриба шиїтаке, більш високий коефіцієнт регідратації та твердість, при цьому тривалість сушіння на 66% менша у порівнянні з сублімаційним способом сушіння. При вакуумному способі сушіння, при високій якості продукту, тривалість процесу значно збільшується і знижується вміст ароматоутворювальних речовин. Радіаційний спосіб сушіння у поєднанні з гарячим повітрям дозволяє отримати суху форму гриба шиїтаке з високим вмістом білка та біологічно активних полісахаридів, високими фізико-хімічними властивостями та скоротити час процесу на 37,5% у порівнянні з конвективним сушінням. Використання розпилювального сушіння має високу економічну доцільність і можливість організації промислового виробництва високоякісного сухого грибного порошку у великих обсягах. Характерним є незначний температурний вплив на продукт, що надає можливість збереження термолабільних біологічно активних речовин. При цьому методі сушіння доцільним є внесення декстринових добавок, що покращують структуруючі та вологопровідні властивості суспензії і її термостійкість, а також сприяє збереженню унікального аромату гриба за рахунок капсулювання одоруючих сполук. Вивчення впливу різних способів сушіння на фізико-хімічні властивості гриба шиїтаке дозволить удосконалити існуючі технологічні процеси та отримати продукт із заданими властивостями.

Ключові слова: гриб шиїтаке, конвективне сушіння, радіаційне сушіння, вакуум-сублімаційне сушіння, розпилювальне сушіння.

Список літератури:

1. Patel S., Goyal A. Recent developments in mushrooms as anti-cancer therapeutics: a review // 3Biotech. 2012. № 2 (1) P. 1-15. DOI: https://doi.org/10.1007/s13205-011-0036-2

2. Биологические особенности лекарственных макромицетов в культуре : в 2 т. Т. 1 / под ред. Вассера С. П.. Киев: Альтерпрес, 2012. 212 с.
3. Wasser S. P. Medicinal mushroom science: current perspectives, advances, evidences, and challenges // Biomedical Journal. 2014. Vol. 37. P. 345-356. DOI: https://doi.org/10.4103/2319-4170.138318
4. Shiitake Culinary-Medicinal Mushroom, Lentinus edodes (Agaricomycetes): A Species with Antioxidant, Immunomodulatory, and Hepatoprotective Activities in Hypercholesterolemic Rats / Nisar J. et al // International Journal of Medical Mushrooms. 2017. Vol. 19, Issue 11. P. 981-990. DOI: https://doi.org/10.1615/IntJMedMushrooms.2017024504
5. Rahman T., Choudhury MBK. Shiitake Mushroom: A Tool of Medicine. Review article. Bangladesh Journal of Medical Biochemistry. 2012. Vol. 5, Issue 1. P. 24-32. DOI: https://doi.org/10.3329/bjmb.v5i1.13428
6. Consuming Lentinula edodes (Shiitake) Mushrooms Daily Improves Human Immunity: A Randomized Dietary Intervention in Healthy Young Adults / Dai X. et al // Journal of the American College of Nutrition. 2015. Vol. 34, Issue 6. P. 478-87. DOI: https://doi.org/10.1080/07315724.2014.950391
7. Wasser S. P. Medicinal Mushroom Science: History, Current Status, Future Trends and Unsolved Problems // International Journal of Medical Mushrooms. 2010. Vol. 12, Issue 1. P. 1-16. DOI: https://doi.org/10.1615/IntJMedMushr.v12.i1.10
8. Recent advances in polysaccharides from Lentinus edodes (Berk.): Isolation, structures and bioactivities / Sheng K. et al // Food Chemistry. 2021. Vol. 358, Issue2. P. 129883. DOI: https://doi.org/10.1016/j.foodchem.2021.129883
9. Chien R.-C., Yen M.-T., Mau J.-L. Antimicrobial and antitumor activities of chitosan from shiitake stipes, compared to commercial chitosan from crab shells. Carbohydrate Polymers. 2016. Vol. 138. P. 259-264. DOI: https://doi.org/10.1016/j.carbpol.2015.11.061
10. A polysaccharide from Lentinus edodes inhibits human colon cancer cell proliferation and suppresses tumor growth in athymic nude mice / Wang J. et al // Oncotarget. 2017. Vol. 8, Issue 1. P. 610-623. DOI: https://doi.org/10.18632/oncotarget.13481
11. Fortune business insights. URL: https://www.fortunebusinessinsights.com/industry-reports/mushroom-market-100197 (viewed on: 20.01.2021).
