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CRICKET POWDER (*ACHETA DOMESTICUS*): NUTRITIONAL VALUE, PROCESSING, AND FOOD APPLICATIONS

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Abstract

In the context of a growing population and the increasing demand for sustainable protein sources, edible insects – particularly crickets – are emerging as a highly promising alternative food option. This article focuses on synthesizing and analyzing existing research related to the nutritional composition of cricket powder from various geographical sources, such as Thailand, Kenya, and Canada. Cricket flour has been reported to contain high levels of protein (42.0–48.87%) and fat (23.6–29.1%), along with essential minerals such as potassium (826–1 224 mg/100 g), iron (4.06–5.99 mg/100 g), zinc (2.17–21.8 mg/100 g), etc. — micronutrients that are vital for human health. The variation in nutritional content among samples indicates the role of the species of cricket, the feed, the rearing conditions, and the processing methods. When incorporated at substitution levels of 2–50% compared with conventional ingredients, cricket powder demonstrates great potential as both a meat alternative and a functional ingredient. Its diverse nutritional profile makes it suitable for specialized applications in the food industry. Overall, this overview clarifies the potential applications of cricket powder in the future food system, supporting directions toward sustainability, safety, and improved nutrition.

Keyword: *Acheta domesticus*, cricket powder, edible insects, sustainable food source

INTRODUCTION

In recent decades, the issues of food security and climate change have driven scientists, businesses, and governments around the world to seek sustainable and environmentally friendly alternative food sources. Among the alternative protein sources, edible insects are emerging as a potential option due to their high biological conversion efficiency, low resource use, and impressive nutritional content. Indeed, the house cricket (*Acheta domesticus*) is one of the most commonly farmed insect species for food in many countries, especially in Asia, Africa, and recently in European and North American countries (van Huis *et al.*, 2013).

Crickets have a very high protein content, ranging from 58 to 65% of dry weight, while also providing all essential amino acids, minerals such as iron, zinc, calcium, potassium, phosphorus, and vitamins, especially vitamin B12 – a micronutrient that is often deficient in plant-based diets (FAO, 2013). In addition, crickets contain chitin, a special form of fiber with potential prebiotic activity that contributes to the health of the gut microbiome (Różyło *et al.*, 2022). With their nutrient-rich characteristics, ease of farming, and environmental friendliness, crickets are considered the "food of the future" (FAO, 2013). Insect flour can be added to food as a nutritional supplement, providing a source of high-quality protein, essential minerals (such as iron, zinc, calcium), unsaturated fatty acids, B vitamins, and chitin fiber, thereby enhancing the overall nutritional value of the product (Duda *et al.*,

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2019; Pauter *et al*., 2018). However, consumers do not accept eating whole insects, both larvae and adults (Hartmann *et al*., 2015). Therefore, one of the methods to increase the acceptance and consumption of insects is to provide insects in a ground form. Some countries in the European Union have regulated the production of food from insects, for example, the General Food Law (Regulation (European Commission-EC) No 178/2002) and Hygiene Package Law (Regulations (EC) No 852/2004, 853/2004 and (EU) 2017/625) (Meijer *et al*., 2025). A global change in legislation in this area could contribute to increasing the consumption of insects in Europe. Widespread adoption of insect-based foods has the potential to significantly enhance global food security by providing a highly efficient and nutritious solution to combat hunger, while simultaneously mitigating environmental pollution through a drastic reduction in greenhouse gas emissions and resource consumption compared to conventional livestock farming (Lange and Nakamura, 2021).

Cricket powder (CP) - is processed from dried crickets and finely ground, emerging as a promising alternative to traditional protein sources such as meat, eggs, or milk, thanks to its rich nutritional content and versatile applications. According to the research by Montowska *et al.* (2019), CP contains 42–46% protein (dry weight) and is rich in fats, fiber, and minerals such as Ca, Mg, Fe, Cu, Mn, Zn (Ruggeri *et al*., 2023). Not only that, Boonarsa *et al.* (2025) noted that CP provides a complete supply of essential amino acids, fiber from chitin, and micronutrients such as vitamins B2, B12, iron, calcium, and zinc - sometimes even surpassing beef or chicken (Boonarsa *et al*., 2025; Nowakowski *et al*., 2021).

A comparative study with whey protein showed that CP has a digestibility of about 80%, just lower than whey (over 97%) but still sufficiently absorbed and is a valuable source of protein (Lampová *et al*., 2024).

In terms of biological function, spray-dried cricket powder has been shown to have strong antioxidant activity, the ability to eliminate free radicals, and to maintain the stability of bioactive peptides when heated - indicating high potential applications in the field of functional foods and pharmaceuticals (Ruggeri *et al*., 2023).

Therefore, CP is not only a rich energy protein source - with superior benefits in micronutrients and bioactive compounds - but also a versatile ingredient that can be easily incorporated into various food products such as beverages, baked goods, noodles, protein bars, or functional foods. This characteristic helps CP quickly become a suitable choice for modern consumption trends that emphasize health, sustainability, and environmental friendliness. This overview aims to provide a comprehensive look at the nutritional components, potential health benefits, processing technology, and practical applications of CP in the food and nutrition industry

TERMS DESCRIPTION AND METHODOLOGY

Terms Description

To establish a common understanding for this review, the following key terms are defined:

- Cricket powder:

A fine flour obtained from dried and milled whole crickets (*Acheta domesticus*). It is characterized by its high protein content and is used as a food ingredient.

