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Nutritional Status and Safety Assessment on Edible Insect Reared in Indonesia

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ABSTRACT

Stunting in children, pregnancy complications, and osteoporosis in the elderly remain prevalent in Indonesia, often linked to protein deficiency. This issue is particularly common among lower socio-economic groups, where limited purchasing power reduces protein consumption. The availability of protein sources is further threatened by climate change and declining environmental quality. Conventional protein sources also contribute to environmental degradation. Hence, there is a pressing need for sustainable, affordable, and environmentally friendly protein alternatives. The FAO has recognized edible insects as a viable future protein source. This study focuses on evaluating the nutritional content and food safety of three types of edible insects: mealworms, superworms, and Black Soldier Fly Larvae (BSFL). The research uses a Completely Randomized Design (CRD) with two factors: species (S) and larval condition (K). Six treatments are tested, each with three replications. Nutritional parameters assessed include carbohydrates, fats, proteins, antioxidants, and vitamins, while food safety is evaluated through microbial contamination and heavy metal analysis. Edible insects, such as mealworms, superworms, and BSFL, offer a varied nutritional profile, including protein, fat, carbohydrates, vitamin E, and antioxidants, making them a promising alternative protein source.

Kata kunci:

Ketahanan Nutrisi
Keamanan Pangan
Sumber Protein
Sustainable
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ABSTRAK

Stunting pada anak, komplikasi kehamilan, dan osteoporosis pada lansia masih menjadi masalah prevalen di Indonesia, yang sering kali terkait dengan kekurangan protein. Masalah ini terutama terjadi pada kelompok masyarakat dengan status sosial ekonomi rendah, di mana keterbatasan daya beli mengurangi konsumsi protein. Ketersediaan sumber protein semakin terancam oleh perubahan iklim dan penurunan kualitas lingkungan. Sumber protein konvensional juga berkontribusi pada kerusakan lingkungan. Oleh karena itu, diperlukan alternatif protein yang berkelanjutan, terjangkau, dan ramah lingkungan. FAO telah mengakui serangga yang dapat dimakan sebagai sumber protein yang layak di masa depan. Penelitian ini bertujuan untuk mengevaluasi kandungan gizi dan keamanan pangan dari tiga jenis serangga yang dapat dimakan: mealworm, superworm, dan Black Soldier Fly Larvae (BSFL). Penelitian ini menggunakan Rancangan Acak Lengkap (RAL) dengan dua faktor: spesies (S) dan kondisi larva (K). Enam perlakuan diuji, masing-masing dengan tiga replikasi. Parameter gizi yang dianalisis meliputi karbohidrat, lemak, protein, antioksidan, dan vitamin, sementara keamanan pangan dinilai melalui kontaminasi mikroba dan analisis logam berat. Serangga yang dapat dimakan, seperti mealworm, superworm, dan BSFL, menawarkan profil gizi yang bervariasi, termasuk protein, lemak, karbohidrat, vitamin E, dan antioksidan, menjadikannya sumber protein alternatif yang menjanjikan.

INTRODUCTION

Nutritional adequacy in Indonesia remains a significant challenge, particularly for vulnerable populations such as children and pregnant women. According to the latest estimates, one in five children aged 0–5 years in Indonesia was at risk of stunting in 2020 (UNICEF/WHO/WBG, 2022). Stunting has long-term effects on physical and cognitive development, increasing the risk of poor academic performance and reduced economic productivity in adulthood. Recent studies show that nutrient intake across regions in Indonesia is uneven. For instance, in Jakarta, 71% of children aged 25–30 months consumed less than the recommended daily energy intake, averaging only 865 kcal per day (Fikawati et al., 2021). In Nabire, 30% of children aged 6–24 months were found to be protein deficient (Ibrahim et al., 2023). These data highlight an urgent need for strategies to improve protein intake, particularly in rural and economically disadvantaged areas.

Protein plays an essential role in growth, development, and overall health, with a minimum daily requirement of 0.8 grams per kilogram of body weight (Russell et al., 2023). Deficiencies in protein intake are strongly associated with increased risks of stunting in children (Fikawati et al., 2021) and pregnancy complications that can affect both maternal and fetal outcomes (R. Ekawati et al., 2022). Protein deficiency in Indonesia is closely linked to the socio-economic status of families, especially in lower-income groups where limited purchasing power reduces access to high-quality protein sources (Beal et al., 2018). Economic disparities in Indonesia have driven a growing need for affordable and sustainable protein alternatives that can meet the nutritional requirements of vulnerable populations (Ekawati et al., 2022).

