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# Innovative utilization of chicken feet bones (*Gallus gallus domesticus*) and mung beans (*Vigna radiata*) in crackers: A sustainable nutritional approach to combat childhood malnutrition

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## ABSTRACT

**Background**: Malnutrition leads to weakened immunity, making children more susceptible to infectious diseases and affecting future generations if not promptly addressed. Chicken feet bones (*Gallus gallus domesticus*) are a food waste product rich in calcium, while mung beans (*Vigna radiata*) are high in vitamins and minerals, making them potential sources of additional nutrition. This study aims to investigate the processing of Hi-C Crackers using chicken feet bones and mung beans, analyze its macronutrient content qualitatively, and determine its calcium content qualitatively. **Methods:** This experimental research involved processing Hi-C Crackers and analyzing their nutritional composition qualitatively. **Findings:** Hi-C Crackers were successfully processed using a 2:1 ratio of chicken feet bones to mung beans. The macronutrient content was determined using qualitative reagent tests: Lugol's iodine test for carbohydrates (blue-black color), Biuret test for protein (purple color), and Benedict's test for glucose (greenish-blue color). Calcium content was confirmed using ammonium oxalate and acetic acid reagents, producing a brownish-white precipitate. **Conclusion:** Hi-C Crackers is a nutritious snack with essential macronutrients and calcium. **Novelty:** This research introduces a new food innovation utilizing commonly discarded ingredients to combat malnutrition.

**KEYWORDS**: childhood; nutritional; sustainable; utilization.

## 1. Introduction

Nutritional issues are public health problems caused by multiple factors. Nutritional deficiencies, primarily caused by insufficient food intake and inadequate consumption of essential nutrients, are a significant public health concern (Kiani et al., 2022). This issue can also be attributed to nutritional disparities within communities, particularly among low-income families who often face challenges in accessing adequate and nutritious food (Agurs-Collins et al., 2024). In Indonesia, the development of nutritional problems is categorized

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into three groups: nutrition issues that are already under control from a public health perspective, unresolved (unfinished) problems, and emerging nutritional issues that are escalating and threatening public health. The government has demonstrated its commitment to improving the quality of human resource competitiveness, as evidenced by the increase in the Human Development Index (HDI) from 73.77% in 2022 to 74.39% in 2023, an increase of 0.62 points (0.84 percent) (Central Bureau of Statistics (Indonesia), 2023).

However, many challenges related to human development remain, particularly in improving public health standards. According to the Global Nutrition Report (2020), In Indonesia, there is a significant disparity of malnutrition; the rate of stunting can vary up to fourfold between regions, while the rate of wasting can differ by as much as ninefold across areas. Malnutrition weakens the immune system, reducing the body's ability to combat infections effectively (Foolchand et al., 2022; Morales et al., 2023). This study questions are how to process crackers using chicken feet and mung beans, what the qualitative macronutrient content of crackers is, and how to assess their calcium content qualitatively. Enriched cracker biscuits are also designed for dietary purposes, sharing the same concept of promoting healthy snacks while improving the nutritional profile of the product (Ujong et al., 2023).

The short-term effects of malnutrition on child development include apathy, speech disorders, and other developmental delays, while long-term effects involve a 10-13 point reduction in Intelligence Quotient (IQ) scores, impaired cognitive development, sensory integration issues, attention deficits, reduced self-esteem, and declining academic performance (Moehji, 2003). Additionally, malnutrition contributes to stunting, a condition caused by insufficient dietary intake, particularly of protein, which affects plasma insulin-like growth factor I (IGF-I) levels, bone matrix proteins, growth factors, and essential minerals like calcium and phosphorus, all of which are critical for optimal bone growth and height development (Hawkes & Grimberg, 2015). The paper aims to present an examination of the potential of chicken feet and mung beans as primary ingredients in developing crackers, a nutrient-rich snack product aimed at addressing malnutrition and stunting.

Data from the Nutritional Status Monitoring (PSG) indicate that the prevalence of stunting in children under five has consistently been higher than other nutritional issues, such as undernutrition, wasting, and obesity. The prevalence of stunting increased from 27.5% in 2016 to 29.6% in 2017, reaching 30.8% in 2018, before declining to 27.67% in 2019 (Ministry of Human Development and Cultural Affairs, 2020). However, the prevalence of stunting in Indonesia to fall from 24.4% in 2021 to 21.6% in 2022 (Ministry of Health of the Republic of Indonesia, 2023). This demonstrates the Indonesian government's commitment to persistently reducing stunting rates caused by malnutrition. The subject of the study is important because malnutrition and stunting have significant long-term impacts on human development, economic productivity, and public health.

