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Growth performance and nutritional composition of field crickets (*Gryllus bimaculatus* De Geer) fed with diets containing dried cassava leaves

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Abstract Crickets are among the most popular insects used as food due to their high nutritional value and ease of culture. The rearing of field crickets on diets containing dried cassava leaves as a substitute for soybean meal at levels of 0%(0CL), 30%(30CL), 50%(50CL), 70%(70CL), and 100%(100CL) was studied, focusing on their growth performance and nutritional value. After 45 days of cricket rearing, it was found that replacing soybean meal with dried cassava leaves at 30% and 50% showed no statistically significant difference (p>0.05) in cricket weight (279.82 g/box and 260.42 g/box, respectively) compared to the control treatment (284.08 g/box). There were statistically significant differences ($p \leq 0.05$) in individual body weight among the treatments. Crickets reared on the diet containing 100% dried cassava leaves (100CL) had the lowest individual body weights, measuring 0.688 g for males and 0.930 g for females. The number of eggs per female cricket had no statistically significant differences (p>0.05) across all treatments, ranging from 1,415.67 to 1,574.67 eggs. Additionally, field crickets fed diet containing dried cassava leaves had higher crude protein content (57.30-58.79% dm) than the control treatment (55.18% dm), with a statistically significant difference ($p \leq 0.05$). However, the crude protein, crude fat, and crude fiber contents decreased with increasing levels of dried cassava leaves in the diet. In conclusion, dried cassava leaves can replace up to 50% of soybean meal without reducing the yield, fecundity, or nutritional value of field crickets.

Keywords: Edible insect, Cassava leaves, Nutritional value

Introduction

Crickets are widely cultivated and consumed as edible insects. Currently, three types of crickets are popular to cultivate in Thailand: field crickets (*Gryllus bimaculatus* De Geer), giant crickets (*Brachytrupes portentosus* Lichtenstein), and house crickets (*Acheta domesticus* L.), locally known as 'mang–sa–ding' (Kemsawasd *et al.*, 2022). Crickets offer numerous

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nutritional benefits, including high protein content, essential amino acids, and fatty acids such as oleic acid, linoleic acid, and linolenic acid (Wang *et al.*, 2004). House crickets contain a high amount of the essential amino acid valine, while field crickets are a source of the essential amino acids leucine and valine (Magara *et al.*, 2021). Additionally, crickets contain minerals like calcium, magnesium, and iron, with particularly high levels of copper, manganese, and zinc (Montowska *et al.*, 2019).

Cricket farming yields high production while using fewer resources such as water, electricity, and space for cultivation. This reduces pollution and is more environmentally friendly compared to other forms of livestock farming (Moruzzo *et al.*, 2021). Crickets are popularly cultivated on farms, with approximately 20,000 households spread across all regions of Thailand, particularly concentrated in the Northeast. Most of the diets used for raising crickets is commercial diets, which is quite expensive and thus drives up the cost of raising them. Approximately 50% of the expenses for raising crickets are attributed to diet costs (Hanboonsong *et al.*, 2013). Additionally, rearing crickets with commercial diets containing 21% protein increases costs by 60-68% (Ruangsuriya, 2010). In October 2022, the price of commercial diet nearly doubled, leading many farmers to reduce their cricket farming activities or even cease farming altogether.

To address this problem, various plants have been studied and used as ingredients in cricket diet or as supplements to reduce the cost of commercial diet. These plants include cassava, pumpkin, purslane, and spinach, all of which have been shown to promote cricket growth and yield (Ssepuuya *et al.*, 2021). Similarly, kale and sweet potatoes have been used to diet crickets, resulting in favorable weight gain and growth rates, with crickets achieving high crude protein content of 82.4% and 78.6%, respectively (Oloo *et al.*, 2020). Furthermore, red clover has also been used to diet house crickets (Vaga *et al.*, 2020).

