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Research article

Crickets As An Alternative Source of Protein: Development of Nutritious Local Foods and a Cost-Benefit Analysis

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Abstract: This study aimed to develop processed food products incorporating cricket powder by creating formulas that optimize both nutritional benefits and consumer acceptability. The findings indicated that formulas incorporating cricket powder at 0.33%, 1.20%, and 0.33% by weight were optimal for pork sausages, grilled pork sausages, and pork meatballs, respectively. This aligned with the results regarding color and textural qualities, where the majority of scores were comparable to the control groups, while the water activity score was relatively high, potentially influencing microbial growth in the food. The three food products were rich in essential nutrients required by the body, including macronutrients and micronutrients such as carbohydrates, proteins, fats, vitamins B1 and B2, sodium, potassium, iron, and calcium. Furthermore, the protein content in pork meatball and pork sausage products complied with the Thai Community Product Standard (TCPS304/2555 and TCPS102/2555). The nutritional value per serving provided energy of 170, 150, and 80 kilocalories for grilled pork sausage, pressed sausage, and pork meatballs, respectively. Furthermore, the cost-benefit analysis indicated that project expenses comprised 93.33% fixed costs and 6.67% variable costs. The returns from this project will be beneficial over the following five years, as the NPV (38,790.29 USD) ≥ 0, the BCR (3.76) ≥ 0, and the IRR (31.80%) ≥ 5% interest rate of the cost of capital. The cricket protein serves as an alternative that can enhance the nutritional value of local food products and represents a prudent investment of project funds to bolster local community enterprises.

Keywords: Cricket powder; cricket processing; local food

1. Introduction

Despite crickets being economically viable insects with production potential and alternative protein sources that could address future food security issues [1], the majority of cricket farmers continue to experience elevated production costs and inconsistent yields [2]. A significant number of farmers are pursuing cricket farming as their primary vocation, leading to oversupply and diminished sales. However, food expenses constitute 48.9% to 60% of total production costs [3], resulting in financial losses and the eventual discontinuation of production.

Consequently, one potential solution to these issues is the enhancement of cricket's value as an alternative product, which can yield a market value tenfold greater [4], given that 100 g of cricket contains approximately 69% protein, whereas beef, pork, and chicken contain 43%, 29%, and 31% protein, respectively [5]. Cricket powders contained high levels of protein (42.0 to 45.8% of dry matter) and fat (23.6 to 29.1% of dry matter) [6]. Moreover, edible insects may offer enhanced health advantages owing to their elevated concentrations of vitamin B12, iron, zinc, fiber, essential amino acids, omega-3 and omega-6 fatty acids, and antioxidants [7]. The predominant cricket products in Thailand consist of frozen crickets, crispy baked crickets, and fried crickets [8]. Other processed cricket items are uncommon. Survey findings from farmers and small entrepreneurs reveal a demand for the development of cricket-based products that incorporate a straightforward production process and consist of a minimum of 60% cricket ingredients [9]. This strategy seeks to optimize the utilization of cricket raw materials in significant volumes while satisfying consumer preferences for product variety [10]. Additionally, it aims to enhance consumer acceptability of novel products—specifically edible insect products—by highlighting safety certifications and nutritional labeling, which have demonstrated an impact on purchasing decisions [11].

Finely comminuted products, including pork meatballs, pork sausages (Moo Yor), and grilled pork sausages (Naem Nuong), are created by blending deboned meat with seasonings and ingredients using a bowl cutter. This process results in emulsified meat, wherein the salt in the mixture facilitates fat extraction, enabling the emulsified meat to maintain cohesion. Additionally, modified starch may be incorporated to reduce costs, enhance texture, improve elasticity, and better retain moisture [12]. These pork-based products are popular among the Thai population and are commonly prepared in a variety of formulas or enjoyed with fresh vegetables by health-conscious consumers [13-15]. In response to growing interest in healthier and more sustainable food options, crickets have emerged as a valuable source of alternative protein. Currently, they are being utilized as a key ingredient in innovative food products [16]. This shift aligns with a broader trend in health-focused food development, which emphasizes the integration of high-protein ingredients—particularly cricket protein—into everyday items such as baked goods, muffins, flakes, and cookies [17-18].

Sa Kaeo Province, situated in eastern Thailand, is a multicultural society known for its Vietnamese-style Yuan cuisine, regional specialty dishes that both visitors and locals favor. The province holds significant geographical importance as the biggest hub for Thai-Cambodian border trade within ASEAN. According to the ASEAN Community Blueprint Plan (AEC blueprint), agriculture employs a substantial portion of the population and contributes significantly to the provincial GPP of 13,515 million Thai baht (THB) in 2022 [19-20]. Despite this economic contribution, the province experiences high levels of poverty, with Tapraya District among the nine districts reporting the lowest average income at 77,033.58 THB per person per year in 2022 [21-22]. Historically, the Tapraya District, Sa Kaeo Province, has engaged external organizations to foster diverse community economies, including organic agriculture and livestock, as well as the cultivation of economic insects such as crickets; yet, a significant risk remains concerning market volatility, input costs, and income instability [23-24]. The greater the risk associated with initiating a community business, the more essential it becomes to assess this risk through financial performance evaluations such as break-even analysis. A comprehensive cost-benefit analysis, alongside project cost-effectiveness indicators—including the Net Present Value (NPV), the Benefit-Cost Ratio (BCR), and the Internal Rate of Return (IRR)—can be employed to evaluate the efficiency of budget utilization and the socio-economic impact of the project. These tools are particularly valuable in measuring how such initiatives contribute to enhancing the overall quality of life within the community. Despite their importance, studies specifically examining cricket-based products developed by Community Enterprise Groups remain limited [23-24]. Therefore, the objective of this study was to examine the nutritional status and cost-benefit value of cricket protein supplementation. This aims to enhance cricket's viability as a protein supplement. By addressing low-yield production issues, cricket-based products can offer enhanced nutritional values, including potassium, protein, fat, sodium, carbohydrate, sugar, and vitamin A, B1, and B2, comprehensive nutritional information labels, and improved product acceptance. Furthermore, the findings can evaluate the project's cost-effectiveness, encourage community entrepreneurs, and facilitate more sustainable production and consumption models for local products.