- Nutritional value:

The composition of macro- and micronutrients in cricket powder, including but not limited to protein, fat (particularly lipids like oleic and linoleic acid), fiber (chitin), vitamins, and minerals.

- Processing:

The sequence of operations applied to live crickets to transform them into a stable, edible powder. This typically includes stages such as fasting, euthanizing, washing, blanching, drying, and milling. The specific methods at each stage (e.g., freeze-drying vs. oven-drying) are of particular interest.

- Food Applications:

The utilization of cricket powder as a functional ingredient in various food products, such as bakery goods, snacks, protein bars, and pasta, to enhance their nutritional profile.

Methodology

This article is structured as a literature review. The primary objective is to collect, synthesize, and critically evaluate the existing scientific knowledge on cricket powder (*Acheta domesticus*). Given the interdisciplinary nature of the topic, an integrative review approach was adopted.

This review was conducted following a systematic literature review methodology, which was effectuated in six sequential steps:

1. Selection of fitting keywords.
2. Comprehensive search on scientific databases.
3. Screening and selection of articles.
4. Supplementary search via reference tracking.
5. Development of key categories and analytical framework.
6. Comparative analysis and synthesis.

Step 1: Selection of Fitting Keywords

An initial scoping review was performed to identify the most relevant and effective keywords. The final set of search terms included: "cricket powder," "*Acheta domesticus*," "edible cricket," "insect flour," "nutritional composition," "protein quality," "chitin," "food processing," "drying," "thermal processing," "food application," "bakery products," "sensory evaluation," "food safety," and "consumer acceptance." These terms were used in various combinations to maximize the coverage of relevant literature.

Step 2: Comprehensive Search on Scientific Databases

A systematic search was executed using the identified keywords across major scientific databases, including Google Scholar, Scopus, and Web of Science. The search strategy was designed to be inclusive, focusing on peer-reviewed journal articles, conference proceedings, and academic reviews. Only journals listed in these systems were chosen for the final core analysis to ensure scientific quality.

Step 3: Screening and Selection of Articles

The retrieved articles were subjected to a rigorous screening process based on their titles and abstracts. Studies were selected for in-depth analysis if they met the following criteria:
(a) primary focus on *Acheta domesticus*;
(b) contained original data on nutritional value, processing, or food applications; and
(c) were published in peer-reviewed journals.
The literature from the last 22 years (2002–2024) has been reviewed to capture modern advancements, while acknowledging that a lack of standardized methodologies may limit earlier literature.

Step 4: Supplementary Search Via Reference Tracking

To ensure no key studies were overlooked, a supplementary search was conducted by examining the reference lists of all articles selected in Step 3. This "snowballing" technique helped identify additional relevant sources that were not captured by the initial database search.

Step 5: Development of Key Categories and Analytical Framework

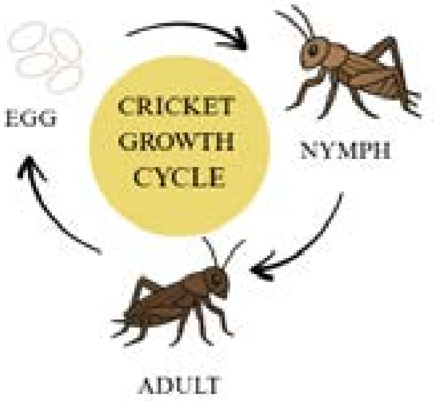
The content of the selected studies was analyzed to identify major thematic clusters. This process led to the development of an analytical framework based on the following key categories: Nutritional Value, Processing Techniques, Functional Properties, Food Applications, and Safety & Regulatory Aspects. This framework structured the subsequent synthesis of findings.

Step 6: Comparative Analysis and Synthesis

In this final step, articles within each category were systematically compared. The analysis aimed to: present the main researched fields, summarize the resulting findings, identify consensus or contradictions across studies, compare the trustworthiness of evidence, highlight the importance for researchers and industry practitioners, and reveal the methodologies used as well as the scientific gaps that remain today. This synthesis provides a comprehensive and critical overview of the current state of knowledge regarding cricket powder.

Growth Characteristics of House Cricket (*Acheta domesticus*)

The house cricket (*Acheta domesticus*) is one of the most commonly farmed insect species in the world due to its rapid growth, adaptability, and high nutritional value. They thrive in dark, well-ventilated environments with an ideal temperature of 28–32 °C and humidity around 50–70% (Steinhausen *et al.*, 2024). The cricket has an average lifespan of about 8–10 weeks, going through three stages: egg, nymph, and adult (Fig. 1). Eggs are usually laid in moist substrates such as sand or coconut coir and will hatch after about 10–12 days if the temperature is maintained at 30 °C (Mitchaothai *et al.*, 2024).



1: *Cricket growth cycle*

An adult female cricket can lay 100–200 eggs per batch and reproduce regularly for 2–3 weeks. Crickets begin mating just 3–4 days after reaching maturity, with high reproductive capacity if provided with protein-rich food (~30%) from grain bran, vegetables, or agricultural by-products (Tan *et al.*, 2022). However, the breeding density needs to be controlled (not exceeding 0.4 individuals/cm^2) to limit disease outbreaks, especially the *Acheta densovirus* – a common disease under high-density farming conditions (Takacs *et al.*, 2023).

Crickets have an efficient feed conversion ratio – it only takes 1.7 kg of feed to produce 1 kg of biomass, which is much lower than traditional livestock such as cattle or pigs (van Huis *et al.*, 2013). This makes the cricket farming model sustainable and environmentally friendly. In Thailand, there are over 20,000 households raising crickets for commercial purposes, primarily house crickets, with production reaching thousands of tons each year, demonstrating significant potential for application in food and animal feed (Pilco-Romero *et al.*, 2023).

