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Impact of Mealworm Powder (*Tenebrio molitor*) Fortification on Ice Cream Quality

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Abstract: The study's objective was to characterize the effects of mealworm powder fortification on ice cream's properties and nutritional value. The approximate composition and the mineral and fatty acid profiles were analyzed. Moreover, the antioxidant activity and physical properties as well as color were studied. As expected, insect powder substitution increased the protein content from 1.48 ± 0.13% for the control to 3.08 ± 0.22% for the sample with the highest insect substitution. The ash content increased as well. There was also a significant increase in zinc (2.5-fold), magnesium (3-fold), iron (4-fold) and unsaturated fatty acids. The ice cream with the highest percentage of insect powder had the slowest melting rate (0.094 ± 0.04 g/min) but the lowest overrun value (13.10 ± 0.22%) compared with the melting rate (0.145 ± 0.02 g/min) and overrun value (32.58 ± 0.6%) of control ice cream. Moreover, the ice cream turned darker in color. Furthermore, adding mealworm powder caused a significant increase in antioxidant properties as evaluated by ABTS and DPPH scavenging activity. Therefore, using mealworm powder in ice cream gave a product with better characteristics than the control sample, thus demonstrating the possibility of producing high-quality ice cream.

Keywords: *Tenebrio molitor*; novel food; entomophagy; edible insect

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1. Introduction

Edible insects are becoming increasingly accepted as a sustainable form of protein in European countries. Its popularity is growing due to increasing knowledge about insect breeding and processing and confidence in its safety when used in food. Interest in insects has grown due to promotion by the FAO and the emergence of new EU legislation that includes insects as a novel food.

Edible insects are known primarily for their nutritional benefits. For example, Rumpold and Schlüter [1] and Finke [2] have evaluated the content of their basic nutrients, including vitamins, minerals, amino acid spectrum and fatty acid content. The nutritional value of insects was found to be comparable to commonly consumed meat [3]. Payne et al. [4] state that some species have a higher nutritional value than commonly consumed beef and chicken. According to Kóhler et al. [5], food source diversification is one of the main strategies for ensuring enough food for all and for fighting against undernutrition.

Fat is the second most abundant component in insects [6]; however, the more significant parts of these fats contain more unsaturated fatty acids than saturated ones [1]. Mealworms' primary unsaturated fatty acids are oleic, linoleic and saturated palmitic acid. Beef milk fat mainly comprises saturated fatty acids—palmitic acid followed by myristic and stearic acid [7]. The intake of dietary fatty acids plays an important role in the cause and prevention of cardiovascular disease. The risk of these diseases can be reduced by consuming less saturated fatty acids or eliminating trans-fatty acids [8].

Despite all their positive characteristics that are beneficial to society, insects are still perceived as unusual, or even uninviting. Consumption is often rejected to a large extent for psychological reasons, but even so, several industries and start-ups are trying to attract attention by promoting their environmental friendliness and sustainability. Products containing insects are currently under development, along with new technologies [9]. One way to incorporate insects into food is to use them in standard products and, if possible, in a ground or otherwise processed state so that the ingredient is not visible [6,10]. Common products such as bread [11], bars [12,13] and biscuits [14–16] fortified by insects have been made. Snacks and sweets are also readily enriched because they have a positive association for consumers. One of the most popular desserts is ice cream. This generates positive associations among consumers, so they are a suitable matrix for disguising insects for anyone reluctant to try them. In addition, the texture of the ice cream makes it easy to incorporate the insect powder into its recipe. In Europe, per capita ice cream sales in 2020 were highest in Belgium, at roughly 16.16 kg, in Portugal (14.18 kg) and in Poland (13.6 kg) [17]. These arguments prompt a consideration of ice cream as a valuable product for supplementation. However, these are not the only challenges posed by the products chosen for supplementation. The addition of insects will not be without effect on the taste of the ice cream. The taste of mealworm is described as that of whole wheat bread [18] or nuts [19]. Moreover, the taste of insects may depend on the type of food used; mealworms fed on cereal bran or flour have a characteristic sweet, almost nutty flavor, and a nutty cocoa smell [20]. The listed descriptors are suitable for ice cream and can increase its flavour appeal.

This research aimed to study the incorporation of powder from mealworms (*Tenebrio molitor*) into ice cream by assessment of its physical parameters, nutrient composition and bioactive properties.

2. Materials and Methods

2.1. Insect Processing and Ice Cream Manufacturing

Live *Tenebrio molitor* (TM) larvae were obtained from Bugstore (Krakow, Poland), fasted for 48 h and then frozen at −20 °C for another 48 h. Mealworms were lyophilized and ground in a laboratory grinder to obtain a powder. A 20-mesh sieve was used for uniform coarseness.