The objective of this study was to develop suitable formulas for processed food products incorporating cricket powder as an ingredient. The study aimed to evaluate these products through consumer acceptance testing, nutritional analysis, and sensory profile assessment conducted by trained panelists. Additionally, the research sought to assess the economic viability of cricket-based food production through cost-benefit analysis.

2. Materials and Methods

2.1 Production of Food Products Supplemented with Cricket Protein

1. *Gryllus bimaculatus* field crickets obtained from the Ta Praya Community Enterprise in Sa Kaeo Province were utilized to generate cricket protein powder for incorporation into processed meat products supplemented with cricket protein. The area of the cricket farm is located in the agriculture community with the 1,800 m2 or 0.18 ha per one cultivation building with 35-45 days/crop. Water and commercial feed (21 % of protein, 5 % of fiber, and 4 % of fat) were provided after the incubation period. For animal ethical consideration, the research investigator (NT) was trained for an animal use license (U1-04867-2559) by the National Research Council of Thailand. The preparation method for cricket protein powder was adapted from Pansuntia et al. [18]. Seven kilograms of frozen crickets were thoroughly rinsed with clean water five to seven times or until pristine, and thereafter cooked at high temperature in a steam basket for thirty minutes. The roasted crickets were dehydrated in a hot-air oven (Series HT-D10P, Kitchen Mall Manufacturing, Thailand) at 85–105°C for approximately 10 hours or until completely desiccated. After chilling, the crickets were carefully pulverized, sieved through a 50-mesh filter (Test sieve, brand Endecotts, England), and then roasted with lemongrass at 60–70°C for 15 minutes. This process yielded one kilogram of cricket protein powder for the creation of food products supplemented with cricket protein.

2. The creation of food products supplemented with cricket protein was developed using formulas and processing techniques adapted from Wongnai Media Company Limited [25-27] and Wangkawan et al. [28], as illustrated in Table 1 and Figures 1–3, and implemented through the following procedures.

Table 1. Percentage by weight (% w/w) of processed food ingredients in each formula (F) and control (C).

Ingredients	Percent by weight of ingredients								
	Pork sausages			Grilled pork sausages			Pork meatballs		
	C 1.0	F 1.1	F 1.2	C 2.0	F 2.1	F 2.2	C 3.0	F 3.1	F 3.2
Pork loin	53.30	53.30	53.30	48.90	48.90	48.90	66.58	66.58	66.58
Pork lard	26.65	26.32	26.20	24.45	23.25	22.81	–	–	–
Cricket powder	–	0.33	0.45	–	1.20	1.64	–	0.33	0.45
Iodized refined salt	0.53	0.53	0.53	0.73	0.73	0.73	0.67	0.67	0.67
Seasoning powder	–	–	–	–	–	–	0.40	0.23	0.17
Tapioca flour	0.53	0.53	0.53	–	–	–	0.40	0.40	0.40
Pepper	2.66	2.66	2.66	1.22	1.22	1.22	0.40	0.40	0.40
Garlic	–	–	–	9.78	9.78	9.78	0.40	0.40	0.40
Pure refined sugar	–	–	–	0.49	0.49	0.49	1.20	1.04	0.98
Crushed ice	14.99	14.99	14.99	11.01	11.01	11.01	29.95	29.95	29.95
Baking powder	1.34	1.34	1.34	–	–	–	–	–	–
Seasoning sauce	–	–	–	3.42	3.42	3.42	–	–	–

Source: Adapted from Wongnai Media Company Limited [25-27] and Wangkawan et al. [28]

The preparation of cricket protein-supplemented pressed sausages involves the following steps: Initially, pork loin and lard undergo fine grinding before being subjected to freezing for 45 minutes. Concurrently, pre-measured dry ingredients—comprising seasoning salt, baking powder, tapioca flour, finely ground black pepper, and cricket protein powder—are homogeneously combined in a mixing vessel, followed by the incorporation of cold potable water. The mixture undergoes thorough agitation to ensure uniform ingredient distribution. The chilled pork loin and lard are subsequently incorporated into the prepared mixture and blended until achieving a homogeneous, cohesive consistency. The mixture is then subjected to a

secondary freezing period of approximately 15 minutes, after which it undergoes re-blending until attaining a sticky, aerated texture while maintaining an optimal processing temperature range of 10–15°C. Pre-cleaned banana leaves, lightly treated with vegetable oil, serve as the wrapping medium for the pork mixture, which is then tightly rolled and hermetically sealed at both termini. The encased sausages are secured with binding material and subjected to steam treatment in a steam basket positioned over vigorously boiling water for a duration of 30–45 minutes. Each packaged pressed sausage unit maintains a standardized net weight of 100 g.

The preparation of cricket protein-supplemented grilled pork sausages involves the following steps: Initially, pork loin and lard undergo fine grinding before being subjected to freezing at approximately -18°C for 45 minutes. Pre-measured dry ingredients (including seasoning salt, seasoning sauce, tapioca starch, granulated sugar, cricket protein powder, accord powder, granulated pepper, and garlic) are combined in a mixing vessel. The mixture undergoes thorough agitation, followed by the gradual incorporation of cold potable water until complete ingredient integration is achieved. Subsequently, the chilled pork loin and lard are incorporated into the prepared seasoning mixture using mechanical blending until a homogeneous, cohesive consistency is obtained. The mixture is then subjected to extended freezing for approximately 3 hours, after which it undergoes secondary blending until achieving a sticky, aerated texture. Throughout the blending process, the mixture temperature is maintained within the optimal range of 10–15°C through continuous cooling. The processed mixture is then formed into uniform rounds and secured onto skewers for grilling. The products undergo low-temperature grilling until achieving complete doneness, as determined by internal temperature monitoring. Following the cooking process, the grilled sausages are packaged in standardized units, with each package maintaining a net weight of 150 g.