Cricket Powder

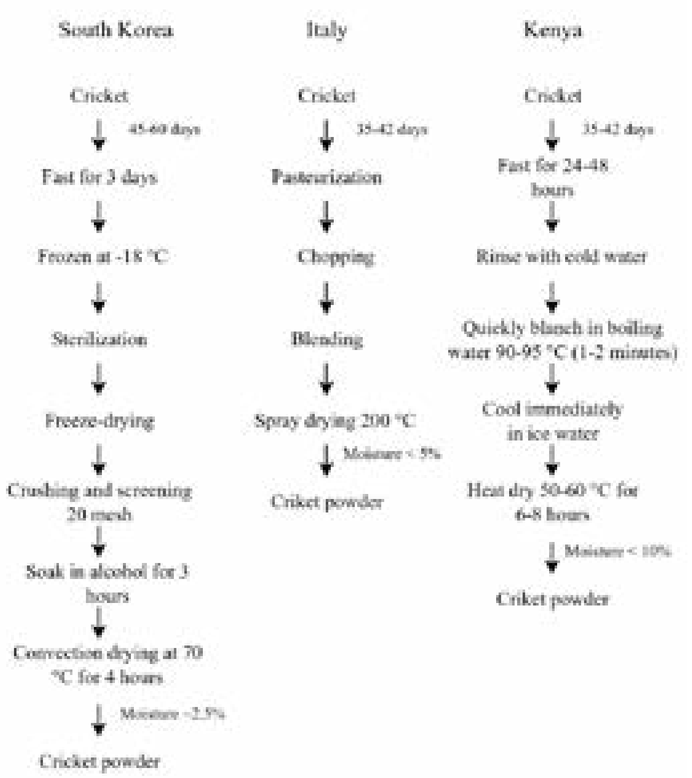
In the industry, crickets can be processed into various product forms such as: whole dried crickets, crispy fried crickets, protein extracts, cricket snacks, nutritional bars, noodles containing protein, and various functional foods. However, CP is the most popular and convenient form due to its easy storage, easy blending into many types of food, while also helping to reduce consumers' hesitation about the whole insect shape (Ruszkowska *et al.*, 2022; Ardoin *et al.*, 2020). In current studies, the most commonly used species of cricket is the house cricket (*Acheta domesticus*), thanks to its rapid growth, high nutritional content, and ease of breeding under controlled conditions. Most of the raw materials come from farmed crickets, not wild ones, to ensure uniformity in quality and food safety. Breeding farms typically apply standard feeding regimes and environmental conditions, helping to optimize the growth rate as well as the nutritional composition in the bodies of the crickets (Gantner *et al.*, 2024).

Studies by Kim *et al.* (2016) in South Korea, Ruggeri *et al.* (2023) in Italy, and Ayieko *et al.* (2016) in Kenya have developed CP production processes with distinctly different characteristics (Fig. 2). It is worth noting that these countries are also among the largest annual consumers of edible insects and insect-based products globally, which has driven the development of distinct processing technologies tailored to their respective market needs and regulatory environments.

Despite differences in technology and production scale, some processes – particularly in South Korea and Kenya – share the common feature of fasting before slaughter to clean the digestive tract (Megido *et al.*, 2017). This step has been proven to significantly reduce the amount of food and waste remaining in the intestines of insects, thereby enhancing the hygiene quality and nutritional value of the final product.

In Italy, the CP production process is implemented with modern technology to create high-quality products. Specifically, crickets are harvested at the mature stage (35–42 days old). Insects are sterilized, then chopped and ground to obtain a homogeneous mixture. This mixture is spray-dried at 200 °C (inlet temperature), resulting in a fine powder with a moisture content of less than 5%. Suitable for high-quality protein products or functional foods that require absolute uniformity and microbiological safety (Ruggeri *et al.*, 2023).

Meanwhile, in Korea, the processing procedure focuses on the harmony between thermal efficiency and food safety requirements according to European standards. Crickets are frozen to inhibit enzyme activity and slow down the biological decomposition process, thereby preserving the original sensory and nutritional quality of the raw material. After that, the crickets are sterilized to kill bacteria, then freeze-dried for more than 72 hours to ensure microbial stability and product structure (Kim *et al.*, 2016). The crickets, after being crushed, are soaked in alcohol for about 3 hours to remove impurities, reduce the characteristic odor of crickets, while also aiding in disinfection, and then dried in a hot air dryer (Noviana *et al.*, 2024). As a result, the



2: *Cricket powder production processes in South Korea, Italy, and Kenya (Kim et al., 2016; Ruggeri et al., 2023; Ayieko et al., 2016)*

CP can be integrated into baked goods, noodles, or snacks while still retaining its characteristic flavor and original nutritional value.

Conversely, in Kenya – where industrial production conditions are still limited – the production process of crickets is manual, making the most of the available conditions. After harvesting, the crickets are fasted for 24–48 hours. Next, the crickets are thoroughly washed with cold water to remove impurities, dirt, and reduce odor. After that, they are briefly boiled in hot water to kill some bacteria and fix the color (Rosa *et al.*, 2010). The drying process is carried out by natural sun exposure or drying at low temperatures (50–60 °C) for about 6–8 hours, ensuring the final moisture content is below 10% to prevent spoilage. The finished CP is mainly used in traditional dishes such as samosas, soups, or porridge (Ayieko *et al.*, 2016). Cooling or freezing crickets after harvest helps limit the growth of microorganisms, reduce the activity of degrading enzymes, and preserve the raw material before drying or further processing. This process is commonly applied in South Korea and Kenya to ensure food quality and safety (Cao *et al.*, 2003). Although the process in Kenya does not meet the quality control standards of South Korea or Italy, it reflects a flexible adaptation to local economic conditions and still ensures basic nutritional needs.