The ice cream was prepared in 4 variations, one of which was a control (C) and did not contain mealworm powder. The remaining variants were prepared by replacing the cream with 2% (IC2), 5% (IC5) or 10% (IC10) of insects. The basic recipe contains 200 g of cream, 100 g of milk and 30 g of sugar. All ice creams were prepared in two replicates. A 50 g of cream was mixed with sugar and heated to caramelize the sucrose. After cooling down, the rest of the cream, milk and insect powder were added. This mixture was poured into the ice cream maker (Unold 48865, Hockenheim, Germany) and stopped after 40 min of processing. Ice cream was then stored in the freezer (Samsung, Suwon, Republic of Korea) at −20 °C until further analyses could be performed.

2.2. Nutrient, Mineral and Fatty Acid Composition

The value of the moisture, ash, fat, protein and mineral content of the ice cream samples and mealworm powder were estimated according to standard methods [21]. The concentration of minerals was determined using flame atomic-absorption spectrophotometry (FAAS, Solaar 939, Unicam, CA, USA), according to Jorhem and Engman [22]. The percentage content of fatty acids was determined by the GC/FID method (Varian 450-GC, Bruker, Billerica, MA, USA) in the Central Analyses Laboratory at the University of Life Sciences in Lublin.

2.3. Ice Cream Overrun

The overrun was calculated by weight according to Ismail et al. [23] by using the following formula:

$$\text{Overrun \%} = [(\text{weight of a unit volume of mix}) - (\text{weight of a unit volume of ice cream})]/(\text{weight of a unit volume of ice cream}) \times 100 \quad (1)$$

2.4. Melting Properties

As one of the characteristic parameters of ice cream, the melting time and melting resistance were measured. Samples were prepared as Góral et al. [24] described. Briefly, a metal ring was used for cutting to obtain ice cream samples of an identical shape and quantity, which were then stored in a freezer for 48 h. After that, samples were transferred in a strainer over a beaker and placed in a chamber at 25 °C. The time required for the first drop of melted ice cream to drip was recorded. Melting resistance was determined according to the method of Silva Junior and Lannes [25], modifying the sample size and melting time. It was determined by measuring the dripped volume every 5 min from the first drop. The data recorded were used to determine the melting rate (g/min). The maximum meltdown rate (MDR) was determined at the highest gradient in the ascending meltdown curve. The meltdown is defined as the mass of the drip loss divided by the total mass of the ice cream sample and plotted against time [26].

2.5. Color Measurements

An EnviSense colorimeter NH310 (EnviSense, Lublin, Poland) was used to measure the ice cream color. Color differences were recorded into CIE L*a*b*. The L* is represented as an axis that indicates lightness, and chromatic colors are denoted as a* (green to red) and b* (blue to yellow). The total color difference (ΔE), browning index (BI) and whiteness index (WI) were calculated using the following formulas:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}, \quad (2)$$

where ΔL*, Δa* and Δb* are differences in the L*, a* and b* values between the reference and test samples, respectively.

$$BI = \frac{100(x - 0.31)}{0.17}, \quad (3)$$

where

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 0.012b^*)} \quad (4)$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (5)$$

2.6. Fourier-Transform–Infrared (FT-IR) Spectroscopy

The FT-IR spectra of ice cream samples in the wavelength range of 4000–400 cm^{-1} were recorded on a spectrophotometer (FT-IR Alpha II, Bruker, Billerica, MA, USA) fit with a Miracle Single Reflection Diamond ATR device with a spectral resolution of 4 cm^{-1}.

2.7. Antioxidant Properties of Ice Creams

2.7.1. Extraction of Bioactive Compounds

Samples containing 10 g of ice cream or mealworm powder were extracted with 90 mL of 80% methanol for 3 h on a stirrer at 20 °C and left for 12 h in the dark for effective extraction. Next, the samples were centrifuged for 10 min at 14,000 rpm, and the supernatants were filtered through a 0.45 μm nylon syringe filter just before analysis [27].

2.7.2. Antiradical Activity

Re et al.'s [28] procedure was used for the ABTS radical scavenging activity assay. Briefly, 0.1 mL of extract was mixed with 3.9 mL of ABTS$\cdot^{+}$ solution and left in the dark at 20 °C. After 30 min, the absorbance was measured at 734 nm.

Similarly, the Brand-Williams, Cuvelier and Berset [29] method with slight modifications was used to evaluate the DPPH· scavenging activity. An aliquot of 0.1 mL of extract was mixed with 3.9 mL of DPPH· solution and left in the dark at 20 °C. After 30 min, the absorbance was measured at 515 nm.

The scavenging effect was calculated according to the equation:

$$\text{Scavenging activity (\%)} = [1 - (\text{A sample}/\text{A control})] \times 100 \quad (6)$$

The results were expressed as Trolox equivalent antioxidant activity (TEAC) values (mM Trolox).

