

Research article

DEVELOPMENT OF INSECT-BASED TRADITIONAL CRACKERS: NUTRITIONAL PROFILE, PHYSICAL CHARACTERISTICS, AND SENSORY ACCEPTANCE

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ABSTRACT

Entomophagy, or the consumption of insects, has been an integral part of food culture in several regions of Indonesia, where crickets (Gryllidae) and grasshoppers (Acrididae) are typically fried and eaten as snacks or protein-rich side dishes. While these insects are usually served in simple fried forms incorporating them into widely recognized local foods could enhance consumer acceptance. *Kerupuk*, a culturally-familiar and widely-consumed popular Indonesian traditional cracker made from a starch–protein blend that is steamed dried, and deep-fried to achieve its airy crunch, is traditionally prepared with shrimp, fish, or plant-based ingredients, but rarely with insects. This study presents a novel approach by incorporating insect flour into Indonesian *kerupuk* as a strategy to improve the nutritional value of the product while reducing potential consumer resistance toward visible insect-based foods. Traditional crackers were produced using cricket flour (CC) and grasshopper flour (GC), comparing them with conventional shrimp crackers (SC) in terms of nutritional profile, physical characteristics, and sensory acceptance. Proximate analysis showed that fried insect crackers contained higher protein (CC: 24.93%, GC: 23.72%) than SC (19.65%), despite showing a slightly lower protein and lipid digestibility. Color analysis indicated insect crackers were darker than SC, yet expansion ratios (~375-379%) and crispness metrics were higher compared to SC (~313%). Sensory evaluation with 186 untrained panelists found no significant differences ($p>0.05$) among CC, GC, and SC in overall liking, but a higher preference related to crispness and hardness towards CC and GC compared to SC. These findings demonstrate that Indonesian *kerupuk* can serve as a practical and culturally acceptable food vehicle for edible insect incorporation, producing a protein-enriched snack with desirable crispness and sensory acceptance while supporting protein diversification and sustainable entomophagy in modern diets.

1. Introduction

The global population is projected to reach 9.8 billion by 2050, which is expected to cause a concurrent rise in food demand of up to 98% (Omuse *et al.*, 2024). Meeting this demand would put an unprecedented strain on natural resources, threatening the long-term viability of our current global food systems. Protein production is a major component of this challenge, as meat demand has already tripled over the last 50 years, reaching approximately 340 million metric tons per year (Ritchie & Poser, 2019). This immense scale of livestock farming is a primary driver of environmental pressure and raises significant questions about future food security (Imathiu, 2020). This unsustainable trajectory creates an urgent need for innovative and alternative ways to ensure that nutritious foods are available and accessible to all.

The human consumption of insects, known as entomophagy, has been a common practice throughout history in many cultures, particularly in parts of Africa, Asia, and Latin America (La Barbera *et al.*, 2018; Tedjakusuma *et al.*, 2022). It is estimated that close to 2,000 species are consumed globally, with the most common orders being beetles (31%), caterpillars (18%), and bees, wasps, and ants (14%), locusts, crickets and grasshoppers (13%) (Van Huis, 2019). In recent years, interest in entomophagy has surged as a potential solution to global food security challenges. This growing attention stems from the exceptional nutritional profile and sustainability of insects as a food source. Their crude protein content, which ranges from 40-75%, often surpasses that of traditional livestock and many plant proteins (Pereira & Vicente, 2013; Tang *et al.*, 2019; Tanga & Ekesi, 2024). Furthermore, insects are highly efficient, with about 80% of their body weight being consumable, compared to 55% for chicken and 40% for cattle. Beyond protein, they also offer diverse essential nutrients, including healthy fats, vitamins, antimicrobials, and chitin (van Huis & Rumpold, 2023).

Despite the potential benefits of insects as food, psychological factors such as food neophobia (reluctance to ingest unknown foods)

and disgust represent a significant barrier to the widespread adoption of insects persists, especially in Western cultures and urbanized society (Sogari *et al.*, 2019; Dagevos, 2021). A key strategy to overcome this psychological hurdle is to incorporate insects into familiar and well-liked food products in an ingredients such as powder, which are then incorporated into familiar foods such as pasta, snack, biscuits, or crackers (Boukid *et al.*, 2022; Montanari *et al.*, 2021).

