QUALITY AND NUTRITIONAL CHARACTERISTICS OF BUTTER COOKIES FORTIFIED WITH DRIED SAGO PALM WEEVIL LARVAE (*Rhynchophorus ferrugineus*)

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Abstract

Sago palm weevil larvae (*Rhynchophorus ferrugineus*) are widely consumed in Thailand and are recognized as a promising alternative protein source. This study aimed to improve sago palm weevil larvae quality through rearing diet modification and to investigate their application in butter cookies. Larvae were reared using two regimes: a conventional animal-based diet and a plant-based "clean" diet designed to eliminate the dark gut and off-odor requested by entrepreneurs. The clean diet successfully produced larvae with white intestines and improved aroma, making them suitable for food application. Dried larvae were subsequently ground and partially substituted with wheat flour into butter cookies at levels of 0% (control), 5%, 10%, 15%, and 20% (w/w). The cookies were analyzed for their physical properties, appearance, and sensory acceptance. All physical properties, including darker color, coarser texture, and reduced hardness and expansion, were significantly affected by increasing larval levels ($p<0.05$). Sensory evaluation indicated that the 10% substitution cookies achieved the highest acceptability, with properties comparable to the control. This formulation (10% substitution) exhibited significantly higher protein (6.88%) than the control (4.70%), indicating a nutritional enhancement. These findings demonstrate that using a clean diet improves raw material quality, which is essential for developing nutritionally enhanced cookies with acceptable sensory properties."

Keywords: Sago palm weevil larvae; Edible insect fortification; Butter cookies; Alternative protein

Introduction

Edible insects have gained increasing attention worldwide as a sustainable, nutritionally rich alternative protein source, particularly amid global food security challenges. Insect-based foods are recognized for their high protein content, essential amino acids, and overall nutritional quality comparable to conventional livestock such as pork, chicken, and beef. Approximately 1,900 insect species are reported to be consumed globally, including beetles, weevils, crickets, grasshoppers, and termites (van Huis et al., 2013). Among these, weevils account for a significant proportion of edible insect consumption, accounting for approximately 29.6% of global intake (Food Intelligence Center, 2022). Edible insects are predominantly found in tropical regions, where they have long been integrated into traditional diets. In Thailand, insect consumption has been practiced for decades, and insect farming has evolved into both a domestic and export-oriented industry (Food Intelligence Center, 2022).

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Sago palm weevil larvae (*Rhynchophorus ferrugineus*), commonly known as coconut weevil larvae, are widely found in southern Thailand. Although considered an agricultural pest that damages palm species such as coconut, oil palm, and sago palm, the larval stage has become economically valuable due to its high nutritional content and consumer acceptance. These larvae are rich in protein, fat, and minerals and can be efficiently cultivated due to their short life cycle and high reproduction rate (Ministry of Agriculture and Cooperatives, 2023). Previous studies have demonstrated that the nutritional composition of sago palm weevil larvae varies depending on rearing conditions and feed formulations, with protein and fat contents ranging from 18.0–28.5% and 52.4–60.1% (dry weight), respectively (Chinarak et al., 2020).

However, the quality of larvae is often affected by undesirable characteristics such as dark gut coloration and strong odor, which reduce consumer acceptance and market value. These attributes are closely related to feeding regimes. Modification of feed composition, particularly the replacement of animal-based feed with plant-based ingredients such as corn meal, soybean residue, and rice bran, has been reported to improve larval quality by producing lighter-colored guts and reducing off-odors (Chinarak et al., 2021). Therefore, optimizing feeding strategies is essential for improving both the quality and economic value of sago palm weevil larvae.

In addition to improve raw material quality, the incorporation of edible insects into processed foods has emerged as an effective approach to enhance nutritional value and increase consumer acceptance. Bakery products, particularly cookies, are widely consumed due to their convenience, long shelf life, and versatility in formulation. Previous studies have demonstrated that partial substitution of wheat flour with insect-based ingredients, such as mealworm or cricket powder, can improve protein content while maintaining acceptable sensory properties (Sriprablom et al., 2022; Cheng et al., 2022).

Therefore, this study aimed to (i) evaluate the effects of different feeding formulations on the quality and chemical composition of sago palm weevil larvae and (ii) develop protein-enriched butter cookies by incorporating dried larvae at varying substitution levels. The physical, chemical, and sensory characteristics of the resulting products were systematically investigated to determine the optimal formulation for consumer acceptance and nutritional enhancement.

