

REGULATION OF STRUCTURAL AND MECHANICAL PROPERTIES OF SHIITAKE MUSHROOM SUSPENSION AS AN OBJECT OF SPRAY DRYING

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Introduction. Formulation of the problem

In the context of the man-caused environmental deterioration and the steady growth of the so-called diseases of civilisation, the demand for health-improving, dietetic, and functional products has sharply increased throughout the world. A modern person's diet is deficient in micronutrients and important food compounds. The products the human body especially needs are those that can stimulate and activate its defences against viruses, intoxications of various nature, cancer, and other serious diseases. The deficiency of many nutrients important for the body's normal functioning significantly increases the risk of

Abstract. The article considers whether a shiitake basidiomycete can be processed into powder. This mushroom is a source of valuable nutrients: it contains, on a dry basis, 18.76% of protein, 74.5% of carbohydrates, 1% of lipids, and 5.73% of ash. It has been determined that to obtain a uniform mushroom suspension, it is advisable to use the mechanisms of discrete-pulse energy input, which is an effective tool to influence the high-strength structural elements of heterogeneous systems of different nature. It has been determined that the mechanostuctural properties of a mushroom suspension as an object of spray drying need to be changed. Studies of the microstructure have shown that in a suspension obtained from a whole fruiting body, particles of the insoluble fractions of a shiitake mushroom aggregate into chaotic clusters. These are spatial associates up to 3–4 mm in size, with individual hyphae of their caps or their fragments that are significantly shorter (10–15 μm) than the hyphae of the stems (50–5000 μm). The three-cycle processing of the suspension obtained from a whole mushroom by discrete-pulse energy input led to a decrease in the average particle size by 2–3 times. The same processing of the mushroom suspension obtained from the shiitake caps made it possible to reduce the average particle size by 20 times (to $\delta_{\text{max}} \leq 100\text{--}150 \mu\text{m}$). Microstructural analysis of the powder obtained from the whole fruiting body of the mushroom has shown that while the size of the particles generally ranges 4–120 μm , the bulk of them (80–85%) are quite large agglomerates, 40–120 μm in size. The powder obtained from the caps of the mushroom had smaller particles (ranging 4–60 μm), mostly round-shaped, and 75–80% of these particles were 4–20 μm in size. This improved its drying conditions and increased the yield from the spray dryer up to 92% (while the yield of powder prepared from the whole shiitake mushroom was less than 50%). The complex of studies carried out has shown the advantages of obtaining a mushroom suspension from the caps of shiitake mushrooms. The use of mechanisms of discrete-pulse energy input allows a 6-fold increase in the bioavailable health-improving polysaccharide complex contained in the powder from shiitake caps, as compared with the powder obtained from mushroom's whole fresh fruiting body.

Key words: shiitake mushroom, discrete-pulse energy input, dispersion, dispersion composition, structural and mechanical properties, spray drying.

occurrence and development of many diseases. In this regard, more and more attention is paid to available natural sources of bioactive substances and nutrients: proteins, fats, polysaccharides, vitamins, and others, which can prove useful in modern advanced, scientifically based food technologies.

At present, the priority areas of food production are innovative technologies of functional nutrition, natural enriched foods, and special-purpose medicinal products [1–5]. Scientists and specialists in various fields of expertise are involved in solving these problems: microbiologists and biotechnologists, doctors and geneticists, nutritionists and food scientists, thermal physicists and pharmaceutical chemists.

Analysis of recent research and publications

Basidiomycetes are rich in nutrients and bioactive substances. They are high in protein containing all essential amino acids, vitamins, macronutrients, and trace elements [6–8]. The traditional Japanese mushroom shiitake belongs to these products with unique properties. Its healing potential has been confirmed by numerous experiments and clinical studies. Patents from Japan, France, Germany, Great Britain, and other countries confirm the pronounced immunomodulatory, antitumor, and antiviral effects of bioactive compounds found in this mushroom. The most valuable is its carbohydrate component. Besides reserve monosaccharides, disaccharides, and glycogen, it contains pharmacologically active polysaccharides. Of them, the one in particular demand is the polysaccharide lentinan (β -1.3-1.6 glucan), which has proved to have antitumor properties. Its positive effect consists in stimulating the human immune system [7–10]. The activity of polysaccharides is determined by their molecular weight, the degree of branching, and the structural features of the side chains. For the antitumor effect of glucans, it is essential that there should be a β -1.3-bond in the main chain of the molecules and β -1.6-bonds in linear side chains [11].