2.8. Statistical Analysis

All assays were performed in triplicate, and the obtained data are presented as means ± SEM (the standard error of the mean). Statistical analyses were carried out using Statistica (version 13.0, StatSoft, Krakow, Poland) for the comparison of means using ANOVA with post hoc Tukey's honestly significant difference (HSD) test at the significance level of $p < 0.05$.

3. Results and Discussion

3.1. Nutrient Composition

Using insects in common popular foods seems suitable for increasing some of the nutritional parameters of the product. Only a few types of insects are allowed for human consumption by European legislation. These species include the migratory locust (*Locusta migratoria*) [30], yellow mealworm (*Tenebrio molitor*) [31], house cricket (*Acheta domesticus*) [32] and the lesser mealworm (*Alphitobius diaperinus*) [33]. In general, insects have a high environmentally sustainable protein content. Proteins in mealworm larvae reach up to about 50% [1], while our value for the powder is slightly higher (52.12 ± 0.29%). Nutritional parameters may vary depending on the type of insect used [2]. The parameters are also influenced by differences in breeding [34]. Only one type of insect was used for ice cream, obtained from one supplier. Mealworm was chosen because it is approved as a novel food in the EU. Moreover, as a larva, it contains more fat than crickets and, thus, can partially replace the cream in ice cream. The control ice cream sample reached only half the protein value (1.48 ± 0.13%) of the IC10 sample (3.08 ± 0.22%). With insect powder addition, the protein content increased, with a statistically significant difference ($p < 0.05$) (Table 1). Moreover, we can observe that IC10 had a higher ash content than the other samples. The carbohydrate content ranges from 14.03–14.92% and is not statistically significant from the control sample. Since the main ingredients are cream and sugar, the content will be mainly lactose and sucrose. In ice cream in with the cream has been replaced by TM, the polysaccharide chitin, which is significantly represented in the exoskeleton of insects, also features [35]. The content did not change statistically significantly in terms of fat, carbohydrate and energy values ($p < 0.05$). All these properties did not change after replacing the cream with TM. The replacement of fats and sugars in ice cream seems suitable for producing ice creams with functional properties. However, this change should not cause a change in the sensory attributes that are important for the consumer [36]. When replacing fats, there is a risk of many textural and sensory defects. Additions of various fat substitutes are well described in the study by Akbari et al. [37].

Table 1. Approximate composition (%) and energy values of the obtained ice cream and mealworm powder samples.

Sample	Protein (%)	Fat (%)	Carbohydrate (%)	Ash (%)	Moisture (%)	Energy Value (kcal)
C	1.48 ± 0.13 ^{d}	19.40 ± 1.61 ^{a}	14.26 ± 1.12 ^{a}	0.57 ± 0.05 ^{b}	64.29 ± 1.74 ^{a}	238 ± 18 ^{a}
IC2	1.85 ± 0.09 ^{c}	19.82 ± 1.11 ^{a}	14.43 ± 1.05 ^{a}	0.60 ± 0.05 ^{b}	63.30 ± 1.83 ^{a}	244 ± 15 ^{a}
IC5	2.32 ± 0.03 ^{b}	19.86 ± 0.17 ^{a}	14.03 ± 0.85 ^{a}	0.63 ± 0.02 ^{b}	63.16 ± 1.15 ^{a}	244 ± 5 ^{a}
IC10	3.08 ± 0.22 ^{a}	18.33 ± 0.64 ^{a}	14.92 ± 0.96 ^{a}	0.73 ± 0.02 ^{a}	62.94 ± 1.57 ^{a}	237 ± 9 ^{a}
MP	52.12 ± 0.29	34.28 ± 0.27	2.77 ± 0.24	4.85 ± 0.04	5.98 ± 0.77	528 ± 5

C—control sample; IC2—2% insect; IC5—5% insect; IC10—10% insect; MP—mealworm powder. Values followed by a similar superscript in a column do not differ significantly ($p < 0.05$).

3.2. Mineral Content

From the determined mineral substances, it can be seen that insects contributed higher values of Mg, K, Fe and Zn to the ice creams ($p < 0.05$). The measured values are shown in Table 2. Magnesium was increased by up to 3-fold in the case of IC10 compared with the control and iron by up to 4-fold. Zinc was also increased more than 2.5-fold in this case. Insects are generally a good source of minerals. Rumpold and Schluter [1] highlight the mineral content in some species. For *Tenebrio molitor* (larvae), magnesium is reported in the range of 210.24–280 mg/100 g; in our case, 293.07 ± 4.36 mg/100 g. *Acheta domesticus* has only 80–160 mg/100 g of magnesium. Insects have a very low calcium content, corresponding to the results where calcium was not increased after TM substitution. It is believed that the consumption of insects could help replenish zinc and iron. The bioavailability of these elements is still under discussion. Mwangi et al. explain the change in bioavailability as being due to iron occurring in non-heme molecules in insects. Iron is difficult to absorb in vertebrates' intestines, and other inhibitors can also reduce absorption in food. Correlations between the crude protein content and the zinc and iron content are described [38].

