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Processing of plant waste by black lionfly larvae (*Hermetia illucens* L.)

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Abstract. The issue of waste disposal of plant origin is a problem, the solution of which is currently an urgent task. The issue and problematic of excessive accumulation of waste is recognized by the vast majority of highly developed countries of the world. In order to overcome this problem, disposal mechanisms are permanently improved, procedures for their processing and biological cleaning and incineration technologies are introduced. A significant reason for the collection of a large amount of waste as a result of agricultural activity is the organization of their disposal at an insufficient level. As one of the options for solving this ecological situation can be the processing of organic waste with the help of larvae of the Black Lionfly (Hermetia illucens Linnaeus, 1758) (Diptera: Stratiomyidae). Thus, the purpose of this article is to study the processing of various agricultural wastes of plant origin using Black Lionfly larvae and to clarify the structure and sequence of technological processes of a biological-technological enterprise. The breeding process of the Black Lionfly on plant waste was studied, and the biological and technological parameters of the obtained biomaterial were determined. It has been proven that the Black Lion fly is highly effective for processing waste from agricultural production of plant origin. It has been proven that obtaining a highly viable culture of insects is possible under the conditions of feeding the larvae with wheat bran, cake, a mixture of watermelon + cantaloupe, non-standard zucchini, a mixture of potato + carrot + cabbage, non-standard; substandard bread cereals. The structure of a waste processing enterprise is proposed, which includes four stages: obtaining 1st instar larvae for waste processing; preparation of waste for processing by larvae; waste processing; final (receiving humus and larvae)

Keywords: biotechnology, black lioness, processing, plant waste

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INTRODUCTION

Processing of plant waste is an issue, the solution of which is an urgent task today. The problem of waste accumulation is recognized by most of the developed countries of the world. To overcome it, disposal methods are constantly being improved, procedures for their processing and biological cleaning and incineration technologies are being introduced. The main reason for the accumulation of a large amount of waste as a result of agricultural activity is the unsatisfactory organization of their disposal. The solution to this ecological problem can be the processing of organic waste with the help of larvae of the black lionfly (Hermetia illucens Linnaeus, 1758) (Diptera: Stratiomyidae). The purpose of this work is to study the processing of various agricultural wastes of plant origin with the help of black lionfly larvae and to substantiate the structure and sequence of technological processes of a biotechnological enterprise.

The accumulation of agricultural production waste leads to the deterioration of the ecological conditions of human existence and disrupts the homeostatic properties of ecosystems. It should be noted that due to global warming and the accumulation of greenhouse gases, incineration, as a traditional method of waste disposal, is considered a harmful process and is significantly limited in many countries. This encourages more and more attention to be paid to the possibility of using biological methods of waste processing.

In the post-Soviet space, a large amount of unused waste remains in the agro-industrial complex. A significant amount of waste goes to the landfill due to the lack of a modern technological base for processing secondary raw materials at most enterprises [1]. The problem of waste from the agro-industrial complex, which is not used, is characteristic of many countries [2]. The modern practice of handling plant waste involves either storing it in open areas or burning the harvest residues in the fields. Thus, significant losses of unused nutrients contained in waste occur every year [3].

In economically developed countries, considerable attention is paid to the processing of agro-industrial waste. For example, countries such as Germany, Japan, and Great Britain import secondary agricultural raw materials for further processing. The reason for this is the obsolescence of equipment in other countries and the lack of investment, despite the fact that the products of the processing of these wastes are exported from Germany. The solution to this problem can be the processing of organic waste with the help of larvae of the black lionfly (*H. illucens* L.) with the subsequent use of the larvae as a complete protein feed for animals, and the processed substrate as a fertilizer for crop production [4-10].

These insects belong to the few species of invertebrates capable of developing around the clock in a pure culture in a closed space under artificially created conditions of industrial production. Features of the development of insects allow their use for biotechnological purposes, which is one of the main advantages of this species [11].