Bioactive shiitake glucans are enclosed in high-strength cell membranes and combined with chitin and protein molecules in specific complexes. The percentage of the chitin-glucan complex in a mushroom varies and depends on many factors: age, growing conditions, morphological parts of the mushroom's fruiting body. The stipes are higher in fibre, including chitin (45%), than the caps are (36–37%), though the latter make up about 75% of the total weight of the fruiting body of shiitake [7,8].

Without special processing, chitin-glucan complexes are hardly available and indigestible and cannot display all their medicinal properties. That is why isolating them requires sophisticated equipment and special chemical modification methods. However, in this process, the mushroom's bioactive substances (proteins, fats, vitamins, and minerals) lose much of their unique natural potential. So, the complex processing of the whole fruiting body of shiitake and its further use to manufacture therapeutic foods is a promising and cost-effective direction [6].

To develop new technologies of functional products and additives, it is essential to obtain products of processing mushrooms in the form of dry powder, because it significantly extends their shelf life and expands the range of their applications. To obtain a powdered product, various heat-technology methods of mushroom pretreatment are used in different combinations: grinding, boiling, blanching, and freezing. Besides, there are various methods of subsequent drying: convective, vacuum, sublimation, infrared radiation, and others [12–15]. However, the technology of spray drying of mushrooms and the peculiarities of preparing raw materials for drying are described but insufficiently [16,17].

The choice of the method and temperature parameters of drying determines the qualitative and quantitative characteristics of mushroom powder [18, 19]. These characteristics include:

- dispersion composition, mechanostructural properties, moisture content, and hygroscopicity;
- regenerating ability of the dried mushroom's structural elements (its fibre);
- chemical composition including the amount of proteins and polysaccharides that have passed into an easily digestible form;
- preservation of the properties of proteins, polysaccharides, vitamins, etc. during heat drying, and hence retention of the nutritive and pharmacological qualities of the powdered product.

To ensure effective spray drying, the particles of the insoluble fractions of a mushroom suspension (MS) should not be larger than 100–150 μm [20, 21]. To obtain dispersed systems with particles of this size, researchers of the Institute of Engineering Thermophysics at the National Academy of Sciences of Ukraine suggested implementing discrete-pulse energy input mechanisms (DPEI mechanisms) in the working space of rotary-pulse apparatuses (RPA). The impact of the energy locally directed to a dispersed particle during its processing is concentrated in the form of a pulse, which is a significant advantage of DPEI mechanisms [22, 23]. This method results in nanoscale effects and allows increasing instantly the total area of phase surface contact and intensifying the synchronic hydromechanical processes and heat and mass transfer. Treating a MS with DPEI makes the system highly homogeneous and resistant to immiscibility when fed into the spray dryer. Besides, the bioactive substances extracted from the structural and molecular systems of the pharmacologically active polysaccharide complex actively pass into a bioavailable form.

The morphological parts of shiitake have their individual structural features and physicochemical composition [7,8] that affect the mechanostructural properties of the suspensions with anomalous viscosity obtained after DPEI treatment [20,24]. This is due to:

- the intensity of the forces of interaction between the particles, which is determined by their size and concentration in the dispersion medium;
- anisometricity of hyphae (cylindrical in shape) and their fragments in the composition of the suspension, as evidenced by the huge difference between the their diameter, which varies along their entire length from 1 to 13 μm , and length, which ranges 50 to 5000 μm [20];
- the microfibrillar structure of the cell wall of the hyphae (0.2–1.0 μm thick) that are filled [20] with a fine-grained spongy structure giving the hyphae such shock-absorbing properties as resilience, flexibility, and high resistance to mechanical stress. This structure of the hyphae complicates the dispersing process and obtaining an MS uniform by its dispersion composition, thus making it difficult to produce high-quality powder by spray drying;

– the tendency of fragments of the hyphae of a heterogeneous MS system to form aggregations up to 3–4 mm in size and, subsequently, to arrange themselves into three-dimensional plastic spatial associates. This adversely affects the dispersion composition of the droplets in the spray cone in the drying chamber, the efficiency of drying, and the quality of the powder, because larger powder fractions accumulate on the chamber walls and form viscoplastic deposits of the product [25].

