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INFLUENCE OF DRYING AND PRETREATMENT METHODS ON CERTAIN PARAMETERS OF YELLOW MEALWORM LARVAE (*TENEBRIO MOLITOR*)

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Abstract

Nowadays alternative protein sources like edible insects are becoming widely used as human food. One of the most popular insect is yellow mealworm (Tenebrio molitor) due to its high nutrition value. However, pretreatment and drying are necessary to increase the food shelf life and the efficiency of its use. Due to this, the purpose of the present work was the determination of influence of pretreatment methods (freezing of larvae for 1 month, freezing for 2 hours, freezing for 1 month followed by defrosting for 2 hours at room temperature, blanching) and drying methods (convection drying at 40 °C and 60 °C, microwave drying) of yellow mealworm on its color (determination of L, a*, b*, ΔE_{lab}, Ch, H, BI), moisture content (gravimetric method), fatty acid composition (determined by gas chromatography with mass spectroscopy) and time of drying (time required to reach constant weight). It was found that all used pretreatment and drying methods had no effect on the fatty acid composition of the larvae. In terms of drying rate and color retention, microwave drying showed better results than convection drying at 40 °C and 60 °C. Meanwhile, convection drying at 40 °C leads to the higher final moisture content of the samples. Among the pretreatment methods, only blanching the larvae samples before drying retained their color better and also accelerated the rate of the convection drying.*

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Introduction

By 2050 the world's population may reach 9–11 billion people. It will lead to an increase in food production by 70% due to necessity of providing an adequate supply of food for the population [1]. Meanwhile, food industry itself has a significant impact on the environment [2–5]. In particular, animal husbandry contributes to greenhouse gas emissions, soil acidification, nitrification and soil erosion [6]. Moreover, water expenses in the agricultural sector are about 70% of total consumption [7], and 1/3 of this volume is used for raising animals [8].

Edible insects, which variety accounts for more than 2,000 species, can potentially be used for partial replacement of meat in the human diet, as well as a feed additive for farm animals [9]. Currently in the world, insects are regularly consumed by about two billion people [10]. The cultivation of insects has a lower environmental impact, in comparison with the cultivation of cattle, pigs and poultry, since this type of cultivation requires less feed, soil and water [11]. Moreover, the high nutritional value of insects and easiness of their breeding led to the intensive development of the insects-producing industry and insect-based food products manufacture even in European countries [12–14]. In [9,15] the edible insects are characterized as one of the food sources that are able to cover the growing need for food and can prevent world famine. In the countries where human entomophagy is a tradition, the insects are considered to be culinary delight and a valuable source of protein [14].

The yellow mealworm (*Tenebrio molitor*) is one of the most common edible insect species. Currently, yellow mealworm is already approved as a novel food in the European Union [16]. Experts from the European Food Safety Authority have acknowledged it to be safe as an ingredient in biscuits, snacks, snack bars and pasta [17]. According to scientific literature data, the taste of the yellow mealworm resembles the taste of nuts, umami and cereals [18,19]. In the other research, its taste is described as savory, similar to the taste of dried shrimp [17]. Yellow mealworm contains approximately 46 wt.%. protein and 33 wt.%. fat, the main fatty acids

are linoleic, oleic and palmitic ones [20]. *Tenebrio molitor* contains essential amino acids, polyunsaturated fatty acids, minerals and vitamins [11, 21–23]. In addition, the edible fraction of the yellow mealworm accounts for almost 100%, which significantly exceeds the edible fraction in chickens and pigs (55%) and cattle (40%) [17].

Killing and drying are among the main stages of insect processing that affect the quality of the final product and its shelf life [24]. Killing method influences significantly on the physical and chemical parameters and microbiota of insects [25]. Among the methods tested, it was shown that longer time of killing can cause stress, which contributes to acceleration of oxidative processes in insects, including the breakdown of triglycerides into fatty acids and acylglycerol [26]. In this regard the most humane methods of killing insects are freezing and blanching [27,28].

Meanwhile, the larvae contain a lot of water (59–68 wt.%) [29,30], which makes them vulnerable to lipid oxidation, enzymatic, non-enzymatic reactions and microbiological deterioration. In fact, when the optimum level of moisture content is reached, the rates of oxidation reactions and microbiological contamination are reduced to minimum, thus the shelf life of the product increases [31]. Based on this, reducing the moisture content of biomass is an important condition for maintaining the proper quality of the food product. Moreover, drying significantly decreases the mass of insects, which helps to reduce the cost of transportation and storage.