Table 2. Mineral composition of ice cream and mealworm powder (mg/100 g).

Sample	Ca	Mg	K	Na	Fe	Zn
C	94.86 ± 5.25 ^{a}	7.84 ± 1.39 ^{c}	128.43 ± 11.64 ^{ab}	29.70 ± 1.41 ^{a}	0.23 ± 0.09 ^{b}	0.41 ± 0.04 ^{b}
IC2	85.63 ± 11.97 ^{a}	11.35 ± 1.60 ^{c}	119.15 ± 17.39 ^{b}	26.85 ± 5.37 ^{a}	0.18 ± 0.01 ^{b}	0.57 ± 0.15 ^{b}
IC5	95.26 ± 2.84 ^{a}	17.78 ± 0.08 ^{b}	150.26 ± 4.06 ^{ab}	32.04 ± 0.81 ^{a}	0.35 ± 0.09 ^{b}	0.70 ± 0.04 ^{b}
IC10	96.67 ± 2.14 ^{a}	24.31 ± 0.67 ^{a}	168.93 ± 3.20 ^{a}	34.02 ± 0.91 ^{a}	0.92 ± 0.08 ^{a}	1.14 ± 0.01 ^{a}
MP	56.27 ± 2.99	293.07 ± 4.36	880.76 ± 24.29	128.93 ± 0.17	4.95 ± 0.15	12.99 ± 0.29

C—sample; IC2—2% insect; IC5—5% insect; IC10—10% insect; MP—mealworm powder. Values followed by a similar superscript in a column do not differ significantly ($p < 0.05$).

3.3. Fatty Acid Profile

Table 3 shows the fatty acid profile of the studied ice creams. Generally, the fortified formulations have a different profile than the control ice cream because *Tenebrio molitor* has a high unsaturated fatty acid content [39]. The control and IC2 samples were characterized by a saturated fatty acid (SFA) content of about 70%. However, a higher TM supplementation level caused a decrease in SFA content to 66.58% in IC5 and 63.87% in IC10. The main saturated fatty acid in the ice creams was palmitic acid, which varied from 34.68 ± 0.65% for the control to 32.44 ± 0.55% for IC10, and among the unsaturated fatty acids, it was oleic acid, which ranged from 19.97 ± 0.5% for the control to 22.99 ± 0.82% for IC10; these differences were statistically significant ($p < 0.05$). Differences in the polyunsaturated fatty acid content—linoleic acid—are worth noting. Its content in ice cream with a 5% TM addition was nearly 2-fold, and in ice cream with a 10% TM addition, it was 2.5-fold higher than in the control. Generally, with the addition of mealworm powder, the content of saturated fatty acids decreased and mono- and polyunsaturated fatty acid content increased. Similar results were obtained by Hernández Toxqui et al. for ice creams fortified with mealworm powder [40]. The main saturated fatty acid in the ice creams was palmitic acid (32.96 ± 0.77%); among unsaturated fatty acids, it was oleic acid (25.3 ± 0.61%).

Table 3. Fatty acid composition of ice cream (%).

