Review: Nutritional Contents and Bioactive Compounds of Mealworm (Tenebrio molitor) as Edible Insect

I. Hanif¹, A. Apriantini², & Y. C. Endrawati¹,²,³*

¹Department of Animal Production and Technology, Faculty of Animal Science, IPB University
Jl. Agatis, Kampus IPB Darmaga Bogor 16680, Indonesia
²Research Center for Bioresources and Biotechnology, IPB University, Indonesia
³Halal Science Center, IPB University, Indonesia
*Corresponding author: y-cahya@apps.ipb.ac.id
(Received 14-08-2023; Revised 04-10-2023; Accepted 11-10-2023)

ABSTRACT

Mealworms (ulat hongkong) are larvae of the rice beetle (Tenebrio molitor) which are considered pests but are also known to have a high content of nutrition and bioactive compounds. These bioactive compounds include antioxidants, anti-inflammatory agents, antidiabetic substances, and antihypertensive components. This literature study aims to review works of literature on the nutritional content and bioactive compounds present in mealworms, as well as the factors that influence this composition. The data search method used keywords such as nutrient content, bioactive composition, and factors influencing mealworms, conducted in reputable journals published within the last 10 years. The results of the literature study indicate that mealworms have high and complete nutritional content. The nutritional content and bioactive compounds in mealworms were influenced by feed, extraction methods, hydrolysis processes, and processing methods used. Freeze drying and microwave drying were recommended processing methods to maintain the nutritional content of mealworms. The main bioactive compounds in mealworms that provide health benefits were the bioactive peptides, omega-3, oleic acid, and chitosan.

Keywords: bioactive compounds, edible insect, mealworm, Tenebrio molitor
INTRODUCTION

Edible insects (insects that are fit for human consumption) are alternative food sources and nutritional resources with high potential. According to Jongema (2021), more than 2,100 insect species worldwide have been consumed such as mealworm, cricket, silkworm pupae, etc. Generally, edible insects are rich in protein, fats, several minerals (such as calcium, iron, and phosphorus), vitamin A, B-complex vitamins, and vitamin C (Pal and Roy 2014; Kuntadi et al. 2018).

Mealworms (Tenebrio molitor), commercially known as ulat hongkong, are a potential edible insect that can be developed in Indonesia. They are the larvae of the mealworm beetle and are commonly considered pests in grain products as they consume and degrade grain quality (Vigneron et al. 2019). Mealworms have a complete nutritional profile, comprising 52.35% protein, 24.70% fat, 2.20% carbohydrates, and 3.62% ash content (Zielińska et al. 2015). Kim et al. (2017) explain that mealworms are rich in oleic acid, α-linolenic acid, and linoleic acid. According to Oonincx & De Boer (2012), mealworm farming produces fewer greenhouse gas emissions and requires less land compared to other animal protein sources such as chicken, pork, and beef. This makes mealworm farming more environmentally friendly.

Figure 1. Mealworm (Tenebrio molitor)

These insects find primary use as animal feed and pets in Indonesia. However, in recent years, mealworms have been developed as an alternative food source and therapeutic agent, meaning they can be used for healing or medicinal purposes. Roncolini et al. (2019) conducted a study where they fortified bread with mealworm flour, resulting in highly nutritious bread. Moreover, mealworms were reported to contain bioactive compounds that offer various benefits to humans, including antioxidants, antidiabetic properties, antihypertensive effects, and anti-inflammatory properties (Zielińska et al. 2017; De Carvalho et al. 2019; Yoon et al. 2019; Zielińska et al. 2020).

Edible insects like mealworms were not widely known among the Indonesian population as a regular food or daily consumption, despite numerous studies demonstrating their high nutritional content and beneficial health effects for humans. This was primarily due to the lack of widespread information concerning the benefits and safety of consuming mealworms as a daily food source. Therefore, this study aims to examine and summarize various literature on the safety, nutritional content, composition of bioactive compounds, and factors influencing their contents. Additionally, the study aims to investigate the properties of these bioactive compounds as antioxidants, antidiabetic agents, antihypertensive substances, and anti-inflammatory agents.