H. Illucens thrives in a wide variety of decomposing waste, including rotting fruits and vegetables. The use of larvae of this species for the processing of organic waste is proposed by many authors as a promising and effective technology [12-16]. It is noted that the technology of removing organic residues using *H. illucens* is more effective than traditional composting technologies, and is based on the ability of fly larvae to destroy large masses of various organic wastes in the shortest possible time. Eating waste, *H. illucens* larvae reduce their weight by two or three times in a few days. The ecological benefit from the use of entomological technologies for processing food waste is unquestionable. Their implementation in the processing of food (and not only) waste will make it possible to significantly reduce storage and huge deposits of unprocessed raw materials.

Examples of companies in the world that already use *H. illusens* are Hermetia Baruth GmbH (Germany), Agri Protein Technologies (South Africa) and Corporation Enterra Feed (Canada) [17]. The Environmental Technology and Engineering Corporation (Environmental Technology and Engineering Corporation) has invented a biotransformer of *H. illucens* larvae for home use. In 2007, the Institute of Entomology of Guangdong Province (China) developed a bioconversion system for effective large-scale processing of organic waste. The system has achieved satisfactory reduction, disinfection and recycling of waste [18]. In Southern Italy, there is an experimental facility where processing 10 tons of household waste allows you to get 300 kg of dried larvae and 3346 kg of compost. The productivity of the enterprise can reach 30 tons of waste per day [19]. There are currently no similar productions in Ukraine, which prompts us to conduct research and develop technological schemes for enterprises processing agricultural waste using fly larvae of the above species.

The aim of the work is to establish the possibility of processing plant-derived waste from the food industry and agricultural production by larvae of the *H. illucens* fly. Determine the technological parameters of waste processing, the structure of the enterprise and the sequence of processing processes and operations.

MATERIALS AND METHODS

An artificial population of *H. illucens,* which is maintained at the Center for Insect Maternal Cultures of the ITI "Biotechnique" of the National Academy of Sciences of Ukraine, was used for the research. During the life cycle, the fly goes through four stages: egg, larva, pupa and imago [20]. Fly larvae are pale yellow in color (Fig. 1).

Figure 1. *Larvae of H. illucens of the 3rd instar. Source: Photo by O.D. Molchanova*

Larvae usually grow to 18-20 mm [21]. It is noted that in the last age group they can reach a size of 27 mm [19]. Pre-pupae change their color from whitish-yellow to dark brown [22; 23]. Adult individuals of *H. illucens* reach sizes from 15 to 20 mm. Having a fat body formed at the larval stage, imagos have no need for food, therefore the licking oral apparatus is weakly expressed (Fig. 2) and suitable only for water consumption. There are no digestive organs, which makes it impossible to eat food directly.

Figure 2. *Imago H. illucens*

Source: *Photo by O.D. Molchanova*

Experiments were conducted in an insect box under hygrothermal conditions optimal for the species – air temperature +25-27°C, relative humidity 55-65% according to standard methods of working with insects [24-26]. There are three repetitions in each version.

The experiment was carried out with different variants of the nutrient substrate for growing larvae:

1. Control of the growth of larvae on wheat bran.
2. Growing larvae on potato pulp.
3. Growing larvae on oil production waste (cake).
4. Cultivation of larvae on mushroom production waste.
5. Cultivation of larvae on grape pomace.
6. Growing larvae on sugar beet pulp.
7. Growing larvae on apple pulp.
8. Growing larvae on vegetable residues.
9. Larvae rearing on substandard mulberry fruits.
10. Larvae rearing on substandard plum fruits.
11. Cultivation of larvae on substandard grapes.
12. Rearing of larvae on fallen corn cobs.
13. Growing larvae on dry corn stalks.
14. Rearing larvae on a mixture of watermelon and cantaloupe.
15. Growing larvae on substandard zucchini.
16. Rearing larvae on a mixture of potatoes, carrots, and substandard cabbage.
17. Growing larvae on potato tops.
18. Growing larvae on cucumber tops.
19. Cultivation of larvae on substandard bread cereals.

20. Growing larvae on wheat straw.
21. Growing larvae on barley straw.
22. Larvae rearing on sunflower stems, leaves, baskets.

It is known that the ovipositors of flies are open, the eggs are soft, attached to the substrate and glued together by the secretions of the gonads, it is difficult to extract individual eggs without damage, therefore, the selection of material for experiments was carried out at the larval stage of the first instar.

