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

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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*

ABSTRAK

Ulat tepung (ulat hongkong) merupakan larva dari kumbang beras (*Tenebrio molitor*) yang dianggap hama, namun diketahui juga memiliki kandungan gizi dan senyawa bioaktif yang baik. Ulat tepung diketahui memiliki kandungan senyawa bioaktif yang bermanfaat sebagai antioksidan, antiinflamasi, antidiabetes dan antihipertensi. Studi pustaka ini bertujuan mereview antar literatur mengenai kandungan zat gizi dan senyawa bioaktif yang terdapat pada ulat tepung, serta faktor yang mempengaruhi kandungan tersebut. Metode pencarian data menggunakan kata kunci kandungan nutrisi, komposisi bioaktif, dan faktor yang mempengaruhi ulat tepung, yang dicari pada jurnal bereputasi terbit 10 tahun terakhir. Hasil studi pustaka menunjukkan bahwa ulat tepung memiliki kandungan gizi yang lengkap. Kandungan gizi dan senyawa bioaktif pada ulat tepung dipengaruhi oleh pakan, metode ektraksi, proses hidrolisis, serta metode pengolahan yang digunakan. *Freeze drying* dan *microwave drying* merupakan pengolahan yang direkomendasikan untuk mempertahankan kandungan gizi ulat tepung. Senyawa bioaktif utama ulat tepung yang memiliki manfaat kesehatan adalah peptida bioaktif, omega-3, asam oleat dan kitosan.

Kata kunci : edible insect, senyawa bioaktif, *Tenebrio molitor*, ulat tepung

INTRODUCTION

Edible insects (insects that are fit for human consumption) are alternative food sources and nutritional resources with high potential. According to Jongema (2017), more than 2,100 insect species worldwide have been consumed such as mealworn, 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 2009). 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.

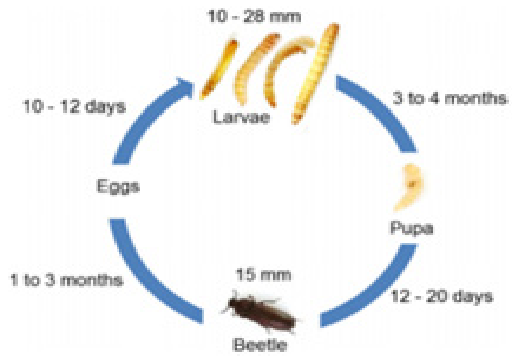

Figure 2. Life cicle of Tenebrio molitor (Ong *et al.* 2018)

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

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

Literature	Protein	Fat	Carbohydrat	Fiber	Ash
		----------------------------------	%	----------------------------------	
Wu *et al.* (2020)	52.23	29.42	11.22	-	4.30
Jajic *et al.* (2019)	55.83	25.19	-	7.15	4.84
Ghosh *et al.* (2017)	53.22	34.54	-	6.26	4.04
Zielińska *et al.* (2015)	52.35	24.70	2.2	1.97	3.62
Bednářová *et al.* (2013)	50.86	36.10	-	-	3.84
Ravzanaadii *et al.* (2012)	46.44	32.70	-	4.58	2.86

beneficial properties such as antioxidants, antidiabetic effects, antihypertensive properties, and anti-inflammatory activities (Zielińska *et al.* 2017; De Carvalho *et al.* 2019; Yoon *et al.* 2019; Zielińska *et al.* 2020).

Table 1 provides data on the nutritional content of mealworms from various literature sources, showing variations in their composition. Adámková *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). Adámková *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 content of chicken, fish, and beef on a dry weight basis (Van Huis *et al.* 2013; Bosch *et al.* 2014).

The highest 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 Ravzanaadii *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 Zielińska *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, Ravzanaadii *et al.* (2012) solely used wheat bran as the feed with the addition of cabbage and carrot provided twice a week. The inclusion of vegetables in the diet in the study by Ravzanaadii *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 Zielińska *et al.* (2015) was 24.70%, while the highest fat content was obtained in the study by Bednářová *et al.* (2013) was 36.10%. This difference can be attributed to the boiling pre-treatment method employed by Jajic *et al.* (2019) and Zielińska *et al.* (2015), whereas other studies did not utilize boiling. This aligns with the findings of Adámková *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 found in mealworms contains a complete profile of essential amino acids, as indicated in Table 2. This demonstrates the protein quality of mealworms. According to Zhao *et al.* (2016), mealworm protein extract contains 449.30 g of essential amino acids per kg of mealworm protein, which is sufficient to meet human requirements of 277 g/kg of protein. Mealworm protein has a digestibility of approximately 75.7% as tested in vitro (Stone *et al.* 2015). Marono *et al.* (2015) attribute this to the presence of chitin in mealworms. The content of chitin and chitosan in mealworms was reported as 4.92% and 3.65%, respectively (Song *et al.* 2018). Mealworms have cuticular proteins bound with chitin (Finke 2007), and chitin is not digestible in the small intestine. Therefore, proteins bound by chitin are also not digestible. Additionally, Marono *et al.* (2015) suggest that chitin can protect proteins from digestive enzymes. The chitin content is reported to be influenced by the age at harvest. Mealworms harvested at 2 months of age have lower chitin content compared to those harvested at 3 months of age. This is because mealworms at 2 months of age have thinner exoskeletons compared to those at 3 months of age (Siregar and Suptijah 2014).