Recent food product development studies have increasingly focused on improving the quality of familiar food matrices through the incorporation of alternative, sustainable, or underutilized ingredients (Petsong *et al.*, 2025; Karnjanapratum *et al.*, 2025). More specifically, several studies have demonstrated the feasibility of incorporating insect flour into familiar food products such as cookies, biscuits, pasta, bread, and other snack products, where insect powder is used to improve protein content while reducing the visual presence of whole insects (Colamatteo *et al.*, 2025; Adeniji *et al.*, 2025). However, many of these products are based on relatively dense bakery or cereal matrices, whereas expandable crackers such as *kerupuk* depend strongly on starch gelatinization, moisture vaporization, and the formation of a porous structure during frying. The incorporation of insect flour into this type of product may therefore affect not only nutritional value, but also expansion behavior, color development, oil absorption, microstructure, and crispness. Since insect flour contains high levels of protein, lipid, and chitin, its interaction with tapioca starch during steaming, drying, and frying may produce different physicochemical and sensory characteristics compared with conventional shrimp-based crackers. Therefore, traditional *kerupuk* provides a distinct and relevant food matrix for evaluating the application of insect flour in a culturally familiar snack product.

Kerupuk is a traditional expandable cracker widely consumed in Southeast Asia, particularly in Indonesia (Kusumaningrum *et al.*, 2019). It is typically prepared from tapioca starch combined with a protein source such as fish or shrimp,

followed by steaming, drying, and deep-frying to produce its characteristic airy and crispy texture (Mohamed *et al.*, 1989). Their expandable, crispy texture and savory flavor have made them a staple snack for all age groups. By substituting the traditional protein source with a sustainable insect-based alternative, there is a significant opportunity to enhance the nutritional value of a beloved food product while simultaneously increasing consumer acceptance of entomophagy.

While research has explored the fortification of various foods like bread and pasta with insect powder, there remains a specific gap in the literature concerning the development of traditional, deep-fried, expandable crackers. The unique physicochemical properties of these crackers, particularly their nutrition value and physical properties, present a novel challenge when incorporating a new protein ingredient. Therefore, this study aims to develop a traditional crackers made from cricket flour (CC) and grasshopper flour (GC), comparing them with conventional shrimp crackers (SC) in terms of nutritional profile, physical characteristics, and sensory acceptance.

2. Materials and methods

2.1. Materials

Live house crickets (*Acheta domesticus*) and live Javanese grasshoppers (*Valanga nigricornis*) were obtained from a local supplier in Gunung Kidul, Yogyakarta, Indonesia. The insects were selected based on visual quality, including intact body structure, absence of visible defects, and apparent healthy condition. Fresh whiteleg shrimp (*Litopenaeus vannamei*) was purchased from a local market in Jakarta, Indonesia, and used as the conventional animal protein source for the control cracker formulation. Tapioca starch, salt, sugar, and palm oil for frying were also purchased from a local market in Jakarta, Indonesia. All raw materials were transported to the laboratory under hygienic conditions and processed immediately or stored appropriately before cracker preparation.

2.2. Methods

2.2.1. Preparation of insect flour and traditional crackers

The preparation of insect-based traditional crackers was performed following the traditional method communicated by a local cracker producer in Jakarta, Indonesia, with minor adjustments for hygienic and laboratory-scale handling. Insect handling until euthanization was performed as previously described by Surya *et al.* (2025). Wingless live house crickets and Javanese grasshoppers in the juvenile stage (approximately 3 weeks and 4 weeks post-hatch respectively, sex-mixed), clinically healthy and free of visible defects, were obtained from a local commercial farm. Insects were held off-feed for 48 h with access to moisture only to purge gut contents. Live insects were then humanely euthanized by rapid cryo-immersion in liquid nitrogen ($-196\text{ }^{\circ}\text{C}$; 60–120 s) using a perforated stainless-steel cup, thawed on ice, rinsed with potable water, and blanched in boiling water for 5 min. Blanched insects were drained and dried in a hot-air oven at $60\text{ }^{\circ}\text{C}$ until constant weight, ground with a high-speed blender, and sieved through a 60-mesh screen to obtain uniform cricket flour (CF) and grasshopper flour (GF). Commercial shrimp raw material was similarly processed to produce shrimp flour (SF) as the conventional control protein source.

Kerupuk dough was prepared based on a traditional formulation communicated by a local cracker producer in Jakarta, Indonesia, with minor adjustments for hygienic and laboratory-scale handling. The same base formulation was used for all treatments, consisting of 45% tapioca starch, 50% protein source, 2% salt, 3% sugar, and 60 mL water per 100 g dry mix. The protein source consisted of shrimp flour, cricket flour, or grasshopper flour for the preparation of shrimp crackers (SC), cricket crackers (CC), and grasshopper crackers (GC), respectively. Water was added gradually at approximately 60 mL per 100 g of dry mixture to obtain a thick and cohesive dough suitable for steaming and slicing. The protein source was substituted at the same proportion across treatments to ensure that differences in nutritional composition, physical