Larvae usually grow to 18-20 mm [21]. It is noted that in the last age group they can reach a size of 27 mm [19]. Pre-pupae change their color from whitish-yellow to dark brown [22, 23].

Adult individuals of *H. illucens* reach sizes from 15 to 20 mm. Having a fat body formed at the larval stage, imagos have no need for food, therefore the licking oral apparatus is weakly expressed (Fig. 2) and suitable only for water consumption. There are no digestive organs, which makes it impossible to eat food directly.

Different types of plant waste were placed in cages measuring 127×95×100 mm with 200 g of waste in each variant. The food substrate had a soft, moist consistency. For this, a small amount of water was added to the waste as needed and thoroughly mixed. 500 larvae were added to each garden with medium.

When the larvae ate the substrate, new feed was added, which was pre-weighed. The feeding time was determined visually by the appearance of the environment, or by the state of the larvae, which climbed to the surface of the substrate in search of food.

During the experiment, the following indicators were determined: average weight of larvae of one age group (mg); average weight of pupae (mg); viability of larvae (%); duration of development from the egg stage to the prepupa stage (days).

The average weight of larvae in all variants of the experiment was determined as the arithmetic mean of the weight of 30 individuals weighed in triplicate.

To collect prepupae, cages with larvae were placed in trays measuring 150×130×50 mm. 30 prepupae were selected and the average weight was determined. During the research, the period of transformation of larvae into pre-pupae was fixed, and the number of pre-pupae obtained was counted. The viability of larvae was determined as the ratio of the number of prepupae to the number of larvae introduced into the substrate, expressed as a percentage.

RESULTS AND DISCUSSION

The process of growing flies on twenty-two types of vegetable waste was studied, using wheat bran as a control.

It was established that on mushroom waste, sugar beet pulp, corn straw (wheat and barley) fly development practically did not occur, only single specimens of first-instar larvae were recorded (Table 1). Also, rather low indicators of viability were observed when growing larvae on potato and cucumber tops – 21 and 23%, respectively, dry corn stalks – 28% and collapsed corn cobs – 35%. Significantly high ($p<0.001$) viability was observed in the options of feeding with wheat bran 96%, cake 84%, watermelon + melon mixture non-standard 95%, zucchini non-standard 92%, potato + carrot + cabbage mixture non-standard 91%; non-standard bread cereals 84%. In other variants, the viability ranged from 50 to 80%.

Significantly higher ($p<0.01$) in relation to other options was noted the average weight of larvae and pupae when grown on bran media; vegetable trimmings and peelings; mixtures of watermelon + cantaloupe; potatoes + carrots + cabbage substandard; substandard bread cereals; sunflower stems, leaves and baskets (Table 1)

Table 1. *Biological indicators of H. illucens when grown on plant waste*

The composition of the nutrient substrate	Average weight, mg		Larvae viability, %	Duration of development, up to the pre-pupa stage±2
	Older larvae	Larva		
Bran (control)	270±1.5**	160±0.14	96±3.8*	30
Potato mash	170±1.3	110±0.11	71±1.8	51
Makuha	175±1.2	150±0.12	84±3.0*	38
Mushroom waste	-	-	-	-
Grape pulp	90±3.2	65±0.11	78±2.1	37
Sugar beet pulp	-	-	-	-
Apple jam	130±2.1	93±0.12	58±1.1	44
Vegetable trimming and cleaning	230±2.4**	210±0.52	76±2.0	41
Mulberry fruits (non-standard)	100±1.2	60±0.14	49±1.4	54

