Development and Evaluation of Cricket Flour-Fortified Crackers as a Novel Protein-Enriched Snack

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Abstract. Cricket flour (CF), derived from domestic crickets (Gryllus sp.), is a high-protein, mineral-rich alternative food ingredient with significant potential to support sustainable food systems. This study aimed to formulate and evaluate crackers fortified with cricket flour at concentrations of 0% (control), 5%, and 10%, alongside a commercial cracker sample as a benchmark. The developed formulations were evaluated for their chemical composition and sensory characteristics, including colour, texture, crispness, hardness, and overall acceptability. The organoleptic properties were evaluated using a 9-point hedonic scale with untrained panellists. Among the experimental samples, the 5% cricket flour (CF-5) cracker exhibited the most favourable volume expansion (140.43±12.21) and received the highest scores for colour and overall sensory acceptance, indicating its suitability for further nutritional analysis. Proximate analysis of the CF-5 sample revealed an increase in protein content (2.87%) and ash content (5.10%), indicating enhanced mineral contribution compared to the control and commercial samples. The increased protein and mineral contents were accompanied by a reduction in carbohydrate content, measured at 88.81%. These results demonstrate that cricket flour fortification can improve the nutritional quality of snack products without compromising sensory appeal at moderate inclusion levels. Overall, the incorporation of cricket flour in cracker formulations presents a promising strategy for developing value-added, nutrient-dense, and environmentally sustainable food products. This study supports the integration of edible insects into mainstream food applications to address global challenges in food security and environmental sustainability.

1 Introduction

The global population is projected to reach 9.7 billion by 2050, resulting in a significant increase in protein demand. According to FAO, the world's protein needs are expected to rise by almost 60% by mid-century, while demand for meat alone is estimated to grow by 14% by 2030 compared to 2018–2020 levels. This rapid growth puts tremendous pressure on conventional food systems. Livestock farming, including cattle and poultry production,

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consumes substantial amounts of land, water, and feed, while also accounting for approximately 14.5% of total global greenhouse gas emissions. The rapid growth of the global population, combined with rising demand for animal-based protein, has placed significant pressure on conventional food systems. Traditional meat production—such as beef and poultry—requires substantial resources including land, water, and feed, and contributes heavily to greenhouse gas emissions. In response to these challenges, the search for sustainable alternative protein sources has become a top priority in achieving the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action)..

Edible insects, such as crickets (*Gryllus* sp.), have emerged as a promising alternative protein source. Cricket flour is rich in protein, ranging from 45% to 70% and contains all essential amino acids needed for a balanced diet. Moreover, crickets are rich in vitamin B2, B3, B12, iron, calcium, sodium, phosphorus, potassium, and zinc, making them a strong candidate for food fortification.

Cricket farming has a significantly smaller ecological footprint compared to conventional livestock farming. Producing protein from crickets requires significantly less water and land while generating lower greenhouse gas emissions. For instance, it would take 2.1 kilograms of dried feed to produce 1 kilogram of edible crickets, but 25 kilograms of dried feed would be needed to produce beef.

Despite these advantages, consumer acceptance of insect-based foods remains a significant challenge, particularly in cultures where entomophagy is not a traditional practice. One effective strategy to enhance acceptance is to incorporate insects into familiar food products. In Indonesia, crackers (*kerupuk*) are a widely consumed snack and offer a suitable medium for delivering protein fortification through cricket flour.

This study aims to develop cricket flour-based crackers and evaluate their chemical and sensory characteristics. Additionally, it highlights the potential of such products to contribute to achieving the relevant Sustainable Development Goals (SDGs).

2 Materials and Methods

2.1 Cricket flour preparation

The cricket flour used in this study was sourced from a home-based, certified edible cricket farm in Grogol, West Jakarta. The preparation of cricket flour in this study followed a method with some modifications, as described by [7], which includes washing, boiling for 30 minutes in boiling water (100˚C), oven-drying for 12 hours at 80˚C, and grinding into fine flour. This cricket flour was used to fortify the cracker formulation to enhance the protein content of the final product [8].

2.2 Cricket flour-fortified crackers preparation

The formulation of the cricket flour-fortified crackers used in this study is presented in Table 1.