Dehydration can be achieved using various methods such as freeze drying, convection, infrared, vacuum and microwave drying [32]. In addition to the type of drying, the quality of the final product is influenced by the drying parameters, which can vary over a wide range. Thus, manufacturers encounter the challenge of finding the appropriate drying technologies to preserve the quality characteristics of insects for a long time [30]. One of the most efficient methods of drying is freeze drying [24]. In this case, the frozen product is dehydrated as a result of the sublimation of moisture under vacuum. The freeze-dried products almost completely retain their original characteristics due to the low temperature and lack of oxygen during the drying process. However, freeze drying takes a long time, which implies high capital expenses and energy costs. Based on this, it is relevant to study more affordable and faster drying methods, for example — convection drying and microwave drying.

The research [32] represents the results of the comparison of the samples colors obtained in case of applying various drying methods. The samples dried by convection drying have dark color, which can be described as brownish, contrasting with the golden color. At the same time, the degree of the color change did not depend on the drying temperature from 60 °C to 80 °C. [33]. Browning produces consumers' negative perception of the food appearance, although the brown pigments, formed during drying, do not affect the sensory characteristics of the final product. The authors reported the efficiency of blanching before drying the larvae of *Tenebrio molitor* to preserve their color, due to the fact that during the temperature treatment, the activity of enzymes leading to the browning of the biomass is reduced [34]. In [29], yellow mealworm larvae, previously killed by freezing, were dried by various methods like freeze drying, fluid bed drying, vacuum drying, convection and microwave drying. The results of the study showed that vacuum and microwave drying can be an alternative to freeze-drying of mealworms. However, currently there are no data on the influence of pretreatment methods (freezing, blanching) on the quality characteristics of mealworm dried by convection drying or microwave drying. Based on this, the aim of the work was to determine the effect of the pretreatment methods (freezing for 2 months, freezing for 2 hours, freezing for 2 months, followed by defrosting at room temperature for 2 hours, blanching) and drying (convection drying at 40 °C and 60 °C, microwave drying) on moisture content, drying rate, fatty acid composition, appearance and color of the mealworm larvae.

Objects and methods

The larvae of the yellow mealworm at the age of two months were used for the study. The insects were taken from the breeding stock of the yellow mealworm (*Tenebrio molitor*) of the Laboratory for the Structural Processing of Bioresources of the All-Russian Research Institute for Food Additives.

Determination of humidity

The water content of the larvae samples (moisture) was determined in accordance with the procedure described in AOAC950.46 [35]: the larvae sample with known weight was dried in the convection oven at 105 °C to constant weight, then the dry residue was weighed on an analytical balance GR-200 (AND, Japan, measurement range 0.01–210 g, resolution 0.1 mg), and the moisture was calculated using the following equation (1):

$$W = \frac{m_0 - m_{dry}}{m_0} \times 100\% \quad (1)$$

where:

W — moisture of the sample, %;

m_0 — sample weight before drying, g;

m_{dry} — sample weight after drying at 105 °C for 8 hours, g.

The moisture of each sample was measured three times, then the average value was calculated and the confidence interval was estimated at a significance level of 0.05. Calculations were carried out using the software Microsoft Excel 2016 (Microsoft Office, US).

Processing and drying methods

As a pretreatment stage, yellow mealworm larvae were killed by freezing (2 hours or 30 days, –20 °C) or blanching (20 seconds, 100 °C). Moreover, some of the frozen insects

were defrosted at room temperature for 2 hours before drying. Then, each of the samples was dried to a constant weight using three following ways:

- CD 40 °C — convection drying in the drying oven UF110plus (Memmert, Germany) at 40 °C;
- CD 60 °C — convection drying in the drying oven at 60 °C;
- MW — microwave drying in the UOMO-T150 microwave system (Omitex, Russia) at the frequency of 2450 MHz.

The following terms are introduced in the research:

1) Blanched — larvae processed in boiling water for 20 seconds;
2) Frozen (2 hours) — larvae frozen at –20 °C for 2 hours;
3) Frozen (1 month) — larvae frozen at –20 °C with a shelf life of 1 month;
4) Defrosted — Frozen (1 month) larval samples kept at room temperature for two hours before analysis.

During the drying insect samples were periodically weighed to assess the rate of moisture removal. The moisture of the larvae at different times was determined based on the data on moisture of the larvae at the end of the experiment and the change in the sample weight during drying.