Table 1, Continued

The composition of the nutrient substrate	Average weight, mg		Larvae viability, %	Duration of development, up to the pre-pupa stage±2
	Older larvae	Larva		
Plum fruits (non-standard)	110±1.5	70±0.12	83±2.7	71
Grapes (unconditioned)	120±2.3	70±0.11	71±1.7	47
Corn cobs (collapsed)	100±1.1	63±0.13	35±1.2	-
Corn stalks (dry)	60±2.1	40±0.11	28±1.0	53
Watermelon + melon (unconditioned)	210±5.2**	180±0.14	95±3.7*	-
Zucchini (unconditioned)	160±1.4	90±0.12	92±3.4*	60
Potatoes + carrots + cabbage (non-standard)	150±2.3**	100±0.12	91±3.0*	55
Potato tops	90±1.7	60±0.11	21±0.6	-
Top of cucumbers	50±1.6	290±0.17	23±0.7	-
Bread cereals (non-standard)	300±1.9**	220±0.15	84±2.8*	35
Wheat straw	50±1.7	30±0.15	-	-
Barley straw	-	-	-	-
Stems, leaves, sunflower heads	120±1.2**	110±0.11	7±0.2	-

Note: **p<0.001 in relation to variants with low viability; **p<0.01 in relation to other options*

Based on the results of research, it was established that the term of development of the black lionfly on agricultural waste of plant origin of different types is different. In control, when cultivated on wheat bran, it lasted 30 days. At the same time, it was more than 5 days on non-standard bread cereals. A relatively short period of development was observed when using grape pulp and cake – 37 and 38 days, respectively. The longest period was observed when grown on substandard fruit (plum) – 71 days. Establishing the causes of this phenomenon requires further research. It can definitely be stated that the different nutritional value of the substrate determines the differences in the biological indicators of the insect culture.

We have established the effectiveness of using the black lionfly for the processing of various types of agricultural waste of plant origin, but it is necessary to take into account the different duration of the processing process for each type of waste. Such technology can be used in the creation of enterprises for the processing of vegetable waste in Ukraine.

The analysis of the situation in the world showed that the commercial products of the waste processing enterprise, depending on the demand, can be: larvae; fly pupae; biohumus The enterprise must be equipped with special equipment for crushing and processing of waste, qualified personnel, have a convenient infrastructure for transporting waste and delivering the products of their processing to consumers. We proposed the structure of such an enterprise (Fig. 3).

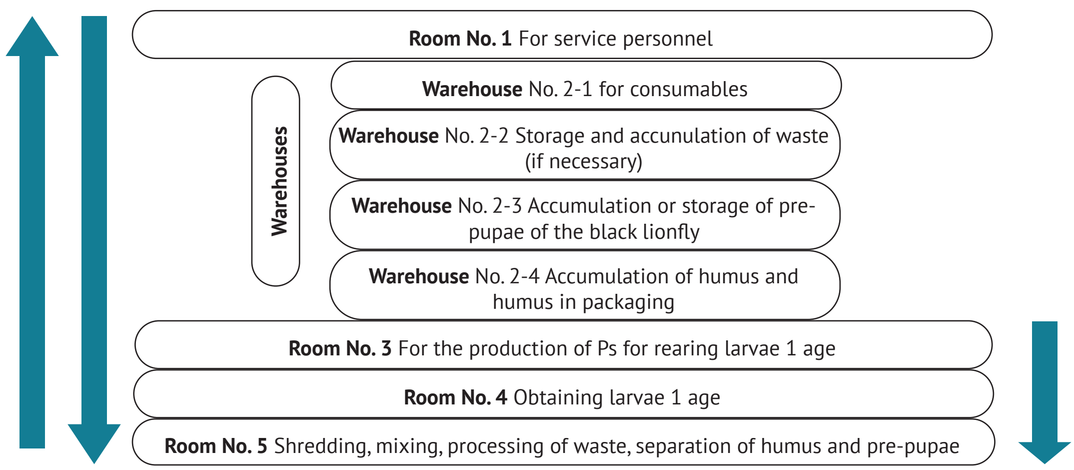

Figure 3. *Structure of a waste processing enterprise*

When organizing waste processing, it is necessary to have five main rooms and storage rooms for consumables, storage and accumulation of waste (if necessary), accumulation or storage of pre-pupae, accumulation and packaging of humus. The main premises are used for service personnel; production of nutrient medium for growing larvae of the first age; obtaining larvae of the first age; grinding, mixing, waste processing, separation of humus and pre-pupae; product formation, marking. In the process of processing waste, it is necessary to create optimal hydro-thermal conditions for keeping larvae, which will contribute to a faster process of their transformation into useful products that can be used later. The technological parameters of the waste processing process using black lionfish larvae are shown in the table (Table 2).