One approach to preventing malnutrition and stunting is by ensuring adequate nutritional intake, particularly calcium, which is essential for bone development. Chicken feet (*Gallus gallus domesticus*) are a highly affordable and accessible source of calcium. Indonesia produces 1.9 million pairs of chicken feet annually, equivalent to 42,750 tons of chicken feet, calculated based on a poultry meat production of 1,500.47 thousand tons, multiplied by a carcass conversion of 1.33 kg per chicken and a chicken feet weight conversion of 45 grams per pair (Susanto, 2019). However, chicken feet bones are often discarded or used solely for broth, leading to environmental issues due to the waste generated. Despite this, chicken feet bones are rich in calcium, which can be harnessed as a nutritional supplement. Mung beans contain a significant amount of protein, approximately 20-32%, with about 60% of this protein consisting of globulin and 25% albumin, which are storage proteins, along with essential amino acids (Mubarak, 2005). These nutrients play a vital role in physical and mental development. Researchers who have looked at this subject include Hawkes & Grimberg (2015), who emphasized the role of protein and minerals in combating stunting.

Malnutrition is a critical public health issue requiring innovative solutions, while utilizing local food resources can effectively address nutritional deficiencies. The utilization of local ingredients, such as anchovy flour, moringa leaf flour, and corn flour, combined to create snack biscuits, serves as a supplementary food intervention to prevent nutritional deficiencies (Picauly et al., 2023). Local resources can be sourced directly from the area and are available in sufficient quantities such as mung beans and chicken feet. Mung beans demonstrate potential for enhanced micronutrient content through biofortification, offering significant opportunities to improve the nutritional quality of food, particularly in South and Southeast Asia, where protein and micronutrient deficiencies are among the highest globally (Nair et al., 2013). While chicken feet has collagen derived, it can serve as a fat substitute due to its supportive bioactive properties, thereby enhancing the quality of food products (Araújo et al., 2021). Other studies also suggest that chicken feet can be utilized for gelatin fortification due to their high collagen content (Santana et al., 2020; Santana et al., 2021). Combining traditional knowledge with modern nutritional science can yield sustainable solutions. Debate centres on the issue of how to balance economic, environmental, and nutritional considerations when developing food-based interventions. There is still work to be done on creating affordable, accessible, and culturally acceptable nutritional products that can address the triple burden of malnutrition. What has not been done is the development of a snack product that utilizes chicken feet and mung beans to provide a high-calcium, nutrient-rich food option.

Given the high prevalence of malnutrition and stunting in Indonesia, coupled with the nutritional potential of chicken feet and mung beans, this study aims to develop an innovative snack product called Hi-C Crackers, utilizing chicken feet and mung beans as primary ingredients. This research is closest to that of Susanto (2019) in that it explores the utilization of chicken feet as a nutritional resource. But this study extends the research by incorporating mung beans to enhance the product's nutritional profile. The contribution of this study is the development of a practical, economical, and nutrient-rich snack that addresses calcium deficiency and supports efforts to reduce malnutrition and stunting.

This study is important for a number of reasons. Firstly, it addresses a critical public health issue by providing an innovative solution to malnutrition and stunting. Secondly, it promotes the utilization of local food resources, reducing waste and supporting sustainable food systems. Thirdly, it offers a practical and accessible nutritional product that can be easily adopted by communities. This paper presents a case study of the development and qualitative analysis of Hi-C Crackers, highlighting their potential as a nutritional intervention. The study hypothesizes that Hi-C Crackers can be processed using chicken feet and mung beans and that their macronutrient and calcium content can be qualitatively identified. Theoretically, this research is expected to contribute by innovating a nutrient-rich snack product, providing original ideas to reduce malnutrition rates, and serving as a reference for future studies. Practically, it benefits researchers by enhancing their knowledge and experience in creating innovations, while also offering the general public a practical and economical solution to meet nutritional needs, particularly calcium, using readily available ingredients. Thus, this research is expected to contribute to efforts in addressing malnutrition and stunting in Indonesia.

## 2. Methods

### *2.1 Time and location of the research*

This research was conducted over two months, from April to May 2023. This timeframe was chosen to ensure the availability of fresh raw materials and optimal laboratory conditions. Additionally, this period was selected to allow the research to be completed on time without interference from other activities.