Fatty Acid Composition	Studied Ice Cream			
	C	IC2	IC5	IC10
C6:0	1.01 ± 0.01^{a}	1.0 ± 0.01^{a}	0.94 ± 0.01^{b}	0.92 ± 0.01^{b}
C8:0	1.16 ± 0.01^{a}	1.13 ± 0.02^{a}	1.06 ± 0.01^{b}	0.99 ± 0.01^{c}
C10:0	3.21 ± 0.02^{a}	3.09 ± 0.01^{b}	2.95 ± 0.02^{c}	2.74 ± 0.01^{d}
C11:0	0.07 ± 0.01^{a}	0.07 ± 0.01^{a}	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}
C12:0	3.93 ± 0.02^{a}	3.81 ± 0.04^{b}	3.67 ± 0.04^{c}	3.41 ± 0.04^{d}
C13:0	0.13 ± 0.01^{a}	0.13 ± 0.01^{a}	0.12 ± 0.01^{a}	0.12 ± 0.01^{a}
C14:0	12.74 ± 0.12^{a}	12.6 ± 0.1^{a}	12.13 ± 0.02^{b}	11.52 ± 0.02^{c}
C14:1n5	1.12 ± 0.01^{a}	1.05 ± 0.01^{b}	1.08 ± 0.01^{c}	0.99 ± 0.01^{d}
C15:0	1.28 ± 0.03^{a}	1.27 ± 0.02^{a}	1.2 ± 0.01^{b}	1.13 ± 0.01^{c}
C16:0	34.68 ± 0.65^{ab}	34.85 ± 0.5^{a}	33.45 ± 0.4^{bc}	32.44 ± 0.55^{c}
C16:1n7	1.65 ± 0.1^{a}	1.62 ± 0.06^{a}	1.7 ± 0.02^{a}	1.75 ± 0.02^{a}
C17:0	0.6 ± 0.01^{a}	0.6 ± 0.01^{a}	0.57 ± 0.01^{b}	0.55 ± 0.01^{b}
C17:1n7	0.2 ± 0.01^{b}	0.21 ± 0.01^{b}	0.3 ± 0.01^{a}	0.19 ± 0.01^{b}
C18:0	10.67 ± 0.21^{ab}	10.72 ± 0.15^{a}	10.14 ± 0.6^{ab}	9.75 ± 0.3^{b}
C18:1n9c + C18:1n9t	19.97 ± 0.5^{b}	20.14 ± 0.2^{b}	21.65 ± 0.84^{ab}	22.99 ± 0.82^{a}
C18:2n6c + C18:2n6t	1.51 ± 0.09^{c}	1.53 ± 0.08^{c}	2.91 ± 0.07^{b}	3.82 ± 0.07^{a}
C18:3n3 (alpha)	0.19 ± 0.01^{b}	0.12 ± 0.01^{c}	0.32 ± 0.01^{a}	0.3 ± 0.01^{a}
C20:0	0.16 ± 0.01^{a}	0.17 ± 0.01^{a}	0.15 ± 0.01^{a}	0.15 ± 0.01^{a}
C20:1n9	<LOD	<LOD	0.04 ± 0.01^{a}	0.05 ± 0.01^{a}
C20:2n6	0.04 ± 0.01^{a}	<LOD	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}
C21:0	0.06 ± 0.01^{b}	<LOD	0.1 ± 0.01^{a}	0.09 ± 0.01^{a}
C22:0	0.03 ± 0.01	<LOD	<LOD	<LOD
C22:1n9	0.12 ± 0.01^{a}	0.13 ± 0.01^{a}	0.12 ± 0.01^{a}	0.13 ± 0.1^{a}
C22:2n6	0.03 ± 0.01	<LOD	<LOD	<LOD
C23:0	0.04 ± 0.01^{a}	<LOD	0.04 ± 0.01^{a}	<LOD
SFA	69.77	69.44	66.58	63.87
MUFA	23.06	23.15	24.89	26.1
PUFA	1.84	1.71	3.35	4.22
OMEGA 3	0.24	0.18	0.38	0.35
OMEGA 6	1.6	1.53	2.97	3.87
OMEGA 9	20.09	20.27	21.81	23.17

SFA (saturated fatty acids): C14:0—myristic acid; C16:0—palmitic acid; C18:0—stearic acid. MUFA (monounsaturated fatty acids): C16:1n7—palmitoleic acid; C18:1n9—oleic acid. PUFA (polyunsaturated fatty acids): C18:2n6—linoleic acid; C18:3n3—α-linolenic acid; C18:3n6—γ-linolenic acid; C20:3n6—dihomo-γ-linolenic acid; C20:4n6—arachidonic acid; C20:5n3—eicosapentaenoic acid (EPA). Different superscript letters in the row indicate a significant difference ($p < 0.05$).

Nevertheless, the fatty acid profile in insects is very variable. For example, different authors report palmitic acid content in the range from 17.48 to 23.05% and oleic acid from 29.14 to 39.37% [39,41]. In insects, fatty acid biosynthesis/accumulation is highly dependent on environmental conditions, such as substrate type, and these differences are most likely the result of the fact that the mealworms of each study are not reared identically [41,42]. Furthermore, the linoleic acid content is much higher than in traditional animal products, and given its indispensable nature in human nutrition, this aspect is a distinct advantage for insects [41]. Since saturated fats comprise 70% of the total fat weight in dairy products, any addition of material rich in unsaturated fatty acids results in an improved fatty acid profile. The intake of unsaturated fatty acids is important because they positively affect our body. In general, unsaturated fatty acids have antiarrhythmic effects and play a fundamental role in reducing the risks derived from diseases such as type 2 diabetes or hypertension as well [40].

3.4. Melting Time and Resistance

Ice cream is a complex matrix of ice crystals, fat globules and air bubbles with phases containing dissolved proteins, salts etc. Fat and fat destabilization appears to be significant. Fat globules are found individually or in clusters in ice cream. The formation of clusters is influenced by the addition of emulsifiers and the contained proteins. Emulsifiers are usually added to the product to reduce the surface tension of the spheres, which subsequently enables the formation of clusters. These clusters affect the physical properties of ice cream, especially its melting [43]. Milk proteins are the primary source for the production of ice cream and also have emulsifying properties. The functional properties of milk proteins and their adsorption are described, for example, in the study by Ye [44]. However, it turns out that an excessive protein content in the mixture affects the tight connection of fat droplets because it is surrounded by a thick cover [45]. Gould and Wolf [46] used insects (*Tenebrio molitor*) for protein-stabilized emulsions. Their study shows that insect protein is a suitable alternative to current emulsifiers.