Table 2. *Technological parameters of the waste processing process using H larvae.illucens*

Technological process	Food substrate	Air temperature in the insect holding area, °C	Relative air humidity in the holding area, %	Air aeration in the holding area	Lighting in the holding area
Incubation of eggs, obtaining larvae of the first age	Wheat bran + boiling water Additional hydration	25-26	60	According to the order of the MHU No. 254A dated 20/09/1997, 0.2-0.7 m/s	Not obligatory
Waste processing (larvae rearing)	Waste of vegetable origin or their mixtures Additional hydration	22-24	65	According to the order of the MHU No. 254A dated 20/09/1997, 0.2-0.7 m/s	Not obligatory
Removal of prepupae from the substrate	-	22-24	65	According to the order of the MHU No. 254A dated 20/09/1997, 0.2-0.7 m/s	Not obligatory
Preparation of the substrate for packaging	-	-	45-60	According to the order of the MHU No. 254A dated 20/09/1997, 0.2-0.7 m/s	-

The technological process of waste processing can be divided into four stages: obtaining larvae of the first age for waste processing; preparation of waste for processing by larvae; waste processing; obtaining humus and larvae (Fig. 4).

Obtaining larvae of the first age. At this stage, the following operations are carried out: production of nutrient medium for growing larvae of the first age; placement of eggs in the device for incubation; incubation of eggs; settlement of the nutrient medium by larvae that have just hatched from the eggs.

After two or three days, larvae hatch from the eggs, and they are settled in the PS. After seventy days, the young larvae are ready for settlement in the tank for processing waste.

Preparation of waste for processing. After the waste is delivered to the enterprise, it is sorted. Solid and large fractions of waste are crushed with the help of a feed grinder. The fodder shredder is positioned so that the crushed waste enters the hopper of the screw conveyor. The screw conveyor is designed to move shredded waste into tanks for processing.

Waste processing. The tank for processing waste has dimensions of 2.0×3.0×0.3 m and is placed on a bed, its internal volume is 1.8 m^3, the working volume in which the substrate with larvae is located is 0.9 m^3. In a tank with waste or a mixture of waste, add a food substrate with larvae of the 1st instar black lionfish. The required quantity is determined according to the mass of waste being processed and its composition.

In the process of feeding the larvae, the surface of the tank with the nutrient medium and the growing larvae is covered with shutters of the roller type to create darkness and preserve humidity. The processing plant must be equipped with a sprinkler system and a water tank.