The product development process was carried out at the researcher's home, located at Melati Street, Cilandak Timur, Pasar Minggu, South Jakarta. Subsequently, product testing was conducted at the Chemistry Laboratory of SMA Negeri 28 Jakarta, following health

protocols and using safe equipment and materials. This laboratory was chosen due to its adequate facilities and suitability for conducting qualitative tests on samples.

*2.2 Data sources, tools, and materials*

Research data were obtained from direct experiments and testing of samples at the Chemistry Laboratory of SMA Negeri 28 Jakarta. These tests were conducted in stages to ensure data accuracy. Additionally, the researcher conducted direct observations of the production and testing processes. The creation of Hi-C Crackers was inspired by Simping cake, a traditional West Javanese snack made from tapioca flour with added spices. Tools used in making Hi-C Crackers included a porcelain mortar and pestle for grinding and mixing ingredients. Other tools included a Vicenza pressure cooker, a Rinnai two-burner stove, a stainless steel stirring spoon, a Simping mold (purchased via marketplaces), a 250 ml measuring cup, and a Kenmaster 2 kg scale.

For qualitative calcium testing, tools such as Erlenmeyer flasks, droppers, Pyrex test tubes, and 10 ml measuring cylinders were used. Macronutrient testing utilized tools like Pyrex test tubes, test tube holders, 250 ml beakers, droppers, glass stirring rods, porcelain spot plates, spirit burners, tripods, wire gauze, and matches. These tools were selected in accordance with laboratory standards to ensure safety and accuracy. The main ingredients for Hi-C Crackers were chicken feet bones, mung beans, tapioca flour, and sesame seeds. The ratio of ingredients was adjusted based on calcium content, with chicken feet bones used in double the quantity of mung beans due to their higher calcium content. These materials were chosen for their availability and nutritional value. For qualitative calcium testing, reagents such as 10% acetic acid filtrate and 1% ammonium oxalate were obtained from the Chemistry Laboratory of SMA Negeri 28 Jakarta. Macronutrient testing used biuret, Lugol's, Benedict's reagents, and filter paper, also provided by the laboratory. All materials were selected for their tested quality and compliance with laboratory standards.

*2.3 Research procedures*

Chicken feet were obtained from Pasar Mitra Tani, South Jakarta. The feet were cleaned, the skin was removed, and they were rinsed under running water to ensure cleanliness. Mung beans of the Merbabu brand were purchased from Pasar Pondok Labu, South Jakarta. The beans were soaked until the skins loosened naturally, facilitating processing and improving quality.

Chicken feet bones were pressure-cooked for 20 minutes, left to rest for 30 minutes, and pressure-cooked again for another 20 minutes. The bones were then ground using a mortar and pestle. Boiled and ground mung beans were mixed with chicken feet bones in a 2:1 ratio (200 grams of bones to 100 grams of beans). Tapioca flour (300 grams) and sesame seeds (20 grams) were added to the mixture. The dough was baked using a Simping mold for 2 minutes until cooked. The resulting Hi-C Crackers had a grayish-brown color and a crispy texture.

Organoleptic analysis was conducted based on sensory evaluation with the following parameters: 1) Color: Grayish-brown; 2) Shape: Flat and round, following the Simping cake pattern; 3) Aroma: Distinct sesame fragrance without any fishy smell; 4) Taste: Savory with a slight sweetness; and 5) Texture: Crispy and smooth when consumed. One-eighth of a Hi-C Cracker was ground and mixed with 2 ml of distilled water. The sample solution was placed in a test tube, and 10% acetic acid filtrate and 1% ammonium oxalate were added. A positive control using chicken eggshells was included. A positive result was indicated by the formation of a white to light brown precipitate.

Qualitative Macronutrient Content Testing was conducted based on Benedict's Test is Ground Hi-C Crackers were mixed with Benedict's solution and heated. A positive result was indicated by a brick-red color change. Lugol's Test is ground samples were mixed with Lugol's solution. A positive result was indicated by a blue-black color change. Biuret Test is Ground samples were mixed with Biuret solution. A positive result was indicated by a

purple color change. Fat Spot Test is Ground samples were placed on opaque paper. A positive result was indicated by the appearance of transparent spots.

*2.4 Data collection methods*

This research used experimental and literature review methods. The experimental method aimed to determine the cause-and-effect relationship between independent and dependent variables (Creswell, 2012). Macronutrient and calcium content testing were conducted independently at the Chemistry Laboratory of SMA Negeri 28 Jakarta.