characteristics, microstructure, and sensory acceptance were mainly attributable to the type of protein flour used. Dry ingredients were homogenized, water was gradually added to form a thick cohesive dough, and the dough was kneaded until uniform. The dough was then shaped into cylindrical logs (approximately 3–4 cm diameter), wrapped in heat-resistant plastic, and steamed at 100 °C for 60 min. After steaming, the logs were cooled to room temperature and stored at 4 °C overnight (about 12–16 h) to stabilize the gel structure. The chilled logs were sliced into discs of uniform thickness (2 mm) using a stainless-steel slicer and sun-dried for approximately 48 h under hygienic conditions until a moisture content below about 10% was reached, yielding dried raw crackers. For final preparation, dried crackers were deep-fried in palm oil at 180 °C for 30–45 s until fully expanded and light golden, producing shrimp crackers (SC), cricket crackers (CC), and grasshopper crackers (GC), which were drained of excess oil, cooled to room temperature, and stored in airtight containers prior to analysis.

2.2.2. Proximate composition and oil uptake analysis

The proximate composition of the samples was determined using standard methods from the Association of Official Analytical Chemists (AOAC), adapted from the procedure described by Surya *et al.* (2024) with minor modifications. Specifically, moisture content was measured gravimetrically after oven-drying at 135°C for 2 hours, and ash content was determined by incineration at 550°C. Crude fat was quantified using a Soxhlet apparatus with petroleum ether, while crude protein was analyzed via the Kjeldahl method. Total carbohydrate content was then calculated by difference, with all final values expressed on a wet weight basis.

Frying oil uptake was estimated based on the increase in crude fat content after frying. The calculation was performed by subtracting the crude fat content of the corresponding dried raw cracker from that of the fried cracker, as follows: oil uptake (%) = fat content of fried cracker (%) – fat content of dried raw cracker (%). Using this approach, the estimated oil uptake values were

calculated for each treatment based on the proximate composition data.

2.2.3. *In vitro* nutrient digestibility

Aqueous extract of crackers was prepared by homogenized it with distilled water in a 1:10 (w/v) ratio. The resulting puree was filtered through cheesecloth, and the collected filtrate was used for subsequent analysis.

2.2.3.1. Protein digestibility

The *in vitro* protein digestibility was carried out based on a previously described method (Surya *et al.*, 2024). In brief, a 5 mL aliquot of samples was subjected to enzymatic hydrolysis with a protease mixture containing trypsin, chymotrypsin, and pancreatin (1 mg each). The digestion was carried out at 37°C for 30 minutes. A blank sample (extract without enzymes) and a control sample (casein) were run concurrently. Following incubation, undigested proteins were precipitated by adding 2 mL of 0.5 M trichloroacetic acid and separated via centrifugation. The quantity of soluble, digested peptides in the resulting supernatant was then quantified using the Folin-Ciocalteu reagent. The absorbance of the final mixture was measured spectrophotometrically at 750 nm.

2.2.3.2. Lipid digestibility

In vitro lipid digestibility was evaluated by measuring the release of free fatty acids (FFAs) using a modified titration method (Lie & Surya, 2024). Briefly, 25 mL of samples were subjected to enzymatic hydrolysis with a mixture of lipase (10 mg), pancreatin (10 mg), and bile salt (20 mg) during a 15-minute incubation at 37°C. Following digestion, a 5 mL aliquot of the digestate was prepared for Formol titration by adding 1.35 mL of 37.5% formaldehyde and phenolphthalein indicator. The free fatty acids were then quantified by titrating the mixture against 0.1 N sodium hydroxide (NaOH). Lipid digestibility was calculated based on the FFA content and expressed as a percentage of oleic acid equivalents.

2.2.4. Physical properties analysis

The surface color of the fried crackers was measured using a HunterLab colorimeter, recording the CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) values. The crispness

parameter of the crackers were evaluated using a texture analyzer equipped with an acoustic sensor according to Sanz *et al.*, (2007). To simulate the action of biting, a wedge-shaped aluminum probe (30° angle, 15 mm wide) was used to fracture the cracker transversally at a speed of 40 mm/s. During penetration, a force-deformation curve was generated. Simultaneously, the sound emitted during the fracture event was recorded by a microphone placed at a fixed distance of 5 cm from the sample. To ensure the accuracy of the acoustic data, all tests were conducted inside an isolated acoustic chamber to eliminate external noise interference. The linear expansion ratio was calculated by measuring the average diameter of the crackers before and after frying, expressed as a percentage increase.