The results of melting ice cream containing insects are shown in Figure 1. The ice cream with the highest percentage of TM (IC10) showed the slowest melting. Within 30 min, this ice cream had the least amount of ice cream loss compared with the other samples and the control. Also, sample IC5 showed promising results in terms of melting. The control ice cream (IC) was the least resistant in the controlled conditions. The first drop was seen at 26.8 min. The insects in the ice cream caused the first drop to be delayed to 49.9 min in the case of IC10 (Table 4).

Table 4. Melting properties and overrun of the ice cream samples.

Sample	Overrun (%)	Melting Rate (g/min)	Melting Start (min)	Maximum Meltdown Rate (g/min)
C	32.58 ± 0.6^{a}	0.145 ± 0.02^{a}	26.8 ± 2.12^{c}	0.248 ± 0.05^{a}
IC2	17.69 ± 0.3^{b}	0.136 ± 0.02^{b}	37.6 ± 0.78^{b}	0.19 ± 0.02^{bc}
IC5	15.94 ± 0.28^{c}	0.099 ± 0.01^{c}	40.3 ± 0.1^{b}	0.154 ± 0.02^{c}
IC10	13.10 ± 0.22^{d}	0.094 ± 0.04^{c}	49.9 ± 6.5^{a}	0.122 ± 0.02^{c}

C—control sample; IC2—2% insect; IC5—5% insect; IC10—10% insect. Values followed by a similar superscript in a column do not differ significantly ($p < 0.05$).

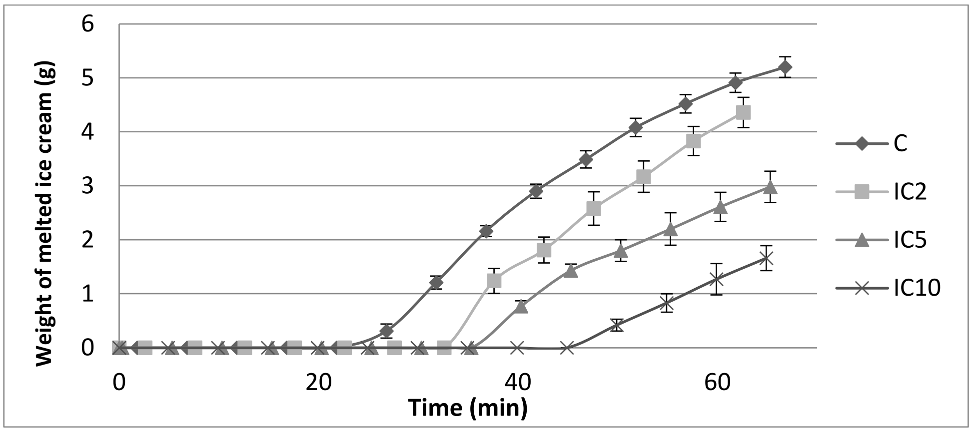

Figure 1. Melting rate of ice cream.

Statistical differences were found among the melting rates for the different mealworm powder concentrations, ranging from 0.145 ± 0.02 g/min for the control to 0.094 ± 0.04 g/min for IC10 (Table 4). Similarly, the maximum meltdown rate decreased as the proportion of insect meal in ice cream increased. The melting rate was influenced by the proteins present, which were of both milk and insect origin. The nutritional profile and protein content are shown in Table 1. In their study, Daw and Hartel [27] claim that the lowest protein concentration had a prolonged melt rate. However, they did not consider a protein source other than milk protein. In contrast to milk protein concentrate and procream, they also found that the ice creams made with whey protein isolate had excellent stand-up properties and prolonged melt rates, so the protein's origin may have a crucial role. Moreover, another component may be responsible for the changed melting properties of ice cream with insects. Birman et al. [47] considered the chitin content to be the key factor influencing the observed viscosity in ice cream produced from silkworm pupae.

3.5. Overrun

Another critical parameter for expressing texture parameters is overrun. It was observed that the aeration level of the ice cream was highest in the control sample (34.90 ± 4.90%) (Table 4). The control sample was almost two times higher than the lowest substitution TM ice cream (IC2). The overrun decreases with TM substitution, reaching the value of 13.10 ± 0.22% for the ice creams with the highest insect content ($p < 0.05$). Warren and Hartel [48], in their observation of the structural properties of ice creams, describe a similar phenomenon where the reduction of overrun increased viscosity. The results showed that substituting TM increased the ice cream's melting resistance. The study by Kurt and Atalar [49] describes similar properties in ice creams made with the addition of quince seed. That study attributed this ability to the contained proteins and other components that have water-holding effects.