The literature review involved analyzing books, literature, and reports relevant to the research topic (Nazir, 2003). The researcher collected nutritional data from various sources to support the study. Additionally, the literature review helped the researcher understand the concepts and theories underlying the research. The experiment included the production of Hi-C Crackers and laboratory testing to determine qualitative nutritional content. Laboratory test results provided precise data on the nutritional content of Hi-C Crackers. This process was conducted systematically to ensure data accuracy and reliability.

## 3. Results and Discussion

*3.1 Processing of Hi-C crackers (with Chicken Feet Bone and Mung Bean Ingredients)*

The production of Hi-C Crackers begins with processing chicken feet bones, which are presto-cooked until tender, then ground into a dough. The chicken feet used are from broiler chickens obtained from South Jakarta. Meanwhile, the mung beans used are of the Merbabu brand, purchased from Pasar Pondok Labu, Jl. Raya Fatmawati, Pondok Labu Village, Cilandak District, South Jakarta. Peeled mung beans are boiled, ground, and mixed with the chicken feet bone dough. The amount of mung beans used is 100 grams, while the chicken feet bones used amount to 200 grams. The ingredients were from local resources. The concept of developing biscuits from local resources has also been explored.

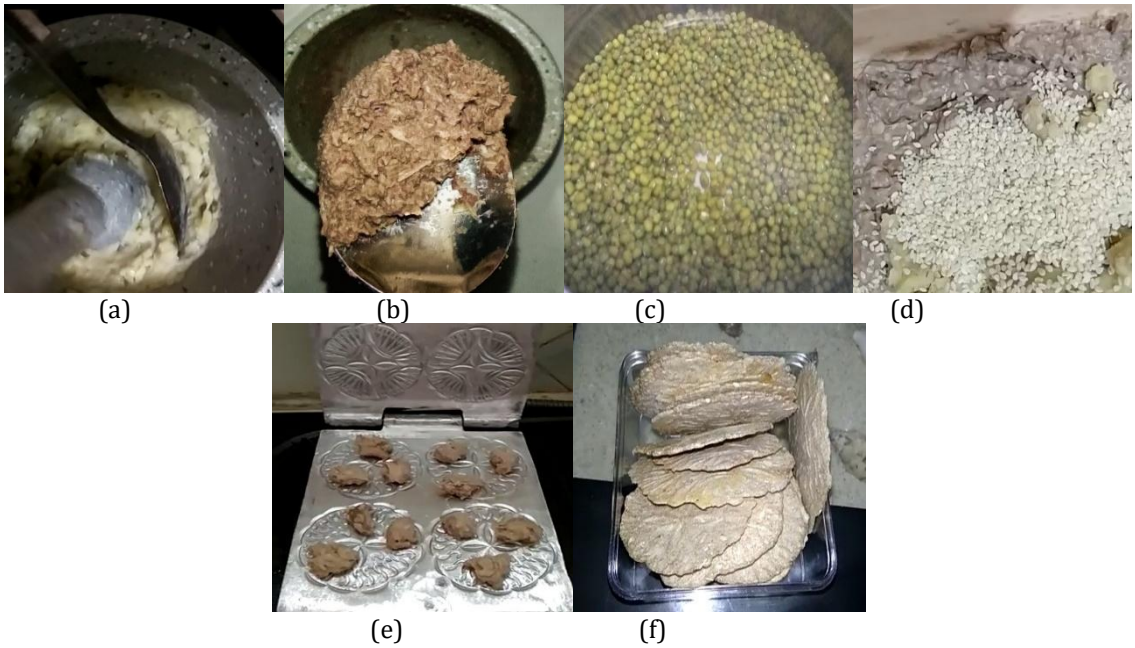


Fig.1. Processing of Hi-C Crackers: a) chicken feet bone dough; b) soaking mung beans before peeling; c) grinding process of peeled mung beans; d) mixing all cracker ingredients; e) baking process of hi-c crackers; f) visual of Hi-C crackers

Local resources offer the advantage of being low-cost, as demonstrated in Sub-Saharan Africa, where biscuits developed as affordable ready-to-use supplementary foods have

shown promising results in integrating protein and lipids for the prevention and management of child malnutrition (Reggi et al., 2024). Mung beans are a source of plant-based protein with high nutritional content, while chicken feet bones are a good source of animal protein and calcium. Specifically in mung beans, the ACE inhibitory and antifungal activities of mung bean protein hydrolysates and peptides have medical applications, while trypsin inhibitors in mung bean protein fractions can serve as additives to prevent food proteolysis (Yi-Shen et al., 2018). While, Chicken feet extract (CF) contain protein can be used as precursors for edible films, with CF films showing potential as suitable food packaging materials, particularly for applications like burger slice separators, warranting further research (Kalantarmahdavi et al., 2022).