Table 1. Formulation of cricket flour (CF)-fortified crackers.

Ingredients	Formulation (gr)		
	CF-0	**CF-5**	**CF-10**
Tapioca starch	150	150	150
Crickets flour	0	7.5	15
Chicken stock powder	3	3	3
Garlic	6	6	6
Baking powder	1	1	1
Ground coriander	2.4	2.4	2.4
Water	80	84	88

All dry ingredients, excluding water, were mixed until evenly distributed. Boiling water was then gradually added while stirring to initiate gelatinization. The dough was kneaded until smooth and elastic, then shaped into elongated cylindrical forms approximately 30 cm in length. The shaped dough was steamed for 45 minutes until fully cooked. Following steaming, the dough was refrigerated for 24 hours to allow it to harden, facilitating the slicing process.

After cooling, the hardened dough was sliced into pieces with a thickness of 1–3 mm. The slices were then oven-dried at 50°C for 4 h until the moisture content was sufficiently reduced. Once dried, the crackers were deep-fried in hot oil at a temperature of 180–200 °C for approximately 10 seconds until they puffed and developed a crispy texture. Crackers are stored in airtight containers at room temperature prior to the proximate and organoleptic analyses.

2.3 Physiochemical analysis

The physical properties of the crackers, including hardness, expansion volume, and color [3]. Hardness was measured using a Texture Analyzer (Trapezium X) to determine the force required to break the sample. Meanwhile, color was evaluated with a chromameter (Konica Minolta) to obtain objective values for lightness (L*), redness (a*), and yellowness (b*) of the crackers. To compare visual changes in a product's appearance due to formulation or processing variations use ΔE to serves as a quantitative measure of color difference. ΔE was calculated using the following equation, where letters c and s next to L*, a*, and b* values indicate control sample and sample under investigation respectively [4].

$$\Delta\mathrm{E} = \sqrt{(\mathrm{L}c^{*} - \mathrm{L}s^{*})^2 + (ac^{*} - as^{*})^2 + (bc^{*} - bs^{*})^2}$$

Expansion volume was assessed using the silica bead displacement method, which involved measuring the volume change of the beads before and after sample immersion.

2.4 Organoleptic analysis

The nine-point facial hedonic scale was employed at the Sensory Laboratory of BINUS University, where 100 untrained student panellists, aged 18-21 years old, were asked to assess its reliability and validity [5]. Panellists evaluated four developed cracker formulations and one commercial cracker (Brand Finna, Sidoarjo, East Java, Indonesia) as a comparison, based on attributes including colour, tactile texture, crispiness, hardness, and overall rating. The panellist was instructed to rate based on their personal preference, with a scale ranging from 1 (strongly dislike) to 9 (strongly like) [6]. Sensory evaluation was followed by a ranking test, in which panellists ranked the samples from most preferred (rank 1) to least preferred (rank 5) [7].

2.5 Proximate analysis

A proximate analysis was conducted on the most preferred sample, and the results were compared with those of a commercial cracker sample, as described by [5]. The analysis followed the AOAC method [3], which covered the determination of moisture, fat, ash (mineral), crude fibre, and protein content. Approximately 50 grams of each cracker sample were ground for analysis. The moisture content was determined using the gravimetric method, where 3 grams of the sample were dried in an oven at 105°C for 12 hours until a constant weight was achieved. Ash content was also determined gravimetrically by ashing 2 grams of the sample in an oven furnace at 600°C for 4 hours after carbonization. The fat content was analysed using Soxhlet extraction with n-hexane as the solvent under controlled heating for 3 hours. Crude fiber content was determined by the weight loss method, where a 1-gram fat-free sample was digested with 1.25% H_2SO_4 followed by 3.25% NaOH under controlled conditions. The residue was then washed sequentially with 1.25% K_2SO_4, hot distilled water, and 96% ethanol using a Büchner funnel. The protein content was analyzed using titrimetric (Kjeltec) method. The carbohydrate content was determined by difference, calculated by subtracting the sum of moisture, protein, fat, ash, and crude fibre contents from 100%. All the results were expressed in dry basis (%).