Materials and Methods

1. Raw Materials and Preparation of Dried Sago Palm Weevil Larvae (DSWL)

Frozen sago palm weevil larvae were obtained from a commercial producer in Khok Kloi District, Phang Nga Province, Thailand. Two groups of larvae were classified according to feeding regimes: (i) a traditional diet containing animal-based feed and (ii) a plant-based diet consisting of sago palm trunk, rice bran, corn meal, and soybean residue.

Before processing, frozen samples were thawed at 4°C for 12 h. The larvae were dried in a hot-air oven (Memmert UF110, Germany) at 70°C until the moisture content was reduced to below 5% (w/w). The dried samples were ground using a laboratory grinder (Philips HR2221, Netherlands) to obtain dried sago palm weevil larvae (DSWL). Due to the high lipid content, the resulting material exhibited a semi-powdered texture. Samples were stored in moisture-proof, air-impermeable containers at ambient temperature (25±2°C) until analysis.

Proximate composition was determined according to AOAC (2000) methods: moisture content (AOAC 925.10), ash content (AOAC 923.03), crude fat (AOAC 920.39), and crude protein (AOAC 984.13; Kjeldahl method, conversion factor N×6.25). Carbohydrate content was calculated by difference. All analyses were performed in triplicate ($n = 3$). Statistical differences between feeding treatments were evaluated using an independent samples t-test at a significance level of $p<0.05$ (SPSS version 18.0, SPSS Inc., Chicago, IL, USA).

2. Preparation of Cookies Enriched with DSWL

Dried sago palm weevil larvae derived from the plant-based feeding treatment were used for cookie formulation. The control butter cookie formulation consisted of 40.78% all-purpose wheat flour, 18.43% margarine, 6.53% shortening, 22.02% granulated sugar, 9.79% whole egg, 0.82% baking powder, and 1.63% vanilla extract (w/w basis).

Wheat flour was partially substituted with DSWL at levels of 0% (control), 5%, 10%, 15%, and 20% (w/w). Margarine, shortening, and sugar were creamed using a planetary mixer (KitchenAid Artisan, USA) at medium speed for 5 min until light and fluffy. Eggs were then added and mixed for 2 min until homogeneous. The dry ingredients (wheat flour/DSWL blends and baking powder) were incorporated and mixed to form a uniform dough.

The dough was shaped into circular pieces (4 cm diameter, 2 cm thickness) using a piping nozzle and baked in a preheated oven (Electrolux EOB2100AOX, Sweden) at 200°C for 15 min. After baking, cookies were cooled at ambient temperature (25±2°C) for 1 h and packed in polyethylene bags prior to analysis.

3. Quality Evaluation of Cookies

3.1 Sensory Evaluation

Sensory evaluation was conducted with 30 trained panelists under controlled laboratory conditions. Five cookie formulations (0–20% DSWL) were randomly coded and presented. Panelists evaluated appearance, color, aroma, taste, texture, and overall liking using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely).

The experimental design followed a randomized complete block design (RCBD), where panelists were treated as blocks. Each sample was evaluated in duplicate sessions to ensure reliability.

3.2 Physical Properties

Color measurements (L*, a*, b*) were determined using a colorimeter (HunterLab Miniscan EZ, USA) calibrated with a white standard under D65 illumination.

Geometrical properties, including diameter (mm) and thickness (mm), were measured using a digital Vernier caliper (Mitutoyo, Japan). The spread ratio was calculated as the ratio of diameter to thickness.

Texture analysis was performed using a texture analyzer (Brookfield CT3, USA) equipped with a 5 kg load cell. Hardness was measured in compression mode using a TA-MTP probe at a test speed of 1.0 mm/s and a compression distance of 5 mm. Each sample was measured at three different positions, and the mean value was expressed in Newtons (N).

The physical properties experiment was conducted using a completely randomized design (CRD) with three replications per treatment (n = 3).

3.3 Statistical Analysis

All data were expressed as mean ± standard deviation. Statistical analysis was performed using analysis of variance (ANOVA). Differences among means were determined using Duncan's Multiple Range Test (DMRT) at a significance level of $p<0.05$. Statistical analyses were conducted using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA).