MATERIAL AND METHODS

This study was conducted based on literature studies by analyzing secondary data and synthesizing research from various data sources originating from books, nationally accredited journals, and reputable international journals. The data source consists of 60 references, comprising 80% from publications within the last 10 years and 20% from publications within the last 15 years. The literature/articles topic discuss the nutritional content, composition of bioactive compounds, and factors influencing their contents.

RESULTS AND DISCUSSION

Mealworm

Mealworms belong to the taxonomy kingdom Animalia, phylum Arthropoda, class Insecta, order Coleoptera, family Tenebrionidae, genus Tenebrio, and species Tenebrio molitor L (Anderson et al. 1997). Mealworms, also known commercially as ulat hongkong in Indonesia, are the larvae of the rice beetle. The T. molitor insect has a positive value, particularly in its larval stage as a mealworm, as it can be farmed and traded as a food source for fish, reptiles, amphibians, and birds. However, in their adult form as beetles, they have a negative value as they can damage grains and human food reserves (Ramos-Elorduy et al. 2002).

The life cycle of T. molitor consists of egg, larva, pupa, and adult stages (Ong et al. 2018). The female can lay 250-1000 eggs, with an average of 400-500 eggs. The eggs are laid individually or in groups on substrates. They have a length ranging from 1.7-1.8 mm and a width of 0.6-0.7 mm. The incubation period of the eggs is highly influenced by the optimal temperature (Ghaly and Alkoaik 2002). At a temperature of 25 °C, the eggs will hatch after approximately two weeks of incubation. Around two weeks after hatching, the larvae will emerge.

Figure 2. Life cicle of Tenebrio molitor (Ong et al. 2018)

Nutritional Content of Mealworms

Mealworms have high and complete nutritional content, making them a potential source of good nutrition for humans. In addition to their rich nutritional profile, mealworms also contain bioactive compounds that have
beneficial properties such as antioxidants, antidiabetic effects, antihypertensive properties, and anti-inflammatory activities (Zielinski et al. 2017; De Carvalho et al. 2019; Yoon et al. 2019; Zielinski et al. 2020).

Table 1 provides data on the nutritional content of mealworms from various literature sources, showing variations in their composition. Adamková et al. (2017a) stated that these differences can be attributed to factors such as feed, climate, and environmental conditions. A complete feed has a positive impact on the nutritional content of mealworms. Protein and fat are the predominant components of mealworms. The percentage of protein, fat, and ash content in mealworms among studies does not differ significantly, ranging from approximately 46% to 55% for protein, 24% to 37% for fat, and 2.86% to 4.84% for ash content.

A protein source food was defined as food that contains 5 g of protein per 100 g in an edible portion, while high protein food refers to food containing 10 g of protein per 100 g in an edible portion. Data in Table 1 shows that mealworms fall under the category of protein source and high protein food. Mealworms meet the criteria for being a protein source food and a high protein food (Nowak et al. 2016). Adamková et al. (2016) reported that the protein content of mealworms was higher than that of superworms (Zophobas morio), which belong to the same order as mealworms. Furthermore, the protein content of mealworms was higher than that of soybeans and comparable to the protein, 24% to 37% for fat, and 2.86% to 4.84% for ash content.

Protein and fat are the predominant components of mealworms. The percentage of protein, fat, and ash content in mealworms among studies does not differ significantly, ranging from approximately 46% to 55% for protein, 24% to 37% for fat, and 2.86% to 4.84% for ash content. The main essential amino acids found in mealworms are leucine, tyrosine, and valine (Table 2). The data also indicate some differences between the findings of Ghosh et al. (2017) and Stone et al. (2019), although the differences of vegetables in the diet in the study by Ravzanaadidi et al. (2012) may have influenced the fiber content of mealworms in that particular research.