Cassava is an economic crop that can be utilized for both its tubers and leaves. Cassava leaves offer high nutritional value, with a crude protein content ranging from 29.3% to 32.4% dry weight (Awoyinka *et al.*, 1995). The leaves also include various vitamins and minerals, such as thiamin, riboflavin, niacin, ascorbic acid, vitamin A, calcium, phosphorus, and magnesium (Montagnac *et al.*, 2009; Fanelli *et al.*, 2023). Despite its nutritional benefits, cassava contains high levels of cyanide (in the form of cyanogenic glycosides, linamarin, and lotaustralin), which can pose dangers to humans and pets. However, these toxins can be effectively reduced through processes such as drying, fermentation, and boiling (Padmaja, 1995; Montagnac *et al.*, 2008; Madalla *et al.*, 2016). Both tubers and leaves of cassava are widely used as animal feed. Cassava has been employed as a substitute protein source in broiler feed (Adeyemi *et al.*, 2012; Ramadhanti *et al.*, 2024), pig feed (Diarra *et al.*, 2017), and goat feed (Tilahun *et al.*, 2013). Additionally, cassava leaves are utilized in rearing crickets, where fresh cassava leaves serve as a supplement (Fuah *et al.*, 2015; Miech *et al.*, 2016; Thu Hang *et al.*, 2020). The objective of this study was to evaluate the growth performance and nutritional composition of field crickets fed diets containing dried cassava leaves as a partial substitute for soybean meal.

Materials and methods

Preparation of dried cassava leaves

Cassava leaves of the variety Rayong 72 (bitter variety) were collected from an experimental plot at the Nong Rawiang Educational Center, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand. The cassava leaves were dried at room temperature for 24 hours and in a hot air oven at 50 °C for 24 hours, then ground into fine powder using an electric blender. The leaves were subsequently analyzed for chemical composition (crude protein, crude fiber, crude fat, ash, and carbohydrate), moisture content, and gross energy. The method for chemical composition analysis was performed according to the standard methods of AOAC (1995).

To determine the moisture content, 100 g of a fresh cassava leaves sample was placed on an aluminum dish and spread evenly. The moisture content was measured using the oven-drying method at 105 °C for 24 hours.

Crude protein content was analyzed using the Kjeldahl assay method, expressed as g/100 g (dry weight basis), and calculated by multiplying the crude nitrogen content by 6.25.

Crude lipid content was determined using Soxhlet extraction. A 2-g dried sample was extracted with petroleum ether for 16 hours. Following extraction, the solvent was evaporated, and the remaining lipid residue was weighed. Total lipid content was subsequently expressed as g per 100 g on a dry weight basis.

Crude fiber content was analyzed by digesting the sample with 1.25% sulfuric acid, then filtering, and washing it. Subsequently, the sample was digested with 1.25% sodium hydroxide, filtered, washed, and dried. This dried sample was then ignited at 550 °C. The difference between the weight of the dried residue before ignition and the weight of the ash after ignition was expressed as the weight of the crude fiber.

Ash content was determined by incinerating a sample powder in a muffle furnace at 550 °C for 24 hours and was expressed as g/100 g (dry weight basis).

Carbohydrate content was calculated as 100 minus the sum of moisture (%), ash (%), crude protein (%), crude fat (%), and crude fiber (%).

All proximate analyses are reported as mean values (± standard deviation, SD.) of at least three replicates.

The analysis of gross energy was conducted using bomb calorimetry according to the methods reported by Fulton *et al.* (2016). To prepare the sample, crickets were dried in a 55°C hot air oven for approximately 24 hours and ground with a mortar and pestle until a coarse powder was attained. A standard sample weight of 100 mg was used, which was then pressed into a pellet using a pellet press machine and analyzed with a Bomb Calorimeter AC500 (LECO Corporation, USA).

Preparation of cricket diets

The protein content of the analyzed cassava leaves was calculated. Then, the diets were formulated with 21–23% protein content, equivalent to instant chicken diet. Diet formulations that provide sufficient energy, vitamins, and minerals for chickens were developed following the method outlined in NRC (1994). In the diet formulations, dried cassava leaves were substituted for soybean meal at 30%, 50%, 70%, and 100% (w/w), with a control diet containing 100% soybean meal and no dried cassava leaves. The chemical composition of each diet formulation was then analyzed, and the ingredients for each diet formulation are detailed in Table 1.

Table 1. Diet formulation for rearing field cricket (*Gryllus bimaculatus*) with dried cassava leaves substituting soybean meal

Ingredients	Diet formulation [1/]				
	0CL	**30CL**	**50CL**	**70CL**	**100CL**
Corn meal (8.7 %CP)	54.1	54.1	54.1	54.1	54.1
Soybean meal (44 %CP)	38	26	18	10	0
Dried cassava leaves (19.50%CP)	0	11	18	25	34
Urea (287% CP)	0	1	2	3	4
Palm oil	6	6	6	6	6
Salt	0.2	0.2	0.2	0.2	0.2
Dicalcium	0.5	0.5	0.5	0.5	0.5
Premix	0.5	0.5	0.5	0.5	0.5
Lysine	0.7	0.7	0.7	0.7	0.7
Net weight (gram)	100	100	100	100	100