4. Proximate Composition of Selected Cookie Formulation

Based on sensory evaluation, the formulation with the highest overall liking (10% DSWL substitution) was selected for proximate composition analysis and compared with the control. Moisture (AOAC 925.10), ash (AOAC 923.03), crude fat (AOAC 920.39), and crude protein (AOAC 984.13) were determined as described in Section 1.

Carbohydrate content was calculated by difference, and energy value (kcal/100 g) was estimated using Atwater factors (4 kcal/g for protein and carbohydrate, 9 kcal/g for fat). Water activity (a_w) was measured using a water activity meter (AquaLab Series 3, Decagon Devices, USA) at 25°C. All measurements were performed in triplicate (n = 3).

Results and Discussion

1. Effect of Feeding Regime on the Quality and Chemical Composition of Sago Palm Weevil Larvae

The feeding regime significantly influenced both the physical, appearance and chemical composition of sago palm weevil larvae. Larvae reared on the plant-based ("clean") diet exhibited improved visual quality, characterized by lighter gut coloration (yellowish-cream to light brown), whereas those fed the traditional animal-based diet showed darkened gut content. This improvement is critical for commercial value, as gut color is a key determinant of consumer acceptance. The reduction in dark coloration may be associated with differences in feed composition, particularly the absence of animal-based materials, which may reduce pigment accumulation and microbial degradation products responsible for discoloration and off-odors.

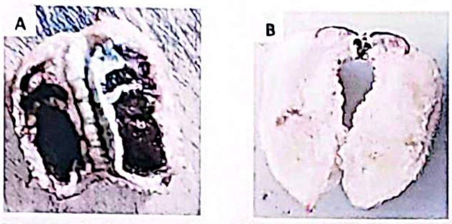

Figure 1. Appearance of frozen, boiled sago palm weevil larvae reared on different feed formulations: traditional feed (A) and plant-based feed (B).

Proximate analysis revealed that larvae fed the plant-based diet contained significantly higher protein, fat, and ash contents than those fed the traditional diet ($p<0.05$). This observation is consistent with previous findings indicating that insect nutritional composition is strongly influenced by feed substrates and nutrient availability (Chinarak et al., 2020). Similar trends have been reported in recent studies, where plant-based feeding strategies improved protein and lipid accumulation in edible insects due to enhanced nutrient assimilation efficiency (Mancini et al., 2022).

Table 1. Proximate composition of frozen, boiled sago palm weevil larvae reared under different feeding regimes, and of larvae reared on a plant-based diet after drying in a hot-air oven at 70°C for 13 h.

Proximate compositions (% w/w, dry weight)	Frozen boiled sago palm weevil larvae		Dried sago palm weevil larvae reared on plant-based
	Traditional feeding regime	Plant-based feeding regime	
Ash	1.90 ± 0.20^{b}	4.28 ± 0.14^{a}	3.09 ± 0.15
Fat	45.86 ± 0.99^{b}	62.13 ± 4.69^{a}	59.26 ± 2.18
Protein	21.18 ± 1.58^{b}	27.12 ± 1.29^{a}	21.88 ± 0.09
Carbohydrate	31.06	6.47	15.77

$^{a\text{-}b}$ The means of data in the same column of frozen boiled sago palm weevil larva are significantly different ($p<0.05$).

Drying at 70°C reduced moisture content to approximately 1.69% (w/w), resulting in a shelf-stable product. However, due to the high lipid content (~56–58%), the ground dried larvae exhibited a semi-moist, paste-like consistency rather than a free-flowing powder. This characteristic can significantly affect ingredient functionality, particularly its dispersion and interaction within dough systems.

2. Physical Properties of Cookies Enriched with DSWL

2.1 Color and Appearance

Increasing levels of DSWL incorporation significantly affected cookie color ($p<0.05$), as indicated by decreased lightness (L*) and increased redness (a*). This trend can be attributed to the intrinsic dark color of DSWL as well as enhanced Maillard reactions during baking. The higher protein content of DSWL increases the availability of amino groups, promoting non-enzymatic browning and melanoidin formation.

Figure 2. Appearance of cookies formulated with 0–20% (w/w) dried sago palm weevil larvae blends (DSWL) following baking at 200°C for 15 min.

These findings are consistent with recent studies on insect-enriched bakery products. For example, Bawa et al. (2022) reported that cookies fortified with cricket powder exhibited significantly lower L* values due to intensified Maillard browning. Similarly, Kim et al. (2023) observed darker coloration in mealworm-enriched cookies, attributing this effect to increased protein–sugar interactions during thermal processing.

