ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 392
Ecological-Socio-Economic Systems: Models of Competition and Cooperation (ESES 2019)

Identification of Energy-Saving Methods of the *Hermetia illucens* Larvae Drying

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***Abstract*—The promising direction of using the black soldier fly larvae as a feed additive necessitated the use of drying to preserve their organoleptic characteristics and biological value. The following drying methods were investigated: convective drying, convective drying in the infrared field, drying in the microwave field, combined drying (convection in a vibrated bed with heating by a gas infrared generator). For a preliminary assessment of the drying parameters of the black soldier fly larvae, one-factor experiments on the drying kinetics were conducted. In the course of the experiments, the drying regimes and the rate of moisture evaporation were clarified. The moisture content of the dried material was measured over the entire drying period. The energy consumption for moisture evaporation was controlled. As a result, a rational energy-saving method for drying the black soldier fly larvae was revealed.**

Keywords—larvae of flies, black soldier fly, feed additive, drying, energy conservation.

I. Introduction

Nutrition remains the most important factor in a person's life, determining his health and well-being. The ecological and economic situation in the country and the world, as well as a steady increase in the global population and a stable decrease in the proportional ratio of the produced and consumed products, leads to a shortage of food raw materials. The development of the future food industry is aimed at using an unconventional raw material resource. This, in particular, is stated in the "Forecast of the scientific and technological development of the agro-industrial sector of the Russian Federation for the period until 2030" [1]. "Since the main source of feed for beef cattle breeding is potentially edible grain, higher meat consumption means increased pressure on ecosystems and less access to simple food for the general population". One of the promising areas of feed production is the use of dry biomass of the black soldier fly larvae and the possibility of further obtaining high-quality natural protein feed for livestock, poultry, aquaculture, etc. [2].

The advantages of dried feed additives are obvious: ease of use, time saving, the ability to choose the feed and its daily intake, taking into account the age, weight and physiological condition of the animal. However, major part of drying methods is characterized by high energy intensity of the process with varying degrees of preservation of the raw materials' properties.

The "Entoprotech" company is engaged in the industrial cultivation of the black soldier fly (Russian Federation Patent No. 2654220 dated 05/17/2018, positive conclusion of the state environmental review of technology is Order No. 227-7 dated 07/18/2018) in Russia. Having reached the level of daily production of 3 tons of live insect biomass with a moisture content of 70%, which must be reduced to 4-6%, "Entoprotech" faced a non-trivial technological problem, because most of the drying methods are characterized by high energy intensity of the process with varying degrees of preservation of properties of the raw material. "Entoprotech" specialists had experience in drying products in industrial vacuum microwave systems, infrared systems, as well as in traditional convection ovens. Energy costs for drying take up 45% of the cost of production of finished products in the form of feed additives. This joint study was organized to identify energy-saving methods for drying the larvae of *Hermetia illucens* flies.

II. Literature review

Black soldier fly (*Hermetia illucens*) is a widespread species of flies from the *Stratiomyidae* family. The adults of *Hermetia illucens* are from 15 to 20 mm long. Females are slightly larger than males. The body is completely black. Only legs and tarsi are white. The larvae are white or yellow with a yellow-brown head. Body length is up to 27 mm [3]. They develop in various decaying organic substances of plant and animal origin, including vegetables, fruits, compost, manure, etc. [4].

There are several main utilization options for the larvae:

- Processing of livestock waste, plant residues, substandard products, food waste – by living specimens in the larval stage.
- As a feed additive – alive, in the form of meal, protein concentrate and biologically active feed additives (Figure 1).

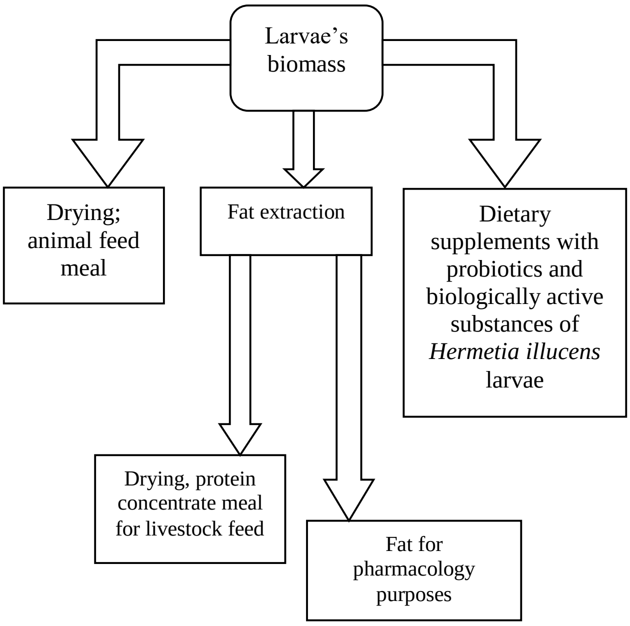

Fig. 1. Utilization of biomass of the black soldier fly larvae

However, this is not the whole range of larvae utilization. They are edible and are an excellent source of protein. There is the possibility of their targeted breeding [5].

Chemical composition of the dry larvae's biomass is presented in Table I.

TABLE I. CONTENT OF THE MAIN CHEMICALS IN THE *HERMETIA ILLUCENS* LARVAE (4)

Element	Quantity in %
Total protein	42.1 (56.9)*
Lipid	26.0
Calcium	7.56
Phosphorus	0.9
Ca/P	8.4

* in the defatted biomass

Table data confirms the possibility of using dry larvae as a protein source.