The differences in production methods in these three countries not only demonstrate the diversity of technology but also clearly reflect the economic and social characteristics and application goals of each region. While South Korea focuses on advanced processing technology to target the high-end market, Italy prioritizes food safety according to European standards, and Kenya aims for feasible and cost-effective solutions for its people. The strengths of each method can complement each other: spray drying ensures uniformity and convenience, multi-stage thermal processing enhances safety, while traditional methods are more sustainable and energy-efficient. In summary, it is necessary to design a drying process tailored to each species to ensure food safety (Grabowski and Klein, 2017).

From there, it can be seen that CP is a potential ingredient with flexible applications ranging from functional foods, protein-enhancing products, snacks to local cuisine. Depending on the development orientation, target market, and technical conditions, each country can choose and adjust the production process accordingly to maximize the value of this promising ingredient.

Nutritional Composition of Cricket Powder

Tab. I shows the differences in the nutritional composition of CP from three countries: Thailand and Canada (Montowska *et al.*, 2019; Osimani *et al.*, 2018), and Kenya (Ayieko *et al.*, 2016). Overall, all samples have a high protein content, but the sample from Thailand stands out with 42.0–48.87%, compared to 44.8% (Canada) and approximately 47.1% (Kenya). This suggests that crickets may be a promising source of protein, especially in the context of seeking high-protein food alternatives to traditional meat.

The fat content varies slightly between samples: Thailand has the highest level (23.7–29.1%), followed by Kenya (25.8%) and Canada (23.6%) (Montowska *et al.*, 2019; Osimani *et al.*, 2018; Ayieko *et al.*, 2016). Such variation suggests that dietary inputs and processing techniques may influence fat deposition in crickets. Importantly, cricket fat is known to contain a favorable ratio of unsaturated to saturated fatty acids, making it a healthier lipid source compared with many animal fats (Umebara *et al.*, 2024). This enhances its application in functional foods targeting cardiovascular health.

Regarding ash – representing mineral content – the three samples have relatively similar values: 4.2% (Canada), 3.8% (Kenya), and 3.5–4.3% (Thailand), indicating stable mineral content regardless of geographical origin (Montowska *et al.*, 2019; Ayieko *et al.*, 2016). This consistency indicates that geographical origin has limited effect on overall mineral content, although specific minerals (e.g., potassium, iron, zinc) may differ. From a nutritional standpoint, the stable mineral contribution ensures that CP can reliably provide essential micronutrients, reinforcing its role in combating iron- and zinc-deficiency-related malnutrition (Wakeel *et al.*, 2018).

I: *Nutritional value of cricket powders*

	Thailand (Montowska *et al.*, 2019; Osimani *et al.*, 2018)	Canada (Montowska *et al.*, 2019)	Kenya (Ayieko *et al.*, 2016)
Protein (%)	42.0–48.87	44.8	47.1
Fat (%)	23.7–29.1	23.6	25.8
Ash (%)	3.5–4.3	4.2	3.8
Fibre (%)	3.5–7.64	7.4	5.5
Carbohydrate (%)	19.6–21.8	20.0	10
Energy value (kcal/100 g)	476.86–524.1	486.4	-

Note: “-” Not tested

Notably, the insoluble fiber in the Canadian sample reached the high level (7.4%), compared to Kenya (5.5%) and Thailand (3.5–7.64%) (Montowska *et al.*, 2019; Ayieko *et al.*, 2016). This may help improve gut health when applied in functional foods.

The carbohydrate content shows a significant difference: the sample from Kenya has the lowest content (10%), which is half that of Canada (20.0%) and Thailand (19.6–21.8%) (Montowska *et al.*, 2019; Ayieko *et al.*, 2016). This is a factor that can be considered when using for low-carbohydrate diets (Fields *et al.*, 2016). This low-carbohydrate profile may be advantageous for low-carb or ketogenic diets (Bolla *et al.*, 2019), expanding the market potential of Kenyan CP. Conversely, higher carbohydrate values in other samples may contribute positively to energy supply when CP is used in fortified food products.

Finally, the energy value of CP from Thailand (476.86–524.1 kcal/100 g) and Canada (486.4 kcal/100 g) is quite similar, indicating that this is a rich energy source (Montowska *et al.*, 2019; Osimani *et al.*, 2018; Ayieko *et al.*, 2016). Meanwhile, CP from the species *Gryllus bimaculatus* has significantly different nutritional components, with a higher protein content (61.05%), also higher ash content (4.41%), slightly lower fat content (19.08%), and average carbohydrate levels (11.60%) (Kim *et al.*, 2020). Compared to ground beef – which contains 25.5 g of protein, 14.0 g of fat, and 13.5 g of ash per 100 g (Long and Mohan, 2021) – CP shows a clear advantage in protein and fat content. This reinforces CP's position as a nutritional alternative, aligning with the trend of high-protein but low saturated fat foods.

Compared to yellow mealworm (*Tenebrio molitor*), which have a protein content ranging widely from 18.51–63.34%, fat 1.3–32.7%, fiber 4.58–25.96%, and ash 2.86–7.29% (Ravzanaadii *et al.*, 2012), it shows that both types of insects are nutritionally rich; however, the specific values depend on the species and processing methods.