[1/] Diet formulation with dried cassava leaves substituting soybean meal; 0CL = 0% dried cassava leaves, 30CL = 30% dried cassava leaves, 50CL = 50% dried cassava leaves, 70 CL = 70% dried cassava leaves, and 100CL = 100% dried cassava leaves

Cricket rearing

100 grams of cricket eggs in rice husk (approximately 357.23±67.43 cricket eggs) were placed simultaneously into a 35 cm x 45 cm x 35 cm plastic box covered with a net. Upon hatching, water and diet were provided ad libitum. The rearing process was conducted under laboratory conditions at

25–30°C and 65–90% relative humidity, following the method described by Miech *et al.* (2016). After 45 days of rearing, grain yield (weight/box), individual body weight (male and female crickets), fecundity (number of eggs per female cricket), and the nutritional value of crickets were examined.

The experiment was conducted using a completely randomized design (CRD) with 5 treatments (diet formulation). The data were subjected to analysis of variance (ANOVA) using SAS program (Version 9.00; SAS Institute Inc., 2006). Significant differences between treatment means were delineated by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

Results

Nutritional composition of cassava leaves and cricket diet

The nutritional composition of the dried cassava leaves consisted of 19.50%dm crude protein, 5.59%dm crude fat, 8.10%dm crude fiber, and 5,204.74 cal/g of gross energy. The cricket diet containing dried cassava leaves had crude protein (22.05 – 22.75%dm) and energy (5,271.40 – 5,449.57 cal/g), with no statistically significant differences (p>0.05) across all treatments. The crude fiber content of the control treatment was 6.69%dm, while that of the cricket diet containing cassava leaves ranged from 5.05% to 6.82%dm. Additionally, the cricket diet containing cassava leaves had a higher crude fat content (8.24–10.92%) compared to the control treatment (7.70%) (Table 2).

Growth performance of crickets

The growth analysis was conducted after 45 days of rearing with different diet formulations containing dried cassava leaves, under conditions with a mean temperature of 30.23°C (25.90 – 34.0°C) and relative humidity of 78.9% (69.0 – 91.0%) (Table 3). The results showed that the cricket yields from the diet containing 30% and 50% dried cassava leaves were 279.82 g/box and 260.42 g/box, respectively, which were not statistically significantly different (p>0.05) from the control treatment (284.08 g/box). The individual body weights of both male and female crickets in all treatments were statistically different ($p\leq$0.05). Crickets reared on diet containing 100% dried cassava leaves had the lowest individual body weights, measuring 0.688 g for males and 0.930 g for females. The number of cricket eggs ranged from 1,415.67 to 1,574.67 eggs/ female cricket, with no statistically significant differences (p>0.05) across all treatments.

Table 2. Nutritional composition of cricket diets with dried cassava leaves substituting soybean meal

Parameters	Dried cassava leaves	Diet formulations[1/,2/]					*P–value*
		0CL	30CL	50CL	70CL	100CL	
Crude Protein (%dm)	19.50 ±0.44	22.11±0.62	22.75±0.96	22.35±1.61	22.05±1.26	22.26±1.09	**0.4078**
Crude Fat (%dm)	5.59±0.22	7.70±0.39^{b}	8.24±0.27^{a}	10.13±0.47^{a}	10.47±0.40^{a}	10.92±1.29^{a}	**<0.0001**
Crude Fiber (%dm)	8.10±0.07	6.69±0.98^{a}	5.05±1.06^{b}	5.76±0.06^{ab}	5.66±0.65^{ab}	6.82±0.17^{a}	**0.0275**
Ash (%dm)	6.43±0.04	4.26±0.09^{c}	4.47±0.05^{b}	4.08±0.06^{d}	4.11±0.08^{cd}	4.84±0.15^{a}	**<0.0001**
Carbohydrate (%dm)	60.38 ±1.39	59.24±0.78^{ab}	59.49±1.02^{a}	57.46 ±1.44^{c}	57.71±0.44^{bc}	55.16±0.58^{d}	**0.0013**
Moisture content (%)	66.27±0.25	8.80±0.10^{ab}	8.71±0.10^{b}	8.96±0.09^{a}	8.64±0.09^{b}	7.81±0.20^{c}	**<0.0001**
Dry matter (%)	19.31±0.44	91.02±0.10^{bc}	91.29±0.10^{b}	91.04±0.09^{c}	91.36±0.10^{b}	92.19±0.20^{a}	**<0.0001**
Gross Energy (cal/g.)	5,204.74±160.00	5,271.40±100.95	5,268.15±206.40	5,300.13±122.99	5,449.57±148.89	5,301.56±273.26	**0.5611**