Investigation of the rheological properties of mushroom suspensions makes it possible to characterise more fully the interaction between the dispersion medium and the dispersed phase particles suspended in it [26], to predict the conditions for feeding the material into the drying chamber and carrying out the spray drying. There are a number of factors affecting the process [21,27,28]:

– demixing of mushroom suspensions over time, which complicates feeding them into the drying chamber;

– formation of a polydisperse composition of droplets in the spray cone due to the heterogeneity of the system obtained from unfractionated plant raw materials, which leads to uneven drying and the formation of adhesive deposits on the chamber walls;

– high humidity resulting in agglomeration of the particles and clumping of the powder, deterioration of its free-flowing properties, a decrease in the yield of the product from the chamber and in its overall quality.

The main technological factors affecting the rheological properties of mushroom suspensions are the hydromodulus and the temperature of the process of their preparation. Thus, an increase in the hydromodulus from 1 to 2 at the MS temperature 20°C makes the suspension about 3 times less viscous. A temperature increase from 20°C to 80°C allows reducing its values approximately by half [29].

Besides, the rheological properties of heterogeneous systems from unfractionated feedstock are influenced by the use of:

– dispersed particles of insoluble fractions of the raw material reduced in the course of homogenisation to a uniform size composition ($\delta_p = 4\text{--}100\text{--}150\text{ }\mu\text{m}$) [21,25,28];

– hard spherical particles additionally introduced in low concentrations, which weakens the anomalous properties of the suspension. It was shown in the study of the rheological behaviour of diluted suspensions exhibiting non-Newtonian properties due to the peculiarities of the dispersion medium and the shape of the particles suspended [26];

– soluble biopolymer additives of plant (proteins, dextrin-containing compounds) or animal (skimmed milk powder, whey-protein concentrate) origin. These substances act as surfactants at the phase interface during DPEI treatment of the MS [22].

The addition of β -cyclodextrin in dry form as a structuring biopolymer additive, too, made it possible to change significantly the rheological properties of the MS obtained by applying DPEI mechanisms. β -cyclodextrin introduced into the MS in the amount 5–

10% of the total mass of dry matter at 20°C reduced the suspension's dynamic viscosity from 1.8 Pa·c to 1.1–1.2 Pa·c, and at 60°C, decreased the viscosity from 1.25 Pa·c to 0.75–0.9 Pa·c (i. e. by 30–35% on average). Introduction of this additive improves the mechanostructural, structure-forming, and moisture-conducting properties of liquid microheterogeneous systems, increases the thermal stability of the material during drying, and has a microencapsulating effect [21, 25, 28–33].

When obtaining an MS, rational choice of technological factors determines the conditions and efficiency of a number of processes in a spray dryer and affects the qualitative and quantitative characteristics of the resulting powder, such as:

– stability and regularity of feeding a liquid product to the disc atomiser;

– formation of spherical droplets with uniform dispersion composition in the spray cone, which is crucial to their synchronic uniform drying;

– kinetics and rate of the drying of droplets;

– the thermal and moisture condition of the particles of powder as they leave the spray cone near the walls of the drying chamber. This parameter determines whether dry or plastic deposits are likely to form in the drying chamber;

– the final moisture content of the powder on leaving the dryer, that is, a material's ability to become dry in a certain typical volume of the spray dryer;

– the mechanostructural properties of the powder, which determine its flowability required for its timely evacuation from the high temperature zone and guaranteed preservation of the material's valuable bioactive substances during drying.

Therefore, to obtain a high-quality powder from shiitake, it is necessary to determine rational technological conditions of obtaining an MS with a given dispersity of particles of insoluble fractions. This will ensure the homogeneity of the dispersion composition of the droplets in the spray cone and the uniformity of their drying, and will allow preserving the mushroom's biologically valuable polysaccharide complex during drying.

The **purpose of the research** is to study the factors influencing the properties of the suspension obtained from the fruiting body of the shiitake mushroom as an object of spray drying.

The **objectives of the research** were:

– to determine the chemical composition of the fruiting body of the shiitake mushroom;

– to investigate the microstructure of the MS obtained from whole mushrooms and their caps;

– to study the effect of DPEI mechanisms on the dispersion composition and microstructure of the suspension samples obtained;

– to investigate the microstructure of dry powders obtained from the mushroom's whole fruiting body and its cap, and to determine their yield from the spray dryer;

– to determine the content of the bioavailable complex of polysaccharides in the powder samples for its further use in the food and pharmaceutical industries.