The drying rate of insect samples was calculated using equation (2) given in [31]:

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (2)$$

where:

DR — drying rate, 1/h;
M_t — moisture content at the time t;
$M_{t+\Delta t}$ — moisture content at the time $t + \Delta t$;
Δt — considered time interval, h.

Moisture content M_t was defined by the following equation (3) [36]:

$$M_t = \frac{m_t - m_{dry}}{m_{dry}} \times 100\% \quad (3)$$

where:

m_t — sample weight at the time t, g;
m_{dry} — sample weight after drying for 8 hours at 105 °C, g.

Analysis of the fatty acid composition of insects

The fatty acid composition was determined by gas chromatography with mass spectrometric detection with the gas chromatographic analyzer Varian 450-GC (Varian, USA) with the mass spectrometric detector Varian 240-MS. The following materials and equipment were used: capillary column Varian WCOT fused silica 50M X 0.25MM ID Coating CP-WAX 58 (FFAP)-CB DF=0.2 (Varian, USA); thermostat Termit (DNA-Technology, Russia); helium (grade 6.0), sulfuric acid (≥ 95,6%, JSC «Shchekinoazot», Russia); methanol (HPLC gradient grade CHIMMED, Russia); chloroform (≥99,8%, EKOS-1, Russia); deionized water; fatty acid methyl ester standards (18919 1AMP Supelco F. A.M.E. Mix, C4-C24, USA): butyric acid (C4:0); caproic acid (C6:0); caprylic acid (C8:0); capric acid (C10:0); undecanoic acid (C11:0); lauric acid (C12:0); tridecanoic acid (C13:0); myristic acid (C14:0); myristoleic acid (C14:1); pentadecanoic acid (C15:0); cis-10-pentadecenoic acid (C15:1); palmitic acid (C16:0); palmitoleic acid (C16:1); heptadecanoic acid (C17:0); cis-10-heptadecenoic acid (C17:1); stearic acid (C18:0); elaidic acid (C18:1ω9t); oleic acid (C18:1ω9c); linoleic acid (C18:2ω6t); linoleic acid (C18:2ω6c); arachidic acid (C20:0); gamolenic acid (C18:3ω6); cis-gondoic acid (C20:1); linolenic acid (C18:3ω3); heneicosylic acid (C21:0); cis-11,14-eicosadienoic acid (C20:2); behenic acid (C22:0); dihomo-γ-linolenic acid (C20:3ω6); erucic acid (C22:1ω9); cis-11,14,17-eicosatrienoic acid (C20:3ω3); tricosanoic acid (C23:0); methyl cis-5,8,11,14-eicosatetraenoic acid (C20:4ω6); cis-13,16-docosadienoic acid (C22:2); lignoceric acid (C24:0); cis-5,8,11,14,17-eicosapentaenoic acid (C20:5ω3); nervonic acid (C24:1); cis-4,7,10,13,16,19-docosahexaenoic acid (C22:6ω3).

Analysis conditions were as follows: the flow rate of carrier gas was 1 ml/min, injector temperature 250 °C, split 1:15, start of chromatogram registration: from the 9th minute. The temperature program is presented in the Table 1.

Table 1. Temperature program of the analysis

Temperature, °C	Heating rate, °C/min	Time at a given temperature, min	Total time, min
50	—	4	4
190	6	15	42,33
250	4	10	67,33

Sample preparation: 600 µl of the 15% solution of sulfuric acid in methanol and 600 µl of chloroform were added to microtube (Eppendorf, Germany) with the sample. The microtube was carefully sealed with parafilm and placed in the thermostat for 1 hour at 65 °C. Then the sample was cooled, 200 µl of deionized water was added and thoroughly stirred. After that the organic layer was taken and 1 µl of it was directly injected into the chromatograph using the CPAL autosampler and the 10 µl Hamilton chromatographic syringe. The measurement error was 15%.

Analysis of color characteristics

The color of the yellow mealworm larvae was determined in accordance with the method described in [37]. L^* (whiteness or lightness/darkness), a^* (redness/greenness), b^* (yellowness/blueness) values were determined using Adobe Photoshop CS6 software. Samples photos were taken using the iPhone 11 smartphone in daylight (6500 K).