[1/] Cricket diets with dried cassava leaves substituting soybean meal; 0CL = 0% dried cassava leaves, 30CL = 30% dried cassava leaves, 50CL = 50% dried cassava leaves, 70CL = 70% dried cassava leaves, and 100CL = 100% dried cassava leaves

[2/] Mean±SD. values with the same superscript letters in a row are not significantly different at 95% (DMRT, p>0.05)

Table 3. The grain yield, individual body weight and fecundity of field cricket (*Gryllus bimaculatus*), fed on diet containing dried cassava leaves substituting soybean meal

Treatments (Crickets)[1/]	Parameters[2/]			
	Weight/Box (g)	Mean individual body weight (g)		Fecundity (eggs/female cricket)
		Male	Female	
0CL	284.08±17.04^{a}	0.726±0.02^{bc}	1.158±0.14^{a}	1,415.67±101.28
30CL	279.82±11.41^{a}	0.900±0.09^{ab}	1.195±0.15^{a}	1,534.33±152.62
50CL	260.42±16.96^{a}	0.947±0.09^{a}	1.209±0.18^{a}	1,524.67±188.46
70CL	222.90±17.38^{b}	0.892±0.15^{ab}	1.246±0.11^{a}	1,574.67±104.43
100CL	106.02±28.28^{c}	0.688±0.11^{c}	0.930±0.04^{b}	1,519.12±130.79
P–value	**<0.0001**	**0.0380**	**0.0500**	**0.2413**

[1/] Field crickets were fed diet with dried cassava leaves substituting soybean meal; 0CL = 0% dried cassava leaves, 30CL = 30% dried cassava leaves, 50CL = 50% dried cassava leaves, 70CL = 70% dried cassava leaves, and 100CL = 100% dried cassava leaves

[2/] Mean±SD. values with the same superscript letters in a column are not significantly different at 95% (DMRT, p>0.05)

Nutritional composition of crickets

The nutritional composition of field crickets diet with dried cassava leaves as a substitute for soybean meal at different ratios (Table 4) showed that crude protein, crude fat, and crude fiber did not differ significantly (p>0.05) among the different diets, with values ranging between 55.18-58.79%dm, 18.29-22.15%dm, and 7.23-9.87%dm, respectively. Crude protein, crude fat, and crude fiber tended to decrease as the proportion of dried cassava leaves in the diet increased. The gross energy showed no significant differences (p>0.05) across all treatments.

Table 4. Chemical composition and grose energy of field cricket (*Gryllus bimaculatus*) fed on diet containing dried cassava leaves substituting soybean meal

Parameters	**Crickets[1/2/]**					***P–value***
	0CL	**30CL**	**50CL**	**70CL**	**100CL**	
Crude protein (%dm)	55.18 ± 0.66	58.79 ± 0.67	58.60 ± 1.66	58.34 ± 0.47	57.30 ± 0.61	**0.1591**
Crude fat (%dm)	22.15 ± 1.65	21.48 ± 0.28	19.98 ± 1.39	19.94 ± 0.25	18.29 ± 0.49	**0.0760**
Crude fiber (%dm)	8.75 ± 1.29	9.87 ± 1.58	8.47 ± 1.71	7.56 ± 1.01	7.23 ± 0.76	**0.1891**
Ash (%dm)	3.99 ± 0.19^{bc}	4.12 ± 0.10^{ab}	3.85 ± 0.13^{c}	4.15 ± 0.11^{ab}	4.34 ± 0.19^{a}	**0.0091**
Carbohydrate (%dm)	8.90 ± 1.73^{b}	8.47 ± 1.14^{b}	9.09 ± 3.47^{b}	7.29 ± 0.99^{b}	13.79 ± 1.40^{a}	**0.0328**
Moisture content (%)	72.73 ± 2.75	74.54 ± 2.52	74.55 ± 3.45	73.37 ± 1.80	74.12 ± 2.00	**0.8800**
Dry matter (%)	26.19 ± 2.74	24.91 ± 2.37	25.10 ± 3.41	26.08 ± 2.10	25.19 ± 2.95	**0.9187**
Grose energy (cal/g.)	7,050.41±466.64	6,335.43 ± 317.68	6,425.71 ± 334.67	6,441.36 ± 318.92	6,366.85 ± 126.56	**0.1173**