Research materials and methods

The research material: the fruiting body of clean fresh varietal shiitake mushrooms with closed yellow-brown caps, flattened and having depressions in the centre, 50–100 mm in diameter. The colour of the flesh on its cut was creamy white. The length of stipes was up to 40 mm. The mushrooms were free of mechanical damage and signs of disease according to State Standard of Ukraine (DSTU) ISO 7561-2001 (*TDV Esmash*, Ukraine). β -cyclodextrin powder produced from starch by enzymatic hydrolysis (*OOO Felitsata*, Ukraine) was introduced into the suspension in an amount of 5–10% as a biopolymer additive.

Preparation of mushroom suspensions (MS) from whole fresh shiitake mushrooms or their caps. Fresh shiitake mushrooms or their caps were weighed and crushed in an industrial meat mincer MIM-300 (the holes in the plate 3 mm in diameter), and then mixed with 20°C hot distilled water at the mass ratio 1:1.5 respectively. Then they were dispersed in a flow-type rotary-pulse apparatus (RPA) of cylindrical type (number of revolutions $n = 100 \text{ s}^{-1}$, connection type is stator-rotor-stator, 1–6 processing cycles) (Pat. No. 118426 UA, pat. No. 114264 UA).

The microstructure of the MS was determined with an Axio Imager electron microscope (Carl Zeiss, Germany), the magnification ranged 160x to 1600x.

The dispersion composition of the suspensions and powders was determined with a microscope MBI 3U 4.2 and simultaneous microphotography of the samples with a digital camera. Onto a glass slide, 1–2 drops of glycerol oil were applied, in which the powdered sample was carefully distributed in an even thin layer using a glass rod. The sample was pressed with an ultrathin cover slip (15x15 mm), which helped better distribution of particles in one sheet. For each type of powder, 4–6 samples were prepared. The slide fixed on the microscope stage could be moved in two directions. The scale bar inserted into the eyepiece was used to determine the size and number of particles in each field until statistical data were obtained with ~ 1000 particles. The actual particle size was determined by the eyepiece magnification factor.

Samples of mushroom suspensions were dried on an *experimental spray dryer PIU-1.3* (diameter 1.3 m) with a centrifugal disc atomiser (disc diameter $d=0.12 \text{ m}$, disc revolutions $n=300 \text{ s}^{-1}$), with the capacity 10 kg/h measured by moisture evaporated. Mushroom suspensions prepared from whole shiitake or their caps were fed with a plunger pump through a spray device into the cylindroconical drying chamber and there dried until powdered. The temperature of the heat transfer fluid at the inlet of the chamber ranged $170 \pm 5^\circ\text{C}$ to $190 \pm 5^\circ\text{C}$, and on the exit from the chamber, it was $78 \pm 1^\circ\text{C}$ to $91 \pm 1^\circ\text{C}$.

The dry matter content was determined according to DSTU 7804:2015, the protein content according to DSTU 7824:2015, the fat content according to DSTU

4941:2008, and that of ash according to DSTU ISO 2171:2009.

The content of the polysaccharide complex in the samples was determined by the method developed at M. G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine. Three samples were prepared for the research: Sample 1 (the reference sample) – a whole fruiting body of the mushroom, Sample 2 – powder obtained from a whole mushroom containing 5% of β -cyclodextrin, and Sample 3 – powder obtained from mushroom caps containing 5% of β -cyclodextrin. To extract polysaccharides, the samples under study were destroyed in a homogeniser or ground in a mortar after deep freezing using liquid nitrogen. Then the samples were covered with distilled water in a weight ratio of 1:10 or 1:5 respectively and boiled in a water bath for 12–18 hours. The cytoplasmic content was removed by suspending the destroyed fruiting bodies repeatedly in distilled water and centrifuging them at 3000 g for 15 min. The washing procedure was only stopped when the optical density of the supernatant at 280 nm did not exceed 0.1. The resulting extracts were concentrated 2–3 times on a rotary evaporator, treated with 96% ethanol in a volume ratio of 1:1, and left at 4°C until complete precipitation. The precipitate formed (polysaccharides) was separated by centrifugation and dialysed against distilled water for 3 days. The polysaccharide dialysed was precipitated with ethyl alcohol in a volume ratio of 1:2 respectively, washed with ethanol, ether, and acetone, and dried at 37°C. The homogeneity of the polysaccharide was checked by gel filtration with Sephadex G-200. To detect the polysaccharide in the eluent, the phenol-sulphuric method was used [7, 8, 34].

The yield of the powder product from the drying chamber was calculated as the percentage ratio of the resulting dry powder amount to the initial amount of dry matter in the MS.