12. Выращивание грибов как бизнес. Мой бизнес: [сайт]. 2020. URL: https://moybiznes.org/vyraschivanie-gribov (дата звернення: 20.01.2021).
13. ИКЦ АПК. Современное состояние грибов в мире URL: http://ikc.belapk.ru/upload/iblock/c81/c81e3db14af4c90e946b646b8a4fb99d.pdf (дата звернення: 23.01.2020).
14. Market research future. URL: https://www.marketresearchfuture.com/reports/shiitake-mushroom-market-4731 (дата звернення: 15.01.2021).
15. Шиїтаке. Загальні відомості. Аграрний сектор України. URL: http://agroua.net/plant/catalog/cg-50/c-130/info/cag-235/ (дата звернення: 17.03.2020).
16. UMDIS Грибное информационное агенство. Грибная отрасль Украины: основные цифры. URL: https://www.umdis.org/gribnaya-otrasl-ukrainy-osnovnye-cifry-16829/ (дата звернення: 13.05.2020).
17. Нестеренко Н. Виробництво і споживання культивованих грибів в Україні // Товари і ринки. 2011. № 2. С. 61-68.
18. Самый тихий бизнес // Интернет-газета Экономика. URL: http://economica.com.ua/article/77705609.html (дата звернення: 14.06.2021).
19. Обзор рынка грибов Украины. URL: https://www.marketing-ua.com/article/obzor-rynka-gribov-ukrainy/ (дата звернення: 10.02.2021).
20. Анализ рынка грибов за 2011-2015. URL: http://www.belferma.ru/assets/files/analiz_rynka_gribov_15.pdf (дата звернення: 10.05.2021).
21. Webster J., Weber R. Introduction to Fungi Edinburgh : Cambridge University Press, 2007. 863 p. DOI: https://doi.org/10.1017/CBO9780511809026
22. Сімахіна Г. О., Гойко І. Ю. Виробництво сухого грибного напівфабрикату для збагачення харчових раціонів // Наукові праці НУХТ. 2015. № 21 (2). С. 190-196.
23. Українське грибівництво: погляд у майбутнє. URL: https://a7d.com.ua/novini/40360-ukrayinske-gribvnictvo-poglyad-u-maybutnye.html (дата звернення: 20.04.2021).
24. Kudra T., Mujumdar A. S. Advanced drying technologies. New York: Marcel Dekker, 2002. 459 p.
25. Жук Ю. Т. Консервирование и хранение грибов (биохимические основы). Москва: Легкая и пищевая промышленность, 1982. 144 с.
26. Encyclopedia of Dietary Supplements / edited by Coates P.M. et al. Boca Raton: CRC Press, 2004. 840 p. DOI: https://doi.org/10.1201/b13959
27. Лукин В.Д., Новосельский А.В. Циклические адсорбционные процессы: Теория и расчет. Ленинград: Химия, 1989. 256 с.
28. Лыков А. В. Теория сушки. Москва : Энергия, 1968. 472 с.
29. Mujumdar A. S. Handbook of Industrial Drying. Boca Raton : CRC Press, 2014. 1348 p. DOI: https://doi.org/10.1201/b17208
30. Kinetics of Thin Layer Drying of Button Mushroom / Wakchaure G.C. et al // Journal of Agricultural Engineering. 2010. Vol. 47, Issue 4. P. 41-46.
31. Библиотека о грибах. URL: http://gribochek.su/books/item/f00/s00/z0000022/st011.shtml (дата звернення: 11.06.2021).