2.2.5. Microstructure analysis

The internal microstructure of the insect-based crackers was examined using Scanning Electron Microscopy (SEM). Cracker samples were cut into rectangular pieces (~5 × 5 mm) using a stainless-steel blade to expose the internal fracture surface without compression. Samples were subsequently frozen at -80 °C for 24 h and freeze-dried (-55 °C, <0.05 mbar; 48 h) to remove structural water and prevent collapse of the porous matrix. Dried specimens were mounted onto standard aluminum stubs using conductive carbon adhesive tabs, ensuring that the fractured surface was oriented upward and remained uncompressed. Mounted samples were sputter-coated with a gold layer (~10 nm thickness) using a vacuum sputter coater (60 s coating time; 20 mA current) to improve surface conductivity and image quality. SEM observations were conducted using a high-resolution field-emission scanning electron microscope under high-vacuum mode. Images were captured at an acceleration voltage of 10–15 kV, a working distance of 8–12 mm, and chamber pressure of 5–10 Pa.

2.2.6. Sensory evaluation

All crackers were evaluated by 186 untrained adult panelists aged approximately 18–45 years, comprising both male and female participants. Panelists were recruited from the university community, including students and

staff, and participated voluntarily after providing written informed consent. Before participation, panelists were informed that the products contained shrimp and/or edible insects, and individuals reporting known allergies to crustaceans, shellfish, or edible insects were excluded from the sensory evaluation.

All crackers were evaluated for sensory quality attributes with 186 untrained panelists. Each cracker sample was assigned a randomly generated three-digit code and presented to the panelists in a randomized and balanced serving order to minimize potential order and carry-over effects. Approximately two pieces of each cracker sample were served at room temperature on separate plates. Drinking water was provided, and panelists were instructed to cleanse their palate between samples. For the hedonic rating test, panelists were asked to rate the samples for appearance, aroma, hardness, crispness, mouthfeel, taste, and overall liking using a 9-point hedonic scale, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. In addition, panelists were also asked to perform an overall preference ranking of the three cracker samples. For the ranking test, panelists ranked the samples from 1 to 3, where 1 indicated the most preferred sample and 3 indicated the least preferred sample. The mean ranking score was then calculated for each sample, with a lower mean rank indicating greater overall preference. Written informed consent was obtained from all participants before testing. All procedures related to sensory evaluation were approved by the BINUS University Research Ethics Committee, followed institutional guidelines for human subject research, and complied with the principles of the Declaration of Helsinki.

2.3. Data analysis

All data were organized and analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Nutritional composition, *in vitro* digestibility, color parameters, texture/acoustic parameters, and expansion ratio data were obtained from at least three independent measurements ($n \geq 3$) and are presented as mean ± standard deviation.

Differences among samples were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post hoc test to determine significant differences between means. Sensory hedonic rating data obtained from 186 untrained panelists were also expressed as mean $\pm$ standard deviation and analyzed using one-way ANOVA followed by Tukey's HSD test. For the overall preference ranking test, rank data were analyzed using the Friedman test, followed by pairwise comparison using the Wilcoxon signed-rank test with Bonferroni adjustment when significant differences were observed. For the ranking test, lower mean rank values indicated higher overall preference. Statistical significance was declared at $p < 0.05$.

3. Results and discussions

3.1. Effect of cricket and grasshopper flour on the nutritional profile of fried crackers

Incorporating insect flour into crackers was shown to increase protein content (Table 1).

Both CF and GF had the highest crude protein level, at 75.26% and 72.58%, respectively, which was significantly higher than SF's 63.77%. This pattern was observed in the final product, where fried CF and GF had a significantly higher protein content than fried SF. In contrast, after deep-frying, the fat content in all crackers increased significantly, going from 4-7% in raw forms to more than 25% in fried crackers. Based on the difference in crude fat content between the dried raw and fried crackers, the estimated oil uptake was 21.38% for CC, 20.53% for GC, and 20.82% for SC, with no significant statistical difference ($p > 0.05$). These values indicated that the incorporation of cricket or grasshopper flour did not markedly increase oil uptake compared with the shrimp-based control, suggesting that the higher fat content of the fried crackers was mainly associated with the deep-frying process rather than the type of protein source used.

Table 1. Nutritional proximate composition expressed in wet basis (%) and oil uptake (%) of fried crackers (%)