Results of the research and their discussion

The stage of preparing the shiitake for spray drying with the use of a disc atomiser involves pre-treatment of the raw material to obtain a homogeneous suspension, liquid and sufficiently flowable. On a dry matter basis, fresh shiitake mushrooms have been found to be high in protein (18.76%) and carbohydrates (74.5%). Lipids make up about 1%, and ash 5.73% of the total dry weight.

The mushroom suspension obtained by DPEI is a complex heterogeneous system that is resistant to separation and cannot be filtered or centrifuged. It very quickly passes into a gel-like form characterised by abnormally high viscosity even when it is strongly diluted to a low dry matter content, which is due to the ability of polysaccharides and proteins to form stable colloidal solutions in water.

The studies carried out have shown the microstructure of the dispersed composition of the suspensions obtained from different morphological parts of the mushrooms: their whole bodies and their caps (Fig. 1).

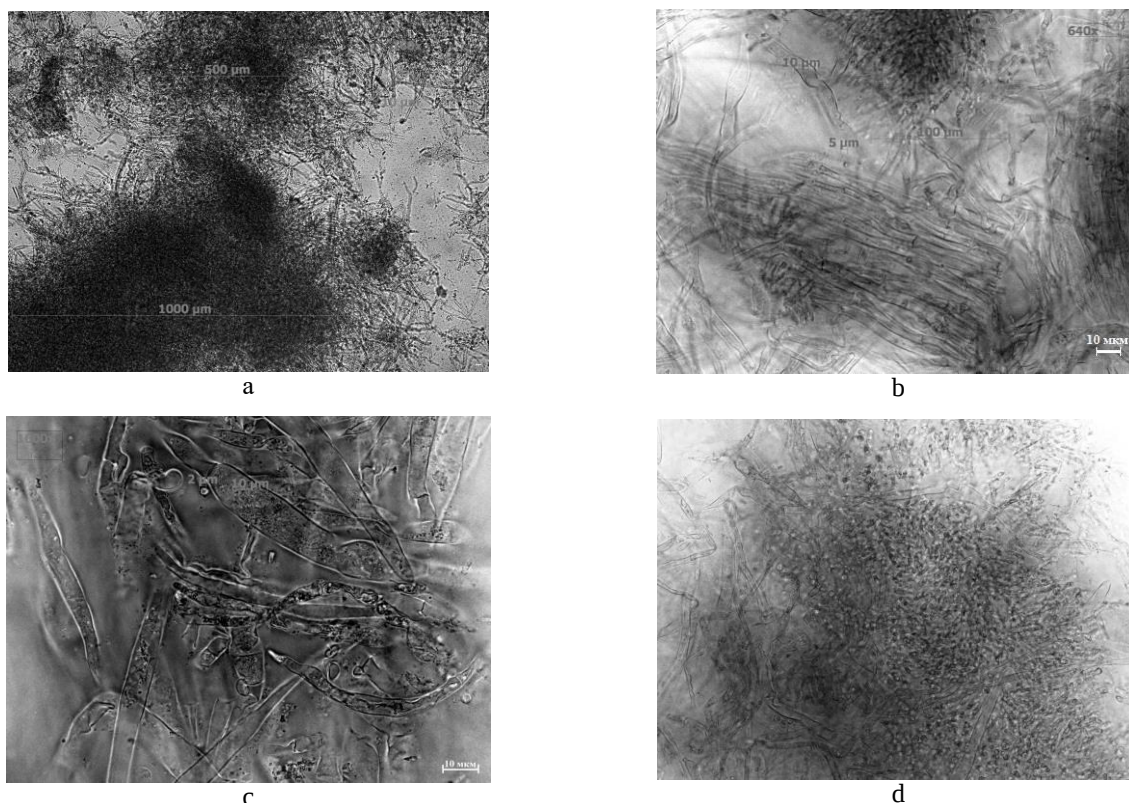


Fig. 1. Microstructure of an MS obtained after DPEI treatment of the shiitake fruiting body:

a) aggregated accumulations of hyphae in a suspension from a whole mushroom after 1 cycle of DPEI treatment; magnification 160x; b) fragments of hyphal aggregations of the stipes (lower part of the photo) and caps (upper part of the photo) after 1 cycle of DPEI treatment; magnification 640x; c) fragments of hyphae from mushroom stipes with partially exposed inner filling; magnification 1600x; d) fragments of hyphae of mushroom caps after 3 cycles of DPEI treatment; magnification 640x