The preparation of cricket protein-supplemented pork meatballs involves the following steps: Initially, pork is sectioned into small pieces and subjected to freezing for 45 minutes or until the meat achieves partial rigidity with visible ice crystal formation on the surface. The partially frozen pork then undergoes mechanical grinding until it achieves a fine, uniform texture. Pre-measured dry ingredients (including seasoned salt, tapioca flour, granulated sugar, ground pepper, garlic powder, and cricket protein powder) are combined in a mixing vessel. The mixture undergoes thorough agitation, followed by the gradual incorporation of cold potable water until complete homogenization is achieved. Subsequently, the ground pork is incorporated into the prepared seasoning mixture through mechanical blending. Ice is gradually added during the mixing process, and blending continues until a homogeneous, cohesive consistency is obtained. The mixture is then subjected to freezing for approximately 30 minutes, after which it undergoes secondary blending until it achieves optimal stickiness. Throughout all blending operations, the mixture temperature is maintained within the range of 10–15°C through continuous cooling. For the cooking process, water is brought to a rolling boil in a suitable vessel, then reduced to maintain a simmering temperature. The processed mixture is formed into uniform spherical shapes and carefully introduced into the heated water until the meatballs achieve buoyancy, indicating complete cooking. The cooked meatballs are subsequently removed and immersed in cold water for 10–15 minutes to halt the cooking process. Following drainage, the products are packaged in standardized units, with each package maintaining a net weight of 1,000 g. The research flow of this study is shown in Figure 1.

2.2 Nutritional and Texture Profile Analysis

Product samples were obtained using a random sampling method, consisting of two packages of pork meatballs with a total weight of 2,000 g, twenty packages of pressed Vietnamese sausage totaling 2,000 g, and fourteen packages of Vietnamese grilled pork sausage totaling 2,100 g. Comprehensive food composition analysis and nutritional labeling assessment were carried out by the Foundation for Industrial Development, National Food Institute, Thailand. The analytical procedures and methodologies applied for the food analysis are presented in Table 2. The nutritional analysis data were utilized to calculate energy, sugar, fat, and sodium values in accordance with nutrient content specifications per unit package, as stipulated in Notification No. 446 of the Ministry of Public Health [29]. Reference unit content for these food products was categorized according to the characteristics of analogous food products, including sausages, meatballs, fermented pork, Vietnamese pork sausage (Mhoo-yor), and Bologna. Serving size determination and servings per container calculations were based on the methodological framework established by the National Bureau

of Agricultural Commodity and Food Standards, utilizing Thailand's food consumption data from 2016 and U.S. reference serving volume requirements [29].

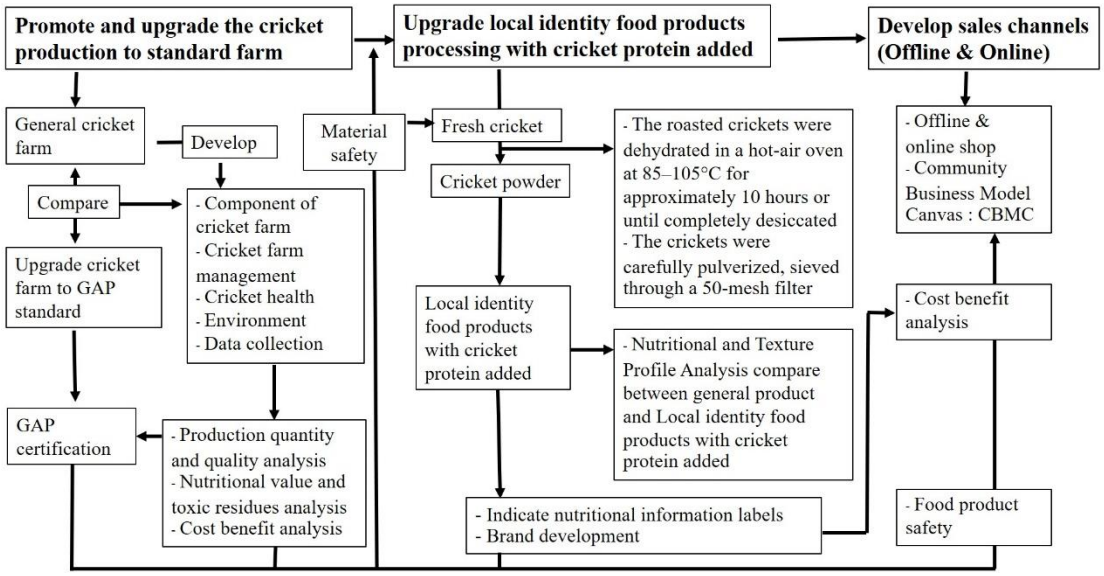

Figure 1 The steps of the research process

Table 2. Test methods for nutritional analysis of food products from cricket ingredients

Item	Test methods	References
Ash	AOAC Official Method 920.153	[30]
Calcium	In-house method T9152 based on AOAC Official Method 984.27	[30]
Calories from fat	Methods of analysis for nutrition labeling, 1993, chapter 1,5	[31]
Cholesterol	In- house method T992 based on the rapid determination of cholesterol in single and multicomponent prepared foods	[32]
Dietary fiber	In-house method T995 based on AOAC Official Method 985.29	[30]
Iron	In-house method T9152 based on AOAC Official Method 984.27	[30]
Moisture	AOAC Official Method 950.46B	[30]
Protein (N x 6.25)	In-house method T927 based on AOAC Official Method 992.	[30]
Potassium	In-house method T9152 based on AOAC Official Method 984.27	[30]
Saturated fat	In-house method T974 based on AOAC Official Method 996.06	[30]
Sodium	In-house method T9152 based on AOAC Official Method 984.27	[30]
Total carbohydrate	Methods of analysis for nutrition labeling, 1993, chapter 1,5	[32]
Total calories	Methods of analysis for nutrition labeling, 1993, chapter 1,5	[32]
Total fat	AOAC Official Method 945.38F	[30]
Total sugars	In-house method T997 based on AOAC Official Method 982.14	[30]
Vitamin A	In-house method T969 based on AOAC Official Method 992.06	[30]
Vitamin B1	In-house method T970 based on AOAC Official Method 942.23	[30]
Vitamin B2	In-house method T971 based on AOAC Official Method 970.65	[30]