32. Argyropoulos D., Mueller J. Convective drying and desorption isotherms of Shiitake (Lentinula edodes) mushroom // Chemsitry. 2013. URL: https://core.ac.uk/download/pdf/56707568.pdf (viewed on: 11.06.2021).
33. Argyropoulos D., Alex R., Müller J. Equilibrium moisture contents of a medicinal herb (Melissa officinalis) and a medicinal mushroom (Lentinula edodes) determined by dynamic vapour sorption // Procedia Food Science. 2011. Vol. 1. P. 165-172. DOI: https://doi.org/10.1016/j.profoo.2011.09.026
34. Rhim J.-W., Lee J. H. Drying kinetics of whole and sliced Shiitake mushrooms (Lentinus edodes) // Food Science and Biotechnology. 2011. Vol. 20, Issue 2 P. 419-427. DOI: https://doi.org/10.1007/s10068-011-0059-9
35. Doymaz I. Drying Kinetics and Rehydration Characteristics of Convective Hot-Air Dried White Button Mushroom Slices // Journal of Chemistry. 2014. Vol. 2012. 8 p. DOI: https://doi.org/10.1155/2014/453175
36. Zhang M., Bhandari B., Fang Z. Handbook of drying of vegetables and vegetable products. Boca Raton: CRC Press, 2017. 554 p. DOI: https://doi.org/10.4324/9781315152677
37. Effects of different drying methods on the product quality and volatile compounds of whole shiitake mushrooms / Tian Y. et al // Food Chemistry. 2016. Vol. 197(A). P. 714-722. DOI: https://doi.org/ 10.1016/j.foodchem.2015.11.029
38. Comparative analysis of taste compounds in shiitake mushrooms processed by hot-air drying and freeze drying / Yang X. et al // International Journal of Food Properties. 2019. Vol.22, Issue 1. P. 1100-1111. DOI: https://doi.org/10.1080/10942912.2019.1628777
39. Mathematical modeling and effect of various hot-air drying on mushroom (Lentinus edodes) / Guo X.-H. et al // Journal of Integrative Agriculture. 2014. Vol. 13, Issue 1. P. 207-216. DOI: https://doi.org/10.1016/S2095-3119(13)60265-8
40. Effects of high-temperature pre-drying on the quality of air-dried shiitake mushrooms (Lentinula edodes) / Xu L. et al // Food Chemistry. 2019. Vol. 285. P. 406-413. DOI: https://doi.org/10.1016/j.foodchem.2019.01.179
41. Mujumdar A. S. Handbook of industrial drying: Boca Raton : RC/Taylor and Francis, 2007, 1280 p. DOI: https://doi.org/10.1201/9781420017618
42. Wu B. K. Encyclopedia of Food Science and Technology. New York, 1992. Vol. 3. P. 1844-1848. URL: https://books.google.com.ua/books?id=80TMBQAAQBAJ&pg=PA660&lpg=PA660&dq=handbook+arun+mujumdar+shiitake&source=b

l&ots=lcr3X6VjNU&sig=ACfU3U1fzgKqe1YMJo_5BQnJ9KYAv-hRMQ&hl=ru&sa=X&ved=2ahUKEwiUq_7v7ZvxAhW0h_0HHSfmAEUQ6AEwDXoECBkQAw#v=onepage&q=handbook%20arun%20mujumdar%20shiitake&f=false (viewed on: 20.12.2020).

43. Drying process of Lentinula edodes: Influence of temperature on β-glucan content and adjustment of mathematical models / Timm T. G. et al // Agricultural Sciences. 2019. Vol. 43. P. 1-12. DOI: https://doi.org/10.1590/1413-7054201943025719
44. Котова Т. И., Хантургаев А. Г., Хараев Г. И. Микроволновый вакуумный метод сушки съедобных грибов. Пищевая промышленность. 2013. № 8. С. 28-29.