In a MS obtained from the whole fruiting body of shiitake, the particles of its insoluble fractions, different in shape and size, randomly aggregate into spatial associates of various sizes (up to 3–4 mm) and densities, looking like tangled yarn balls (Fig. 1a). This is due to the adhesion of a lot of anisometric hyphae from mushroom stems, which are far longer (Fig. 1b – lower fragments of the aggregations) than hyphae from mushroom caps (Fig. 1b – upper fragment). The lengths of hyphae from different parts of a shiitake fruiting body differ by tens and hundreds of times. The lengths of individual hyphae from the caps or their fragments ranged 10–15 μm , whereas those of hyphae from the stipes and their fragments were 50–5000 μm (Fig. 1b, Fig. 1c). This is why the dispersed composition of the MS obtained from the caps (Fig. 1d) is more homogeneous. Additional DPEI treatment in a flow-type RPA of the cylindrical type destroys the structure of hyphae and significantly reduces the size of the resulting particles. The DPEI treatment of the caps resulted in the highest dispersion and uniformity of particles of insoluble fractions in the MS: their maximum size was $\delta_{\text{max}} \leq 100\text{--}150 \mu\text{m}$ (Fig. 1).

The dispersion composition of MS microparticles is a determining parameter of the efficiency of DPEI

treatment of heterogeneous systems. It has a significant effect on their mechanostructural properties, on the processes in the spray dryer, and on the quality of powders obtained. It has been experimentally shown that in an MS, the above dispersion of particles of insoluble fractions (fibre and hyphae fragments) of mushroom caps is achieved after 3 cycles of DPEI treatment (Fig. 2).

As a result of 3 cycles of DPEI treatment, the average particle size in an MS from a whole mushroom decreased by 2.3 times (Fig. 2, Sample 1), while the same treatment of an MS from caps leads to a 20-fold decrease in the average particle size (Fig. 2, Sample 2). Further dispersion of Sample 1 leads to an unjustifiable increase in energy consumption, since in Sample 2, three cycles are enough to achieve the required dispersity ($\delta_{\text{max}} \leq 100\text{--}150 \mu\text{m}$).

Thus, DPEI allows influencing effectively the high-strength chitin-glucan structures of the cell membranes of the mushroom's fruiting body in the working space of the RPA. The resulting particles of the insoluble fractions of the mushroom (in particular the caps) range 2–4 μm to 100–150 μm in size, and their dispersity is enough to feed the MS into the drying chamber.

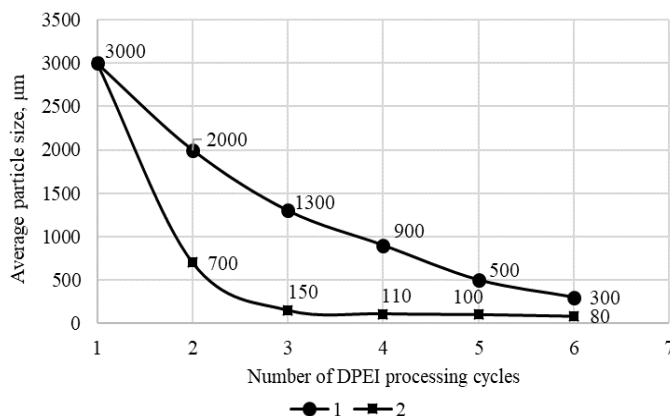


Fig. 2. Dependence of the dispersion composition of MS samples on the number of DPEI treatment cycles:
1 – MS obtained from a whole shiitake fruiting body; 2 – MS obtained from shiitake caps

Spray drying. When drying an MS obtained from a whole fruiting body, with β -cyclodextrin added as a biopolymer structurant, most of the powder settled on the chamber walls. As a result, its yield was low and amounted to less than 50%. This is because the MS contains quite long particles of hyphae the mushroom stipes consist of. These particles of hyphae complicate the formation of spherical droplets the moment the latter leave the edge of the disc atomiser. Besides, the duration and trajectory of the flight of larger particles in the chamber increases until complete drying. The worsened conditions of heat and mass transfer result in adhesion of hot particles to the chamber walls. The increased adhesion properties of these particles led to the formation of a continuous plastic layer of the product over the entire surface of the chamber, which is confirmed by microstructure studies.

When drying the MS obtained from the caps, with β -cyclodextrin added, the powder yield increased to 92%. This was achieved due to the appropriate dispersity of particles (≤ 100 – 150 μm). There were

insignificant losses of the product, because particles of a finely dispersed powder fraction (up to 10 μm) were difficult to capture and the bulk density in the dry cyclonic separator of the experimental spray dryer ПЦ–1.3 was low.