Sample	Water	Ash (minerals)	Fat	Protein	Carbohydrate	Oil uptake
CF	6.69 $\pm$ 0.72 ^{ab}	2.56 $\pm$ 0.16 ^d	11.85 $\pm$ 1.01 ^c	75.26 $\pm$ 4.94 ^a	3.64 $\pm$ 0.35 ^d	-
GF	7.18 $\pm$ 0.63 ^a	3.82 $\pm$ 0.27 ^b	12.32 $\pm$ 0.84 ^c	72.58 $\pm$ 4.88 ^a	4.10 $\pm$ 0.31 ^d	-
SF	5.87 $\pm$ 0.55 ^b	5.85 $\pm$ 0.42 ^a	17.75 $\pm$ 1.15 ^b	63.77 $\pm$ 4.18 ^b	6.76 $\pm$ 0.45 ^c	-
CC (raw)	4.39 $\pm$ 0.36 ^c	2.28 $\pm$ 0.11 ^d	4.24 $\pm$ 0.35 ^e	38.81 $\pm$ 2.31 ^c	50.28 $\pm$ 3.21 ^b	-
GC (raw)	4.68 $\pm$ 0.54 ^c	2.67 $\pm$ 0.20 ^d	4.58 $\pm$ 0.36 ^e	35.25 $\pm$ 2.03 ^d	52.82 $\pm$ 4.72 ^{ab}	-
SC (raw)	4.72 $\pm$ 0.58 ^c	3.08 $\pm$ 0.23 ^c	6.91 $\pm$ 0.55 ^d	27.55 $\pm$ 1.97 ^e	57.74 $\pm$ 3.83 ^a	-
CC (fried)	2.15 $\pm$ 0.16 ^d	0.14 $\pm$ 0.01 ^e	25.62 $\pm$ 2.03 ^a	24.93 $\pm$ 1.78 ^f	47.16 $\pm$ 3.36 ^b	21.38 $\pm$ 1.48 ^a
GC (fried)	1.94 $\pm$ 0.18 ^d	0.16 $\pm$ 0.01 ^e	25.11 $\pm$ 1.84 ^a	23.72 $\pm$ 1.73 ^f	49.07 $\pm$ 4.05 ^b	20.53 $\pm$ 1.26 ^a
SC (fried)	1.99 $\pm$ 0.15 ^d	0.19 $\pm$ 0.01 ^e	27.73 $\pm$ 2.29 ^a	19.65 $\pm$ 1.28 ^g	50.44 $\pm$ 3.91 ^b	20.82 $\pm$ 1.53 ^a

Data (n=3) are reported as mean $\pm$ SD. Different letters in a column indicate significant difference among samples ($p < 0.05$). Abbreviations: CC: cricket cracker, CF: cricket flour, GC: grasshopper cracker, GF: grasshopper flour, SC: shrimp cracker, SF: shrimp flour.

The increasing in protein content was accompanied by a decrease in both protein and lipid digestibility (Table 2). Among the fried crackers, fried SC showed a significantly higher protein digestibility (75.35%) than CC (68.02%) or GC (60.68%). A similar pattern was observed for lipid digestibility, with the fried SC (59.41%) being significantly more digestible

than CC (52.26%) and GC (51.04%). The phenomenon is due to the presence of chitin, a structural N-acetylglucosamine polymer found in the insect exoskeleton (Merzendorfer & Zimoch, 2003). Chitin, which is indigestible by human enzymes, forms a fibrous and robust matrix that can entrap other nutrients (Kouřimská & Adámková, 2016). This

phenomenon, known as steric hindrance, can limit the ability of digestive enzymes, such as trypsin and lipase, to access their target protein

and lipid substrates, thereby reducing the overall rate and extent of digestion (Wang *et al.*, 2025).

Table 2. *In vitro* nutrient digestibility (%)

Sample	Lipid digestibility	Protein digestibility
CF	36.86±3.52 ^d	58.31±5.21 ^d
GF	32.65±3.17 ^e	52.27±4.82 ^e
SF	42.81±4.25 ^{cd}	68.75±5.43 ^{bc}
CC (raw)	46.15±4.19 ^{bc}	62.15±4.51 ^d
GC (raw)	40.35±4.27 ^d	56.67±5.09 ^{de}
SC (raw)	54.15±4.33 ^{ab}	71.26±5.73 ^{ab}
CC (fried)	52.26±4.55 ^b	68.02±5.33 ^{bc}
GC (fried)	51.04±5.58 ^b	60.68±5.25 ^d
SC (fried)	59.41±5.40 ^a	75.35±5.83 ^a

Data (n=3) are reported as mean±SD. Different letters in a column indicate significant difference among samples ($p < 0.05$). Abbreviations: CC: cricket cracker, CF: cricket flour, GC: grasshopper cracker, GF: grasshopper flour, SC: shrimp cracker, SF: shrimp flour

3.2. Effect of cricket and grasshopper flour on the physical characteristic of fried crackers

The physical appearance and internal microstructure of the final fried crackers are shown in Figure 1 and Figure 2, respectively. Visually, SC appeared lighter and more uniform in color (Figure 1A), while CC (Figure 1B) and GC (Figure 1C) exhibited a noticeably darker,

brownish hue. This finding was confirmed in Table 3 where SC had a significantly higher L* value (68.25) compared to CC (42.38) and GC (54.27). The increased in browning may be from melanin that are present in insect and a more intense Maillard reaction during the high heat of deep-frying because of insect high concentration of amino acids (Hamza & Zahran, 2023; Hasnan *et al.*, 2023; El Hosry *et al.*, 2025).