The lowest fat content was reported in the studies by Zielinski et al. (2015) was 24.70%, while the highest fat content was obtained in the study by Bednarova et al. (2013) was 36.10%. This difference can be attributed to the boiling pre-treatment method employed by Jajic et al. (2019) and Zielinski et al. (2015), whereas other studies did not utilize boiling. This aligns with the findings of Adamková et al. (2017b) and Baek et al. (2019), who reported the lowest fat content in boiled mealworms. According to Sundari et al. (2015), boiling leads to a decrease in fat content due to the heat sensitivity of fats. During the cooking process, fats can melt and even vaporize (volatilize), resulting in the formation of other compounds such as flavors. Additionally, fats can undergo hydrolysis during this process. Boiling also results in higher moisture content compared to other cooking methods, potentially leading to lower nutritional values (Baek et al. 2019).

The protein content of mealworms was obtained in the study by Jajic et al. (2019) was 55.83%, while the lowest was reported in the study by Ravzanaadidi et al. (2012) was 46.44%. Similarly, the highest fiber content was observed in the study conducted by Jajic et al. (2019), while the lowest was found in the study by Zielinski et al. (2015). These variations can be attributed to the differences in mealworm feed used during the rearing stage in those studies. Jajic et al. (2019) utilized a combination of feeds such as wheat bran, dried barley germ, dried oat germ, barley flakes, oat flakes, and powdered beer yeast, along with apple slices for moisture requirements. The feed composition used in the study by Jajic et al. (2019) had high protein and fiber content, resulting in higher protein and fiber content in mealworms. On the other hand, Ravzanaadidi et al. (2012) solely used wheat bran as the feed with the addition of cabbage and carrot provided twice a week. The inclusion

### Table 1. Nutrient content of mealworm (per 100 g sample)

<table>
<thead>
<tr>
<th>Literature</th>
<th>Protein</th>
<th>Fat</th>
<th>Carbohydrate</th>
<th>Fiber</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wu et al. (2020)</td>
<td>52.23</td>
<td>29.42</td>
<td>11.22</td>
<td>-</td>
<td>4.30</td>
</tr>
<tr>
<td>Jajic et al. (2019)</td>
<td>55.83</td>
<td>25.19</td>
<td>-</td>
<td>7.15</td>
<td>4.84</td>
</tr>
<tr>
<td>Ghosh et al. (2017)</td>
<td>53.22</td>
<td>34.54</td>
<td>-</td>
<td>6.26</td>
<td>4.04</td>
</tr>
<tr>
<td>Zielinska et al. (2015)</td>
<td>52.35</td>
<td>24.70</td>
<td>2.2</td>
<td>1.97</td>
<td>3.62</td>
</tr>
<tr>
<td>Bednarova et al. (2013)</td>
<td>50.86</td>
<td>36.10</td>
<td>-</td>
<td>-</td>
<td>3.84</td>
</tr>
<tr>
<td>Ravzanaadidi et al. (2012)</td>
<td>46.44</td>
<td>32.70</td>
<td>-</td>
<td>4.58</td>
<td>2.86</td>
</tr>
</tbody>
</table>
observed were not significant, ranging from approximately 0.03 to 1.06 g. Additionally, the study by Ghosh et al. (2017) did not detect the presence of methionine, which could be attributed to the different analytical methods used. Ghosh et al. (2017) employed the Sykam Amino Acid Analyzer S433, while Stone et al. (2019) used the High Performance Liquid Analyzer. Zhang et al. (2019) stated that the amino acid content can be influenced by the feed used during rearing. Ghosh et al. (2017) used wheat bran as a feed with the addition of cabbage as a water source, while Stone et al. (2019) did not specify the feed used. Balandrán-Quintana et al. (2015) reported that the main essential amino acids in wheat bran are leucine, valine, and methionine, with methionine having the lowest content among them. This was consistent with the main and lowest content of amino acids observed in mealworms.