Texture Profile Analysis (TPA) of the products was conducted using a texture analyzer (Brookfield, model CT3, S/N: BEL8749458_DK) equipped with a solid cylindrical probe (No. P/50). Product samples were prepared in standardized 2 cm^3 dimensions for analysis. The TPA measured multiple textural parameters, including hardness, adhesiveness, springiness (rate of deformation recovery), and cohesiveness (degree of product decomposition). Additional derived parameters were calculated as follows: gumminess, representing the energy required for food breakdown to achieve a swallowable state, was determined using the formula gumminess = hardness × cohesiveness; chewiness, indicating the total energy required for mastication, was calculated as chewiness = hardness × springiness × cohesiveness [33]. Color analysis was performed using a

Hunter Lab colorimeter (Konica Minolta, model CR-400) to measure lightness (L*), redness (a*), and yellowness (b*) values according to the CIE color space system. Water activity (aw) analysis was conducted to determine the available water content within the products using a Water Activity Meter (LabSwift-AW Novasina, model LabSwift-aw with battery, S/N: NOV1809006_DK). This parameter is critical for assessing product stability and microbial safety [34-36].

2.3 Acceptance Testing of Cricket Protein-Supplemented Products

Consumer acceptance testing for pork meatballs, pressed pork sausages, and grilled pork sausages supplemented with cricket protein was performed utilizing a Randomized Complete Block Design (RCBD) and assessed via the 9-point hedonic scale (where 1 = extremely dislike, 5 = neutral, and 9 = extremely like) [37]. The hedonic scale evaluated essential sensory characteristics, encompassing appearance, scent, flavor, texture, mouthfeel, and overall attractiveness. Untrained panelists were enlisted to assess 100 sensory food items, adhering to techniques outlined by Peryam and Pilgrim [38]. The gathered data were examined by Analysis of Variance (ANOVA) to identify statistically significant variations in mean sensory ratings. Duncan's New Multiple Range Test (DMRT) was utilized at a 95% confidence level ($p \leq 0.05$) to compare the means of groups. Statistical analysis was conducted utilizing Statistix software, version 8.0 (FL, USA).

2.4 Cost-benefit Analysis

The research project has secured funding allocation and generated profit from sales at the local market, OTOP fair, and university market. The study intends to assess economic impact via a benefit-cost analysis, employing the ex-ante evaluation technique for an additional five years. This comprehensive evaluation occurs during the project's execution, assessing the investment value through quantitative metrics such as the NPV, the BCR, and the IRR. Data for the assessment is collected via participant interviews, utilizing tools specifically created to analyze project cost-effectiveness [39], as illustrated in Eqs. (1-3).

$$NPV = \sum(Bt\text{-}Ct)/(1+r)t \quad (1)$$

$$BCR = \sum Bt/(1+r)t/\sum Ct/(1+r)t \quad (2)$$

$$IRR = \sum(Bt\text{-}Ct)/(1+r)t = 0 \quad (3)$$

The equations encompass the variables t (project duration in years), Bt (project benefit in year t in baht per annum), Ct (project research cost in year t in THB per annum), and r (discount rate in percentage).

The researcher protocol received approval from the Human Research Ethics Committee of Valaya Alongkorn Rajabhat University under Royal Patronage, Pathum Thani Province, with COA No. 0041/2567 and REC No. 0001/2567.

3. Results and Discussion

3.1 Texture Profile Analysis (TPA)

The development of three processed food products containing cricket protein powder—pork sausages, grilled pork sausages, and pork meatballs (Figure 2)—was followed by a texture assessment using the Texture Profile Analysis (TPA) method. The components of cricket powder ingredient were 51.65 % of protein, 22.36 % fat, 16.58 % of fiber, 12.47 % of ash, 9.97 % of moisture, and 3.55 % of carbohydrate with the 3 months of shelf life and room temperature storage conditions. The results indicated that the chewiness of pork sausages, grilled pork sausages, and pork meatballs did not significantly differ from the control groups (ns). Products containing 0.33% cricket powder by weight (pork sausages and pork meatballs) and 1.20% (grilled pork sausages) exhibited higher hardness, springiness, and gumminess compared to those with 0.45% and 1.64% cricket powder, respectively (Table 3), which is consistent with the findings of Samon and Jangchud [40]. Additionally, increasing the concentration of cricket powder was found to significantly reduce the hardness of the products.