In comparison with other animal-based powders, the nutritional composition also shows promising values (Tab. II). Mealworm powder has a protein content of 45.00–70.76%, which is comparable to CP and even higher in some cases, along with a fat content ranging from 13.22–37.55% (Son *et al.*, 2019). Fish powder contains approximately 50.4% protein and 30.1% fat, with a high ash level (12.3%) (Kasozi *et al.*, 2018). Meanwhile, meat and bone meal presents the broadest variation, with protein ranging from 38.5–73.6%, fat from 2.5–18.5%, and ash content from 13.0–56.5% (Hendriks *et al.*, 2002). The energy value also differs: fish powder provides 470.9 kcal/100 g, while meat and bone meal varies widely (224.7–533.3 kcal/100 g). These comparisons highlight that insect powders such as cricket and mealworm offer a balanced profile of high protein and beneficial fat, whereas traditional sources like meat and bone meal show greater variability in composition.

The amino acid composition of CP shows clear superiority over mealworm. Among the essential amino acids, leucine (Leu: 80.44 mg/g), lysine (Lys: 60.93 mg/g), and valine (Val: 66.41 mg/g) in CP are nearly twice as high as those in mealworm (Leu: 48.2–57 mg/g; Lys: 29.5–30.5 mg/g; Val: 36.5–44.4 mg/g). Furthermore, the Leu content was also significantly higher than that of black soldier fly powder (68 mg/g). However, the Lys (74.1 mg/g) and Val (72.3 mg/g) contents in black soldier fly powder were higher than those in CP (Ayllón-Parra *et al.*, 2025; Oliveira *et al.*, 2014; Matin *et al.*, 2021). These branched-chain amino acids play key roles in muscle synthesis and recovery, suggesting that CP protein is of relatively high quality and suitable for muscle-enhancing or meat-alternative formulations. The high lysine level is particularly beneficial for complementing plant proteins that are typically deficient in this amino acid (Kamei *et al.*, 2020).

Regarding non-essential amino acids, CP also exhibits a remarkable advantage, with glutamic acid (Glu: 133.49 mg/g) and aspartic acid (Asp: 87.61 mg/g) being significantly higher than those of mealworm (Glu: 69.3–89.6 mg/g; Asp: 45.3–56.3 mg/g) and black soldier fly powder (Glu: 98.3 mg/g). In contrast, the Asp content in black soldier fly powder (90.8 mg/g) was not significantly different from that in CP (Ayllón-Parra *et al.*, 2025; Oliveira *et al.*, 2014; Matin *et al.*, 2021). These amino acids are known to contribute to nitrogen metabolism and umami flavor formation, thereby improving the sensory

II: *Nutritional value of other powders*

	Mealworm (Son *et al.*, 2019)	Fish (Kasozi *et al.*, 2018)	Meat and bone meal (Hendriks *et al.*, 2002)
Protein (%)	45.00–70.76	50.4	38.5–73.6
Fat (%)	13.22–37.55	30.1	2.5–18.5
Ash (%)	3.65–5.08	12.3	13.0–56.5
Fibre (%)	-	0.1	-
Carbohydrate (%)	11.23–18.21	< 0.1	-
Energy value (kcal/100 g)	-	470.9	224.7–533.3

Note: “-” Not tested

quality of foods (Brosnan and Brosnan, 2013). In addition, alanine (Ala: 118.10 mg/g) and proline (Pro: 69.31 mg/g) in CP are considerably higher than those of the other two species (Ayllón-Parra *et al.*, 2025), reflecting its potential for use in energy or muscle recovery products. However, similar to other edible insects, CP has relatively low methionine (Met: 16.05 mg/g), cysteine (Cys: 5.45 mg/g), and tryptophan (Trp: 5.56 mg/g) contents, suggesting that CP blending with complementary protein sources such as soy or egg could help achieve a more balanced amino acid profile.

Overall, these results indicate that CP is not only rich in essential amino acids but also abundant in flavor- and metabolism-related amino acids, making it a nutritionally and functionally valuable protein source compared with most other edible insect powders.

Generally, CP contains all nine essential amino acids, especially lysine, leucine, and valine in appropriate proportions for the body's needs. Ruggeri *et al.* (2023) spray-dried CP was found to have a protein digestibility-corrected amino acid score (PDCAAS) of nearly 1.0, indicating that the protein in CP is well digestible and absorbed, comparable to high-quality protein sources such as milk or eggs. Several studies have reported that the protein digestibility of CP ranges from 75 to 85%, which is generally higher than that of most plant-based proteins, such as soybean or pea. When combined with its amino acid score, the *in vitro* PDCAAS of cricket protein was estimated at approximately 0.65, surpassing that of common legume proteins such as faba bean and pea (Stones *et al.*, 2019). This indicates that CP possesses a more balanced amino acid composition and superior digestibility compared to typical plant proteins, supporting its potential as a sustainable alternative protein source.

Tab. IV also highlights the potential of CP as a source of essential minerals in the diet. Among them, the sample from Kenya shows a clear advantage in calcium content, with levels reaching up to 314.77 mg/100 g, nearly double that of Canada (163 mg/100 g) and Thailand (139–218 mg/100 g). This is a significant advantage if CP is applied in functional foods to support bone health for children, the elderly, or vegetarians (Morelli *et al.*, 2020). However, this sample also has an unusually high sodium concentration (850.23 mg/100 g), which may stem from processing conditions or the living environment, and should be considered for those who need to control their sodium intake.