3.6. Color

The addition of insect powder had a statistically significant effect on the color of the ice cream (Table 5). The lightness of the samples (L*) decreased with an increase in the addition of insect powder, which was also reflected in an increasing browning index (from −3.71 ± 0.45 for the control to 4.40 ± 0.46 for IC10) and a decrease in the whiteness index (from 93.3 ± 0.12 for the control to 73.62 ± 0.79 for IC10). Additionally, formulations with an increasing content of TM increased the redness (a*) and yellowness tonality significantly. There was also a significant difference in the total color difference between the samples. Such results were expected because mealworm powder is darker than cream. Similar results for color darkening were observed for other products supplemented with mealworms—muffins [50,51], cookies [14,52] and bread [53]. In baked products, color changes may occur additionally by the Maillard reaction, which is related to higher protein content. In the case of frozen products such as ice cream, their color results from the colors and proportions of the ingredients used as their production technique was the same.

Table 5. Colorimetric properties of the ice cream samples.

Sample	L*	a*	b*	ΔE	BI	WI
C	99.62 ± 0.61 ^{a}	−5.12 ± 0.85 ^{c}	5.53 ± 0.96 ^{c}	-	−3.71 ± 0.45 ^{c}	93.3 ± 0.12 ^{a}
IC2	89.88 ± 2.37 ^{b}	1.51 ± 0.43 ^{b}	9.76 ± 0.46 ^{b}	13.17 ± 0.23 ^{c}	1.25 ± 0.26 ^{b}	85.68 ± 0.82 ^{b}
IC5	82.99 ± 1.38 ^{c}	3.56 ± 0.57 ^{a}	11.55 ± 0.91 ^{ab}	20.23 ± 0.37 ^{b}	3.54 ± 0.11 ^{a}	79.13 ± 1.99 ^{c}
IC10	77.37 ± 0.85 ^{d}	4.71 ± 0.53 ^{a}	12.69 ± 0.82 ^{a}	25.84 ± 0.75 ^{a}	4.40 ± 0.46 ^{a}	73.62 ± 0.79 ^{d}

C—control sample; IC2—2% insect; IC5—5% insect; IC10—10% insect; BI—browning index; WI—whiteness index. Values followed by a similar superscript in a column do not differ significantly ($p < 0.05$).

3.7. Antioxidant Properties

The antioxidant activity was expressed by the degree of inhibition for the formation of cation-free radicals from the DPPH and ABTS solution (Table 6). The addition of TM caused a significant increase in the antioxidant properties of extracts in both tests ($p < 0.05$). Similarly, as a result of mealworm addition to muffins or biscuits, their antioxidant properties increased [14,51]. Similar results to ice cream with 10% mealworm were obtained for muffins with an equivalent mealworm addition of 0.223 ± 0.02 mM TE for DPPH and 0.37 ± 0.03 mM TE for ABTS [51]. In turn, tofu prepared with a 50% addition of mealworm protein isolate or mealworm protein hydrolysate was found to have much stronger properties than tofu prepared from 100% soybean flour. The authors stated that the mealworm proteins' hydrophobic and aromatic amino acid content increased their antioxidant properties due to the electron-donating capacity of the amino acids or due to the direct radical-scavenging ability of lipids [54].Generally, there is a lack of research on the antiradical properties of products supplemented with insects, but edible insects' strong free-radical scavenging activity has been reported previously. Moreover, the antioxidant activity reported for edible insect protein hydrolysates/peptides was relatively high compared with other food protein hydrolysates [55]. The consumption of foods rich in antioxidants is important for preventing oxidative stress-related diseases such as cardiovascular disease, diabetes and cancer. Our results show that applying insect powders is a technological option to produce foods with higher nutritional value but that also contain bioactive compounds. Due to their content, health-promoting properties such as the inhibition of the activity of enzymes involved in the pathogenesis of metabolic syndrome or the reduction of oxidative stress have been confirmed [55]. Until a certain time, in the study of insects, most research was devoted to their nutritional value and neglected their nutraceutical effects. These days, an increasingly broad spectrum of properties of edible insects is being analyzed [55].

Di Mattia et al. found that some edible insect species display values of antioxidant capacity 2- or 3-fold higher than popular functional foods such as orange juice or olive oil [56]. The insects' antioxidant activity might be attributed to their phenolic compounds and protein content [55,57]. However, further research in this area is needed to understand the mechanisms of their activity.

Table 6. Antioxidant properties of ice cream and mealworm powder.