The parameter ΔE_{lab} (total color difference) was determined according to the following equation (4) [33]:

$$\Delta E_{lab} = \sqrt{(L^* - L_1^*)^2 + (a^* - a_1^*)^2 + (b^* - b_1^*)^2} \quad (4)$$

where:

L^* — lightness of untreated live larvae;
L_1^* — lightness of treated larvae;
a^* — redness/greenness of untreated live larvae;
a_1^* — redness/greenness of treated larvae;
b^* — yellowness/blueness of untreated live larvae;
b_1^* — yellowness/blueness of treated larvae.

Chroma (*Ch*) was determined according to the equation (5) [38]:

$$Ch = (a^{*2} + b^{*2})^{\frac{1}{2}} \quad (5)$$

Hue angle (*H*) was determined according to the equation (6):

$$H = \text{tg}^{-1}\left(\frac{b^*}{a^*}\right) \quad (6)$$

Browning index (*BI*) was determined according to the equations (7) and (8):

$$BI = \frac{100 \cdot (x - 0.31)}{0.17} \quad (7)$$

$$x = \frac{(a^* + 1.75L^*)}{(5.654L^* + a^* - 3.012b^*)} \quad (8)$$

The L^*, a^*, b^* values were determined at 6 different points, selected at random on each sample image. The image of untreated larvae was used as a control reference. The final values L^*, a^*, b^* were the average of 6 values. Next, the standard deviation and confidence interval were calculated with a confidence level of 0.95. All calculations were carried out using the software Microsoft Excel 2016 (Microsoft Office, US).

Results and discussion

Samples drying

The water content of the larval samples before and after drying is presented in Table 2. The final moisture values obtained were similar for all samples, slightly higher values were observed in case of insects dried in the convection oven at 40 °C.

Table 2. Moisture of the *Tenebrio molitor* larvae samples

Sample	Drying method	*W* before drying, %	*W* after drying, %
Blanched	MW	63.2 ± 4.0	4.0 ± 0.6
	CD 40 °C		4.8 ± 0.7
	CD 60 °C		4.0 ± 0.6
Frozen (2 hours)	MW	58.8 ± 12.5	3.5 ± 0.5
	CD 40 °C		8.8 ± 1.2
	CD 60 °C		3.7 ± 0.5
Frozen (1 month)	MW	60.3 ± 10.0	3.3 ± 0.5
	CD 40 °C		6.5 ± 0.9
	CD 60 °C		4.4 ± 0.6
Defrosted	MW	60.8 ± 8.0	4.6 ± 0.6
	CD 40 °C		7.7 ± 1.1
	CD 60 °C		5.6 ± 0.8

Data on the change in larvae samples moisture during microwave drying are presented in Figure 1. The dependences obtained for insects pretreated in various ways were similar. The difference was observed for Frozen (1 month) larvae, however, this was most likely caused by different drying mode: drying of Frozen (1 month) larvae was carried out in short-term (1–2 min) periods between which the sample was weighed and cooled, while in the other cases there was an initial long drying period (10–12 min), after which the moisture of the sample was already below 30 wt.%.

According to the literature data [39], during the microwave drying after the evaporation of the main amount of water, the moisture of dried samples becomes approximately constant and does not change even during prolonged drying. This fact proves the inexpediency of prolonged microwave drying.

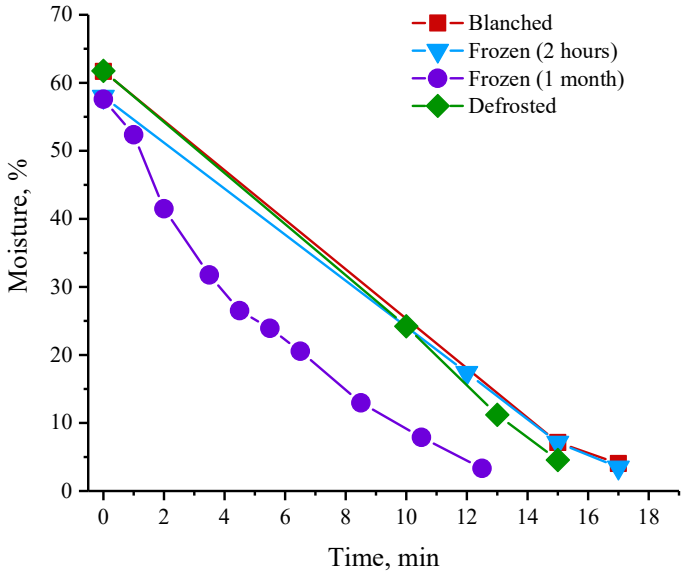

Figure 1. The change of the *Tenebrio molitor* larvae samples moisture during microwave drying

Figures 2 and 3 show the change in moisture of samples during convective drying at 40 °C and 60 °C, respectively. In case of the microwave drying of the *Tenebrio molitor* larvae, the moisture of about 7 wt.% was achieved in 14 minutes on average (Figure 1), while in case of the convective drying at 60 °C the same values were achieved in 19 hours (Figure 3), and with the convective drying at 40 °C — in 72 hours (Figure 2). Thus, larval samples can be dried by the microwave drying approximately 81 times faster than in the convection oven at 60 °C and 309 times faster than by the convection drying at 40 °C.