2.6 Statistical analysis

All data obtained from the physicochemical, organoleptic, and chemical analyses were analysed using IBM SPSS Statistics version 25.0. By using one-way ANOVA to compare the means in all groups of cricket flour-fortified crackers. The difference between the two groups was analysed using a post hoc Tukey's HSD test at a significance level of 0.05. Data from simple ranking test was further analyzed by the Friedman test.

3 Results and Discussion

The color parameters of crackers were evaluated using the CIE Lab* system, which quantifies lightness (L*), redness-greenness (a*), and yellowness-blueness (b*) can be seen on Table 2.

Table 2. Hardness and color profile of crackers.

Sample	Hardness (N)		Color			
		L*	a*	b*	ΔE	Reference
Raw						
CF-0	4.76 ± 0.36b	56.33 ± 2.69b	5.44 ± 0.53c	38.33 ± 2.00a	0.00d	
CF-5	5.35 ± 0.61ab	17.67 ± 2.87d	12.22 ± 0.44a	20.89 ± 2.52c	43.03 ± 3.81b	
CF-10	6.49 ± 0.47a	11.33 ± 2.65e	8.67 ± 0.71b	10.22 ± 2.77d	53.19 ± 4.94a	
Fried						
CF-0	2.30 ± 1.03c	73.11 ± 3.22a	2.44 ± 1.42d	32.67 ± 4.90b	0.00d	
CF-5	2.75 ± 0.86c	53.33 ± 2.78c	5.33 ± 0.87c	24.44 ± 2.01c	22.43 ± 5.18c	
CF-10	2.91 ± 0.74c	53.11 ± 5.13c	6.11 ± 0.78c	18.89 ± 1.76c	25.26 ± 6.26c	

Note: Data are expressed as mean±standard deviation. Superscript letters in the same column denote statistically significant differences according to the Tukey test (p-value≤0.05). CF=Cricket Flour, followed by a number indicating as percentage (%).

The L* values significantly decreased with increasing levels of cricket flour, especially in raw samples. The raw control (CF-0) had a relatively high L* value of 56.33 ± 2.69, while raw crackers with 10% cricket flour (CF-10) dropped to 8.67± 0.71, indicating a much darker appearance. This darkening trend can be attributed to the natural color of cricket flour [4]. The cooked samples (CF-0 to C-15) exhibited higher lightness values than their raw counterparts (R-0 to R-15) at the same level of fortification. Cooking likely promotes starch gelatinisation and moisture evaporation, resulting in a smoother and lighter surface appearance despite the addition of dark-coloured cricket flour [8]. For the a* values, which indicate redness, raw crackers fortified with 5% cricket flour (R-5) had the highest a* value of 12.22 ± 0.44. This suggests an enhancement in reddish-brown hues at lower levels of fortification, while higher concentrations (CF-10) exhibited slightly lower values [4]. In cooked samples, a* values were generally lower than in raw ones, but still increased with the addition of cricket flour, likely due to pigment degradation or redistribution during thermal processing [8]. The b* values (yellowness) also followed a decreasing trend with the addition of cricket flour. Both raw and cooked crackers became less yellow as the percentage of cricket flour increased [10]. Cooked CF-0 maintained a high b* value (32.67 ± 4.90), whereas cooked CF-10 dropped to 18.89 ± 1.76. This decrease indicates a shift toward duller, brownish hues, likely due to the masking effect of the darker cricket flour [8]. Color changes relative to the control (CF-0) or ΔE, showed significant differences across all samples in both raw and cooked conditions. In the raw samples, ΔE values differed significantly among all groups, whereas in the cooked samples, no significant difference in ΔE was observed between CF-5 and CF-10. The addition of cricket flour significantly affected the color characteristics of both raw and cooked crackers. Cooking helped improve lightness and color uniformity, potentially making the appearance more acceptable to consumers. Nevertheless, the darker colour associated with higher cricket flour levels may influence consumer perception and should be addressed through sensory optimisation or product positioning strategies [4].