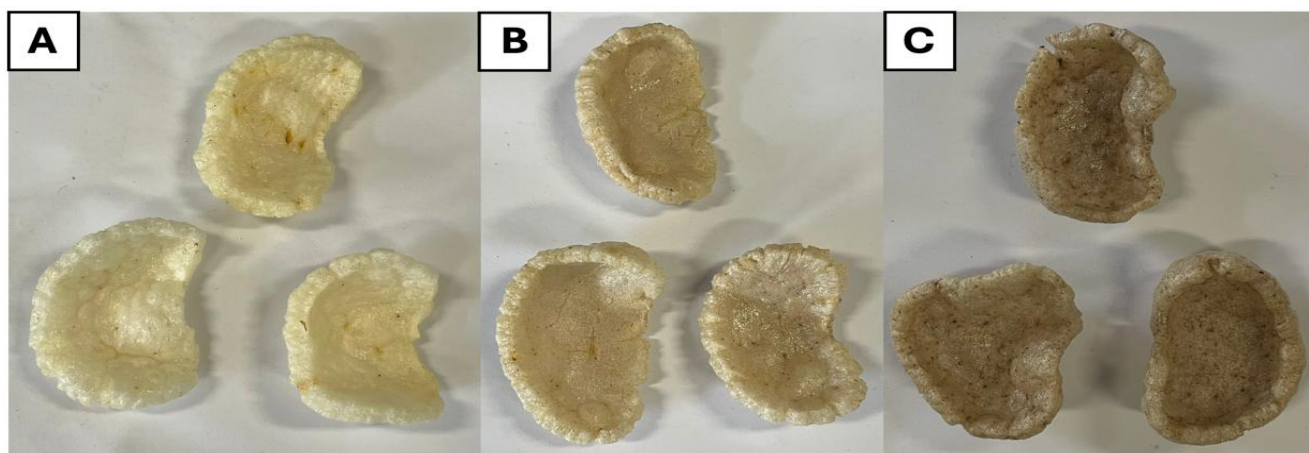


Figure 1. Physical appearance of fried crackers: A) shrimp cracker (SC), B) cricket-flour cracker (CC), and C) grasshopper-flour cracker (GC)

Scanning electron microscopy of the internal structure showed significant changes (Figure 2). SC (Figure 2A) showed a dense,

compact matrix including fewer and smaller air spaces. In contrast, CC (Figure 2B) and GC (Figure 2C) exhibited a highly porous, sponge-

like structure with numerous big spaces. This structural difference was confirmed by the expansion ratio data in Table 3, which showed that both CC and GC had larger expansion ratios than SC. It is hypothesised that insect proteins interact with gelatinized starch to generate a protein-starch matrix, increasing starch swelling (Leach *et al.*, 1959). This swelling may trap water molecules inside the granule, resulting in increased puffing and the creation of bigger voids (Cheow *et al.*, 2004). This difference in internal structure also affected the crispness of

crackers. The dense matrix of SC required a significantly higher breaking force to break, indicating a superior hardness of SC compared to CC and GC (Table 3). Meanwhile, the porous, air-filled structure of both CC and GC resulted in a crispier product, requiring significantly less force to break and higher number of number of peaks and acoustic amplitude as compared to SC (Table 3). Overall, the instrumental texture data indicate that CC exhibits greater crispness than GC.

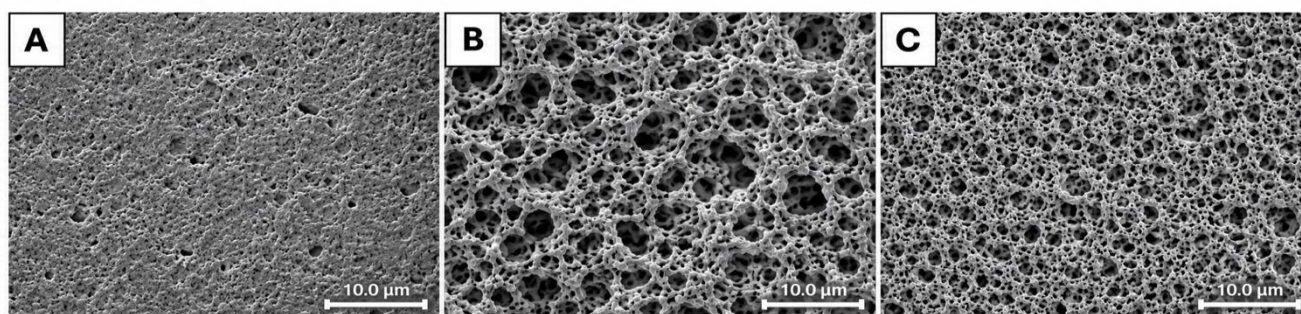


Figure 2. Scanning electron microscope (SEM) imaging of fried crackers: A) shrimp cracker (SC), B) cricket-flour cracker (CC), and C) grasshopper-flour cracker (GC)