In response to this challenge, edible insects have emerged as a promising solution. Since 2010, the Food and Agriculture Organization (FAO) has advocated for the consumption of edible insects as a sustainable protein source (van Huis et al., 2013). Recent studies have reaffirmed the nutritional value of edible insects, emphasizing their high protein content, rich bioactive compounds, and minimal environmental impact (Li et al., 2023). Several countries, including Australia and New Zealand, have approved mealworms, superworms, and house crickets as safe for human consumption (NSW Food Authority, 2021). Additionally, the European Food Safety Authority has recently expanded the list of approved insect species to include Black Soldier Fly (BSF) larvae and lesser mealworms (van Huis, 2023). These developments highlight the growing acceptance of edible insects as part of the global food system.

Despite global advancements in the study and commercialization of edible insects, research on their potential as a protein source in Indonesia remains limited. Most existing studies focus on global contexts, particularly in Europe, Australia, and the United States, where edible insects are increasingly integrated into the food industry as alternative protein sources (van Huis et al., 2013; Li et al., 2023). However, in Indonesia, local research on the nutritional content and food safety of key edible insect species—such as mealworms, superworms, and Black Soldier Fly (BSF) larvae—is scarce and fragmented. This gap is significant given Indonesia's unique ecological and socio-economic conditions, which may influence both the nutritional profile and safety aspects of edible insects cultivated locally (Hanif et al., 2023).

Moreover, while several studies have evaluated the nutritional content of edible insects globally (Alves et al., 2016; Roncolini et al., 2019), these findings cannot be directly applied to Indonesia due to differences in cultivation practices, environmental factors, and feed composition, which are known to affect nutrient profiles and heavy metal accumulation in insects (Noyens et al., 2023). The limited availability of comprehensive local data poses challenges for policymakers and food industry stakeholders aiming to promote edible insects as a sustainable food source.

From a food safety perspective, there is an urgent need for more localized research to assess microbial contamination and heavy metal content in edible insects cultivated in Indonesia. Studies from other countries have highlighted potential risks related to improper processing and contamination during insect farming (Misnayati et al., 2022; Korn et al., 2008). These risks must be thoroughly evaluated in the Indonesian context to ensure consumer safety and establish regulatory frameworks aligned with national food safety standards.

Theoretically, this study draws upon concepts from sustainability science and nutrition transition theory. Sustainability science emphasizes the importance of developing environmentally friendly food systems that reduce reliance on resource-intensive animal protein (Rockström et al., 2009). Meanwhile, nutrition transition theory highlights the shifting dietary patterns in developing countries, where rising incomes often lead to increased consumption of animal-based protein despite the environmental costs (Popkin, 2010). In Indonesia, edible insects offer a practical solution that aligns with both frameworks by providing a high-protein, low-environmental-impact alternative that can bridge the gap between nutritional needs and sustainable food production.

Thus, this study aims to fill these knowledge gaps by conducting a comprehensive assessment of the nutritional content and food safety of edible insects cultivated in Indonesia. By focusing on mealworms (Tenebrio molitor), superworms (Zophobas morio), and Black Soldier Fly (BSF) larvae (Hermetia illucens), this research provides an in-depth evaluation of their potential as alternative protein sources. Specifically, the study investigates their nutritional profiles, including the analysis of carbohydrates, proteins, fats, antioxidants, and vitamins, which are essential components of a balanced diet. In addition to nutritional content, the study also examines critical food safety aspects such as microbial contamination and heavy metal accumulation, which are key factors in determining the suitability of edible insects for human consumption.

This comprehensive approach is expected to generate valuable empirical data that can bridge existing knowledge gaps in the literature. By presenting a detailed analysis of both nutritional benefits and potential safety risks, the study will contribute significantly to the body of knowledge on alternative protein sources. Furthermore, the findings will offer scientific support for the formulation of national policies aimed at promoting edible insects as a sustainable and affordable source of nutrition.