**Fatty Acid Content of Mealworms**

Mealworms have a relatively high fat content, ranging from approximately 24-36% (as seen in Table 1). The high fat content of mealworms makes them a potential alternative source of fats. Data from Table 3 show that the main fatty acids in mealworms were palmitic acid, oleic acid (omega-9), and linoleic acid (omega-6). Additionally, mealworms also contain alpha-linolenic acid (omega-3). However, there are variations in the results obtained by different studies, as shown in Table 4, with variations observed between the findings of Megido et al. (2018) and Paul et al. (2017) compared to the results of Wu et al. (2020). These variations may be attributed to differences in the extraction methods and solvents used. Megido et al. (2018) and Paul et al. (2017) used the Folch method with chloroform and methanol solvents, while Wu et al. (2020) used the Soxhlet method with petroleum ether solvent. This was consistent with the statement by Tzomp-Sosa et al. (2014) that the extraction method can influence the composition of fatty acids.

According to Wu et al. (2020), oleic acid accounts for 43.77% of the fatty acids in mealworms, which was higher than the content found in sunflower oil, corn oil, and soybean oil. The oleic acid content in mealworms is comparable to that found in beef tallow and lamb tallow (Adámková et al. 2016). Linoleic acid and alpha-linolenic acid are essential unsaturated fatty acids found in mealworms. Linoleic acid is a beneficial polyunsaturated fatty acid for heart health (Zielińska et al. 2015), but the ratio of omega-6 to omega-3 fatty acids in mealworms is not in line with the recommended ratio of 5:1 by the World Health Organization for human consumption. Mealworms have a higher ratio of 26:1 (Adámková et al. 2016). Many chronic conditions such as cardiovascular disease, diabetes, cancer, obesity, autoimmune diseases, rheumatoid arthritis, asthma, and depression are associated with increased production of thromboxane A2 (TXA2), leukotriene B4 (LTB4), interleukin-1β, interleukin-6, tumor necrosis factor (TNF), and C-reactive protein. All of these factors increase with higher intake of omega-6 fatty acids and reduced intake of omega-3 fatty acids (Simopoulos 2002).

**Mineral Content of Mealworms**

Mealworms are reported to contain relatively high levels of micronutrients, particularly minerals. Data from Table 4 indicate that the main minerals found in mealworms are phosphorus and potassium. Phosphorus plays a beneficial role in bone health when consumed in appropriate amounts. Most phosphorus in the human body is found in bone minerals (Vorland et al. 2017). Potassium is beneficial for heart and kidney health. According to He and MacGregor (2008), a high-potassium diet can lower blood pressure and inhibit the development of kidney disease.

Data from Table 4 also indicate variations in the results obtained from each study. The difference in sample size used by Kim et al. (2017) and Finke (2015) compared to Ghosh et al. (2017) and Zielińska et al. (2017) was a

**Table 2. Essential amino acids content of mealworms (per 100 g sample)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Valine</td>
<td>2.94</td>
<td>3.45</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>1.98</td>
<td>2.54</td>
</tr>
<tr>
<td>Leucine</td>
<td>3.37</td>
<td>4.43</td>
</tr>
<tr>
<td>Lysine</td>
<td>2.01</td>
<td>2.62</td>
</tr>
<tr>
<td>Threonine</td>
<td>1.83</td>
<td>1.94</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>1.76</td>
<td>1.95</td>
</tr>
<tr>
<td>Methionine</td>
<td>-</td>
<td>0.72</td>
</tr>
<tr>
<td>Histidine</td>
<td>2.80</td>
<td>2.68</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>3.45</td>
<td>3.42</td>
</tr>
</tbody>
</table>

**Table 4. Minerals content of mealworm**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>--------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>---------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Calcium</td>
<td>349.2</td>
<td>156</td>
<td>78.42</td>
<td>41</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>5677.4</td>
<td>2640</td>
<td>1039.2</td>
<td>-</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1376.4</td>
<td>620</td>
<td>315.23</td>
<td>304</td>
</tr>
<tr>
<td>Zink</td>
<td>98.7</td>
<td>49.5</td>
<td>11.74</td>
<td>11.2</td>
</tr>
<tr>
<td>Iron/Cu</td>
<td>62.8</td>
<td>20.7</td>
<td>10.02</td>
<td>3.29</td>
</tr>
<tr>
<td>Copper/Cu</td>
<td>11.4</td>
<td>8.3</td>
<td>2</td>
<td>1.86</td>
</tr>
<tr>
<td>Manganese</td>
<td>7</td>
<td>3.2</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>Potassium</td>
<td>-</td>
<td>3350</td>
<td>737</td>
<td>835</td>
</tr>
<tr>
<td>Sodium</td>
<td>225</td>
<td>-</td>
<td>-</td>
<td>57</td>
</tr>
</tbody>
</table>
factor that can influence the outcomes of these studies. The results obtained by Kim et al. (2017) were higher than those obtained by Finke (2015). This difference could be since Kim et al. (2017) used dried mealworm samples, while Finke (2015) did not perform prior drying. Dried samples have a lower water content, resulting in increased nutrient concentrations.