The results showed that pork sausages containing 0.33% cricket powder by weight (Formula 1.1) and grilled pork sausages containing 1.20% (Formula 2.1) exhibited significantly greater hardness and gumminess than the other formulas ($p \leq 0.01$). Higher hardness indicates a firmer texture, while gumminess refers to the

amount of force required to chew food until it is ready to swallow. Among all formulas, Formula 1.1 and Formula 1.2—both containing lower levels of cricket powder—demonstrated a firmer and more compact texture compared to the others. However, no significant differences (ns) were observed in cohesiveness (ranging from 0.2447 to 0.3967) and springiness (11.6500–13.1000 mm) among the products, indicating similar elastic properties. These findings are consistent with the study by Dholvitayakhun et al. [41], which found no significant differences in cohesiveness (0.19–0.24) and springiness (8.91–10.15 mm) between microwave-cooked pork loin and conventionally steamed pork loin. The creation of pork sausages and grilled pork sausages (Table 1) includes pork loin and pork lard as the main ingredients, comprising 48.90–53.30% and 22.81–26.32% by weight, respectively. These are homogenously mixed with other components. Tapioca flour is added as a thickener, filler, binder, or stabilizer in meat products [42]; salt facilitates emulsification of the mixture [43]; and pepper and garlic are included to enhance flavor and aroma. Cricket powder is incorporated as an alternative protein source to support the development of nutritious food products. In addition to selecting appropriate ingredients, a critical step in the process is blending the emulsion at a temperature below 15°C [44], typically by whisking in the evening. It is not necessary to prepare a separate fat emulsion beforehand; instead, the focus should be on maintaining the chopping and mixing temperature below 10°C. The inclusion of 10% tapioca starch is considered appropriate for achieving desirable texture and overall product quality [45]. This method aligns with the present study, which controlled the blending temperature between 10°C and 15°C and incorporated ice at levels ranging from 11.01% to 14.99% by weight (Table 1). For pork meatballs, the ingredients and production method are similar to those used for pork sausages and grilled pork sausages; however, the primary component is pork loin, comprising 66.58% by weight. The formula containing 0.33% cricket powder (Formula 3.1) exhibited no significant differences in hardness, cohesiveness, or gumminess compared to the control groups (ns). This formula demonstrated a firm texture and similar chewability to conventional pork meatballs. However, when the cricket powder content was increased to 5%, significant reductions in hardness, springiness, gumminess, and chewiness were observed ($p \leq 0.05$). In other words, higher concentrations of cricket powder negatively affected the texture, firmness, elasticity, and internal binding properties of the product (Table 3). This indicates that each category of ingredient possesses specific characteristics and functions that directly influence the properties of food and the final product. According to Utaida [46], the use of pepper at concentrations of 0.2%, 0.3%, and 0.4%, and salt at 2.0%, 2.5%, and 2.9%, increased the hardness and firmness of the texture as ingredient levels rose. However, no significant differences were observed in brightness (L*) or red color values (a*), nor in consumer preferences regarding color, aroma, taste, and overall acceptability. Therefore, the results of this TPA study confirm that ingredient quantities affect the textural quality of the product. The formulas with the lowest amount of cricket powder (Formulas 1.1, 2.1, and 3.1) were selected for nutritional analysis, as their sensory acceptance scores did not significantly differ from the control groups. In contrast, formulas with higher concentrations of cricket powder had significantly lower acceptance scores compared to the other experimental groups (Table 5). The results of color measurement in food products containing cricket powder (Table 4) showed that grilled pork sausages with 1.20% cricket powder by weight (Formula 2.1) exhibited brightness (L*), red (a*), and yellow (b*) values that were not significantly different from those of the control groups (ns). However, when the concentration of cricket powder increased to 1.64%, both a* and b* values increased significantly compared to the control groups ($p \leq 0.05$), indicating that cricket powder influences the color quality of the product. This finding aligns with Gantner et al. [47], who reported that the color intensity of products increases with higher concentrations of cricket powder, reflected in elevated a* and b* values and reduced L* values. These changes are attributed to the brown color of the chitinous exoskeleton, a characteristic feature of insects [48-49]. Moreover, the inclusion of animal fats in the product can contribute to a softer texture, enhance flavor, and increase the brightness of the sausage [50]. Thus, color is a key characteristic that significantly influences consumer preferences and product acceptance. In this study, pork sausages and pork meatballs in the control groups exhibited the highest brightness values, which were significantly different from those of the experimental groups containing 0.33% and 0.45% cricket powder, respectively (Table 4). These findings are consistent with those of Wangkawa et al. [28], who reported L* values of 63.2 for pork yolks with silkworm pupae and 64.1 for the standard formula—values comparable to this study's L* value of 67.90 in Formula 1.1 (Table 4).

Therefore, the color quality of pork sausages, grilled pork sausages, and pork meatballs with the highest consumer acceptance was observed in the formulas containing the lowest amount of cricket powder (Formulas 1.1, 2.1, and 3.1). These findings are consistent with the TPA results, where acceptance scores were similar to those of the control groups, which did not contain cricket powder (Table 3). Regarding water activity (aw), the highest values were found in the control groups. While pork sausages showed no significant difference in aw, grilled pork sausages and pork meatballs containing cricket powder exhibited significantly lower aw values compared to the control groups ($p \leq 0.05$). The formulas containing cricket powder had aw values ranging from 0.901 to 0.916, which may influence microbial growth in food products (Table 4). Since aw is a critical factor in microbial control, bacteria that cause foodborne illness typically cannot grow at aw levels below 0.85 [51-52]. Moreover, low aw ensures the microbiological stability of food products, as aw values below 0.6 significantly inhibit microbial growth [53]. However, the method of storage and packaging also affects food quality. For example, storing pork meatballs in transparent vacuum packaging at 3 ± 1°C results in less microbial growth compared to LDPE packaging, with storage durations not exceeding 12 and 9 days, respectively [46].

Figure 2. Photographs of three processed food products containing cricket powder as an ingredient (pork sausages, grilled pork sausages, and pork meatballs).