Tapioca flour and sesame seeds are added to the dough after all ingredients are thoroughly mixed. Tapioca flour serves as a base ingredient that provides a dense texture to the crackers, while sesame seeds impart a fragrant aroma and umami flavor. The Hi-C Crackers dough is then baked until fully cooked, resulting in a product with a grayish-brown color and a crispy texture. Baking is a crucial process for achieving optimal biscuit texture and structure, as oven temperature influences moisture loss and surface evaporation, resulting in a final product moisture content of approximately 2-4% (Saadoudi et al., 2024).

Based on the ingredient composition, the product yields 188 pieces of crackers with a total weight of 400 grams. Organoleptic testing was conducted qualitatively using sensory evaluation. The results of the organoleptic analysis are presented in Table 1. All organoleptic parameters, including color, shape, aroma, taste, and texture, meet the predetermined criteria for Hi-C Crackers.

Table 1. Qualitative organoleptic test results

| No | Organoleptic Parameter | Criteria | Results |
|---|---|---|---|
| 1 | Color | Grayish-brown | Grayish-brown |
| 2 | Shape | Flat and round | Flat and round, matching the traditional simping cake motif |
| 3 | Aroma | Distinct sesame aroma | Distinct sesame aroma with no fishy smell |
| 4 | Taste | Savory | Savory with a slight sweetness |
| 5 | Texture | Crispy | Crispy and smooth when consumed |

Overall, Hi-C Crackers are characterized by their crispiness, lightness, and umami flavor, attributed to the inclusion of sesame seeds and mung beans. The product not only uses healthy and natural ingredients but is also low in calories due to the absence of oil and low in sugar as it contains no added sweeteners. Another significant advantage is the complete absence of any fishy taste. The organoleptic test results indicate that Hi-C Crackers meet the expected quality standards. The grayish-brown color is consistent with the natural ingredients used, such as mung beans and chicken feet bones. One of the key assessments in biscuits is color, as it holds a unique philosophy, with its external appearance creating the first impression for consumers, particularly children (Jan et al., 2018). The flat and round shape aligns with the traditional simping cake motif, making the product visually appealing. The distinct sesame aroma, combined with the absence of a fishy smell, enhances the sensory experience. The savory taste with a slight sweetness is well-balanced, while the crispy texture ensures a pleasant mouthfeel. These results confirm that Hi-C Crackers are not only nutritious but also enjoyable to consume

### *3.2 Macronutrient content of Hi-C crackers*

Hi-C Crackers utilize biofortification to enhance nutrient content. Aligning with other studies that have demonstrated fortifying biscuits with natural ingredients such as monofloral bee pollen is intended to enhance their protein content (Végh et al., 2022). Macronutrient analysis was conducted to determine the content of essential nutrients required by the body in large amounts, such as carbohydrates, proteins, glucose, and fats.

The macronutrient content of Hi-C Crackers was analyzed qualitatively. Protein content was tested using the Biuret Test, which yields a positive result indicated by a purple color. Carbohydrate content was tested using the Lugol Test, which yields a positive result indicated by a bluish-black color. The Benedict method is used to quantify reducing sugars (Hernández-López et al., 2020). The yields a positive result indicated by a brick-red, orange-red, or green color in the test tube, depending on the amount of reducing sugar present. Fat content was tested using the grease spot test, which yields a positive result indicated by a transparent stain.