Table 2 also presents the hardness values of the crackers. The addition of cricket flour significantly influences the hardness of the raw crackers. As the concentration of cricket flour increases, the hardness of the crackers also increases, which is consistent with the findings of the study by [9]. This increase in hardness can be attributed to the high protein content in cricket flour, which interferes with the starch gelatinization process and inhibits expansion due to the formation of cross-links in the matrix, resulting in a denser and harder texture [10]. Hardness decreased significantly after frying, as shown in Table 2. However, there was no significant difference in hardness between the fried control sample (CF-0) and the fried samples with added cricket flour (CF-5 and CF-10). The addition of cricket flour at levels of 5% and 10% did not significantly affect the hardness of the crackers [4].

Based on Table 3, the expansion ratio of the crackers, assessed using the bead displacement method, showed a significant decrease ($p < 0.05$) with increasing levels of cricket flour. The main component of crackers is starch, which consists of two fractions: amylose and amylopectin. Amylopectin plays a crucial role in determining the expansion capacity of crackers. The gelatinization of starch during the preparation of cracker dough significantly influences expansion, proper gelatinization results in optimal puffing. However, a high protein content can interfere with starch gelatinisation by forming a matrix around starch granules and limiting their expansion. Consequently, as the protein content in the crackers increases, the expansion ratio tends to decrease. This can be seen from sample CF-10, which has the highest concentration of cricket flour but the lowest expansion ratio [11]. Puffing happens when heat causes the water inside the material to turn into steam and replaced with oil, creating pressure that pushes outward. This pressure forms air pockets, causing the product to expand and create a crispy texture [10].

Table 3. Expansion ratio of crackers.

Sample	Expansion Ratio (%)
CF-0	198.83 ± 5.39^a
CF-5	140.43 ± 12.21^b
CF-10	102.79 ± 8.19^c

Note: Data are expressed as mean±standard deviation. Superscript letters in the same column denote statistically significant differences according to the Tukey test (P-value≤0.05). All samples are in cooked conditions.

The organoleptic evaluation of the cricket flour-fortified crackers was conducted based on colour, tactile texture, crispness, hardness, and overall rating. The sensory test results are presented in Figure 1. Significant differences were observed in the attributes of color, tactile texture, crispiness and hardness. Meanwhile, for overall rating attribute there is no significant difference between the samples. In terms of color, increasing concentrations of cricket flour resulted in lower scores, attributed to the progressively darker appearance of the crackers. On crackers, CF-0 and CF-5 have not statistically different, indicating that the addition of up to 5% cricket flour did not substantially affect panellists' acceptance of the product colour. This is a favourable outcome, as it suggests that lower concentrations of cricket flour (CF-5) can be incorporated into crackers without compromising their visual appeal. However, both CF-0 and CF-5 still received lower scores compared to the commercial ceackers. This difference can be attributed to the darker pigmentation introduced by the addition of cricket flour, which alters the typical bright appearance of conventional crackers. At higher concentrations (CF-10), colour acceptance decreased significantly, resulting in the lowest hedonic score among the treatments. This darker colouration negatively influenced the acceptance score [10], which reported that higher levels of cricket flour addition (CF-10) resulted in a darker product appearance, subsequently reducing consumer acceptance due to visual preferences. The sensory scores for tactile texture revealed that both the commercial sample and CF-0 received the highest ratings, with no significant difference between them. This suggests that the absence of cricket flour (CF-0) enables the product to maintain a texture similar to that of conventional crackers. Meanwhile, the CF-5 formulation was not significantly different from CF-0, although its score showed a slight decline. This indicates that the addition of 5% cricket flour is still within an acceptable range in terms of tactile texture. In contrast, CF-10 received the lowest score and was significantly different from among samples. The high protein and fibre content in cricket flour may alter the dough structure, resulting in harder and less crispy crackers, especially with the highest cricket flour addition (CF-10). This is evidenced by the decreasing acceptance scores tactile texture attributes with increasing concentrations of cricket flour, as well as the lower crispiness scores compared to commercial crackers [12]. The control and cricket flour-enriched crackers did not achieve the same level of crispness and hardness as commercial crackers, likely due to variations in formulation and ingredient selection. Figure 1 illustrates that the lack of a significant difference in overall rating supports the feasibility of using a substitute ingredient in product formulation without negatively affecting consumer perception. The large error bars across some attributes suggest variability in panelist preferences, which could be due to subjective taste differences or panelist familiarity with the product [13].