[1/] Field crickets were fed with diet with dried cassava leaves substituting soybean meal; 0CL = 0% dried cassava leaves, 30CL = 30% dried cassava leaves, 50CL = 50% dried cassava leaves, 70CL = 70% dried cassava leaves, and 100CL = 100% dried cassava leaves

[2/] Mean±SD. values with the same superscript letters in a row are not significantly different at 95% (DMRT, p>0.05)

Discussion

Dried cassava leaves could be added to crickets' diet as a protein source, replacing up to 50% of the protein from soybean meal, without significantly affecting cricket productivity compared to the control treatment. This aligns with the findings of Lam *et al.* (2022), who reported that cassava leaf meal could be used to partially substitute up to 20% of soybean and fish meal in cricket feed without negative effects. Crickets fed on dried cassava leaves exhibited both higher body weight and a greater number of eggs than the control treatment without cassava leaves.

This is similar to the study of Fuah *et al.* (2015), which reported that rearing *G. mitratus* crickets on an instant diet supplemented with cassava leaves resulted in good fertility and a maximum number of eggs (1,478.22 eggs). They also reported an egg-laying duration of 45 days, with an average of 32.85 eggs per day. As reported by Miech *et al.* (2016), young cassava shoots have high potential for rearing crickets (*Teleogryllus testaceus*), and the cyanide content in cassava leaves did not affect the growth of the crickets. Additionally, rearing crickets (*T. testaceus*) on instant diet mixed with cassava leaves also contributed to an increase in cricket weight and protein content (Caparros *et al.,* 2016). Moreover, Thu Hang *et al.* (2020) reported that feeding crickets on cassava leaves increased their yield by 14%. Additionally, Miech *et al.* (2023) reported that fresh top parts of cassava (*M. esculenta*) could be used as a sole diet for Jamaican field cricket (*G. assimilis*) reared in captivity. The combination of dry meal from cassava tops and its root ratio should not exceed 60% of cassava root in the diet formula. It can be observed that nutrient sources, especially protein, are crucial factors for the growth of crickets. High-protein diets for crickets significantly affect their growth and productivity (Sorjonen *et al.*, 2019). Additionally, an adequate amount of nutrients influences females in accumulating energy for mating, the quality of eggs, and the duration of laying eggs (Bulfer, 2011). However, besides the quality of the feed being an important factor, the rearing environment also plays a crucial role. Crickets raised in crowded conditions yield higher body weight and a greater number of eggs compared to those raised in less crowded conditions. This also influences their foraging behavior and reproductive performance (EL–Damanhouri, 2011; Shah, 2017).

In addition to growth, using cassava leaves to diet crickets also results in an increase in crude protein and crude fat in the crickets. High-protein diets for insects generally lead to high protein content in the insects themselves. Typically, crickets aged 13 weeks and older have a protein content ranging from 30.00% to 60.00%, and a fat content ranging from 12.00% to 25.00%, depending on their diet. (Kipkoech *et al.*, 2017). Håkansson (2018) reported that crickets (*T. testaceus*) raised on young cassava shoots exhibited increased amino acid levels and better protein quality compared to crickets fed a commercial diet or various types of grasses. Additionally, the levels of cyanide and nitrates in cassava leaves had no effect on crickets (Miech *et al*., 2016). Consuming crickets raised on cassava leaves is therefore safe and does not lead to accumulation of cyanide in the bloodstream or tissues (Simenova and Fishbein, 2004).

The gross energy of field crickets raised on diets mixed with cassava leaves tended to show increased gross energy, with no significant differences across all diet formulations. They also provided more than 6,000 cal/g, which is higher than the amount reported for *Acheta* spp. crickets, which provided only 4,676.0 cal/g (Abulude, 2004). Studies comparing energy content of crickets raised on different diets are very limited, particularly when compared to other edible insects such as *Verlarifictorus asperses* crickets (22.2 MJ/kg dry weight), which rank second after mealworms (23.9 MJ/kg dry weight) (Kim *et al.*, 2017). Additionally, crickets provide energy comparable to corn and higher than soybean meal (Razak *et al.*, 2012), making them suitable for both human and animal nutrition. They also offer good nutritional value and energy.

It is concluded that dried cassava leaves can replace up to 50% of soybean meal in cricket diet formulations without causing a statistically significant difference in growth yield compared to the control diet. Moreover, feeding crickets cassava leaf–based diets tend to reduce their crude protein, crude fat, and crude fiber contents.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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