Table 2. Color parameters (L*, a*, b*) of cookies enriched with 5–20% (w/w) dried sago palm weevil larvae blends (DSWL), compared with the control (0% DSWL).

Treatment	L*	a*	b*
Control	64.15 ± 2.01^{a}	13.70 ± 0.68^{c}	41.05 ± 0.77^{b}
5%DSWL	53.69 ± 3.98^{c}	16.81 ± 1.37^{a}	46.84 ± 8.72^{a}
10%DSWL	58.08 ± 1.39^{b}	14.23 ± 0.65^{c}	39.91 ± 0.86^{b}
15%DSWL	54.60 ± 4.03^{c}	15.25 ± 1.09^{b}	40.62 ± 0.63^{b}
20%DSWL	38.62 ± 3.31^{e}	17.25 ± 0.32^{a}	36.09 ± 1.76^{c}

$^{a\text{-}c}$ The means of data in the same column are significantly different ($p<0.05$).

In addition, the high lipid content of DSWL may facilitate heat transfer and accelerate browning reactions. The uneven dispersion of lipid-rich insect particles within the dough matrix also contributed to a coarser surface structure compared to the control.

2.2 Texture and Geometrical Properties

Cookie hardness significantly decreased with increasing levels of DSWL substitution ($p<0.05$). This reduction can be explained by the dilution of gluten network, as partial replacement of wheat flour reduces the availability of gluten-forming proteins, resulting in a weaker structural matrix. Consequently, the cookies exhibited lower resistance to compression.

Table 3. Textural and geometrical characteristics of cookies enriched with 5–20% (w/w) dried sago palm weevil larvae blends (DSWL), compared with the control (0% DSWL).

Treatments	Hardness (N)	Diameter of cookies (mm)	Thickness of cookies (mm)	Spread ratio
Control	11.85±1.89^{a}	59.96±1.50^{a}	6.15±0.35^{b}	9.49±0.20^{b}
5%DSWL	9.98±0.99^{b}	56.08±0.74^{b}	7.03±0.39^{a}	8.00±0.52^{c}
10%DSWL	9.68±1.56^{b}	54.22±0.66^{c}	6.99±0.41^{a}	7.80±0.47^{c}
15%DSWL	7.00±1.20^{c}	59.58±1.80^{a}	6.15±0.57^{b}	9.49±0.13^{b}
20%DSWL	6.81±0.58^{c}	56.53±1.77^{b}	5.64±0.46^{c}	10.15±0.83^{a}

$^{a-c}$ The means of data in the same column are significantly different ($p<0.05$).

Moreover, the high lipid content of DSWL likely exerted a tenderizing effect, reducing internal friction and weakening intermolecular interactions within the dough system. This effect is widely reported in bakery science, where lipids act as shortening agents, leading to softer textures.

These results are in agreement with recent studies on edible insect incorporation. Alfieri et al. (2021) reported that substitution of wheat flour with insect protein powder significantly reduced cookie hardness due to both gluten dilution and increased lipid content. Similarly, Bawa et al. (2022) demonstrated that cricket-enriched cookies exhibited reduced hardness and altered dough rheology, attributed to weaken gluten structure and modified water absorption properties.

The geometrical properties further supported these findings. Increasing DSWL levels resulted in reduced diameter and spread ratio, indicating restricted expansion during baking. These changes can be explained by alterations in dough rheology, particularly reduced elasticity and gas retention capacity caused by gluten dilution. The presence of insect proteins and lipids may also interfere with starch gelatinization and matrix formation, further limiting cookie spread.

3. Sensory Evaluation of Cookies Enriched with DSWL

Sensory evaluation indicated that moderate levels of DSWL incorporation (5–10%) resulted in high consumer liking, with no significant differences compared to the control ($p\geq0.05$). The 10% DSWL formulation achieved the highest overall liking, suggesting an optimal balance between improved nutritional value and desirable sensory properties.