Currently, the study of the use of biomass of larvae is going on in various directions, in particular, as a new non-traditional high-protein raw material: addition of the black soldier fly meal to first grade wheat flour in order to improve the quality of bakery products [6].

An analysis of the sources of information on this issue showed the need to identify the most optimal methods of drying the biomass of larvae in order to determine the most energy-saving method with maximum preservation of the active properties of the raw materials [7-8].

In this regard, the existing drying technologies were investigated and rational modes determined.

III. RESEARCH METHODOLOGY

The following methods for drying the *Hermetia illucens* larvae were considered:

- convective drying;
- convective drying in the infrared field;
- drying in the microwave field;
- combined drying (convection in a vibrated bed with heating by a gas infrared generator).

Drying was carried out by a series of one-factor experiments in triplicate by two stages. At the first stage, preliminary measurements of the drying parameters (final humidity and energy consumption) were carried out in order to assess the prospects of using each drying method. The object of drying was live larvae. After a preliminary assessment, the results were specified in the second stage.

For a preliminary assessment of the drying parameters of the black soldier fly larvae, one-factor experiments of the drying kinetics were conducted. In the course of the experiments, the drying regimes and the rate of moisture evaporation were clarified. The moisture content of the dried material was measured over the entire drying period. The energy consumption for moisture evaporation was controlled.

IV. RESULTS

A. *Convective drying (drying cabinet).*

The larvae were placed in the cabinet and heated. Heating was carried out at 80 ... 120 °C.

It was revealed that the rate of moisture evaporation increases with increasing temperature of the cabinet, however, the possibility of irreversible overheating of the dried material also increases. Figure 2 shows the larvae's appearance after convective drying.

Fig. 2. Larvae's appearance after convective drying

B. *Convective drying in the infrared field.*

The larvae were placed in the cabinet and heated. Heating was performed at 80 ... .120 °C. It was revealed that the rate of moisture evaporation is higher than with standard convective drying.

Figure 3 shows the larvae's appearance after convective drying in the infrared field.

The larvae slightly swelled after the drying, they appeared fried, but not burnt.

Fig. 3. Larvae's appearance after convective drying in the infrared field

C. Drying in the microwave field.

The efficiency of microwave drying is higher; however, the energy consumption is increased, which is associated with the high power of the magnetron with a small mass of the processed product.

Figure 4 shows the larvae's appearance after processing in a microwave field.

The larvae swelled after the intensive processing in the microwave field; an air layer formed under the chitin shell, they appeared fried, but not burnt.

Fig. 4. Larvae's appearance after drying in a microwave field

D. Combined drying (convection in a vibrated bed with heating by a gas infrared generator).

A closed container with perforated walls is installed in the working chamber (a vertical pipe). It makes vertical vibrations. The oscillation frequency varies depending on the drying degree. At the bottom of the pipe there is a gas infrared generator.

The larvae had a dense structure after drying; they appeared fried, but not burnt.

Figure 5 shows the larvae's appearance after combined drying (convection in a vibrated bed with heating by a gas infrared generator).

Fig. 5. Larvae's appearance after combined drying (convection in a vibrated bed with heating by a gas infrared generator)

V. CONCLUSION

Convective drying of the black soldier fly larvae stands out in the smallest energy consumption. The removal of evaporated moisture from the cabinet was carried out by two fans, which created a directed air flow from the upper part of the working chamber to the lower. This is explained not only by the higher drying efficiency when creating mass transfer processes (convection), but also by the correct selection of the larvae's weight during drying for the power of the heating elements. At the cabinet air temperature in the range of 100 ... 105 °C, the drying passes efficiently to a humidity of at least 10 ... 11%. Then it is necessary to increase the temperature up to 120 °C in the drying zone.

Convective drying in the infrared field has the highest energy consumption. Drying kinetics is characterized by a relatively constant speed up to a moisture content of 8 ... 10%. Then a slight decrease in the drying rate occurs. However, the duration of the process is significantly higher than with microwave drying. This explains the significantly increased energy consumption. The larvae swelled slightly after the drying, their appearance was of a fried, but not burnt product.

Drying the black soldier fly larvae in the microwave field is one of the energy-efficient methods. However, the drying process has a low efficiency at the last stage, when drying with a moisture content of less than 10 ... 12%. The drying speed is significantly reduced and leads to an excessive consumption of energy when the humidity reaches 4 ... 6%. Energy consumption can be reduced by increasing the larvae's load weight. Nevertheless, it is necessary to provide an automatic system for the cyclic process of switching on magnetrons. In addition, the installation must provide shielded protection against electromagnetic radiation., The larvae swelled extremely after microwave heating; an air layer formed under the chitinous membrane, which increases the energy consumption during subsequent granulating or pressing.

Combined drying (convection in a vibrated bed with heating by a gas infrared generator) of the black soldier larvae allowed to obtain satisfying quality of the final product by its appearance. A large gas flow rate can be attributed to a small sample of the dried product. We can point out the economic feasibility of this method, due to the low gas cost, but the operation of gas equipment is associated with increased risks (fire or explosion). It is also more difficult to control the process, since the gas flow through the IR generator cannot be taken outside the limits set by the manufacturer. Therefore, the process temperature must be controlled by changing the distance between the product container and the burner. There are also restrictions on the location of the gas infrared generators. They can be located only under the drying product, since they most efficiently direct the heat only upwards.

VI. Acknowledgment

We express our gratitude for the provided materials and their experience for research by Entoprotech LLC.

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