The study by Ghosh et al. (2017) reported higher mineral content compared to Zielnińska et al. (2017), except for potassium content. The difference in drying methods between the two studies was believed to have influenced the results obtained. Ghosh et al. (2017) used freeze drying, while Zielnińska et al. (2017) used oven drying. Back et al. (2019) also stated that freeze drying produces better mineral content compared to oven drying. This is because freeze drying involves very low temperatures, which helps preserve the mineral content and other nutrients, whereas oven drying involves higher temperatures that can degrade the mineral content and other nutrients, resulting in lower nutritional content.

**Activity of Bioactive Compounds in Mealworms**

Bioactive compounds are functional compounds found in animal or plant-derived food ingredients that can exert biological effects. Mealworms were reported to contain various bioactive compounds that offer benefits to humans, including antioxidant, antidiabetic, antihypertensive, and anti-inflammatory properties (Table 5).

**Antioxidant**

Antioxidants are compounds that can inhibit oxidation reactions by capturing free radicals and highly reactive molecules. Reactive oxygen species (ROS) are oxidants produced within the body that can trigger oxidative stress and lead to tissue dysfunction and degenerative diseases (Ali et al. 2008). In food products, antioxidants are used to inhibit oxidation reactions that can cause damage, rancidity, color changes, and off-flavors.

Data from Table 6 shows that the mealworm extract in the study by Kim et al. (2018) exhibited better inhibition percentage and inhibition concentration of DPPH (2,2-diphenyl-1-picrylhydrazyl) compared to the study by Baek et al. (2019). This can be attributed to the optimization of mealworm extract extraction for obtaining good antioxidant activity in the study by Kim et al. (2018). The optimization process included the concentration of ethanol, temperature, and extraction time. The optimal results showed that mealworm extract extraction using 72% ethanol at a temperature of 88.1 °C for 43.7 minutes. In addition, Kim et al. (2018) used two solvents, ethanol, and water, while Baek et al. (2019) used only ethanol. According to del Hierro et al. (2019), the higher polarity of the ethanol: water solvent compared to ethanol alone can result in higher total phenolic compound content, which correlates positively with the antioxidant activity of the mealworm extract. Baek et al. (2019) also diluted the crude extract obtained using dimethyl sulfoxide (DMSO), which affected the extract concentration tested in the DPPH test.

The data from Table 6 shows that the percentage and inhibition concentration of DPPH in the mealworm protein hydrolysate, as reported by Zielnińska et al. (2017), are better than those reported by Messina et al. (2019). This difference can be attributed to the variation in enzymes and hydrolysis treatments used in the two studies. Zielnińska et al. (2017) performed the hydrolysis of mealworm protein using digestive enzymes (α-amylase, pepsin, pancreatin, and bile extract solution), while Messina et al. (2019) used the enzymes proteamex, flavourzyme, and alkalase for hydrolysis.

Baek et al. (2019) reported that mealworms subjected to different cooking methods exhibit varying antioxidant activities. The DPPH test was conducted on mealworms processed using various methods, including microwave, freeze drying, frying, steaming, boiling, and oven baking. Mealworms processed using these methods showed antioxidant activities ranging from 20.9% to 29.0% at a concentration of 2000 μg ml⁻¹, which is similar to the antioxidant activity levels of 40-60 μM of tocopherol (22.7% to 33.2%). However, mealworms treated with hot air drying, roasting, and pan frying exhibited lower antioxidant activities of 13.7% to 14.8% at 2000 μg ml⁻¹.