III: *Amino acid of cricket powders and other insect powders (mg/g protein)*

Amino acid	Cricket (Ayllón-Parra *et al.*, 2025)	Mealworm* (Oliveira *et al.*, 2014)	Black soldier fly* (Matin *et al.*, 2021)
Essential amino acids			
Val	66.41	36.5–44.4	72.3
Ile	47.55	25.1–30.5	46.3
Leu	80.44	48.2–57.0	68.0
Lys	60.93	29.5–30.5	74.1
Thr	35.98	28.4–33.2	39.0
Phe	40.71	33.7–39.1	44.7
Met	16.05	14.2–14.6	17.7
His	25.85	25.8–30.4	27.8
Trp	5.56	-	14.6
Non-essential amino acids			
Asp	87.61	45.3–56.3	90.8
Glu	133.49	69.3–89.6	98.3
Ser	38.11	35.1–40.4	35.3
Gly	56.65	41.1–43.9	52.5
Ala	118.10	35.9–38.1	63.7
Arg	63.54	42.3–50.5	46.6
Cys	5.45	9.8–10.5	10.4
Pro	69.31	43.2–45.8	47.3
Tyr	48.26	60.7–70.9	59.8

Note: “-” Not tested; “*” Converted to mg/g protein

IV: *Mineral composition of cricket powders (mg/100 g)*

Minerals	Thailand (Montowska *et al.*, 2019; Osimani *et al.*, 2018)	Canada (Montowska *et al.*, 2019)	Kenya (Ayieko *et al.*, 2016)
Ca	139–218	163	314.77
K	826–1 224	993	979.75
Mg	110–113	86	-
Na	284–312	263	850.23
Cu	2.33–4.51	4.30	2.94
Fe	4.06–4.07	5.99	5.18
Mn	4.10–12.5	7.25	5.87
Zn	13.5–21.8	12.8	2.17

Note: "-" Not tested

Regarding trace minerals, the Canadian sample stands out with the highest iron (5.99 mg/100 g) and copper (4.30 mg/100 g) content among the three samples, playing an important role in blood formation and neurological function. Meanwhile, the Thai sample has a zinc content ranging from 13.5–21.8 mg/100 g, which is superior to Canada (12.8 mg/100 g) and particularly much higher than Kenya (2.17 mg/100 g) (Montowska *et al.*, 2019; Ayieko *et al.*, 2016). Zinc is an essential element for the immune system and many enzyme reactions in the body, so this is a notable advantage of Thai CP (Wessels *et al.*, 2021). In contrast, the CP from the species *Gryllus bimaculatus* shows a different mineral structure, with a lower calcium content (110.8 mg/100 g), but a significantly higher zinc content (22.1 mg/100 g), potassium (724.7 mg/100 g), and sodium (289.3 mg/100 g) (Kim *et al.*, 2020). This difference indicates that each cricket species has its own potential in providing essential trace minerals for the diet.

Compared to the *Tenebrio molitor* powder studied by Ravzanaadii *et al.* (2012), CP generally has mineral levels that are equivalent to or superior in some components. For example, potassium in the larvae reaches about 947.97–2117 mg/100 g, while iron is 5.58–12.77 mg/100 g, sodium 364.48–634.31 mg/100 g, copper 1.04–1.80 mg/100 g, zinc 10.13–26.51 mg/100 g, and magnesium 138.80–713.51 mg/100 g (Montowska *et al.*, 2019; Ayieko *et al.*, 2016).

It can be seen that CP, depending on its geographical origin and processing conditions, can compete with other commercial insect powders in terms of mineral nutrition. This is an important basis for expanding the application of CP in fortified foods, especially in areas at risk of micronutrient deficiency. The variation in mineral composition between countries also reflects the influence of species, living conditions and processing methods (Montowska *et al.*, 2019; Ayieko *et al.*, 2016).

From the two tables above, it can be seen that CP is a functional food source rich in protein and minerals, suitable for supplementing modern diets. The clear differences between the three samples in protein, lipid and trace mineral composition partly show the impact of living environment, food source, species and processing techniques, thereby posing a research direction on optimizing the farming process to achieve the expected nutritional quality. The nutritional indices obtained also open up the potential for CP application not only in meat substitutes but also in sports foods, food for the elderly or children, as well as products for humanitarian relief, where a concentrated source of nutrients is needed, convenient to preserve and easy to transport.

Application of Cricket Powder in Food

The use of CP in the food industry has been increasingly studied, not only because of its superior nutritional value but also because of its flexible application in many types of products. Recent studies have shown that CP can partially replace traditional ingredients such as wheat flour or gluten-free flour to increase the content of protein, minerals, and antioxidants, while creating more environmentally friendly products (Tab. V).

When added to bread, CP at 10% (Osimani *et al.*, 2018) and 20% (Mafu *et al.*, 2022) significantly increased the content of protein, fatty acids, essential amino acids, lipids, and minerals. In particular, gluten-free breads also benefited from the addition of 2–10% CP, showing increases in protein, iron, copper, zinc, and polyphenols, while improving texture and extending shelf life (Kowalczewski *et al.*, 2021). However, some studies by Bawa *et al.* (2020) also showed that the addition of CP can cause bread and cookies to become darker in color. Because CP has a naturally dark brown color and is rich in protein, it increases the Maillard reaction during baking, resulting in darker bread colors (Bawa *et al.*, 2020).