Table 2. Qualitative macronutrient test results

| No | Reagent | Positive Control | Control result | Test Sample | Sample result | Remarks |
|---|---|---|---|---|---|---|
| 1 | 0.1 ml Biuret | Condensed Milk | Purple | Hi-C Crackers | Purple | Positive (+) |
| 2 | 0.1 ml Iodine | Rice porridge | Bluish black | Hi-C Crackers | Bluish-black | Positive (+) |
| 3 | 0.1 ml Benedict | Granulated sugar | Brick-red | Hi-C Crackers | Greenish-teal | Positive (+) |
| 4 | Grease spot test | Baby oil | Transparent | Hi-C Crackers | No stain | Negative (-) |

The macronutrient test results reveal that Hi-C Crackers contain protein, carbohydrates, and glucose but no fat. In the Biuret Test, the positive control (Condensed Milk) turned purple, and Hi-C Crackers also turned purple, confirming the presence of protein. The mung bean, a globally consumed food, is a rich source of protein (20.97–32.6%), essential minerals, dietary fiber, and bioactive compounds, making it a valuable functional food that meets daily nutritional needs, particularly in regions like India and Pakistan where it is consumed as a staple (Hou et al., 2019). The iodine/Lugol solution test is only capable of detecting polysaccharides and cannot identify monosaccharides (Zaman et al., 2024). Hi-C Crackers turned bluish-black, indicating the presence of carbohydrates. This is consistent with the use of tapioca flour as a base ingredient, which is a carbohydrate-rich material. In the Benedict Test, the positive control (granulated sugar) turned brick-red, while Hi-C Crackers turned greenish-teal. This variation in color is due to the difference in sugar types; granulated sugar is a simple sugar (sucrose), while Hi-C Crackers contain complex carbohydrates from mung beans and tapioca flour. The grease spot test showed no transparent stain for Hi-C Crackers, indicating the absence of fat. This result is advantageous, as it makes the product low in calories and suitable for health-conscious consumers.

### *3.3 Qualitative calcium content of Hi-C crackers*

Calcium is an essential mineral beneficial for bone and teeth growth and maintenance, as well as supporting nervous system function. In this study, the primary ingredient used is chicken feet bones, which theoretically contain high levels of calcium. The calcium content of Hi-C Crackers, made from processed chicken feet bones, was tested qualitatively. The sample was reacted with 1 ml of 1% ammonium oxalate and 10% acetic acid filtrate in a test tube. A positive result is indicated by the formation of a white to light brown precipitate.

Based on the qualitative calcium analysis, Hi-C Crackers tested positive (+) for calcium. In the test using 1 ml of 1% ammonium oxalate and 10% acetic acid filtrate, the positive control (chicken eggshell) formed a white to light brown precipitate, and Hi-C Crackers also formed a white to light brown precipitate. This result confirms that the sample contains calcium. This result aligns with the theoretical chicken bones, as by-products of slaughter, are often discarded or processed into low-value animal feed, despite their rich calcium content and potential for utilization (Wang et al., 2022). Calcium and vitamin D have been proven effective in supporting normal bone growth and development in children and adolescents (Higgs et al., 2017). The inclusion of chicken feet bones in Hi-C Crackers makes the product a functional food that can contribute to meeting daily calcium requirements.

Table 3. Qualitative calcium test results

| No | Sample | Reagent | Reference | Result | Remarks |
|---|---|---|---|---|---|
| 1 | Chicken eggshell | 10% acetic acid filtrate + 1 ml 1% ammonium oxalate | White to light brown precipitate | White to light brown precipitate | Positive (+) |
| 2 | Hi-C Crackers | 10% acetic acid filtrate + 1 ml 1% ammonium oxalate | White to light brown precipitate | White to light brown precipitate | Positive (+) |

### *3.4 Overall treatment*

The production of Hi-C Crackers successfully combines the nutritional benefits of chicken feet bones and mung beans into a functional food product. Chicken feet bones provide high-quality animal protein and calcium, while mung beans contribute plant-based protein and essential amino acids. The addition of tapioca flour and sesame seeds enhances the texture and flavor of the crackers, making them a nutritious and enjoyable snack.

The organoleptic and macronutrient test results demonstrate that Hi-C Crackers meet quality standards and are rich in protein, carbohydrates, and calcium while being low in fat. The absence of a fishy taste and the presence of a savory, slightly sweet flavor make the product appealing to a wide range of consumers. Furthermore, the low-calorie and low-sugar nature of Hi-C Crackers makes them suitable for health-conscious individuals, including children and adults.