For more objective comparison of the drying modes kinetics the drying rate (*DR*) at different times was calculated for several samples. Figure 4 shows the rate of drying of Blanched and Frozen (2 hours) samples by convection drying at 40 °C and 60 °C as a function of moisture content. As a rule, food drying curves feature an initial period of increasing of drying rate associated with heating of the product, followed by a period of the rate decreasing [40,41]. In this study, during the initial period of drying, the samples weight was not measured; therefore, the period of rate increase was not recorded. During the convection drying at 40 °C, a plateau on the dependence of the drying rate (*DR*) on the moisture content was observed. The presence of the constant *DR* period is not typical for most food products [31,40,42,43] and, in this case, may be associated with frequent cooling of the samples during the weighing process and subsequent heating when placing them back in the drying oven. During convection drying

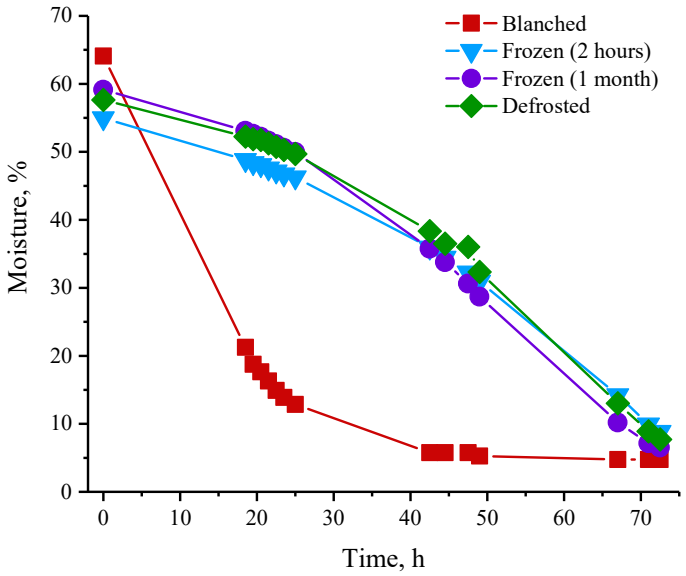

Figure 2. The change of the *Tenebrio molitor* larvae samples moisture during convective drying at temperature 40 °C

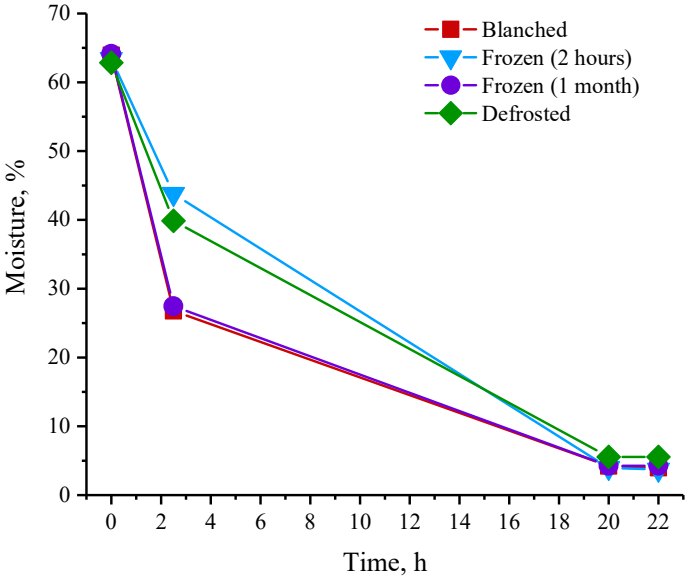

Figure 3. The change of the *Tenebrio molitor* larvae samples moisture during convective drying at temperature 60 °C