For bakery products such as cookies and muffins, the addition of 10–20% insect powder results in darker color, softer texture, rise, and acceptable flavor (Pauter *et al.*, 2018). Crisps with 15% powder can become noticeably darker and harder (Ardoin

V: *Application of powder in food*

Application	CP ratio	Main impact	References
Bread	10%	Significantly increased protein, fatty acids and essential amino acids; acceptable at 10%	Osimani *et al.* (2018)
Whole wheat bread	20%	Increased protein (18.97–25.94%), fat (10.91–15.07%), ash (2.09–2.33%)	Mafu *et al.* (2022)
Cookies/Muffins	10–20%	Darker color, softer texture, acceptable rise, and flavor	Pauter *et al.* (2018)
Pasta (durum noodles)	10–15%	Increased protein, minerals; slightly chewy texture, darker color	Duda *et al.* (2019)
Gluten free bread	2–10%	Increased protein, iron, Cu, Zn, polyphenol; soft texture, beautiful yellow color, longer preservation	Kowalczewski *et al.* (2021)
Crispy biscuits	15%	Noticeably darker and harder	Ardoin *et al.* (2021)
French fries	10%	Ash, calcium, high iron	Cheng *et al.* (2022)
Shortcake biscuits	2%	Increased protein content, including essential amino acids, as well as minerals and fats.	Smarzyński *et al.* (2021)
Bread, biscuits	10%	High in protein, iron, phosphorus and low in carbohydrates and darker in color of bread and biscuits	Bawa *et al.* (2020)
Sausages, pasta, brownies	-	Fat, carbohydrates increase, green and blue increase	Ho *et al.* (2022)
Sausages	5%	Elasticity, white hardness	Vlahova-Vangelova *et al.* (2023)
Instant congee	50%	Balance sensory and emotional appeal	Wongthahan *et al.* (2025)

Note: “-” Not tested

et al., 2021), while shortcake biscuits with just 2% powder have significantly increased protein, essential amino acids, minerals, and fat content (Smarzyński *et al.*, 2021).

Beyond bakery products, CP also shows potential in pasta. With 10–15% CP, pasta increases its protein and mineral content, despite a slightly chewy texture and darker color (Duda *et al.*, 2019). In products such as sausages, adding 5% CP can increase elasticity and hardness (Vlahova-Vangelova *et al.*, 2023). Other applications include potato chips (10% CP increases ash, calcium, iron - Cheng *et al.*, 2022) and even brownies, although some studies such as Ho *et al.* (2022) note an increase in fat, carbohydrates and a change in color towards green and blue.

Consumer acceptance of CP-added products is generally quite positive when the addition rate is reasonable. Puleo *et al.* (2025) surveyed 164 consumers and found that biscuits containing 10% CP achieved an average sensory score of 6.55 on a 9-point scale, corresponding to the level of “mild preference”. In another study in Thailand, when instant porridge was supplemented with CP at 30%, 50% and 70%, the sample containing 50% CP was rated highest in terms of satisfaction and positive emotions such as “delicious” and “safe” (Wongthahan *et al.*, 2025). In addition, van Huis *et al.* (2020) also noted that adding about 5% CP to pasta did not reduce the sensory acceptance level, and was even rated higher by consumers than the traditional product. These results suggest that CP has potential applications in food, especially when used at appropriate levels and in familiar products.

Overall, the application of CP provides superior nutritional benefits, increasing the protein, essential amino acids, minerals and fat content of many foods. However, changes in color and texture are factors that need to be considered and adjusted by manufacturers to ensure consumer acceptance, paving the way for insect foods to become an important part of sustainable diets. In Vietnam, the market is also witnessing the emergence of commercial products from CP such as protein powder, energy bars, biscotti, and boat cakes, showing the initiative in exploiting the potential of this new food source.

Thus, the application of CP in food brings many benefits in terms of nutrition, technological properties and even sensory – if the mixing ratio is controlled properly. Current research is aimed at optimizing the mixing process and processing technology to maximize the potential of CP in functional foods, baked goods, noodles and gluten-free products.

Taste and Sensory Acceptance

The addition of CP to foods, such as muffins, has been shown to have a significant impact on consumer sensory acceptance. In a study by Pauter *et al.* (2018), CP-added products were negatively evaluated for their appearance and color, which tended to be darker than expected, and for their “off-flavor” taste that was perceived as unfamiliar. However, on the positive side, CP improved the flavor and texture of the product, suggesting the potential for sensory enhancement if properly adjusted.

In Kenya, although insects – including crickets – are recognized as a valuable source of nutrition, they are not yet considered a staple food in the daily diet. This is mainly due to difficulties in harvesting and cultural barriers to food. Insects are often consumed as snacks or seasonal specialties. However, studies such as Ayieko *et al.* (2016) have noted increased acceptance when crickets are incorporated into traditional dishes such as fried rice, chapatti, mandazi or served with ugali – a popular paste. Research by Barton *et al.* (2020) demonstrated that consumers in Atlantic Canada were more willing to eat insects after trying them in protein powder.

Consumers were more willing to buy and recommend crickets to friends after eating them (in processed form); however, they were still concerned that insects could carry harmful bacteria and toxins. In Vietnam, although insects are not unfamiliar in traditional cuisine, cricket-based products such as protein powder, sausages or cricket burgers are still quite new concepts. However, a positive sign is that Vietnamese people show a fairly high level of acceptance (from 58% to 71%) for these products (Hoang *et al.*, 2023). This opens up significant market development potential, with consumer understanding and positive attitudes being key factors. To bring cricket-based foods closer to daily meals, businesses need to invest heavily in promotion, reasonable pricing, and especially transparency about quality and safety, contributing to dispelling initial concerns and building long-term trust.