Microstructural analysis of the powder samples obtained from the whole shiitake mushrooms and their caps has confirmed that the dispersion composition of powders formed during spray drying depends on the morphological parts of a mushroom and the size of particles of insoluble fractions of suspensions fed into the spray dryer (Fig. 3).

Microstructural analysis of the powder obtained from the MS of a mushroom's whole fruiting body (Fig. 3a) has shown that the bulk of the particles is made up of rather large agglomerates (80–85% of the total mass) and particles of various shapes and sizes ($<15\%$). Agglomerates of various shapes range in size 20 μm to 120 μm , smaller agglomerates (15 – 30 μm) have shapes close to square or rectangular, with straight broken edges (Fig. 3a).

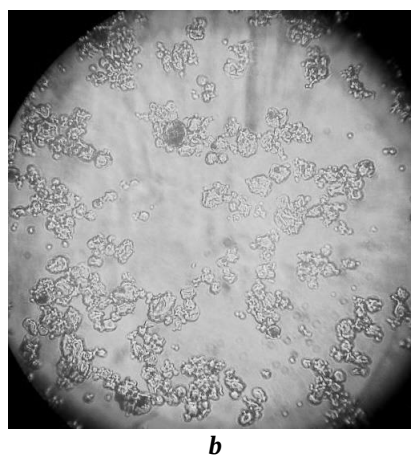
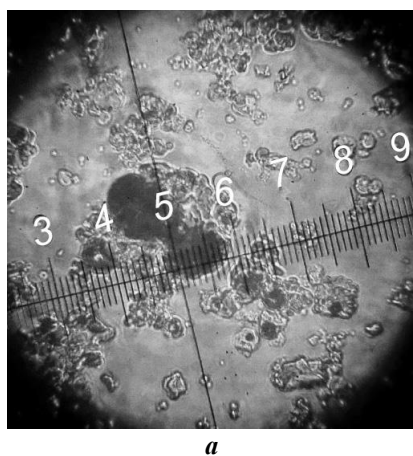


Fig. 3. Microstructure of the powder samples obtained on the experimental spray dryer ПЦ–1.3:

a) from the MS obtained from a whole fruiting body with the biopolymer additive; b) from the MS obtained from caps with the biopolymer additive. Scale: 1 division = 4 μm . Immersion medium: oil.

The powder sample obtained by drying the MS from the caps (Fig. 3b) significantly differed from the previous sample: there were almost no large agglomerates, and those in the field of view were 20–60 µm in size and made up no more than 20–25% of the total weight. The bulk of this powder sample (75–80%) consisted of round-shaped particles, 4–20 µm in size, with the even, solid, and smooth surface. The spherical shape of the particles resulted in the powder's better mechanostrength properties, helped its timely removal from the action of heat in the chamber, and increased its yield.

The effectiveness of applying DPEI mechanisms has been revealed when determining the content of a bioavailable pharmacologically active polysaccharide complex in the powder samples. To compare the amounts of the complex, a sample of fresh shiitake and two powder samples obtained by using the experimental spray dryer PIQ-1.3 have been studied (Table 1).

The research has shown that in Samples 2 and 3, the content of the bioavailable health-improving

polysaccharide complex increased significantly as compared with Sample 1. In the powder obtained from shiitake caps (Sample 3) on the experimental spray dryer PIQ-1.3 at the Institute of Engineering Thermophysics (National Academy of Sciences of Ukraine), the content of the bioavailable complex of water-soluble polysaccharides having oncostatic and immunoregulatory effects increased almost 6 times (Table 1). This result has been achieved due to the hydromechanical destruction of the polysaccharide structures of the chitin-glucan complex of shiitake. This destruction occurs under the action of DPEI mechanisms that provide high gradients of speeds, accelerations, decelerations, and pressure pulsations in the local zones of the thin channels of coaxial perforated cylinders and inter-cylinder clearances of RPA.

The results of these studies were based upon when developing the technology of a powdered dietary supplement from shiitake with an increased content of the bioavailable polysaccharide complex. The production of the dietary supplement has successfully passed pilot plant tests during manufacture of functional products and pharmaceuticals.

Table 1 – Content of the bioavailable health-improving polysaccharide complex in samples of fresh shiitake and powders obtained from it by spray drying

Content of bioavailable health-improving polysaccharide complex, g/100 g of total dry weight	Sample 1	Sample 2	Sample 3
	2.98	7.5	18.0

Conclusion

Physical and chemical studies have found that shiitake mushrooms have a unique composition and high nutritional and biological value. The dry matter content in the fresh fruiting body of this mushroom is 10–12% and depends on the growing conditions and the cultivar. It contains 18.76% of protein, 74.5% of carbohydrates, 1.01% of lipids, and 5.73% of ash on a dry basis.