**Table 5. Bioactive compound of mealworm**

<table>
<thead>
<tr>
<th>Literature</th>
<th>Sample Source</th>
<th>Bioactive compound</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baek et al. (2019)</td>
<td>Mealworm extract</td>
<td>-</td>
<td>Antioxidant</td>
</tr>
<tr>
<td>Kim et al. (2018)</td>
<td>Mealworm extract</td>
<td>-</td>
<td>Antioxidant</td>
</tr>
<tr>
<td>Del Hierro et al. (2020)</td>
<td>Mealworm extract</td>
<td>Sekuen peptida: NYVADGLG, AAAPVAVAK, YDDGSKYPH, AGDDAPR</td>
<td>Antioxidant Antiinflammatory</td>
</tr>
<tr>
<td>Zielnińska et al. (2017)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>Senyawa flavonoid, tokoferol, kitin dan kitosan</td>
<td>Antioxidant Antiinflammatory</td>
</tr>
<tr>
<td>Son et al. (2020)</td>
<td>Mealworm extract and oil</td>
<td>Omega 9, kitosan, sekuen peptida: NYVADGLG, AAAPVAVAK, YDDGSKYPH, AGDDAPR</td>
<td>Antidiabetic Antihypertensive</td>
</tr>
<tr>
<td>Zielnińska et al. (2020)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kim et al. (2019)</td>
<td>Mealworm extract</td>
<td>-</td>
<td>Antidiabetic</td>
</tr>
<tr>
<td>Yoon et al. (2019)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>-</td>
<td>Antidiabetic Antihypertensive</td>
</tr>
<tr>
<td>Cito et al. (2017)</td>
<td>Mealworm Extract Protein</td>
<td>-</td>
<td>Antihypertensive</td>
</tr>
</tbody>
</table>
Phenolic compounds have been reported to be present in mealworms. Phenolic compounds are known as antioxidants commonly found in natural ingredients. Kim et al. (2018) reported an optimized extraction of mealworms with a phenolic content of 5.6 mg GAE g⁻¹. Baek et al. (2019) found a total phenolic content of 9.23 mg GAE g⁻¹ in freeze-dried mealworms. According to Fu et al. (2011), there was a positive correlation between the percentage of DPPH inhibition and total phenolic compounds. Flavonoids are a group of phenolic compounds that can be found in mealworms (Son et al. 2020).

Tocopherol, also known as vitamin E, is an antioxidant compound that can influence antioxidant activity. Mancini et al. (2019) conducted antioxidant capacity testing with different feed treatments. The results showed that mealworms fed with leftover cookies had the highest tocopherol content, which also made them have the highest antioxidant capacity. This was likely because the feed contained higher levels of fat compared to other feeds, resulting in higher concentrations of tocopherol.

Mealworms, as high-protein insects, contain bioactive peptides. Bioactive peptides are defined as peptide sequences within proteins that provide beneficial effects on body functions and/or have positive impacts on human health beyond their known nutritional value (Kitts and Weiler 2003). These bioactive peptides can function as antioxidants. The reported peptide sequences with antioxidant activity in mealworms are NYVADGLG, AAAPVAVAK, YDDGSYKPH, and AGDDAPR (Zielińska et al. 2017). Zielińska et al. (2017) conducted protein hydrolysis of mealworm proteins using two different heating methods (boiling and baking). Protein hydrolysates are proteins that have been broken down into smaller fragments. The results showed that the IC₅₀ values of mealworm protein hydrolysates in the ABTS and DPPH tests were as follows: for the boiling method, 28.9 µg/ml and 97.45 µg/ml, respectively, and for the baking method, 24.5 µg/ml and 85.85 µg/ml, respectively. The heating treatment was found to enhance the antioxidant activity. These findings indicate that mealworms have the potential to be a source of bioactive peptides that function as antioxidants.

### Antidiabetic

Mealworms were reported to have benefits as antidiabetic agents. The antidiabetic activity of mealworms is characterized by the inhibition of the enzyme α-glucosidase. α-glucosidase is one of the main targets in the treatment of diabetes, as it functions to break down starch into glucose in the mucosa of the small intestine before absorption by the duodenum and the upper jejunum (Asgar 2013). Inhibition of α-glucosidase enzyme activity can help lower blood glucose levels.