Essential Amino Acid Content in Mealworms

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

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

Essential amino acids	Ghosh *et al.* (2017)	Stone *et al.* (2019)
Valine	2.94	3.45
Isoleucine	1.98	2.54
Leucine	3.37	4.43
Lysine	2.01	2.62
Threonine	1.83	1.94
Phenylalanine	1.76	1.95
Methionine	-	0.72
Histidine	2.80	2.68
Tyrosine	3.45	3.42

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 Tzompa-Sosa *et al.* (2014) that the extraction method can influence the composition of fatty acids.

Tabel 3. The content of mealworm fat

Fatty acids	Megido *et al.* (2018)	Paul *et al.* (2017)	Wu *et al.* (2020)
	-----------------------	%------------------------	
Myristic acid	4.40	4.45	2.12
Palmitic acid	21.30	21.33	17.24
Stearic acid	7.90	7.92	0.69
Oleic acid	35.80	35.83	43.77
Linoleic acid	22.80	22.83	29.39
α-linoleic acid	0.10	0.11	2.27

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 4. Minerals content of mealworm

Minerals	Kim *et al.* (2017)	Finke (2015)	Ghosh *et al.* (2017)	Zielińska *et al.* (2015)
	-------mg kg^{-1}------		------mg 100 g^{-1}------	
Calcium	349.2	156	78.42	41
Phosfor	5677.4	2640	1039.2	-
Magnesium	1376.4	620	315.23	304
Zink	98.7	49.5	11.74	11.2
Iron/Fe	62.8	20.7	10.02	3.29
Copper/Cu	11.4	8.3	2	1.86
Manganese	7	3.2	1.5	-
Potassium	-	3350	737	835
Sodium	-	225	-	57

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 Zielińska *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 Zielińska *et al.* (2017) used oven drying. Baek *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 Zielińska *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. Zielińska *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 protamex, 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 $\mu g\ ml^{-1}$, 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 $\mu g\ ml^{-1}$.

Tabel 5. Bioactive coumpound of mealworm

Literature	Sample Source	Bioactive coumpound	Functions
Baek *et al.* (2019)	Mealworm extract	-	Antioxidant
Kim *et al.* (2018)	Mealworm extract	-	Antioxidant
Del Hierro *et al.* (2020)	Mealworm extract	-	Antioxidant
Zielińska *et al.* (2017)	Mealworm Protein hydrolyzate	Sekuen peptida: NYVADGLG, AAAPVAVAK, YDDGSYKPH, AGDDAPR	Antioxidant Antiinflammatorry
Son *et al*. (2020)	Mealworm extract and oil	Senyawa flavonoid, tokoferol, kitin dan kitosan	Antioxidant Antiinflammatorry
Zielińska *et al.* (2020)	Mealworm Protein hydrolyzate	Omega 9, kitosan, sekuen peptida: NYVADGLG, AAAPVAVAK, YDDGSYKPH, AGDDAPR	Antidiabetic Antihypertensive
Kim *et al.* (2019)	Mealworm extract	-	Antidiabetic
Yoon *et al.* (2019)	Mealworm Protein hydrolyzate	-	Antidiabetic Antihypertensive
Cito *et al.* (2017)	Mealworm Extract Protein	-	Antihypertensive

Table 6. Antioxidant Activity of mealworm

Literature	Source	Inhibition percentage (%)	Inhibitory concentration (μg ml^{-1})
Kim *et al.* (2018)	Mealworm extract	50	91.8
Baek *et al.* (2019)	Mealworm extract	29	2000
Zielińska *et al.* (2017)	Mealworm Protein hydrolyzate	50	85.85
Messina *et al.* (2019)	Mealworm Protein hydrolyzate	15	5000

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 7. Inhibitory activity of mealworm α-glycosidase enzymes

Literature	Source	Inhibition percentage (%)	Inhibitory concentration (μg ml^{-1})
Yoon *et al.* (2019)	Mealworm Protein hydrolyzate	35	2000
Zielińska *et al.* (2020)	Mealworm Protein hydrolyzate	50	7.8

Table 8. Inhibitory activity of mealworm angiotensin converting enzyme

Literature	Source	Inhibition percentage (%)	Inhibitory concentration (µg ml^{-1})
Yoon *et al.* (2019)	Mealworm Protein hydrolyzate	80	200
Zielińska *et al.* (2020)	Mealworm Protein hydrolyzate	50	100
Cito *et al.* (2017)	Mealworm Protein hydrolyzate	50	97

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

Table 9. Mealworm anti-inflammatory activity

Literature	Source	Treatment	Inhibitor concentration (IC_{50})	
			Lipoksigenase Inhibition (mg ml^{-1})	Siklooksigenase Inhibition (µg ml^{-1})
Zielińska *et al.* (2017)	Mealworm Protein hydrolyzate	Fresh	94.68	9.88
		Oven	62.17	11.33
		Boil	38.4	11.46
Zielińska *et al.* (2018)	Selected mealworm peptide fractions	Fresh	29.8	3.11
		Oven	2.18	0.91
		Boil	4.83	0.89

Table 10. The nutritional content of processed products with the addition of mealworms

Literature	Processed product	Control			Treatment		
		Protein	Fat	Ash	Protein	Fat	Ash
		--------------%-------------			--------------%------------		
Choi *et al*. (2017)	Frankfurters Sausage	10.03	20.71	2.14	14.33	24.92	2.31
Kim *et al.* (2016)	Sausage	22.63	18.86	5.59	26.08	19.57	5.28
Roncolini *et al.* (2019)	Wheat bread	8.91	0.09	0.49	10.54	0.48	0.53
Gonzalez *et al.* (2018)	Wheat bread	9	0.23	0.69	10.13	0.9	0.85

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 bioactive functional activities in mealworms include NYVADGLG, AAAPVAVAK, YDDGSYKPH, and AGDDAPR.

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