The relevance of this study aligns with Indonesia's 2045 National Long-Term Development Plan (RPJPN), which emphasizes the importance of achieving food sovereignty and sustainability as part of the nation's long-term food security strategy (Government of Indonesia, 2023). Given the increasing global and local demand for sustainable food systems, this research not only addresses an urgent national need but also positions Indonesia to become a leader in integrating edible insects into the future of food security and nutrition. Research Questions:

1. What is the nutritional status of three edible insect species cultivated in Indonesia?
2. What are the food safety aspects of edible insects cultivated in Indonesia?

METHOD

Materials

The materials used in this study were carefully selected to ensure accurate and reliable results across all stages of the experiment. These include basic ingredients and chemical reagents required for sample preparation, nutritional content analysis, and food safety testing. Specifically, Bimandiri okra, Arabic gum, guar gum, xanthan gum, cooking oil, water, and green food coloring were used in sample processing. Analytical reagents, such as buffer solutions with pH 2–9, 1M sodium hydroxide (NaOH), 1M hydrochloric acid (HCl), sodium chloride (NaCl), 96% ethyl alcohol, and acetone, were essential for chemical analysis and microbial testing. These reagents ensured the accuracy and precision of the tests conducted.

The equipment utilized in this study included both general laboratory apparatus and specialized tools to handle the preparation and analysis of edible insect samples. Equipment such as a Philips mixer, Sanyo EM-P microwave, and Panasonic MXJ1G dry blender were used for sample preparation, while a Memmert oven and water bath were employed for sample dehydration and controlled heating processes. The color of the samples was measured using a Minolta CR-300 colorimeter to ensure uniformity in sample preparation. Additionally, a Hettich Zentrifugen EBA 20 centrifuge was used for centrifugation processes, and an 80-mesh sieve ensured consistency in particle size for dry samples. Other laboratory equipment was employed as needed to maintain high standards of accuracy and consistency throughout the experiment.

Experiment Design

This study will be conducted over a period of 10 months. A quantitative experimental approach will be employed using a Factorial Completely Randomized Design (CRD) with two factors and three replications, resulting in 18 sample units. The first factor is species (S) with three levels: Mealworm (S1), Superworm (S2), and BSFL (S3). The second factor is sample condition (K) with two levels: K1 represents live larvae (Fresh), and K2 represents dried larvae. Thus, there will be six treatments with three replications, resulting in 18 sample units. The details of the experimental design are presented in Table 1. .

Table 1. Details of Treatments

Species / Condition	Mealworm (S1)	Super worm (S2)	BSFL (S3)
Fresh (K1)	S1K1 x 3 Replication	S2K1 x 3 Replication	S3K1 x 3 Replication
Dried (K2)	S1K2 x 3 Replication	S2K2 x 3 Replication	S3K2 x 3 Replication
		Total Unit Sample	18

Information :
S1K1 : Fresh *Mealworm*
S1K2 : Dried *Mealworm*
S2K1 : Fresh *Superworm*
S2K2 : Dried *Superworm*
S3K1 : Fresh BSFL
S3K2 : Dried BSFL

The data used in this study are primary data derived from laboratory analysis results. The laboratory tests, which include the identification of nutrient content and food safety aspects, will be conducted at the Integrated Testing Laboratory of the Universitas Trunojoyo Madura. The larval samples used in this study were obtained through direct purchase, both offline and online.

Sample Preparation

1. *Dry Samples*
   a. The dry larva samples were placed in a dehydrator for 30 minutes at 30°C to ensure the moisture content was suitable for milling.
   b. The samples were ground using a blender and sieved with a 100-mesh food-grade sieve.
   c. Each sample was weighed to 20 grams and placed in sterilized airtight glass containers, then stored in insulated packaging.
2. *Live Samples*
   a. Live larva samples underwent a fasting treatment for three days in a greenhouse to eliminate residual feed.
   b. After fasting, the larvae were dried using a dehydrator at 30°C for 180 minutes.
   c. The dried samples were ground and sieved with a 100-mesh food-grade sieve, weighed to 20 grams, and stored in sterilized airtight containers.

Nutrient Content Testing

The nutrient content tests include proximate analysis (to determine carbohydrate, fat, and protein content), antioxidant activity testing, and vitamin content.