On the contrary, in Western countries, the consumption of insect products still faces major obstacles due to psychological hesitation and attachment to familiar foods. According to Tan *et al.* (2015), to overcome this barrier, it is necessary to develop processed products with friendly forms such as powders or snacks, making them more accessible to consumers by blurring the image of whole insects - a factor that often causes repulsion. In addition, the phenomenon of food neophobia - the fear of new or strange dishes - is considered one of the major barriers to the popularization of insect-based foods (Hartmann, 2016; Mancini *et al.*, 2019). This further shows the importance of building appropriate marketing strategies, educating awareness and improving processing technology to increase consumers' sensory acceptance. However, consumers' senses are still dominated by cultural factors and product familiarity, making acceptance clearly different between geographical areas.

Challenges and Potentials

The application of CP in food has significant potential, especially in the context of global food security pressures, declining natural resources and increasing demand for sustainable protein sources. With its high protein content, rich in essential amino acids, minerals, vitamins and fiber, CP is an ideal candidate for nutritious and environmentally friendly food products. In addition, the incorporation of CP into popular foods such as bread, baked goods, pasta, snacks or even local dishes can contribute to diversifying the diet and reducing dependence on traditional protein sources such as beef, pork and chicken (da Rosa Machado and Thys, 2019).

However, the introduction of CP into commercial foods still faces many challenges. One of the biggest obstacles is the negative attitude of consumers, especially in Western countries where the consumption of insects is not part of the culinary culture. Consumers are often deterred by psychological factors, prejudices or feelings of “disgust”, when they think that insects are not legal or safe food. In addition, changes in color, appearance and flavor when adding CP to food can also affect consumer perception. As in the study of muffins, adding CP made the cake darker in color and appeared “strange” in smell, which was rated low in terms of visual and taste (Pauter *et al.*, 2018).

The acceptance of insect products also depends on local customs, culture and practices. In African countries such as Kenya, insect consumption is more common, although it is still considered a snack rather than a staple food due to the difficulty in harvesting. However, integrating CP into traditional dishes such as chapatti, pilaf, mandazi or ugali is seen as a viable way to increase consumption (Ayieko *et al.*, 2016).

CP has no apparent toxicity when used within food limits: acute and chronic toxicity tests in mice (up to 3 000 mg/kg) did not detect abnormalities in blood biochemistry, organ weights or chromosomal mutations (Ververis *et al.*, 2022). However, it can cause allergies, especially in people with a history of allergies to seafood or dust mites: at least two cases of severe allergic reactions have been reported, and analyses have shown that CP contains many proteins similar to shrimp and crab allergens (Yamamoto *et al.*, 2025).

Regarding the possibility of contamination & by-products, CP can contain bacteria (usually *Bacillus*, *Enterobacteriaceae*), but if the production process is followed according to HACCP/GMP standards and heated (steaming/baking), microorganisms can be significantly reduced (Fernandez-Cassi *et al.*, 2019). On the other hand, CP can also accumulate heavy metals (Cd, Pb, As, etc.), mycotoxins, dioxins, PBDEs and aromatic compounds depending on the cricket's diet (Santos *et al.*, 2024). Some studies also recorded that saturated fats are oxidized to produce aldehydes such as hexanal and pentanal if dried at high temperatures (Marzoli *et al.*, 2023). In addition, there may be residual environmental risks from the rinse water (liquid by-product) that must be properly treated to avoid pollution.

Another potential research direction is to optimize the CP blending ratio to ensure harmony between nutritional value and product sensory, as well as find methods to deodorize and improve the structure to increase acceptability. Instead of using whole insects, processing them into fine powder or deeply processed products helps to create a more friendly and accessible experience for consumers (Tan *et al.*, 2015).

In addition, modern consumer trends are moving towards clean, organic, sustainable and low-emission products, which is an opportunity for CP to gradually assert its role in the future food market. In Vietnam, CP is gradually affirming its potential to become a sustainable alternative protein source, thanks to its advantages of high nutritional content, low farming costs and environmental friendliness. However, the widespread application of CP still faces a number of challenges, including consumer psychological barriers, lack of standardization in production, and high product prices compared to traditional protein sources.

Although CP is considered a nutritious food source and has the potential to be used as a functional food, scientific evidence of its actual effectiveness on the human body is still very limited. To date, there have not been many clinical studies demonstrating the specific effects of CP in improving health such as enhancing micronutrient absorption, supporting the digestive system or enhancing resistance. In addition, the safety of CP in long-term consumption has not been clarified. Data related to potential toxicity such as microbial residues, heavy metals or the risk of allergies - especially in people with a history of seafood allergies - are still relatively scarce and incomplete. These gaps pose an urgent need for in-depth studies to comprehensively assess the health effects and safety of CP before it is widely applied in the consumer food chain.

In short, CP has great potential to contribute to solving global problems in nutrition and the environment. However, for CP to be widely applied, further in-depth research on processing techniques, sensory perception, and consumer education strategies is needed to build positive awareness and reduce cultural barriers to accepting insects as food.

CONCLUSION

The review shows that cricket flour is a functional food source rich in protein and minerals, which can compete with traditional protein sources and other commercial insect flours. The nutritional content varies by geographical region, reflecting the influence of species, feed, rearing environment and processing. With its superior nutritional properties, good preservation ability and high sustainability, cricket flour can absolutely become a potential ingredient in the modern food industry, especially in the context of global food security being threatened. To maximize this value, further research is needed on standardization of farming and processing processes as well as sensory evaluation and consumer acceptance in each region.

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