3.2 Acceptance Testing

The consumer sensory acceptance test results for cricket-based products at different levels, compared to the control groups without cricket powder, showed that grilled pork sausages and pork meatballs containing the lowest amounts of cricket powder—0.33% and 1.20% by weight (Formulas 2.1 and 3.1, respectively)—received overall acceptance scores that were not significantly different from the control groups (ns). In contrast, increasing the cricket powder content to 0.45% and 1.64% (Formulas 2.2 and 3.2) resulted in significantly lower acceptance scores compared to the control groups ($p < 0.05$). Pork sausages containing 0.33% cricket powder (Formula 1.1) received the highest flavor acceptance among the experimental formulas. However, their appearance, aroma, mouthfeel, and overall acceptability did not differ significantly from the control groups. Consequently, products with the lowest levels of cricket powder—0.33% in pork sausages, 1.20% in grilled pork sausages, and 0.33% in pork meatballs—were deemed most acceptable by consumers and selected for further food analysis, including nutritional labeling and consumer information (Table 5). In addition to receiving the highest overall liking score, the selected formulas also exhibited physical and sensory characteristics comparable to the control groups. Given that crickets are a valuable source of energy and protein in the human diet, these findings support the suitability of cricket powder for the development of

nutritious local food products. The inclusion of nutritional labeling further facilitates informed consumer choices by highlighting beneficial nutrients while helping to limit the intake of undesirable or restricted nutrients [54].

Table 3. Texture profile analysis of food products in each formula (F)

Food products	Cricket ingredients in formula	Texture Profile Analysis (TPA)					
		Hardness (g)	Adhesiveness (mJ)	Cohesiveness	Springiness (mm)	Gumminess (g)	Chewiness (mJ)
Pork sausages	Control	6,584.33b	0.4333b	0.3967a	12.6100a	1,949.90b	577.43a
	1.1 (0.33%)	11,506.00a	1.0467a	0.3500a	13.1000a	2,795.93a	420.60b
	1.2 (0.45%)	6,300.33b	1.1667a	0.2667a	12.6627a	1,632.47c	230.47c
	F-test	**	**	ns	ns	**	**
	%CV	9.50	19.72	24.81	3.08	7.02	14.13
Grilled pork sausages	Control	3,026.91b	0.5800a	0.2610a	11.6500a	1,424.93b	207.06b
	2.1 (1.20%)	5,291.67a	0.1910b	0.2533a	12.5133a	2,252.53a	315.77a
	2.2 (1.64%)	2,903.29b	0.6067a	0.2447a	12.3133a	1,722.80b	193.20b
	F-test	**	*	ns	ns	*	**
	%CV	17.70	33.64	14.90	5.02	12.78	14.00
Pork meatballs	Control	9,251.33a	0.0333b	0.5053ab	12.6293b	3,996.33a	661.47a
	3.1 (0.33%)	8,566.00a	0.1667a	0.5633a	12.8867a	4,921.40a	575.49b
	3.2 (0.45%)	5,955.00b	0.0333b	0.4800b	12.0980c	2,831.67b	336.69c
	F-test	**	*	Ns	**	**	**
	%CV	6.08	74.23	7.14	0.72	13.72	6.79

Note: a, b, c = significant different at $p<0.05$ with the same row, ns = non-significant ($p>0.05$) and CV = Coefficient of Variation

Table 4. Results of color quality and water activity of food products in each formula

Products	Cricket ingredients in formula	Color quality			Water activity
		L*	a*	b*	aw
Pork sausages	Control	69.350a	3.733c	14.703c	0.914a
	1.1 (0.33%)	67.820b	4.212b	17.823a	0.908a
	1.2 (0.45%)	56.903c	4.947a	15.143b	0.910a
	F-test	**	**	**	ns
	%CV	0.92	2.19	1.05	0.35
Grilled pork sausages	Control	69.923a	3.487b	14.377b	0.912a
	2.1 (1.20%)	70.635a	3.817ab	15.073ab	0.901b
	2.2 (1.64%)	67.880a	4.173a	15.483a	0.902b
	F-test	Ns	ns	ns	**
	%CV	2.63	8.14	3.01	0.01
Pork meatballs	Control	76.463a	2.043c	11.990ab	0.916a
	3.1 (0.33%)	74.673b	2.337b	12.100a	0.909b
	3.2 (0.45%)	71.739c	3.009a	11.853b	0.908b
	F-test	**	**	*	**
	%CV	0.92	4.12	0.59	0.08

Note: a, b, c = significant different at $p<0.05$ with the same row, ns = non-significant ($p>0.05$) and CV= Coefficient of Variation

3.3 Nutritional Analysis

The formulas containing 0.33% cricket powder in pork sausages and pork meatballs (Formulas 1.1 and 3.1), and 1.20% in grilled pork sausages (Formula 2.1), were selected for nutritional analysis to provide nutritional information for consumers (Table 2). The results revealed that, per 100 g serving, pork meatballs contained the highest levels of dietary fiber, cholesterol, moisture, protein, and vitamin B1, followed by grilled

pork sausages and pork sausages, respectively. Grilled pork sausages contained the highest levels of ash, potassium, sodium, total calories, total sugars, and vitamin B1. In contrast, pork sausages were found to contain the highest levels of calcium, iron, total carbohydrates, and total fat. Vitamin A was not detected in any of the three products (Table 6). According to the nutritional information panels, a 50 g serving of grilled pork sausages provided the highest energy content at 170 kilocalories, followed by pressed pork sausages at 150 kcal and pork meatballs at 80 kilocalories. The nutrient data were evaluated based on the Thai Recommended Daily Intakes (% Thai RDI), calculated using a daily energy intake of 2,000 kilocalories, as shown in Table 7. These values align with the Nutrient Reference Values (NRVs) established by the Codex Alimentarius, which are based on the Daily Intake Reference Values (DIRVs) for a healthy population aged 19–50 years. The Thai RDIs are also set to ensure nutrient intake does not exceed the safe maximum consumption levels (Upper Levels of Intake, ULs) for individuals aged 3 years and above with normal health status [29].