1. Carbohydrate Analysis
   The *carbohydrate by difference* method is used to determine the carbohydrate content of the samples. This method is performed by subtracting the percentages of protein, fat, ash, and moisture from 100% (Kusumawati et al., 2019).
2. Fat Analysis
   The principle of this method involves extracting the fat from the sample using diethyl ether as a solvent (Kusumawati et al., 2019). The solvent is then evaporated, leaving only the fat, which is then weighed.
3. Protein Analysis

The Kjeldahl method (Aguirre, 2023) is used to determine the protein content of the samples using the following formula:

$$\% \text{ protein} = \frac{(A-B) \times N \times 14.007 \times 6.25 \times 100\%}{\text{Weight of the sample}}$$

Where,

- AA is the volume of HCl in the sample,
- BB is the volume of HCl in the blank,
- NN is the normality of the standard HCl,
- 14.007 is the atomic weight of nitrogen,
- 6.25 is the protein conversion factor.

4. Antioxidant Activity Analysis

The antioxidant activity is determined using the DPPH method (Yuniastri et al., 2020), also known as the DPPH radical scavenging assay. The percentage of antioxidant activity is measured using the following formula:

$$\% \text{ antioxidant} = \frac{Ac - A}{Ac} \times 100\%$$

Where:

- AcA_c is the absorbance value of the control,
- AA is the absorbance value of the sample.

5. Vitamin Analysis

The vitamin content is analyzed using UV-Vis spectrophotometry method (Kusumawati et al., 2019) by dissolving the sample in distilled water before measuring its absorbance.

Food Safety Testing

The food safety analysis focused on microbial contamination and heavy metal contamination. Microbial testing included Escherichia coli and yeast contamination (Cempaka et al., 2020), while heavy metal analysis tested for tin, lead, and cadmium using spectroanalytical methods (Korn et al., 2008).

Statistical Analysis

The primary data obtained from the laboratory tests are then subjected to statistical analysis to determine the significant effects of species and conditions on the nutritional content and food safety of edible insects. The primary data obtained were subjected to statistical analysis using one-way ANOVA to assess the significant effects of species and sample condition on nutritional content and food safety parameters. Post-hoc tests were conducted to identify significant differences between treatment groups.

RESULTS OF STUDY

Table 2 presents the results of proximate analysis, including the moisture and ash content of edible insect samples across six different treatments. The moisture and ash content varied significantly depending on the insect species and sample condition (fresh or dried). The results of the moisture content analysis show significant variation among the different treatments of edible insect samples. The highest moisture content was observed in S3K1 (dried BSFL) at 46.06%, while the lowest was found in S1K1 (live mealworms) at 12.60%. This substantial difference in moisture content indicates that the species and sample condition (fresh or dried) significantly influence the water content in edible insects.

The statistical analysis using a Completely Randomized Design (CRD) revealed a significance value of 0.00 (<0.05), indicating that the treatments had a significant effect on the moisture content of the samples. Further analysis using the Least Significant Difference (LSD) test showed no significant difference between S1K1 and S1K2 or between S1K2 and S2K1, suggesting that the moisture content in these treatments was relatively similar. However, significant differences were observed in all other treatments, highlighting distinct variations in moisture retention across species and sample conditions. The high moisture content in dried BSFL (S3K1) suggests that even after drying, the sample retains considerable water content, which may affect its storage stability and shelf life. In contrast, the low moisture content in live mealworms (S1K1) indicates better storage potential with less risk of microbial growth due to reduced water activity.

The ash content analysis also revealed notable differences among the treatments. The highest ash content was found in S2K2 (dried superworms) at 8.28%, while the lowest was observed in S1K1 (live mealworms) at 1.99%. Ash content serves as an indicator of the total mineral content in the sample, suggesting that dried superworms have a higher concentration of minerals compared to live mealworms.

The CRD analysis yielded a significance value of 0.00 (<0.05), confirming that the treatments had a significant effect on ash content. Further analysis using the LSD test showed no significant difference in ash content between S2K2 and S3K1, implying similar mineral concentrations in these treatments. Significant differences, however, were observed among the other treatments, reflecting the influence of species and processing conditions on mineral content. The high ash content in S2K2 (dried superworms) may indicate a higher concentration of essential minerals, which could contribute to their nutritional value. On the other hand, the low ash content in S1K1 (live mealworms) suggests a lower mineral concentration, likely due to the higher water content diluting the mineral content.