Sample	DPPH (mM TE)	ABTS (mM TE)
C	0.04 ± 0.01^{c}	0.12 ± 0.01^{d}
IC2	0.06 ± 0.01^{c}	0.16 ± 0.01^{d}
IC5	0.15 ± 0.01^{b}	0.24 ± 0.01^{c}
IC10	0.20 ± 0.05^{b}	0.35 ± 0.02^{b}
MP	0.71 ± 0.05^{a}	0.53 ± 0.02^{a}

C—control sample; IC2—2% insect; IC5—5% insect; IC10—10% insect; MP—mealworm powder. Values followed by a similar superscript in a column do not differ significantly ($p < 0.05$).

3.8. FT-IR

FT-IR analysis identified the functional groups in the samples and revealed how the composition and structure of the ice cream changed with the addition of TM powder (Figure 2). The broad band observed at approximately 3300 cm^{-1} is due to the stretching of the O-H groups, indicating the formation of polysaccharides and aqueous hydroxyl groups in ice cream. The peaks at ~2920 cm^{-1} were attributed to the C-H stretching of aliphatic structures assigned to fatty acids and lipids, and those at ~2850 cm^{-1} are asymmetrical stretching vibrations of C-H in the CH_2 and CH_3 from fatty acids and alkanes [49,58]. These peaks have almost the same intensity in all the tested ice creams and mealworm powder samples. The peaks at ~1750 cm^{-1} result from aliphatic unsaturated C=O vibrations. The band's intensity in the region of 1630 cm^{-1} is attributed to the protein content of samples, so it is evident that mealworm powder has a more intense peak than the ice creams. The ~1150 cm^{-1} and ~980 cm^{-1} peaks are usually named C–O–C stretching modes [59]. The wavenumbers between 450 and 1500 cm^{-1} constitute the "fingerprint" region for structures characteristic of polysaccharides [49].

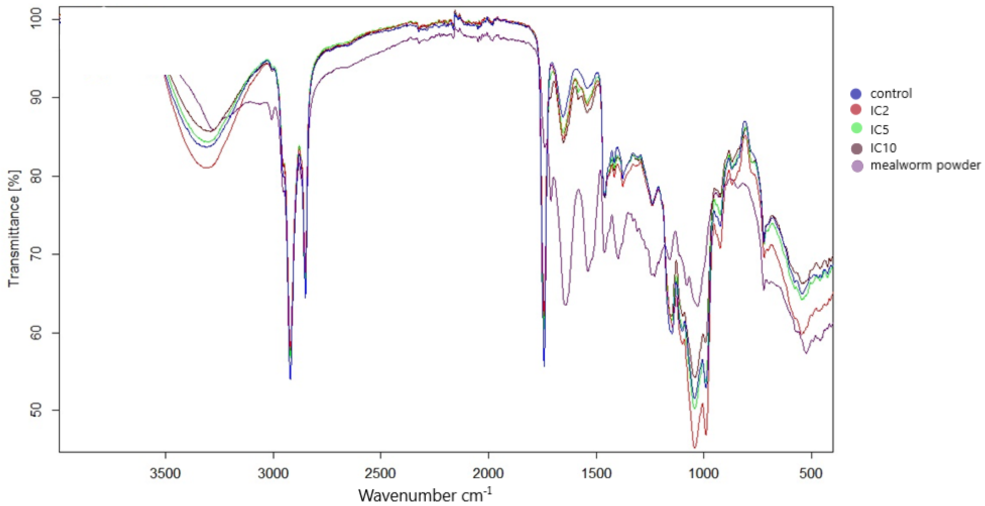

Figure 2. FT-IR spectra of the studied ice creams and mealworm powder.

4. Conclusions

This study was undertaken to identify the potential of edible insects to enhance ice cream's nutritional value and antioxidant properties. Edible insects can be incorporated into traditional products to improve their nutritional value, mainly their protein content. Nevertheless, this study showed that substituting ice cream with mealworm powder also changed the products' antioxidant and physical properties. Generally, the best results were obtained for the sample with the highest insect supplementation—10% by weight of cream. Briefly, mealworm powder fortification caused a significant increase in protein and ash content ($p < 0.05$). In this sample, the content of elements such as iron, magnesium and zinc was determined to be several times higher. The fatty acid profile also improved ($p < 0.05$). The addition of insects significantly delayed the onset of melting and reduced the melting rate, which is highly desirable for logistical reasons. Thus, edible insects, as a raw material with high antioxidant potential, have increased the bioactivity of ice cream. However, the fortification changed the ice cream's color, which is important for consumer acceptance. A necessary aspect of further research is a sensory evaluation of the product to determine the level of insect powder addition that is acceptable to consumers.

The main advantages attributed to insects are that they improve the nutritional and nutraceutical value of food. They are also appreciated for their sustainable impact on the environment, but this study has proved that edible insects might positively impact the physical characteristics of the food matrix. Evaluating the impact of adding insects to different types of food is necessary to learn about their interaction with other food components and to choose the best possible applications for insects in food technology.

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