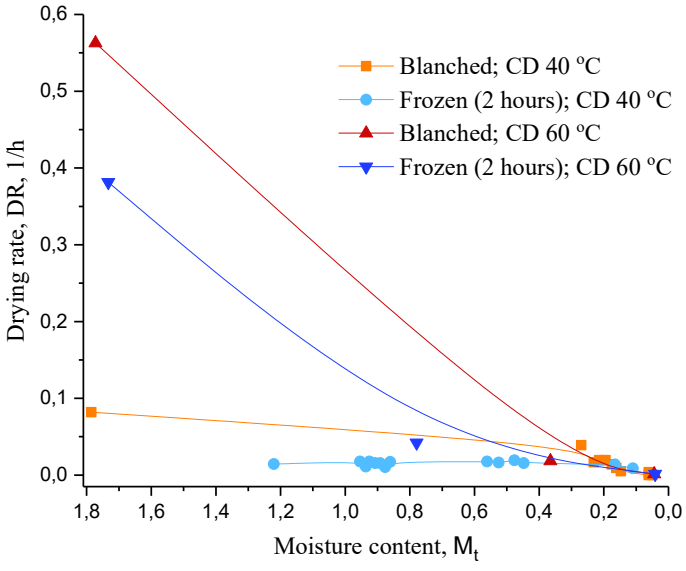

Figure 4. The dependence of the drying rate on moisture content of the *Tenebrio molitor* larvae samples

at 60 °C, the drying rate monotonically decreased during all the experiments (Figure 4).

DR was significantly affected by the drying temperature — the rate increased with increasing temperature (Figure 4). This coincides with the literature data [41]. Similar to the data in [42], the influence of temperature on the drying rate increases with the increase in the moisture content of the samples. It is often assumed that during the period corresponding to the decrease in the drying rate, the mechanism that determines the kinetics of the process is moisture diffusion to the surface [43], and the diffusion coefficient, in its turn, increases due to the temperature increase [44].

The obtained data also showed that the drying rate of blanched samples was higher than that of killed by freezing at –20 °C (Figure 4). During the blanching process, proteins can undergo structural changes such as denaturation, crosslinking, and interaction with lipids. This leads to a decrease in the number of hydrophilic water binding sites (polar side chains, carbonyl and amino groups), as well as to the destruction of the cell membranes. These structural changes can lead to an increase in the drying rate [36] and a decrease in the hygroscopicity of samples of the *Tenebrio molitor* larvae [31].

Fatty acid content

Among the identified fatty acids, myristic, palmitic, palmitoleic, oleic, linoleic and linolenic acids had the highest content. Analysis of the results (Figure 5) showed that the considered methods of drying and pretreatment of insects had no significant effect on their fatty acid composition.

The same results were observed in [24], which reported minor differences in the composition of mealworm larvae dried by various methods. According to [45], *Tenebrio molitor* larvae contain a large amount of unsaturated fatty acids with a high content of oleic and linoleic acids, as well as saturated fatty acids, which characterizes the larvae as potentially beneficial to human health.

Analysis of the color characteristics of the samples

Appearance is one of the main factors that the consumer uses to evaluate the quality of a food. For example, the inclusion of insects in food products can lead to their browning, which gives rise to the negative reaction in neophobic consumers and, therefore, refusal to purchase [46]. Figure 6 and Table 3 show photographs of larvae before and after treatment/drying.

Table 4 shows the color parameters of larvae after various combinations of their pretreatment and drying.

All treated larvae had an uneven color, due to which the L^*, a^*, b^* parameters have a significant degree of deviation.

The ΔE_{lab} reflects the degree of the color difference between untreated and treated larvae [33]. According to the literature, differences in perceived color can be classified