Table 4. Sensory scores of cookies enriched with 5–20% (w/w) dried sago palm weevil larvae blends (DSWL), compared with the control (0% DSWL)

Sensory attributes	Treatments				
	Control	5%DSWL	10%DSWL	15%DSWL	20%DSWL
Appearance	7.60±1.17^{ab}	7.37±1.10^{b}	7.83±1.08^{a}	6.67±1.45^{c}	6.93±1.17^{c}
Color	7.70±1.12^{a}	7.53±1.11^{a}	7.68±1.13^{a}	6.60±1.40^{b}	6.90±0.96^{b}
Odor	7.70±1.15^{a}	7.38±1.28^{a}	7.48±1.31^{a}	6.70±1.70^{b}	6.80±1.85^{b}
Taste	7.68±1.08^{a}	7.55±1.10^{a}	7.45±1.27^{a}	6.00±1.86^{b}	6.13±2.03^{b}
Texture	7.67±1.00^{a}	7.47±1.02^{a}	7.68±1.28^{a}	6.30±1.58^{b}	6.23±1.59^{b}
Overall	7.73±0.93^{a}	7.53±0.93^{a}	7.78±1.01^{a}	6.57±1.48^{b}	6.40±1.54^{b}

$^{a-c}$ The means of data in the same column are significantly different ($p<0.05$).

At higher substitution levels (15–20%), sensory scores decreased significantly ($p<0.05$), particularly for taste and aroma. This decline may be attributed to the intensified characteristic flavor of the larvae and the darker appearance of the product.

These findings are consistent with recent literature. Kim et al. (2023) reported that mealworm-enriched cookies exhibited optimal sensory acceptance at 10% substitution, while higher levels negatively affected flavor and overall liking. Similarly, Bessa et al. (2024) highlighted that consumer acceptance of insect-based bakery products is highly dependent on inclusion level, with moderate incorporation providing the best balance between nutritional enhancement and sensory quality.

4. Proximate Composition of Selected Cookie Formulation

The 10% DSWL formulation showed a significantly higher protein content (6.88%) compared to the control (4.70%) ($p<0.05$), confirming the effectiveness of DSWL as a protein enrichment ingredient.

Table 5. Proximate composition and water activity of cookies enriched with 10% (w/w) dried sago palm weevil larvae blends (DSWL), compared with the control (0% DSWL).

Chemical compositions	Treatments	
	Control	10%DSWL
Moisture (%w/w, wet weight)[ns]	2.30±0.35	2.39±0.35
Ash (%w/w, wet weight)[ns]	1.11±0.00	2.12±1.52
Fat (%w/w, wet weight)[ns]	27.54±4.86	26.04±2.38
Protein (%w/w, wet weight)	4.70±1.20[b]	6.88±0.38[a]
Carbohydrate (%w/w, wet weight)[ns]	64.35	62.58
Energy (kcal/100g)[ns]	524.07	512.19
Water activity (a_w)	0.276±0.001[a]	0.212±0.003[b]

[a-c] The means of data in the same row are significantly different ($p<0.05$).
[ns] The means of data in the same row are not significantly different ($p\geq0.05$).

This trend is consistent with previous studies on insect-based fortification. For instance, Bessa et al. (2024) reported that increasing insect flour substitution significantly enhanced protein content in cookies, while maintaining acceptable fat and moisture levels. Similarly, Mancini et al. (2022) demonstrated that insect-based ingredients can effectively improve the nutritional profile of bakery products without compromising technological properties when used at moderate levels.

No significant differences were observed in fat, ash, and moisture contents ($p\geq0.05$), indicating that partial substitution did not disrupt the overall compositional balance. The slightly lower energy value in DSWL cookies may be attributed to reduced carbohydrate content due to flour substitution.

Low water activity values (0.21–0.28) confirmed good shelf stability, aligning with typical characteristics of low-moisture baked products.

5. Implications for Product Development

The incorporation of DSWL into cookies demonstrates strong potential for developing alternative protein-enriched bakery products. However, formulation optimization is essential to balance nutritional enhancement and sensory acceptability. The findings suggest that a 10% substitution level is optimal, providing improved protein content while maintaining desirable physicochemical and sensory properties.

Conclusions

Larvae reared on the plant-based ("clean") diet exhibited improved quality, including lighter gut coloration and higher protein, fat, and ash contents compared to those fed the conventional diet. Partial substitution of wheat flour with dried sago palm weevil larvae (DSWL) significantly increased the protein content of butter cookies. A substitution level of 10% (w/w) provided the highest sensory liking, with quality attributes comparable to the control and a slightly lower energy value. These findings indicate that DSWL can be effectively utilized as an alternative protein ingredient in bakery products.

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