The microstructure studies have shown that the MS obtained from the whole fruiting body of shiitake contains particles of insoluble fractions of different shapes and sizes, which randomly aggregate into spatial high-density associates up to 3–4 mm in size. It has been determined that in the MS, after DPEI treatment, the lengths of the hyphae from different parts of a shiitake fruiting body differ by tens and hundreds of times. The lengths of individual hyphae from the caps or their fragments range 10–15 µm, whereas those of hyphae from the stipes and their fragments were 50–5000 µm. So, it has been suggested to disperse high-strength

structural elements of mushrooms by DPEI treatment. The highest dispersity and uniformity of particles of insoluble fractions (up to 150 µm in size) have been achieved after three cycles of DPEI treatment of the MS obtained from mushroom caps.

Analysis of the microstructure of the powder obtained by drying a whole mushroom and its parts has shown the advantages of processing the caps. These samples are characterised by higher homogeneity. The bulk of the powder (75–80%) consists of 4–20-µm rounded particles with the even, continuous, and smooth surface. The powder obtained from caps shows no adhesive properties unlike that obtained from the whole fruiting bodies of the mushrooms.

It has been shown that using DPEI mechanisms increases the bioavailability of the polysaccharide complex. This method is the most effective when dispersing mushroom caps: the content of the bioavailable health-improving polysaccharide complex increases 6 times compared with that in the fresh fruiting body of the mushroom.

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РЕГУЛЮВАННЯ СТРУКТУРНО-МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ СУСПЕНЗІЇ ГРИБА ШІІТАКЕ ЯК ОБ'ЄКТА РОЗПИЛЮВАЛЬНОГО СУШІННЯ

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Анотація. Стаття присвячено вивченню можливості переробки плодового тіла базидіального гриба шіітаке в порошкову форму. Гриб є джерелом цінних поживних речовин, що містить 18.76% білка, 74.5% вуглеводів, 1% ліпідів та 5.73% золи сухої маси. Встановлено, що для отримання однорідної гомогенної грибною суспензії доцільне застосування механізмів дискретно-імпульсного введення енергії як ефективного інструменту впливу на високоміцні

структурні елементи гетерогенних систем різної природи. Виявлено необхідність зміни структурно-механічних властивостей грибною суспензії як об'єкту сушіння розпилюванням. Дослідження мікроструктури показали, що частинки нерозчинних фракцій гриба шиїтаке в суспензії, отриманої з цілого плодового тіла, хаотично збиваються в агреговані скупчення – просторові асоціації розміром до 3–4 мм, при цьому довжина окремих гіфів шапинок або їх фрагментів (10–15 мкм) значно менша за довжину гіфів ніжок (50–5000 мкм). В результаті трьох циклів обробки грибною суспензії з цілого гриба методом дискретно-імпульсного введення енергії середній розмір частинок зменшився в 2,3 рази. Така ж обробка грибною суспензії з шапинок дозволяє зменшити середні розміри частинок в 20 разів – до $\delta_{\max} \leq 100\text{--}150\text{ мкм}$. Мікроструктурний аналіз порошку, отриманого з цілого плодового тіла гриба, показав, що при загальному діапазоні розмірів часток 4–120 мкм переважна їх кількість (80–85%) представляє собою досить великі агрегати розміром 20–120 мкм. Порошок, отриманий із шапинок гриба, характеризувався меншим діапазоном розмірів часток (4–60 мкм) переважно округлої форми, 75–80% з яких складали частки 4–20 мкм. Це сприяло покращенню умов його висушування і підвищенню виходу з розпилювальної сушарки до 92% у порівнянні з виходом порошку з цілого гриба шиїтаке (менше 50%). Проведений комплекс досліджень показав доцільність отримання грибною суспензії з шапинок гриба шиїтаке. Показано, що використання механізмів дискретно-імпульсного введення енергії дозволяє підвищити вміст біодоступного лікувального полісахаридного комплексу в порошку з шапинок шиїтаке в 6 разів у порівнянні з цілим свіжим плодовим тілом гриба.

Ключові слова: гриб шиїтаке, дискретно-імпульсне введення енергії, диспергування, дисперсний склад, структурно-механічні властивості, розпилювальне сушіння.

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