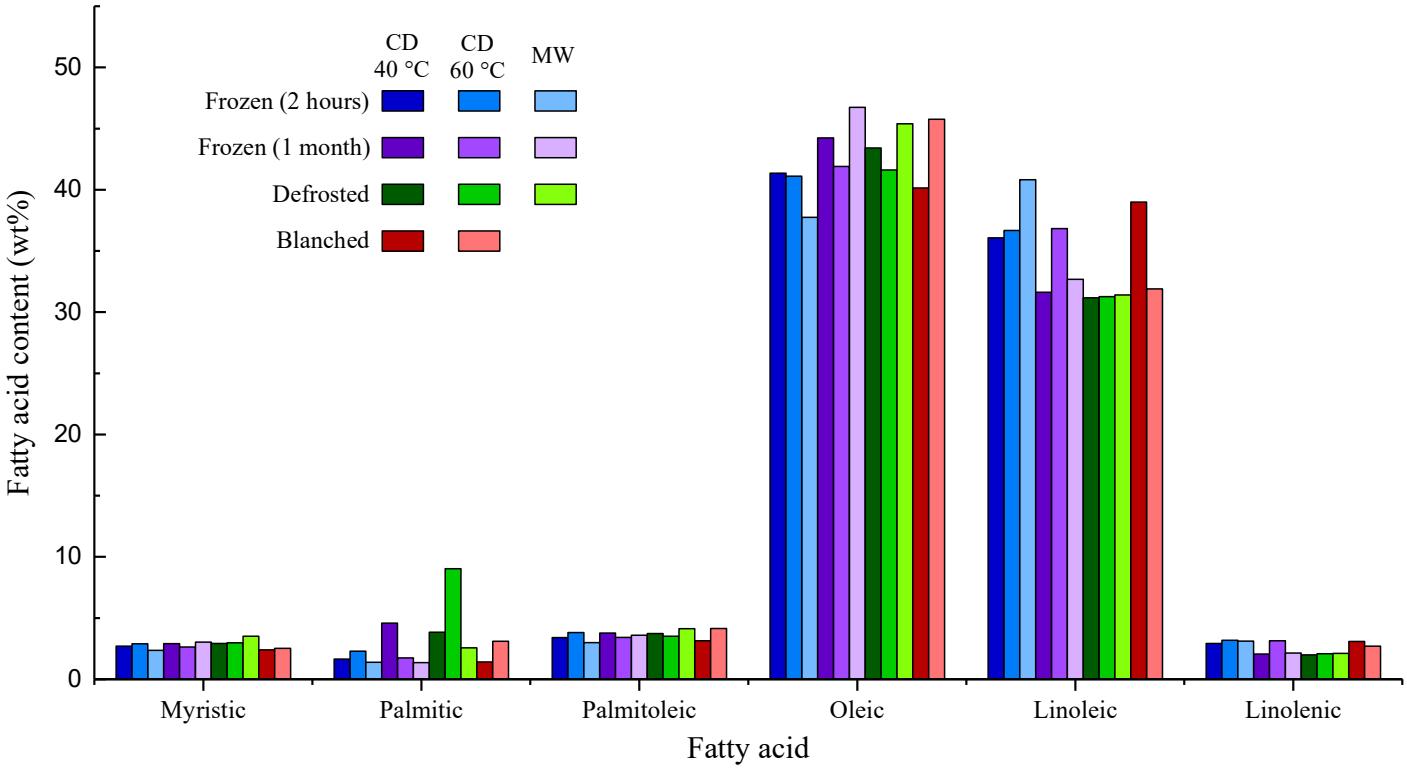

Figure 5. Fatty acid content in the samples of *Tenebrio molitor* larvae

as "significant" ($\Delta E > 3$), "visible" ($1.5 < 3$) and "minor" ($\Delta E < 1.5$). Thus, all methods of processing larvae cause significant changes in their color compared to untreated live larvae.

Blanching before drying comparing to the other treatment methods led to the browning reduction. It can occur as a result of inactivation of browning enzymes, such as polyphenol oxidase. In crustaceans, for example, polyphenol oxidase loses its activity after 2 min at 60 °C [33].

Browning caused by drying at low temperatures between 40 °C and 60 °C may result from the combination of enzymatic and non-enzymatic processes. Non-enzymatic browning occurs due to the degradation of carbohydrates as a result of Maillard reaction or caramelization [47]. Thus, exposure to high temperature for a long time contributes to non-enzymatic browning processes, which leads to the formation of colored Maillard products, and as a result the dried larvae feature darker color [30]. Enzymatic browning is associated with the formation of dark brown pigments through melanosis [31]. After initiating an enzymatic reaction in the presence of oxygen, melanosis continues as a chemical condensation reaction, which rate is not reduced by high temperature.

Figure 6. Live larvae before processing/drying

As a result of prolonged convection drying at 40 °C, all larvae, except for blanched ones, showed low values of lightness, chroma, and browning index. As can be seen from Table 3 and 4, these larvae had a dark gray color, which is likely to be negatively perceived by consumers. Increasing the drying temperature up to 60 °C led to an increase in chroma and browning index of larvae. The reason may be the predominance of the non-enzymatic browning reactions at this temperature as a result of the inactivation of polyphenol oxidase.