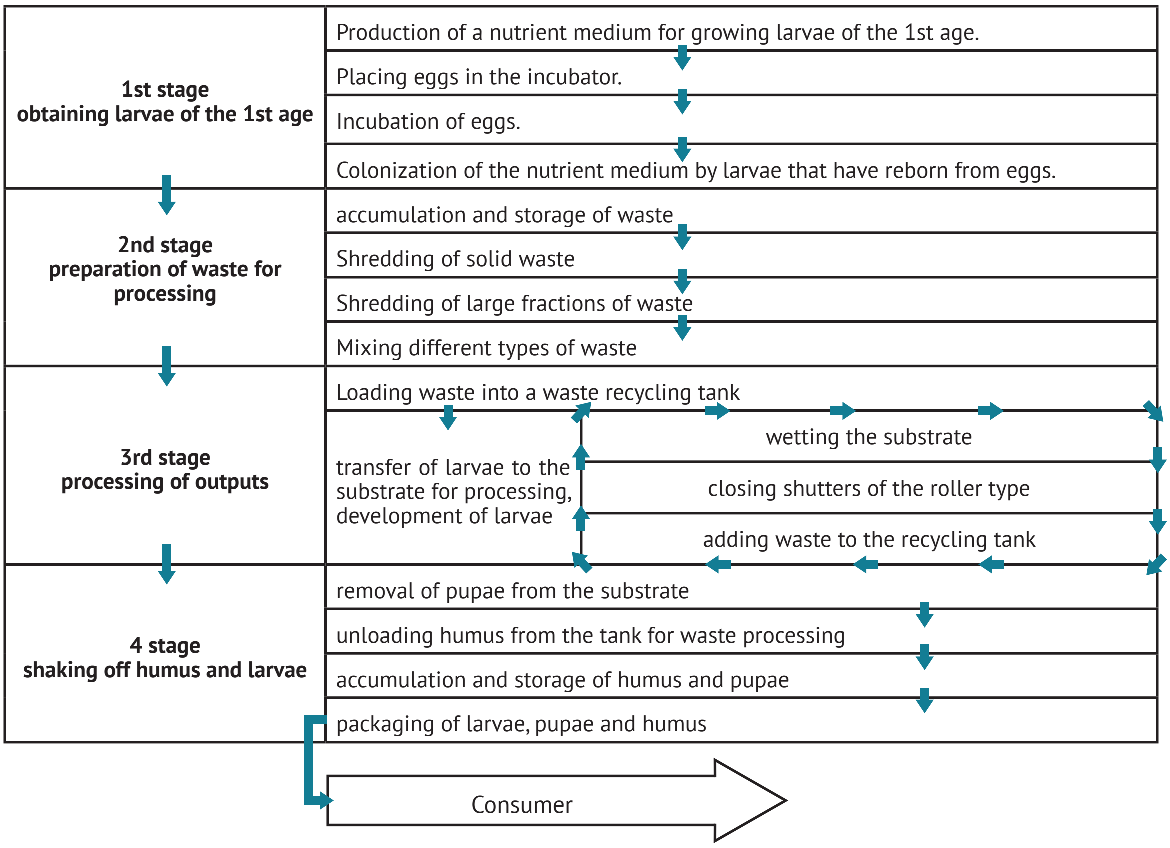

Figure 4. *Scheme of waste processing using H. illucens larvae*

Obtaining humus and pre-pupae

The fourth stage is final. After the end of processing, which lasts 30-55 days depending on the composition of the waste and the conditions of keeping, the pupae are removed from the substrate. The processed substrate is dried and packed. Larvae and pupae, depending on demand, are sold alive or dried and processed into flour.

CONCLUSIONS

1. The effectiveness of the use of the black lionfish fly for the processing of various agricultural wastes of plant origin has been proven.

2. Significantly higher ($p<0.01$) indicators of the average weight of larvae and pupae when grown on bran media were noted compared to other options; vegetable trimmings and peelings; mixtures of watermelon + cantaloupe; mixtures of potatoes + carrots + cabbage are not conditioned; substandard bread cereals; sunflower stems, leaves and baskets.

3. The influence of the nutrient substrate on the duration of larval development was established. Feeding on wheat bran lasted 30 days, on unconditioned bread cereals for 5 days longer. A relatively short period of development was observed when using grape pulp and cake – 37 and 38 days, respectively. The longest development period was recorded when the larvae were grown on substandard fruit (plum) – 71 days. The need to take into account the dependence of larval development rates on the type of nutrient medium is shown.

4. The scheme of the waste processing enterprise was developed, which includes four stages: obtaining larvae of the first age for waste processing; preparation of waste for processing by larvae; waste processing; obtaining humus and larvae.

5. By-products of waste processing are fly larvae and pupae and biohumus.

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Переробка відходів рослинного походження личинками мухи чорна львинка (*Hermetia illucens* L.)

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Анотація. Досліджено процес розведення мухи чорна львинка на відходах рослинного походження, визначено біологічні та технологічні показники отриманого біоматеріалу. Доведено, що отримання високожиттєздатної культури комах можливе за умов годування личинок пшеничними висівками, макухою, сумішшю кавун + диня некондиційні, кабачками некондиційними, сумішшю картопля + морква + капуста некондиційні; злаками хлібними некондиційними. Запропоновано структуру підприємства з переробки відходів, що включає чотири етапи: отримання личинок 1-го віку для переробки відходів; підготовка відходів для переробки личинками; переробка відходів; завершальний (отримання гумусу та личинок)

Ключові слова: біотехнологія, чорна львинка, переробка, відходи рослинного походження