45. Wang H. Mid-Infrared Drying Shiitake Mushrooms and Its Hybrid Study. Wuxi: Jiangnan University. 2014.
46. Drying Of Button Mushroom By Infrared-Hot Air System / Salehi F. et al // Iranian Journal Of Food Science And Technology. 2017. Vol.13, Issue 59. P. 151-159.
47. Бурлака Т. В., Дубковецький І. В., Малежик І. Ф. Дослідження сушіння культивованих грибів різними інфрачервоними випромінювачами // Наукові праці ОНАХТ. 2015. № 47 (2). С. 12-17.
48. Некрутман С. В. Сверхбыстрая кулинария или СВЧ-печь в вашем доме. Москва : ВО Агропромиздат, 1988. 111 с.
49. Тепляшин В. Н., Ченцова Л. И., Невзоров В. Н. Технологии и оборудование для сушки растительного сырья. Красноярск, 2019. 177 с.
50. Supakarn S., Theerakulpisut S., Artnaseaw A. Equilibrium Moisture Content and Thin Layer Drying Model of Shiitake Mushrooms Using a Vacuum Heat-pump Dryer // Chiang Mai University Journal of Natural Sciences. 2018. Vol. 17, Issue 1. P. 1-12. DOI: https://doi.org/10.12982/CMUJNS.2018.0001
51. Drying of shiitake mushrooms in a vacuum dryer and optimization of the process by response surface methodology (RSM) / Šumić Z. et al // Journal of food measurement and characterization. 2016. Vol. 10, Issue 3. P. 425-433. DOI: https://doi.org/10.1007/s11694-016-9321-4
52. Щеглова И. В. Верещагин А. Л. Влияние способа сушки на состав летучих компонентов грибов // Техника и технология пищевых производств. 2010. № 1 (16). С. 21-25.
53. Камовников Б.П., Малков Л. С., Воскобойников В. А. Вакуум-сублимационная сушка пищевых продуктов. Основы теории, расчёт и оптимизация. Москва: Агропромиздат, 1985. 288 с.
54. Comparative study on the effects and efficiencies of three sublimation drying methods for mushrooms / Xu D. et al // International Journal of Agricultural & Biological Engineering. 2015. Vol.8, Issue 1. P. 91-97. DOI: https://doi.org/10.3965/j.ijabe.20150801.012
55. Меньшутина Н. В., Мишина Ю. В., Алвес С. В. Инновационные технологии и оборудование фармацевтического производства. Т.1. Москва : издательство БИНОМ, 2012. 328 с.
56. Evaluation of sensory, textural, and nutritional attributes of shiitake mushrooms (Lentinula edodes) as prepared by five types of drying methods / Zhao Y. et al // Journal of Food Process Engineering. 2019. Vol.42, Issue4. e13029. DOI: https://doi.org/10.1111/jfpe.13029
57. Qi L.-L., Zhang M., Arun S. Mujumdar Comparison of Drying Characteristics and Quality of Shiitake Mushrooms (Lentinus edodes) Using Different Drying Methods // Drying Technology: An International Journal. 2014. Vol. 32, Issue 15. P. 1751-1761. DOI: https://doi.org/10.1080/07373937.2014.929588
58. Бурдо О. Г. Эволюция сушильных установок. Одесса : Полиграф, 2010. 368 с.