Table 5. Result of acceptance testing of food products in each formula

Products	Cricket powder as an ingredient	Acceptance testing						
		Appearance	Color	Aroma	Flavor	Texture	Mouthfeel	Overall acceptability
Pork sausages	Control	5.78	5.83a	6.43a	5.80b	5.87a	5.05a	5.87a
	1.1 (0.33%)	5.61	5.43ab	5.88ab	6.37a	5.36b	5.16a	5.64a
	1.2 (0.45%)	5.55	5.23b	5.35b	5.15c	4.77c	4.69b	5.12b
	F-test	ns	*	*	**	**	**	*
	%CV	4.43	3.77	6.29	4.65	3.46	1.67	3.81
Grilled pork sausages	Control	6.21a	6.32a	6.70a	6.74a	6.08a	5.86a	6.07a
	2.1 (1.20%)	6.05ab	6.36a	6.64a	6.72a	5.68a	5.81a	6.21a
	2.2 (1.64%)	5.32b	5.43b	5.45b	3.69b	5.03b	4.99b	5.32b
	F-test	ns	**	**	**	**	**	**
	%CV	7.20	3.79	2.55	2.97	4.11	2.16	3.07
Pork meatballs	Control	5.92a	6.80a	5.94a	6.00a	5.69a	5.75a	5.87a
	3.1 (0.33%)	5.68a	5.92b	5.79a	5.93a	5.46a	5.55a	5.77a
	3.2 (0.45%)	4.93b	4.95c	4.87b	4.67b	4.49b	4.47b	4.72b
	F-test	**	**	**	**	**	**	**
	%CV	4.36	2.76	2.65	2.55	3.68	2.51	2.77

Note: a, b, c = significant different at $p<0.05$ (*), $p<0.01$ (**) with the same row, ns = non-significant ($p>0.05$) and CV = Coefficient of Variation

Table 6. Result of food composition analysis of processed pork products with cricket ingredients

Items	Units	Amount of food listed (per 100 g edible portion)		
		Pork sausages	Grilled pork sausage	Pork meatballs
Ash	g	2.01	2.60	2.02
Calcium	mg	59	17	25
Calories from fat	kcal	215	261	58
Cholesterol	mg	36	41	45
Dietary fiber	mg	0.8	0.8	2.0
Iron (Fe)	mg	0.99	0.56	0.45
Moisture	g	55.36	49.19	70.89
Potassium (K)	mg	237	292	230

Table 6. Result of food composition analysis of processed pork products with cricket ingredients (Continue)

Items	Units	Amount of food listed (per 100 g edible portion)		
		Pork sausages	Grilled pork sausage	Pork meatballs
Protein (N x 6.25)	g	13.4	16.7	19.0
Saturated fat	g	0.8	9.9	2.5
Sodium (Na)	mg	445	647	511
Total carbohydrate	g	5.3	2.5	2.5
Total calories	kcal	290	338	144
Total fat	g	23.9	29	6.5
Total sugars	g	ND	0.6	0.5
Vitamin A	μg	ND	ND	ND
Vitamin B1	mg	0.29	0.37	0.41
Vitamin B2	mg	0.02	0.03	0.01

Table 7. Nutritional information panels on food labels (per 50 g edible portion)

Items	Units	Pork sausages		Grilled pork sausage		Pork meatballs	
		This study	%Thai RDI	This study	%Thai RDI	This study	%Thai RDI
Amount per serving	g	50	-	50	-	50	-
Total Energy	kcal	150	-	170	-	80	-
Total fat	g	12	18	15	23	3.5	5
Saturated fat	g	4	20	5	25	1.5	8
Cholesterol	mg	7	-	20	7	25	8
Protein	g	7	-	8	-	10	-
Total carbohydrate	g	3	1	1	0	1	0
Dietary fiber	g	0	0	-	0	1	4
Sugars	g	0		0	-	0	-
Sodium	mg	220	11	320	16	260	13
Potassium	mg	120	3	150	4	115	3
Vitamin A	-	-	0	-	0	-	0
Vitamin B1	-	-	10	-	10	-	15
Vitamin B1	-	-	0	-	0	-	0
Calcium	-	-	4	-	0	-	< 2
Iron	-	-	4		< 2	-	< 2

Note: Percent Thai Recommended Daily Intakes (%Thai RDI) are based on a 2,000 kcal diet. Nutrition labeling is provided for net weights of 100 g of pressed sausages (2 servings per container), 150 g of grilled pork sausages (3 servings per container), and 100 g of pork meatballs (20 servings per container).

The results (Table 6) present the protein, fat, and carbohydrate content of the developed products in comparison with the Thai Community Product Standards (TCPS) for pork meatballs (TCPS 304/2012; TISI, 2012) and pork sausages (TCPS 102/2012; TISI, 2012). The analysis indicated that the products met the required protein content standard (> 13% by weight). However, the fat and carbohydrate contents exceeded the TCPS limits, which specify that pork meatballs and pork sausages should contain no more than 6% and 25% fat by weight, respectively, and that the carbohydrate content in both products should not exceed 2% by weight [47]. The developed cricket-based products, per 100 g serving, contained 13.4–19.0 g of protein, 6.5–23.9 g of total fat, 2.5–5.3 g of total carbohydrates, and 2.01–2.60 g of ash (Table 6). These values are comparable to those reported for pork sausages fortified with silkworm pupae, which contained 16.0% protein, 20.73% fat, and 3.19% ash—exceeding the nutritional value of conventional formulas that typically contain 15.2% protein, 16.0% fat, and 2.8% ash [28]. Similarly, pork sausages with Panang curry paste were found to contain 10.6 g of protein, 7.8 g of fat, and 3.0 g of carbohydrates [56]. In another example, pork meatballs with 73% of fat by weight replaced by pastry gel contained 17.16% protein, 6.23% fat, and 71.92% moisture [49]. For pork

meatballs, the protein content is 19 g per 100 g of edible portion (Table 6), which is higher than that found in blanched and fried meatball products across three levels of production—industrial, small business, and retail—commonly available in local markets and supermarkets in Bangkok. According to Chan-Urai [50], the protein content in comparable products is as follows: beef balls (13.8–16.1 g), pork balls (13.2–16.2 g), chicken balls (10.0–15.9 g), shrimp balls (12.7–13.7 g), fish balls (14.9–16.5 g), and traditional Chinese pork balls (9.9–13.2 g) per 100 g of edible portion. The ash, fat, carbohydrate, and moisture values of the developed pork meatballs are comparable to those of other meatball products.