Table 2. Results of Moisture and Ash Content Analysis

Sample	Water (%)	Ash (%)
S1K1	12,60 ± 0,341[a]	1,99 ± 0,031[a]
S1K2	13,41 ± 0,103[ab]	6,26 ± 0,150[b]
S2K1	14,07 ± 0,661[bc]	6,74 ± 0,191[c]
S2K2	16,23 ± 0,971[d]	8,28 ± 0,401[d]
S3K1	21,84 ± 0,513[e]	7,92 ± 0,214[de]
S3K2	46,06 ± 1,429[f]	5,43 ± 0,343[f]

Table 3 presents the proximate analysis results, including protein, lipid (fat), carbohydrate content, vitamin E, and antioxidant activity for edible insect samples across six different treatments. The results indicate that the nutritional content varied significantly depending on the insect species and sample condition (fresh or dried). The statistical analysis using Completely Randomized Design (CRD) revealed a significance value of 0.00 (<0.05) for all parameters, confirming that the treatments significantly affected the nutritional composition of the samples.

The highest protein content was observed in S2K1 (live superworms) at 37.94%, while the lowest protein content was found in S3K1 (live BSFL) at 16.07%. The protein content differed significantly across treatments, with the Least Significant Difference (LSD) test showing no significant difference between S2K1 and S2K2, indicating that the drying process did not substantially affect the protein levels in superworms. In contrast, significant differences were observed between most other treatments, suggesting that both species type and sample condition influence protein content.

Lipid content was highest in S3K2 (dried BSFL) at 25.30%, while the lowest was recorded in S1K1 (live mealworms) at 14.56%. The significant difference in fat content across treatments indicates that BSFL samples generally contained higher lipid levels compared to mealworms and superworms. The drying process also appeared to increase fat concentration in BSFL and superworms, likely due to the reduction in moisture content, resulting in a relative increase in fat proportion.

The carbohydrate content varied widely among treatments. The highest carbohydrate content was found in S1K2 (dried mealworms) at 42.26%, while the lowest was observed in S3K2 (dried BSFL) at 2.95%. The significant variation in carbohydrate content suggests that species type has a strong influence on this parameter. Mealworms, particularly in their dried form, showed the highest carbohydrate levels, making them a potential energy source for consumers.

Vitamin E content was highest in S3K1 (live BSFL) at 17.69 µg/mL, while the lowest content was recorded in S1K1 (live mealworms) at 5.67 µg/mL. The results indicate that BSFL samples generally contain more vitamin E compared to other species, particularly when fresh. The LSD test showed significant differences across all treatments, emphasizing the variability in vitamin E concentration due to both species and processing conditions.

The highest antioxidant activity was observed in S1K1 (live mealworms) at 190.91 ppm, while the lowest was recorded in S3K1 (live BSFL) at 83.03 ppm. The significant differences in antioxidant activity across treatments suggest that live mealworms have higher antioxidant capacity compared to other treatments. The reduction in antioxidant activity in dried samples could be attributed to the effects of heat and prolonged processing, which may degrade antioxidant compounds.

In summary, the proximate analysis highlights the nutritional diversity of edible insects, with each species and sample condition offering distinct nutritional advantages. Superworms and BSFL are high in protein and fat, while mealworms are an excellent source of carbohydrates and antioxidants. These results underscore the potential of edible insects as a sustainable food source with diverse nutritional profiles.`

Table 4 presents the results of heavy metal analysis, focusing on tin (Sn), lead (Pb), and cadmium (Cd) concentrations in edible insect samples across six different treatments. The results show that the levels of these heavy metals varied significantly based on the insect species and sample condition (fresh or dried), as confirmed by the statistical analysis using the Randomized Complete Block Design (RAL) with a significance value of 0.00 (<0.05) for all parameters.

The tin content was highest in S2K2 (dried superworms) at 0.06 ppm, while the lowest tin content was found in S1K1 (live mealworms) and S3K1 (live BSFL) at 0.03 ppm. The significant variation in tin content suggests that the species type and drying process influence tin accumulation in the samples. Post-hoc BNT analysis showed no significant difference between S2K1 (live superworms) and S2K2 (dried superworms), indicating that drying did not significantly alter tin content in superworms. However, significant differences were observed among the other treatments. Despite these variations, all tin levels were well below the maximum allowable limits for human consumption, indicating that the samples are safe in terms of tin content.