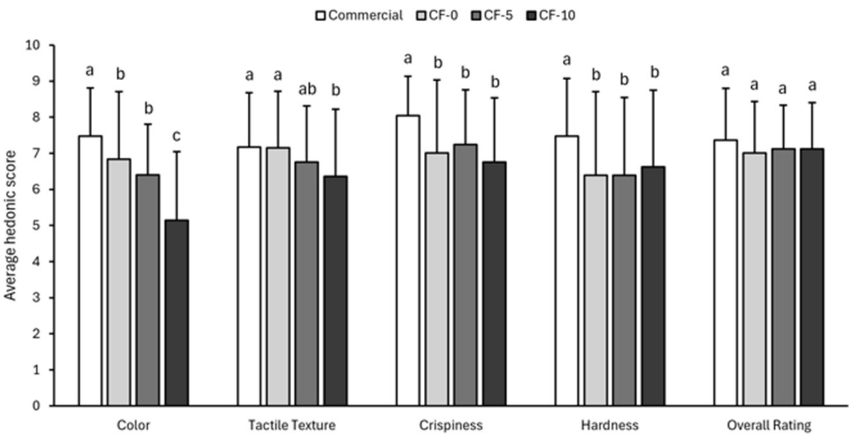

Fig. 1. Sensory acceptance of cricket flour-fortified crackers analyzed using hedonic rating analysis (scale 1-9, higher score indicates higher preference) on color, tactile texture, crispiness, hardness, and overall rating attributes. Data (n=100) were expressed as mean $\pm$ standard deviation. Different letters indicate significant differences among samples on each parameter ($p < 0.05$), as determined by one-way ANOVA and Tukey post hoc test.

A further test was conducted to evaluate overall consumer preferences using a simple ranking test, in which panellists were instructed to rank the samples from most to least preferred. The results of Friedman ranking test are shown in Table 4**.** In the mean rank scores among the cracker samples, including the control (CF-0), the cricket flour-fortified crackers (CF-5 and CF-10), and the commercial product. All samples received similar acceptance levels, as indicated by the identical superscript letters ([a]), suggesting that the addition of 5% and 10% cricket flour did not significantly influence the overall preference compared to both the control and commercial crackers, the experimental formulations could potentially match the acceptability of commercially available products. Factor such as ingredients and the ratio of cricket flour can influence consumer taste preferences [7].

Table 4. Simple ranking Friedman test result of cricket flour (CF)-fortified crackers.

Sample	Mean Rank $\pm$ Standard Deviation
CF-0	3.11 ± 1.38^{a}
CF-5	2.79 ± 1.26^{a}
CF-10	2.88 ± 1.32^{a}
Commercial	2.94 ± 1.50^{a}

Note: Data are expressed as mean±standard deviation. Superscript letters denote statistically significant differences according to the Friedman test ($p \leq 0.05$).

Proximate analysis was conducted based on the results of the best volume expansion and the best color preference, which the CF-5 crackers, comparing to commercial crackers.

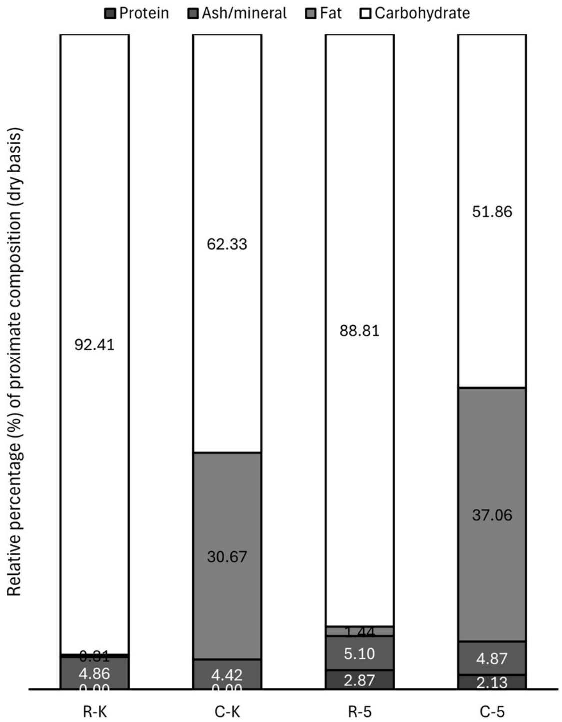

Fig. 2. Nutritional composition of cricket flour-fortified crackers acquired from proximate analysis. R-K: Raw-commercial crackers, C-K: Cooked-commercial crackers, R-5: Raw fortified crackers-5% cricket flour, C-5: Cooked fortified crackers-5% cricket flour.