Hi-C Crackers represent a promising functional food product that leverages underutilized ingredients rich in protein and calcium to deliver significant nutritional benefits, aligning with the government's vision to reduce stunting rates. In a review study on stunting-prevention biscuits, findings suggest that policymakers and healthcare professionals should consider the use of fortified biscuits as part of stunting reduction strategies, particularly in regions with high stunting rates (Mamun et al., 2024). Consumption of nutrient-rich supplementary biscuits for three months among stunted children aged 36-60 months has been shown to improve height-for-age z-scores (HAZ), demonstrating its potential in addressing stunting (Herawati et al., 2020). The product has the potential to address nutritional deficiencies, particularly in calcium and protein, while offering a tasty and convenient snack option. Foods selected for mandatory fortification programs must be based on the consumption habits of the population, meaning they should be regularly consumed by the majority and industrially produced to facilitate effective fortification. When determining fortification levels, it is essential to consider both the lowest and highest intake groups within the population to maximize positive impacts while minimizing the risk of excessive intake (Bourassa et al., 2022). Future studies could explore large-scale production and consumer acceptance to further validate its market potential.

### *3.5 Long-term health benefits of Hi-C crackers for malnourished children*

Malnutrition is a significant global public health challenge, disproportionately affecting children in low-income regions where access to nutrient-rich food is limited. Chronic malnutrition leads to growth retardation, weakened immunity, increased susceptibility to infectious diseases, and cognitive impairments, thereby hindering overall physiological and intellectual development (Black et al., 2013). Addressing malnutrition requires innovative and sustainable dietary interventions that deliver high-quality protein, essential minerals, bioactive compounds, and digestible energy sources to optimize growth and development.

Hi-C Crackers, formulated from chicken feet bone and mung bean, offer a promising solution for malnourished children. Chicken feet bone is a bioavailable source of hydroxyapatite calcium, phosphorus, and collagen-derived peptides, while mung beans provide plant-based proteins, dietary fiber, antioxidants, and micronutrients (Zhang et al., 2018). The combination of these ingredients creates a functional food product designed to enhance muscle development, skeletal integrity, immune response, cognitive function, and

gut health over prolonged consumption.The long-term consumption of Hi-C Crackers can be analyzed through various physiological and biochemical pathways, particularly in relation to protein metabolism, mineral absorption, gut microbiome modulation, immune resilience, and neurological function. A comprehensive understanding of these mechanisms is crucial in determining the efficacy of Hi-C Crackers as a functional nutritional intervention for malnourished children.

### *3.6 Enhancement of physical growth and skeletal development*

Protein-energy malnutrition is a leading cause of growth failure in children, characterized by stunting, muscle wasting, and impaired organ function (de Onis et al., 2019). Hi-C Crackers provide a dual protein source, incorporating animal-derived collagen peptides from chicken feet and plant-based amino acids from mung beans, which together enhance muscle synthesis, tissue repair, and overall metabolic efficiency (Sharma et al., 2020). Collagen-derived peptides are rapidly absorbed and utilized in the body, facilitating cartilage formation and connective tissue repair. Research suggests that collagen hydrolysates improve bone mineral density and joint health, making them particularly beneficial for children recovering from malnutrition-induced skeletal deficiencies (Clark et al., 2016). Additionally, the branched-chain amino acids (BCAAs) from mung bean proteins play a crucial role in muscle protein biosynthesis and metabolic homeostasis, preventing muscle atrophy and promoting physical endurance (Hernández-Ledesma et al., 2019).

The bioavailable calcium and phosphorus from chicken feet bone further contribute to optimal bone mineralization and skeletal growth. Calcium plays a vital role in osteoblast differentiation and hydroxyapatite deposition, while phosphorus is essential for ATP production and cellular energy metabolism (Karpouzos et al., 2017). Malnourished children are particularly susceptible to rickets and osteopenia, conditions that result from chronic deficiencies in these minerals (Prentice, 2019). The Ca:P ratio of approximately 2:1 in Hi-C Crackers supports bone density enhancement and long-term structural integrity, reducing the risk of fractures and skeletal deformities.

### *3.7 Modulation of immune function and disease resistance*

Children suffering from malnutrition frequently exhibit weakened immune responses, leading to higher infection rates and prolonged recovery periods (Chisti et al., 2020). A well-balanced diet rich in immunomodulatory nutrients is essential for maintaining innate and adaptive immunity, thereby reducing disease susceptibility. Hi-C Crackers contain several key micronutrients, including zinc, iron, vitamin C, and bioactive peptides, which collectively enhance immune cell proliferation and antimicrobial defense. Zinc is a cofactor for over 300 enzymatic reactions involved in cellular immunity and cytokine production (Shankar & Prasad, 1998). Zinc deficiency in malnourished children is linked to reduced T-cell function, impaired wound healing, and increased incidence of diarrheal diseases (Wessells & Brown, 2012). Mung beans, a primary component of Hi-C Crackers, provide a bioavailable source of zinc, contributing to lymphocyte activation, macrophage activity, and overall immune resilience.