The highest lead content was recorded in S2K2 (dried superworms) at 0.02 ppm, while the lowest lead content was found in treatments S1K1 (live mealworms), S3K1 (live BSFL), and S3K2 (dried BSFL) at 0.01 ppm. The lead content varied significantly among treatments, with the BNT analysis showing no significant difference between S1K1 and S3K1 or S1K1 and S3K2, suggesting relatively consistent lead levels in those treatments. Despite the presence of lead in all samples, the concentrations were well within the safety standards for processed foods, ensuring that the samples pose no immediate risk to consumers.

Table 3. Results of Proximate Analysis

Sample	Protein (%)	Lipid (%)	Carbohydrate (%)	Vitamin E (µg/ml)	Antioxidant (ppm)
S1K1	36,21 ± 0,711[a]	14,56 ± 0,652[a]	34,52 ± 1, 627[a]	5,67 ± 0,173[a]	190,91 ± 41,09[a]
S1K2	21,78 ± 0,310[b]	16,29 ± 0,740[b]	42,26 ± 0,900[b]	8,26 ± 0,529[b]	107,90 ± 1,172[b]
S2K1	37,94 ± 0,462[c]	17,76 ± 0,290[bc]	23,49 ± 0,784[c]	7,22 ± 0,271[c]	125,17 ± 4,350[b]
S2K2	37,92 ± 0,932[cd]	18,40 ± 0,866[d]	19,17 ± 2,513[d]	8,89 ± 0,199[d]	102,69 ± 7,374[b]
S3K1	16,07 ± 0,401[e]	22,98 ± 0,396[e]	31,37 ± 0,328[e]	17,69 ± 0,040[e]	89,31 ± 0,596[bc]
S3K2	20,26 ± 0,996[f]	25,30 ± 0,533[f]	2,95 ± 0,927[f]	11,32 ± 0,023[f]	83,03 ± 1,906[bd]

Table 4. Results of Metal Analysis

Sample	Tin (ppm)	Lead (ppm)	Cadmium (ppm)
S1K1	0,03 ± 0,00[a]	0,01 ± 0,00[a]	0,00 ± 0,00[a]
S1K2	0,04 ± 0,00[b]	0,01 ± 0,00[b]	0,00 ± 0,00[b]
S2K1	0,05 ± 0,02[c]	0,02 ± 0,00[c]	0,01 ± 0,00[c]
S2K2	0,06 ± 0,00[cd]	0,02 ± 0,00[d]	0,04 ± 0,05[d]
S3K1	0,04 ± 0,00[e]	0,01 ± 0,00[a]	0,00 ± 0,00[e]
S3K2	0,03 ± 0,01[f]	0,01 ± 0,00[ae]	0,00 ± 0,00[bf]

The cadmium content was highest in S2K2 (dried superworms) at 0.05 ppm, whereas the other treatments showed cadmium levels ranging from 0.00 to 0.01 ppm. The RAL analysis indicated a significant effect of treatments on cadmium content, with BNT analysis revealing no significant difference between S1K2 (dried mealworms) and S3K2 (dried BSFL), but significant differences among the other treatments. The relatively low cadmium content in most treatments suggests minimal exposure to cadmium sources during cultivation and preparation. All cadmium concentrations were below the permissible limits for food safety, indicating that the samples are safe for consumption.

The results demonstrate that heavy metal concentrations in edible insects vary depending on species and processing methods. Tin, lead, and cadmium levels across all treatments were below the established safety limits, confirming that the samples meet food safety standards. These findings highlight the importance of monitoring heavy metal content to ensure consumer safety and reinforce the potential of edible insects as a safe and sustainable protein source.

Table 5 presents the results of microbial analysis, focusing on Escherichia coli (E. coli) and yeast counts in edible insect samples across six different treatments. The results indicate significant variations in microbial contamination based on species and sample condition (fresh or dried). The presence of E. coli and yeast serves as an important indicator of food safety and hygiene practices during sample preparation.

The E. coli contamination levels varied significantly across treatments. The highest E. coli count was observed in S1K2 (dried mealworms) at 5.8×10^2 CFU/g, while the lowest was found in S3K2 (dried BSFL) at 1.0×10^2 CFU/g. Statistical analysis using the Randomized Complete Block Design (RAL) confirmed that treatment had a significant effect on E. coli contamination, with a significance value of 0.00 (<0.05).