3.3. Effect of cricket and grasshopper flour on the sensory evaluation of fried crackers

The results of the sensory evaluation involving 186 panelists are shown in Table 4. There were no significant differences ($p > 0.05$) found among CC, GC, and SC for the key attributes of appearance, aroma, mouthfeel, taste, and overall rate. These findings indicate that incorporating insect flour into *kerupuk* did not negatively affect sensory acceptance. The only significant difference was observed in texture-related attributes where panelists rated the shrimp cracker as significantly harder (6.73) and less crispy (7.17) than the insect-based crackers. This sensory finding aligns with the instrumental texture analysis where both CC and GC required a significantly lower breaking force to fracture because of its airy texture.

From a market acceptance perspective, the comparable overall liking scores among SC, CC, and GC suggest that incorporating insects in flour form into a familiar traditional product may be a promising strategy to reduce consumer

resistance toward entomophagy. Unlike whole insects, which may trigger visual rejection or disgust among some consumers, powdered insect ingredients can be integrated into recognizable food matrices while maintaining desirable sensory attributes. *Kerupuk* is also a suitable product for this purpose because it is already widely consumed as a snack or meal accompaniment in Indonesia, has a familiar crispy texture, and can be positioned as a protein-enriched traditional snack. Such a potential has been shown in our previous study (Widjaja & Surya, 2025). The higher protein content and favorable crispness of CC and GC may therefore provide useful selling points for commercialization. However, successful market introduction would require careful consumer education, clear communication of nutritional and sustainability benefits, and transparent labeling (Alhujaili *et al.*, 2023). Safety and regulatory aspects should also be considered, including the use of food-grade insect raw materials, hygienic processing, microbiological

quality control, and allergen labeling, particularly because edible insects may present allergenic risks or cross-reactivity with crustacean allergens (Aguilar-Toalá *et al.*, 2022). Future commercialization studies should therefore evaluate consumer perception, willingness-to-purchase, willingness-to-pay, shelf-life stability, packaging, and scale-up feasibility to determine whether insect-based kerupuk can be developed into a commercially viable alternative protein snack (Siddiqui *et al.*, 2023).

3.4. Limitations of the study

Several limitations of the present study should be considered when interpreting the findings. First, the *in vitro* protein and lipid digestibility assays were performed using aqueous extracts of the crackers rather than the intact food matrix. Therefore, the resulting values primarily reflect the digestibility of water-extractable components and may not fully account for the influence of the starch–protein matrix, insoluble components such as chitin, and the porous structure of the fried crackers during gastrointestinal digestion. Future studies employing standardized simulated gastrointestinal digestion of the whole product would provide a more physiologically representative assessment.

Second, crude protein content was determined using the Kjeldahl method, which estimates protein indirectly from total nitrogen. In insect-based ingredients, part of the measured nitrogen may originate from non-protein nitrogenous compounds, including chitin. Consequently, the use of a conventional nitrogen-to-protein conversion factor may result in some overestimation of the actual protein content. Amino acid analysis and the use of insect-specific nitrogen conversion factors would allow a more accurate evaluation of protein content and quality.

Third, although sensory evaluation involved a relatively large group of untrained panelists, the study assessed immediate sensory liking and preference rather than broader consumer perceptions toward edible insects. Factors such as food neophobia, willingness to purchase, willingness to pay, and responses to information regarding nutritional or sustainability benefits were not directly evaluated. Therefore, comparable sensory acceptance of the insect-based and shrimp-based crackers should not be interpreted as evidence that incorporation of insect flour overcomes food neophobia.

Fourth, the study evaluated only one formulation level, in which the type of protein source was varied while the proportion of the protein ingredient was kept constant. Consequently, the effects of different levels of cricket or grasshopper flour on nutritional composition, expansion, texture, oil uptake, and sensory acceptance remain unknown. Further formulation optimization may identify lower or higher incorporation levels that provide a more favourable balance between nutritional enhancement and product quality.

Finally, the present study focused primarily on nutritional composition, physical properties, digestibility, microstructure, and sensory acceptance. Microbiological safety, allergenicity, oxidative stability, and shelf-life were not directly investigated. These aspects are particularly important for insect-based foods because of potential allergenic cross-reactivity and their relevance to storage, regulatory compliance, and commercial application. Further studies addressing these parameters are therefore required before the practical commercialization of insect-based kerupuk can be fully evaluated.