As shown in Figure 2**, the proximate composition includes raw and cooked commercial crackers, as well as** raw and cooked fortified crackers with 5% cricket flour. When comparing the raw products, the fortified crackers with 5% cricket flour exhibited a higher protein content (2.87%) compared to the commercial crackers (0%). This increase in protein content is attributed to the addition of cricket flour, which has been shown to enhance protein levels [5]. Cricket flour derived from *Gryllus sp.* contains approximately 45–70% protein and provides all essential amino acids required for a balanced diet.. Similar to the cooked samples, the fortified crackers with 5% cricket flour have a higher protein content compared to the cooked commercial crackers. However, the frying process may contribute to a reduction in protein content, the cooked 5% cricket flour-fortified crackers has slightly lower protein compared to their raw counterparts. This decrease in protein content occurs due to high-temperature cooking methods, such as frying, which can lead to protein denaturation and Maillard reactions, ultimately reducing measurable protein levels [14]. The 5% cricket flour-fortified crackers have a slightly higher mineral (ash) content (5.10%) compared to the commercial cracker sample (4.86%), due to the naturally high mineral content of cricket flour. Cricket flour contains various essential minerals such as iron (Fe), calcium (Ca), phosphorus (P), magnesium (Mg), and zinc (Zn) [2]. After the frying process, the mineral content in both the 5% cricket flour-fortified crackers (4.87%) and the commercial crackers (4.42%) decreased, which could possibly be due to the leaching of minerals into the frying oil [14]. The slightly higher fat content observed in the 5% cricket flour-fortified crackers sample is likely due to the natural lipid content of cricket flour, which contains up to 30% fat, including beneficial unsaturated fatty acids such as oleic and linoleic acid, contributes to the overall lipid level in the final product [8]. The frying process increases fat content as crackers absorb oil, and the extent of absorption depends on the cracker's composition.

Crackers fortified with cricket flour have different moisture and porosity levels, which affect oil uptake due to the natural lipid content from crickets. Adding edible insect powder can alter physicochemical properties, including fat content [15]. The 5% cricket flour–fortified cracker sample exhibited higher levels of protein, ash/minerals, and fat, which contributed to a lower carbohydrate content compared to the commercial cracker sample. Consequently, the commercial crackers showed a higher carbohydrate content [15].

Our research reflects a multidimensional approach to addressing issues related to food and sustainability. By developing a high-protein, cricket flour-based product (crackers) that contains essential vitamins and minerals, this initiative not only addresses challenges in nutrition and food security but also supports global efforts toward achieving sustainable, environmentally friendly, and inclusive food systems, as outlined in the Sustainable Development Goals (SDGs).

4 Conclusion

The cricket flour-fortified crackers exhibited a darker color compared to the commercial product. However, overall, the cricket-based crackers were well accepted by panellists, as indicated by similar overall rating scores and ranking results to those of the commercial crackers (which were organoleptically acceptable). Therefore, a proximate analysis was conducted on the selected sample (CF-5), which demonstrated an increase in protein content by 2.87%. This nutritional enhancement is not present in commercial crackers. Cricket flour–based crackers not only represent a nutritionally enriched food innovation but also serve as a practical solution in the transition toward a more sustainable food system. This aligns with several Sustainable Development Goals (SDGs), notably SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

For further studies, it should explore shelf-life stability, packaging optimisation, and consumer acceptance over extended storage periods. Additionally, scaling up production to an industrial level could provide insights into the feasibility of incorporating cricket flour into commercial cracker manufacturing, thereby supporting the wider adoption of sustainable protein alternatives.

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