Post-hoc BNT analysis revealed no significant differences in E. coli contamination between S2K2 and S3K1 or between S3K1 and S3K2, indicating similar levels of contamination in those treatments. However, significant differences were found among the other treatments. The high E. coli count in S1K2 suggests potential issues related to sanitation during drying or handling processes, which may have contributed to bacterial growth. In contrast, the low E. coli levels in S3K2 indicate that proper handling and processing reduced the risk of contamination.

The yeast counts also showed variation across treatments, although the levels remained relatively low. The highest yeast count was observed in S1K1 (live mealworms) at 1.7×10^1 CFU/g, while samples S1K2 and S2K1 had yeast counts of 1×10^1 CFU/g. The other samples (S2K2, S3K1, S3K2) showed no detectable yeast contamination (negative results). According to regulatory standards, the yeast levels across all treatments were well below the allowable limits for processed foods, indicating that the samples were microbiologically safe in terms of yeast contamination. Proper sanitation during sample preparation likely contributed to the absence of yeast in most dried samples (S2K2, S3K1, S3K2).

The microbial analysis highlights that E. coli contamination poses a greater risk compared to yeast in edible insect samples. The high E. coli count in some treatments underscores the importance of stringent hygiene and handling practices during sample preparation, especially for dried samples. Despite these variations, most samples remained within acceptable limits, ensuring their microbiological safety for consumption. Enhanced quality control measures during the drying and storage processes could further minimize microbial risks, ensuring higher food safety standards for edible insect products.

Table 5. Results of Microbial Analysis

Sample	E. Coli (CFU/g)	Yeast (CFU/g)
S1K1	$1{,}8 \times 10^3$	$1{,}7 \times 10^1$
S1K2	$5{,}8 \times 10^2$	1×10^1
S2K1	$4{,}4 \times 10^2$	1×10^1
S2K2	$2{,}6 \times 10^2$	Negatif
S3K1	$1{,}7 \times 10^2$	Negatif
S3K2	$1{,}0 \times 10^2$	Negatif

DISCUSSIONS

Nutritional Composition of Edible Insects

The findings from this study reveal that edible insects such as mealworms, superworms, and Black Soldier Fly Larvae (BSFL) offer diverse nutritional profiles, making them a promising source of alternative protein. Protein content in superworms was notably higher compared to other species, particularly in fresh samples (S2K1), suggesting that superworms could be prioritized as a protein-rich food source. The variation in protein content across treatments highlights the influence of both species and processing methods on nutritional composition. Given the global rise in protein demand, incorporating edible insects into dietary strategies could provide a sustainable and cost-effective solution (van Huis & Oonincx, 2017; Kim et al., 2019; Li et al., 2023).

Lipid content was found to be the highest in dried BSFL (S3K2), indicating that drying concentrates fat content by reducing moisture. This high lipid level makes BSFL a potential energy-dense food source. However, the processing methods, particularly heat treatment, may also lead to the degradation of unsaturated fats, which warrants further investigation (Baek et al., 2022; Sundari et al., 2015). The carbohydrate content was highest in dried mealworms (S1K2), suggesting that mealworms may serve as a suitable energy source, complementing their protein content (Tzompa-Sosa et al., 2019).

The presence of vitamin E, particularly in BSFL, underscores its potential role as a functional food ingredient. Antioxidants, such as those found in mealworms, offer additional health benefits, including reducing oxidative stress and promoting overall health (Kim et al., 2021; Yuniastri et al., 2020). These findings align with global trends in functional foods, where the nutritional value of traditional protein sources is enhanced with bioactive compounds (Finke, 2015; Nowak et al., 2016).

Food Safety Aspects

The food safety analysis of edible insects is crucial to ensure consumer acceptance and trust. Moisture content, which influences microbial growth and shelf life, varied significantly across treatments. Dried BSFL (S3K2) retained higher moisture levels compared to other dried samples, suggesting that more stringent drying protocols may be necessary to improve shelf stability and reduce the risk of microbial contamination (Baek et al., 2022; Mishyna et al., 2020). Moisture reduction techniques like vacuum drying and freeze-drying have been suggested to enhance shelf life and reduce microbial risks in insect-based products (Caparros Megido et al., 2017).