Table 3. Physical parameters (color, crispness, and expansion rate) of fried crackers

Sample	Color parameters			Crispness parameters			Expansion ratio (%)
	L*	a*	b*	Breaking force (N)	Number of peaks	Acoustic amplitude (dB)	
CC (fried)	42.38±1.33 ^c	34.19±1.22 ^c	48.39±2.76 ^c	4.35±0.15 ^b	30.91±3.85 ^c	15.67±2.52 ^b	378.23±8.74 ^b
GC (fried)	54.27±1.81 ^b	10.82±1.03 ^b	40.42±2.08 ^b	4.73±0.18 ^b	25.97±1.33 ^b	16.67±1.15 ^b	375.60±9.65 ^b
SC (fried)	68.25±2.36 ^a	5.62±0.64 ^a	34.70±2.12 ^a	5.68±0.37 ^a	18.68±0.37 ^a	12.67±1.15 ^a	313.27±9.18 ^a

Data (n=3) are reported as mean±SD. Different letters in a column show significant difference among samples (p<0.05). Abbreviations: CC: cricket cracker, GC: grasshopper cracker, SC: shrimp cracker.

Table 4. Sensory acceptance of fried crackers measuring panelists' liking expressed in hedonic rate (scale 1-9) and rank

Sample	Appearance	Aroma	Hardness	Crispness	Mouthfeel	Taste	Overall rate	Overall rank
CC (fried)	7.44±1.16 ^a	7.48±1.06 ^a	7.38±0.95 ^a	7.75±0.92 ^a	6.95±0.88 ^a	7.87±1.25 ^a	7.53±1.15 ^a	1.97±0.35 ^a
GC (fried)	7.36±0.92 ^a	7.72±1.15 ^a	7.62±1.07 ^a	7.52±0.93 ^a	7.21±0.93 ^a	7.63±1.08 ^a	7.68±0.92 ^a	2.09±0.33 ^a
SC (fried)	7.67±1.14 ^a	7.91±1.16 ^a	6.73±0.82 ^b	7.17±1.03 ^b	6.91±0.87 ^a	7.80±1.22 ^a	7.39±1.03 ^a	2.14±0.36 ^a

Data (n=186) are reported as mean±SD. Different letters in a column show significant difference among samples (p<0.05). Abbreviations: CC: cricket cracker, GC: grasshopper cracker, SC: shrimp cracker

4. Conclusions

The current study demonstrated that cricket and grasshopper flour are highly efficient ingredients for nutritional fortification of traditional crackers. In comparison to the shrimp-based control, the addition of insect flour enhanced the protein content of the final product while also resulting in a greater expansion ratio and a crispier, less hard texture. Critically, these insect crackers were well received by customers, with sensory evaluations showing no significant change in overall liking, taste, or aroma when compared to the traditional prawn cracker.

The novelty of this study lies in demonstrating that cricket and grasshopper flour can be successfully incorporated into Indonesian *kerupuk*, a traditional and familiar snack matrix, without reducing overall sensory acceptance. This approach may help bridge the gap between the nutritional and sustainability benefits of edible insects and consumer reluctance toward direct insect consumption. Therefore, insect-based *kerupuk* has practical potential as a culturally acceptable, protein-enriched snack for promoting sustainable protein diversification.

Future studies should further evaluate the nutritional quality and safety implications of insect-based crackers. In particular, amino acid composition, protein quality indices, and protein bioavailability should be assessed to determine whether the higher protein content of cricket- and grasshopper-based crackers translates into improved nutritional value. Further work should also include consumer perception analysis, including food neophobia, willingness-to-purchase, willingness-to-pay, and the influence of product information or sustainability claims on acceptance. In addition, allergenicity should be carefully investigated, especially because edible insects may show cross-reactivity with crustacean and mite allergens, which is relevant for labeling and consumer safety. Other promising directions include optimization of processing conditions to balance expansion, crispness, oil uptake, and nutrient retention, as well as shelf-life, oxidative stability, microbiological safety, and scale-up studies to support the potential commercialization of insect-based traditional crackers.

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Data availability

All data related to this work are presented in the manuscript.

Authors' contribution

Conceptualization: R.S. and D.N.; methodology: R.S. and D.N.; validation: R.S. and D.N.; formal analysis: F.W. and F.T.; investigation: F.W. and F.T.; resources: R.S. and D.N.; data curation: R.S. and D.N.; writing—original draft preparation: R.S. and F.T.; writing—review and editing: R.S. and D.N.; visualization: R.S. and F.T.; supervision: R.S.; project administration: R.S.; funding acquisition: R.S.. All authors have read and agreed to the published version of the manuscript.

Declaration of conflicts of interest

All authors declared no conflicts of interest.