Iron plays a crucial role in oxygen transport, mitochondrial respiration, and immune regulation. Iron-deficiency anemia is a widespread condition among malnourished children, leading to fatigue, cognitive impairments, and increased vulnerability to infections (Pasricha et al., 2021). The iron content in Hi-C Crackers, sourced from both mung beans and animal-derived components, enhances hemoglobin synthesis and erythropoiesis, thereby improving oxygen delivery to immune cells and peripheral tissues. Furthermore, bioactive peptides derived from collagen hydrolysates have been reported to exert antimicrobial and anti-inflammatory properties, promoting wound healing, gut barrier function, and epithelial regeneration (Zague, 2008). These properties are particularly beneficial for malnourished children who suffer from chronic inflammation and gut permeability issues, further supporting immune homeostasis.

*3.8 Impact on cognitive function and neurodevelopment*

Cognitive deficits associated with malnutrition can have long-lasting effects on brain function and academic performance. Essential nutrients such as B-complex vitamins, omega-3 precursors, and neurotransmitter-regulating amino acids play a critical role in neurodevelopment, synaptic plasticity, and cognitive processing (Goyal et al., 2018). Hi-C Crackers provide a neuroprotective nutrient profile, which contributes to optimal brain function and learning capacity.

The presence of iron and folate in mung beans supports myelination and neural conductivity, improving memory retention and executive function (Georgieff, 2011). Additionally, choline and glutamate-derived amino acids from collagen peptides facilitate acetylcholine synthesis, a neurotransmitter essential for attention, cognition, and neural plasticity (Zeisel, 2011). Omega-3 fatty acids, primarily derived from mung bean lipids, enhance neuronal membrane fluidity and anti-inflammatory responses, reducing the risk of cognitive impairments and neurodevelopmental disorders (Dyall, 2015). The integration of Hi-C Crackers into the diet may therefore support intellectual development and enhance academic performance in malnourished children, mitigating the long-term consequences of early-life undernutrition.

*3.9 Gut health and nutrient absorption*

Gastrointestinal health is a critical determinant of overall nutrient utilization and metabolic efficiency in malnourished children. Chronic malnutrition is often accompanied by gut dysbiosis, impaired intestinal permeability, and nutrient malabsorption syndromes (Ghosh et al., 2022). Hi-C Crackers contain prebiotic fibers from mung beans, which selectively stimulate the growth of beneficial gut microbiota (e.g., Lactobacillus and Bifidobacterium spp.), thereby enhancing intestinal barrier integrity and microbial diversity (Slavin, 2013). Dietary fiber promotes regular bowel movements, reduces intestinal inflammation, and enhances colonic fermentation, producing short-chain fatty acids (SCFAs) such as butyrate and acetate. SCFAs act as energy substrates for enterocytes, improving gut epithelial health and reducing systemic inflammation (Silva et al., 2020). By optimizing gut microbiome composition, Hi-C Crackers facilitate nutrient absorption and metabolic homeostasis, further supporting long-term growth and immune function.

The long-term consumption of Hi-C Crackers offers a scientifically validated approach to addressing malnutrition in children. By providing a comprehensive nutritional profile, these crackers support skeletal development, enhance immune function, optimize cognitive performance, and improve gut health. Future research should focus on clinical trials and longitudinal studies to further validate the efficacy of Hi-C Crackers in different demographic settings, ensuring sustainable and scalable solutions for combating child malnutrition worldwide.

## 4. Conclusions

Hi-C Crackers can be produced using chicken feet bones (*Gallus gallus domesticus*) and mung beans (*Vigna radiata*) as the primary ingredients. The qualitative analysis of macronutrients in Hi-C Crackers revealed the presence of carbohydrates (based on the Lugol Reagent Test), proteins (based on the Biuret Reagent Test), and glucose (based on the Benedict Reagent Test). Additionally, the qualitative calcium content in Hi-C Crackers was confirmed to be positive through testing with 1 ml of 1% ammonium oxalate and 10% acetic acid filtrate. However, for further development, additional data are required to quantitatively determine the calcium content in Hi-C Crackers. Furthermore, organoleptic testing involving panelists is necessary to assess consumer acceptance. Moreover, innovations in the processing of Hi-C Crackers should be explored to enhance the product's appeal and competitiveness in the market.

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## Author Contribution
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The authors declare no conflict of interest.

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