Heavy metal analysis revealed that tin, lead, and cadmium levels in all samples were well below the safety limits established by the Indonesian National Standard (SNI 7378:2009) and BPOM Regulation No. 9 of 2022. Although the detected levels pose no immediate health risks, continuous monitoring is essential to prevent potential contamination due to changes in cultivation practices and environmental conditions (Korn et al., 2008; Charlton et al., 2015). The relatively higher cadmium content in dried superworms (S2K2) may be attributed to their feed composition, emphasizing the need for feed standardization in insect farming (Noyens et al., 2023; Purschke et al., 2017). Feed plays a critical role in determining the nutritional composition and safety of edible insects, necessitating regulatory guidelines for insect farming and feed quality (Belluco et al., 2017).

Microbial contamination, particularly with *Escherichia coli*, was observed in several treatments, especially in dried mealworms (S1K2). This finding suggests that hygiene practices during the drying process require improvement to prevent contamination. Implementing Hazard Analysis and Critical Control Points (HACCP) protocols in insect processing facilities could mitigate these risks and ensure product safety (Misnayati et al., 2022; Garrido et al., 2022). Adequate sanitation measures, along with controlled drying temperatures and time, have been shown to significantly reduce microbial loads in insect-based foods (van der Fels-Klerx et al., 2018).

Relevance to Food Sustainability and Policy

The integration of edible insects into food systems aligns with global efforts to promote sustainable food production. As the Indonesian government moves towards achieving food sovereignty under the 2045 National Long-Term Development Plan (RPJPN), edible insects offer a feasible solution to address the growing demand for protein while reducing environmental impact (Government of Indonesia, 2023). The low carbon footprint and minimal resource requirements of insect farming make it an attractive alternative to conventional livestock production (Dobermann et al., 2017; Oonincx & Finke, 2021; van Huis, 2023). Compared to conventional protein sources such as beef or pork, edible insects require less feed, water, and space, while emitting significantly lower greenhouse gases (Halloran et al., 2022).

Furthermore, promoting edible insects could have positive socio-economic impacts in rural areas, where small-scale insect farming could provide additional income and improve food security. Rural communities in developing countries could particularly benefit from insect farming, as it requires minimal investment and can be integrated into existing agricultural practices (Payne et al., 2016; Müller et al., 2021). To support this transition, public awareness campaigns and consumer education programs are essential to overcome cultural barriers and misconceptions about insect consumption (van Huis & Rumpold, 2023; Tan et al., 2023). Enhancing consumer knowledge about the nutritional and environmental benefits of edible insects is critical for fostering wider acceptance and mainstream adoption (Birch et al., 2022).

Limitations and Future Research

Despite the promising findings, this study has several limitations. First, the sample size and species selection were limited to three commonly cultivated species in Indonesia. Future research should explore a broader range of edible insect species to provide a more comprehensive assessment. Additionally, the impact of different feed compositions on the nutritional content and safety of edible insects warrants further investigation. Longitudinal studies on the health effects of regular insect consumption could also provide valuable insights for policymakers and the food industry.

CONCLUSIONS

Superworms demonstrated the highest protein content, particularly in fresh samples (37.94%), positioning them as a superior source of dietary protein. Dried BSFL had the highest fat content (25.30%), making them an energy-dense food option. Mealworms showed the highest carbohydrate content (42.26%) in dried form, while live BSFL had the highest vitamin E concentration (17.69 µg/mL). Antioxidant activity was particularly notable in live mealworms (190.91 ppm), suggesting their potential as a functional food ingredient.

Moisture and ash content varied significantly across species and processing treatments, affecting the shelf life and mineral content of the samples. Heavy metal analysis confirmed that levels of tin, lead, and cadmium in all samples were well below safety limits set by BPOM and SNI standards, ensuring consumer safety. However, the presence of Escherichia coli in some treatments highlights the need for improved hygiene practices during processing and storage.

This study contributes to the growing body of research supporting the integration of edible insects into sustainable food systems. It provides valuable empirical evidence for policymakers and food industry stakeholders to develop regulations and standards for the safe processing and marketing of edible insects. Promoting edible insects can contribute to achieving the goals outlined in Indonesia's 2045 National Long-Term Development Plan (RPJPN), particularly in enhancing food sovereignty and reducing the environmental impact of conventional protein sources.

To fully harness the potential of edible insects, it is essential to standardize insect farming practices, particularly feed composition and hygiene protocols, to minimize safety risks. Future research should focus on a broader range of insect species and explore the long-term health impacts of regular insect consumption. Public education campaigns and consumer engagement strategies are crucial to overcoming cultural barriers and increasing acceptance of edible insects as a mainstream food source.

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