The results showed that the nutritional values per 50 g serving of pork sausages, grilled pork sausages, and pork meatballs were 150 kcal, 170 kcal, and 80 kcal, respectively (Table 7). Grilled pork sausages had the highest energy value, with fat contributing up to 130 kcal, which corresponds to the product's total fat content of 29 g per 100 g (Table 6). This high fat content can be attributed to the inclusion of 23.35% pork lard and 1.20% cricket powder by weight (Table 1). Regarding the cricket powder, the nutritional analysis showed that the highest content was protein (50.84%), followed by fat (22.34%), fiber (16.58%), ash (12.47%), moisture (10.80%), and carbohydrate (3.55%) [24]. This aligns with the findings of Montowska et al. [6], who reported that cricket powder is rich in protein (42.0–45.8% of dry matter) and fat (23.6–29.1% of dry matter). These results suggest that the type and proportion of ingredients—such as pork loin, pork lard, cricket powder, and starch—affect the nutritional value of the final product. In the case of pork meatballs, the absence of both pork lard and cricket powder (0.33%) contributes to their lower energy value of 80 kcal. This is lower than the energy content of commercial pork meatballs, which range from 121 to 158 kcal [58]. Furthermore, the analysis indicates that all three products contribute to daily macronutrient intake based on Thai Recommended Daily Intake (Thai RDI) values, providing 220–320 mg of sodium (11–16%), 115–150 mg of potassium (3–4%), and 10% of the daily value for vitamin B1 per 50 g serving (Table 7). The nutritional values of the three products align with the Thai Recommended Daily Intakes (% Thai RDI) for individuals over 6 years of age, based on a 2,000-kcal diet [29]. The recommended daily caloric intake is 2,600–2,800 kcal for adult males and 2,000–2,200 kcal for adult females [59]. Each product has a standardized serving size of 50 g, corresponding to ½ piece of pork sausage, 1 piece of grilled pork sausage, and 5 pork meatballs (Table 7). These meat products are among the most popular foods in Thailand. They can be consumed as snacks or used as ingredients in various one-dish meals such as noodles, Thai papaya salad, spicy salads, and soups. According to consumption reports (average per person per day), the intake of pork sausage (1.22 g) and pork ball (0.7 g) products in rural provinces is approximately 8 to 10 times higher than in urban areas [58,60]. Notably, the developed pork meatballs were found to contain 1.36 to 1.44 times more protein than those available on the market, while their fat and carbohydrate contents were 4.29 and 6.56 times lower, respectively [50]. These findings suggest that pork sausage, grilled pork sausage, and pork meatballs belong to the category of traditional Thai foods that are widely consumed and have the potential to appeal to health-conscious consumers. As such, incorporating cricket protein presents a promising way to enhance the nutritional profile of these popular local food products.

3.4 Cost-benefit Analysis

An analysis of the project to add value through the use of crickets in developing three processed food products—pork sausages, grilled pork sausages, and pork meatballs—showed that fixed costs, including machinery, kitchen equipment, and personal protective gear, accounted for 93.33% of the total investment (Table 8). The remaining 6.67% consisted of variable costs, primarily raw materials. An economic evaluation of the project's value over five years showed that the returns exceeded the initial investment. The project demonstrated strong financial viability, with the NPV of 1,274,843 THB [(38,790.29 USD): 1USD=33.0880 THB at March 5, 2025], the IRR of 31.80%, and the BCR of 3.76 (BCR Year 1 = 0.94, Year2 = 1.42, Year 3 = 1.97, Year 4 = 2.55, Year 5 = 3.76). This means that for every 1 THB (0.03043 USD) invested, the return was 3.76 times the cost. A return of 3.76 THB (0.11 USD) meets standard cost-effectiveness criteria, with the NPV > 0, the Benefit-BCR > 0, and the IRR > exceeding the funding source's interest rate (5%) [31]. Therefore, the evaluation confirms the cost-effectiveness of allocating the project budget, aligning with the estimated return on investment for cricket-based processed food products, which ranges from 27.45% to 69.26% [61]. This cost-benefit analysis serves as a useful guideline for reducing production costs—particularly variable costs related to raw materials—by fostering partnerships among key stakeholders, including cricket farmers, middlemen,

and Small and Medium Enterprises (SMEs). In the long term, it is recommended that a Social Return on Investment (SROI) assessment be conducted at the project's conclusion to support the sustainable development of Thai local foods incorporating cricket protein.

4. Conclusion

The development of suitable formulas incorporating cricket powder focused on creating pork sausages, grilled pork sausages, and pork meatballs with specific proportions of the ingredient. The most effective formulas contained 0.33%, 1.20%, and 0.33% cricket powder by weight, respectively. This finding is supported by sensory evaluation results, which showed no significant differences in overall acceptance scores compared to the control groups. Therefore, the formulas containing 0.33% cricket powder in pork sausages and pork meatballs, and 1.20% in grilled pork sausages, achieved the highest levels of consumer acceptance. Specifically, the protein content in pork meatballs (19.0 g/100 g) and pork sausages (13.4 g/100 g) meets the requirements of the Thai Community Product Standard (TCPS). For the community enterprise group, 93.33% of the project costs were fixed, while 6.67% were variable costs. The project yielded a return greater than the initial investment, with the NPV of 38,790.29 USD, the IRR of 31.80%, and the BCR of 3.76. The development of pork sausage, grilled pork sausage, and pork meatball products in this project demonstrates that cricket protein is a viable alternative for enhancing the nutritional value of traditional Thai food products. Additionally, it provides a practical solution to the issue of low-value cricket yields and offers valuable insights for promoting community enterprises and supporting sustainable development.

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