Microwave-dried larvae had higher lightness and browning index values compared to convection-dried larvae. This may be explained by the fact that during microwave drying the larvae were exposed to high temperature for a short period of time (up to 17 min). Thus, the high treatment temperature inactivated the enzymatic reaction, and the low duration of the process reduced the duration of non-enzymatic reactions.

Conclusion

In this study the influence of the pretreatment and drying methods on the drying rate, fatty acid composition and color of the yellow mealworm (*Tenebrio molitor*) larvae were investigated. All considered methods had no significant effect on the larvae fatty acid composition. On the other hand, the pretreatment and drying of the samples

Table 3. Appearance of larvae after processing/drying

Before drying	MW	CD 40 °C	CD 60 °C
Blanched			
			
Frozen (2 hours)			
			
Frozen (1 month)			
			
Defrosted			
			

Table 4. Parameters L^*, a^*, b^*, $\Delta E_{lab,}$ *Ch, h, BI* of the *Tenebrio molitor* larvae treated with various methods

Sample	L^*	a^*	b^*	ΔE_{lab}	*Ch*	*H*	*BI*	Color
Initial (not treated)	42.50 ± 6.40	20.33 ± 4.23	39.50 ± 1.41	—	44.43	1.10	212.00	
Blanched	53.83 ± 6.93	15.83 ± 2.60	42.00 ± 7.97	15.69	44.89	1.21	152.66	
Frozen (2 hours)	38.50 ± 13.24	12.50 ± 2.47	31.67 ± 8.22	11.38	34.04	1.20	167.10	
Frozen (1 month)	39.67 ± 8.79	15.84 ± 5.73	33.67 ± 12.99	12.39	37.20	1.13	180.12	
Defrosted	37.00 ± 10.49	6.33 ± 0.97	21.50 ± 9.52	18.85	22.41	1.28	95.59	
Blanched; CD 40 °C	39.83 ± 16.27	11.67 ± 2.24	28.83 ± 8.82	12.72	31.10	1.18	137.45	
Frozen (2 hours); CD 40 °C	34.17 ± 17.64	4.83 ± 3.66	7.33 ± 6.19	33.23	8.78	0.99	34.11	
Frozen (1 month); CD 40 °C	22.50 ± 21.25	4.17 ± 2.93	5.00 ± 5.10	39.89	6.51	0.88	38.22	
Defrosted; CD 40 °C	23.00 ± 13.59	3.17 ± 2.23	4.50 ± 4.52	40.12	5.50	0.96	31.46	
Blanched; CD 60 °C	29.00 ± 9.58	11.17 ± 3.52	26.50 ± 3.91	19.65	28.76	1.17	200.82	
Frozen (2 hours); CD 60 °C	27.33 ± 13.88	5.67 ± 2.46	18.83 ± 9.07	25.64	19.67	1.28	122.48	
Frozen (1 month); CD 60 °C	22.17 ± 14.70	8.33 ± 6.61	21.00 ± 15.33	27.66	22.59	1.19	212.46	
Defrosted; CD 60 °C	18.17 ± 8.23	9.83 ± 5.74	14.83 ± 6.27	34.95	17.80	0.98	179.29	
Blanched; MW	39.83 ± 8.06	5.33 ± 1.09	8.67 ± 5.00	30.95	10.18	1.02	33.94	
Frozen (2 hours); MW	35.50 ± 10.45	10.67 ± 5.96	14.00 ± 6.50	26.99	17.60	0.92	71.17	
Frozen (1 month); MW	36.17 ± 15.16	9.33 ± 2.85	24.50 ± 12.74	16.78	26.22	1.21	123.45	
Defrosted; MW	31.17 ± 11.31	11.33 ± 2.36	29.83 ± 10.31	16.08	31.91	1.21	215.45	

affected the drying rate and the color parameters of the resulting samples. Microwave drying was the fastest and most efficient drying method. It also provided a product with good color characteristics regardless of the insect pretreatment. The convective drying at 60 °C produced the samples of a similar final moisture content compared to the microwave drying, but convection drying was 81 times longer, resulting in browning of the insects. The convective drying at 40 °C was even longer than the drying at 60 °C, and the obtained samples were considerably brown. However, it has been shown that pre-blanching the larvae increases the speed of drying by the convective method and also allows keeping the color of the product close to the untreated one. Thus, convection drying of *Tenebrio molitor* larvae, in combination with pre-blanching, also allows obtaining a product with acceptable color characteristics and low water content. No significant influence of the defrosting of larvae or their prolonged storage at –20 °C on their drying rate or color characteristics was found.

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