The data in Table 7 shows that the percentage and inhibition concentration of protein hydrolysates from mealworms in Zielińska et al. (2020) were better than those in Yoon et al. (2019). The differences in enzymes and hydrolysis conditions in both studies were believed to affect the inhibitory activity against α-glucosidase enzyme. Zielińska et al. (2020) conducted in vitro hydrolysis using digestive enzymes (pepsin, pancreatin, and bile extract solution), while Yoon et al. (2019) performed hydrolysis using the enzymes flavourzyme and alkalase.

Mealworm extract has also been reported to have the ability to improve insulin sensitivity, which plays a role in the treatment of diabetes. Kim et al. (2019) reported that diabetic rats fed a mixture of feed containing mealworm extract showed increased insulin sensitivity and were effective in controlling blood glucose levels. Peptide sequences (NYVADGLG, AAAPVAVAK, YDDGSYKPH, AGDDAPR), omega-3, and chitosan are bioactive components in mealworms that have been reported to have antidiabetic activity (Iwase et al. 2015; Seo et al. 2010; Zielińska et al. 2020).

### Antihypertensive

Mealworms have been reported to have antihypertensive activity through the inhibition of Angiotensin Converting Enzyme (ACE). ACE is an enzyme that plays an important role in blood vessel regulation. Inhibiting ACE can cause blood vessel relaxation, thereby reducing blood pressure levels.

Data from Table 8 shows that the protein hydrolysate of mealworms in the study by Cito et al. (2017) is superior to that of Yoon et al. (2019) and comparable to Zielińska et al. (2017). The differences in enzyme and hydrolysis conditions were likely to be the reasons for the variations in the results. Cito et al. (2017) and Zielińska et al. (2020) conducted in vitro hydrolysis using digestive enzymes (pepsin, trypsin, bile extract, and α-chymotrypsin) under conditions simulating the digestive system.

---

### Table 6. Antioxidant Activity of mealworm

<table>
<thead>
<tr>
<th>Literature</th>
<th>Source</th>
<th>Inhibition percentage (%)</th>
<th>Inhibitory concentration (µg ml⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim et al. (2018)</td>
<td>Mealworm extract</td>
<td>50</td>
<td>91.8</td>
</tr>
<tr>
<td>Baek et al. (2019)</td>
<td>Mealworm extract</td>
<td>29</td>
<td>2000</td>
</tr>
<tr>
<td>Zielińska et al. (2017)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>50</td>
<td>85.85</td>
</tr>
<tr>
<td>Messina et al. (2019)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>15</td>
<td>5000</td>
</tr>
</tbody>
</table>

### Table 7. Inhibitory activity of mealworm α-glycosidase enzymes

<table>
<thead>
<tr>
<th>Literature</th>
<th>Source</th>
<th>Inhibition percentage (%)</th>
<th>Inhibitory concentration (µg ml⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoon et al. (2019)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>35</td>
<td>2000</td>
</tr>
<tr>
<td>Zielińska et al. (2020)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>50</td>
<td>7.8</td>
</tr>
</tbody>
</table>
Table 8. Inhibitory activity of mealworm angiotensin converting enzyme

<table>
<thead>
<tr>
<th>Literature</th>
<th>Source</th>
<th>Inhibition percentage (%)</th>
<th>Inhibitory concentration (µg ml⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoon et al. (2019)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>Zielińska et al. (2020)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Cito et al. (2017)</td>
<td>Mealworm Protein hydrolyzate</td>
<td>50</td>
<td>97</td>
</tr>
</tbody>
</table>

Yoon et al. (2019) performed hydrolysis using alkalase enzyme.