59. Development of a spray freeze-drying method for preparation of volatile shiitake mushroom (Lentinula edodes) powder / Her J-Y. et al // International Journal of Food Science and Technology. 2015. 2015. Vol. 50, Issue 10. P. 2222-2228. DOI: https://doi.org/10.1111/ijfs.12888
60. Comparison of energy consumption and specific energy requirements of different methods for drying mushroom slices / Motevali A. et al // Energy. 2011. Vol. 36, Issue 11. P. 6433-6441. DOI: https://doi.org/10.1016/j.energy.2011.09.024
61. Wang H., Zhang M., Arun S. Mujumdar Comparison of Three New Drying Methods for Drying Characteristics and Quality of Shiitake Mushroom (Lentinus edodes) // An International Journal of Drying Technology. 2014. Vol. 32, Issue 15. P. 1791-1802. DOI: https://doi.org/10.1080/07373937.2014.947426
62. Wang Hc., Benu A., Zhang M. Drying of shiitake mushroom by combining freeze-drying and mid-infrared radiation. Food and Bioproducts Processing. 2015. Vol. 94. P. 507-515. DOI: https://doi.org/10.1016/j.fbp.2014.07.008
63. Kantrong H., Tansakul A., Gauri S. Mittal Drying characteristics and quality of shiitake mushroom undergoing microwave-vacuum drying and microwave-vacuum combined with infrared drying // Journal of Food Science and Technology. 2014. Vol. 51, Issue 12. P. 3594-3608. DOI: https://doi.org/10.1007/s13197-012-0888-4
64. Volatile composition and sensory profile of shiitake mushrooms as affected by drying method /Politowicz J. et al // Journal of Science of Food and Agriculture. 2018. Vol. 98, Issue 4. P. 1511-1521. DOI: https://doi.org/10.1002/jsfa.8622
65. Esser K., Hofrichter M. The mycota: a Comprehensive Treatise on Fungi as Experimental Systems for Basis and Applied Research. Berlin : Springer. 2010. edition: 2nd, Publisher: Springer.393 p. DOI: http://doi:10.1007/978-3-642-11458-8
66. Lai C. L., Yang J. S., Liu M.-S. Effects of gamma-irradiation on the flavour of dry shiitake (Lentinus edodes sing) // Journal of Food and Agriculture. 1994. Vol. 64, Issue 1. P.19-22. DOI: https://doi.org/10.1002/jsfa.2740640104
67. Quality evaluation and drying kinetics of shitake mushrooms dried by hot air, infrared and intermittent microwave-assisted drying methods / Wang Q. et al // Food science and technology. 2019. Vol. 107. P. 236-242. DOI: https://doi.org/10.1016/j.lwt.2019.03.020
68. Role of thermal and non-thermal drying techniques on drying kinetics and the physicochemical properties of shiitake mushroom / Zhang J. et al // Journal of the Science of Food and Agriculture. 2021. DOI: https://doi.org/10.1002/jsfa.11348. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/jsfa.11348 (viewed on: 06.06.2021).
69. Долинский А. А., Малецкая К. Д. Распылительная сушка : в 2-х т. Т 2. Теплотехнологии и оборудование для получения порошковых материалов. Киев : Академпериодика, 2015. 390 с.
70. Encapsulation of Shiitake (Lenthinus Edodes) Flavors by Spray Drying / Shiga H. et al // Bioscience Biotechnology Biochemistry. 2004. Vol. 68 Issue 1. P. 66-71. DOI: https://doi.org/10.1271/bbb.68.66
71. Retention of Cyclodextrin Complexed Shiitake (Lentinus edodes) Flavors with Spray Drying / Yoshii H. et al // Drying Technology: An International Journal. 2005. Vol. 23, Issue 6. P. 1205-1215. DOI: https://doi.org/10.1081/DRT-200059343
72. Мікроструктурний аналіз грибної суспензії на стадії підготовки до розпилювального сушіння / Шаркова Н. О. та ін.// Наукові праці НУХТ. 2018. № 24 (6). С. 240-247. DOI: https://doi.org/10.24263/2225-2924-2018-24-6-29
73. Дослідження динамічної в'язкості водної суспензії плодового тіла гриба шиїтаке / Шаркова Н. О. та ін. // Наукові праці НУХТ. 2017. № 23 (6). С. 219-225. DOI: https://doi.org/ 10.24263/2225-2924-2017-23-6-28
74. Effect of Drying Process on the Physicochemical Properties and Biological Activities of Enzymatic Protein Hydrolysate from Shiitake Mushroom (Lentinula edodes) / Krittalak P. et al // Chiang Mai Journal of Science. 2018. Vol. 45, Issue 2. P. 762-773.