Pessina et al. (2020) reported that defatted mealworms significantly reduced blood pressure in hypertensive rats. Bioactive peptides play an important role in ACE inhibition. Dai et al. (2013) identified the peptide sequence tyrosine-alanine-asparagine as a peptide involved in ACE inhibitory activity. According to Zielińska et al. (2020), the peptide sequences NYVADGLG, AAAPVAVAK, YDDGSYKPH, and AGDDAPR exhibit anti-hypertensive activity. Additionally, oleic acid present in mealworms may also contribute to their anti-hypertensive properties. Ravzanaadii et al. (2012) stated that oleic acid can lower blood pressure and cholesterol levels in humans.

**Anti-inflammatory**

Mealworms have been reported to exhibit anti-inflammatory activity. This activity is attributed to the inhibition of the enzymes lipooxygenase and cyclooxygenase. Lipooxygenase and cyclooxygenase are key enzymes involved in the inflammatory process.

The data in Table 9 indicates the difference in results between the studies conducted by Zielińska et al. (2017) and Zielińska et al. (2018). The peptide fractions of mealworms selected through gel filtration chromatography exhibited superior anti-inflammatory activity compared to the results of protein hydrolysis with different treatments. This indicates that the separation using gel filtration chromatography is effective in producing peptides with anti-inflammatory activity.

Heating treatment can also influence the IC₅₀ results. Heating treatment shows an increase in IC₅₀ values. Bioactive peptides are reported to play a role in inhibiting the enzymes lipooxygenase and cyclooxygenase. According to Zielińska et al. (2017), the peptide sequences NYVADGLG, AAAPVAVAK, YDDGSYKPH, and AGDDAPR found in mealworms could inhibit lipooxygenase and cyclooxygenase enzymes that regulate blood pressure. Mealworms contain chitin and chitosan, which are known to alleviate degenerative joint diseases by preventing inflammation in the joints (Son et al. 2020).

**Mealworms as Processed Food**

**Processed Mealworm Products**

Mealworms have the potential to be used as an ingredient in processed food products, which can enhance the products’ nutritional value. Several countries have researched processed products enriched with mealworms.

The data in Table 10 shows that all processed mealworm products have higher protein, fat, and ash content in comparison to the control. Choi et al. (2017) and Kim et al. (2016) used mealworm flour as a substitute for pork in sausage products at a 10% inclusion level. This resulted in higher protein, fat, and ash content in comparison to the control, which used pork at 50% in Choi et al. (2017) and 60% in Kim et al. (2016). According to Choi et al. (2017), frankfurter sausages formulated with a combination of mealworms and pork showed a higher protein content and lower fat content in comparison to the control, which used pork at 60%.
of 40% pork and 10% mealworm flour exhibited similar characteristics in terms of cooking loss, emulsion stability, and protein solubility compared to the control sausages. The hardness, chewiness, and density of sausages with a combination of 50% pork and 10% mealworm flour were higher than those of the control sausages (Kim et al. 2016).

Roncolini et al. (2019) and Gonzalez et al. (2018) replaced wheat flour with 5% mealworm flour in bread production. The results showed higher protein, fat, and ash content in comparison to the control without mealworm flour. The use of 5% mealworm flour resulted in bread with high volume and low firmness. This could be due to the fat content in the mealworm flour added to the bread, as fat increases the trapped air during mixing. The resulting bread also had a darker color in comparison to the control, which could be attributed to the increased maillard reaction in the bread with the addition of mealworm flour.

CONCLUSION

Mealworms offer a wide range of essential nutrients influenced by factors like feed quality and processing methods. Freeze drying and microwave drying are recommended techniques to maintain the nutritional content of mealworms. The main bioactive compounds in mealworms that provide health benefits were the bioactive peptides, omega-3, oleic acid, and chitosan. The activity of bioactive compounds in mealworms is influenced by the extraction and hydrolysis processes. Bioactive peptides found in mealworms are the predominant bioactive compounds responsible for their functional activities. Reported peptide sequences with functional bioactive activities in mealworms include NYVADGLG, AAAPVAVAK, YDDGSYKPH, and AGDDAPR.

REFERENCES


He, F. J. & G. A. MacGregor. 2008. Beneficial effects of...


Stone, A. K., T. Tanaka, & M. T. Nickerson. 2019. Protein October 2023 161


