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Effects of palm weevil larvae incorporation on proximate composition and mineral content of beef-type sausages

Mercy Amo Aggrey* and Worlah Yawo Akwetey

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ABSTRACT

Palm weevil larvae (*Rhynchophorus phoenicis*), locally known as Akokono, are edible insects traditionally consumed in Ghana and represent a promising alternative protein resource for agricultural value addition and meat product innovation. This study evaluated the nutritional composition of beef-type sausages formulated with Akokono, focusing on proximate composition and mineral content. Akokono was incorporated into beef sausages at graded substitution levels ranging from 0% to 70%, and sausage samples were analysed using standard analytical procedures. The proximate composition of Akokono–beef sausages differed significantly among formulations ($p < 0.05$), with crude fibre ranging from 0.76–7.46%, ash 2.86–7.45%, protein 52.97–85.34%, and fat 5.56–31.77%. Mineral composition also varied significantly across treatments ($p < 0.05$). The sausage samples contained 0.84–1.19% phosphorus, 0.16–0.24% magnesium, 0.05–0.09% sodium, 0.33–0.44% calcium, 1.17–2.18% potassium, 10.68–26.64 mg/kg zinc, and 15.04–30.68 mg/kg iron. The results demonstrate that Akokono incorporation significantly affects the nutritional quality of beef-type sausages and highlight the potential of palm weevil larvae as a nutrient-rich, innovative agricultural protein resource for sustainable meat product development.

Keywords: Akokono, Protein content, Nutritional quality, Agricultural innovation, Insect-based meat products

Department of Animal Science, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana

*Corresponding author's email: mamoaggrey@st.knust.edu.gh (Mercy Amo Aggrey)

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Introduction

The increasing global demand for sustainable, nutritious, and affordable protein sources has intensified pressure on conventional livestock production systems. Rapid population growth, rising feed costs, environmental degradation, and concerns about greenhouse gas emissions and land use associated with meat production have stimulated interest in alternative protein sources that can complement or partially replace traditional animal proteins (FAO, 2013; van Huis *et al.*, 2015). Within this context, edible insects have emerged as promising components of sustainable agri-food systems due to their high feed conversion efficiency, relatively low environmental footprint, and favourable nutritional profiles (Rumpold and Schlüter, 2013; Halloran *et al.*, 2017).

Palm weevil larvae (*Rhynchophorus phoenicis*), locally known as Akokono, are traditionally consumed in several parts of West Africa, particularly in Ghana. Among the Asante communities, Akokono is valued for its palatability and perceived nutritional benefits. Scientific studies have confirmed that palm weevil larvae are rich in protein, lipids, and essential minerals, including iron, zinc, calcium, potassium, and phosphorus (Elemo *et al.*, 2011; Anankware *et al.*, 2015; Egonyu *et al.*, 2024). Despite this nutritional potential, the utilization of Akokono remains largely informal and limited to traditional preparation methods, with minimal integration into value-added or commercially processed food products. This limited utilization has constrained its wider acceptance, commercialization, and contribution to food and nutrition security (Anankware *et al.*, 2016; Sogari and Mora, 2019).

Processed meat products, such as sausages, provide a suitable matrix for incorporating alternative protein ingredients due to their comminuted structure, formulation flexibility, and widespread consumer acceptance. Previous studies have demonstrated that insect-based ingredients can be successfully incorporated into meat products, enhancing nutritional value while facilitating gradual consumer exposure to novel protein sources (Cruz-López *et al.*, 2022; Kolev *et al.*, 2024). However, the nutritional consequences of substituting beef with palm weevil larvae - particularly with respect to proximate compositions and mineral contents- remain insufficiently documented. A clear understanding of these effects is essential for guiding formulation optimization and supporting the development of nutritionally improved and sustainable meat products.

Therefore, this study evaluated the nutritional composition of beef-type sausages formulated with graded levels of palm weevil larvae. Specifically, the study assessed the proximate composition and mineral profile of Akokono–beef sausages, with the aim of providing scientific evidence to support the utilization of palm weevil larvae as a novel agricultural protein resource for sustainable meat product development

Materials and Procedures

Study location

The study was conducted at the Meat Science and Processing Unit of the Department of Animal Science and the laboratories of the Department of Food Science and Technology, all at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Production of samples started, with trials beginning in September 2024, and final laboratory analyses were completed in November 2025.

Experimental materials

Lean boneless beef was obtained fresh from the Kumasi Abattoir Company in Kumasi, Ghana. Ground culinary spices were purchased from Opoku Trading Supermarket, Kumasi. Natural hog casings with a diameter of 32 mm were used to stuff sausages. The equipment used for sausage preparation included a meat grinder fitted with a 15 mm sieve plate, a food processor, a manually operated sausage stuffer, a digital weighing balance, and a probe-type meat thermometer. Farmed Akokono larvae were obtained from the Legendary Food Research Centre.

Preparation of palm weevil larvae and lean beef

Palm weevil larvae, obtained alive and active, were thoroughly washed under running potable water to remove adhering debris and surface contaminants. The larvae were subsequently sealed in sterile Ziplock bags to restrict movement and physiological activity, thereby minimizing post-harvest biochemical changes and preserving lipid and protein integrity. Both the palm weevil larvae (Akokono) and lean beef were then stored at −18 °C for 24 h prior to sausage production to stabilize the raw materials and ensure uniform processing conditions.

Formulations used in sausage production

A negative control formulation containing only palm weevil larvae (Akokono) and additives was evaluated during preliminary trials; however, it exhibited poor binding capacity and weak textural characteristics. This observation aligns with previous reports indicating limited gelation and binding functionality of insect proteins when used alone in comminuted meat systems. Consequently, this formulation was excluded from the main experiment. A positive control consisted of minced beef mixed with ice, without Akokono inclusion. No additional water was added to the beef–Akokono formulations because of the larvae's inherently high moisture content. The prepared sausage batters were stuffed into 32 mm natural hog casings using a manually operated sausage stuffer and tied into uniform links to ensure consistency across treatments. Ground lean beef and palm weevil larvae (Akokono) were proportioned and allocated to the respective experimental treatments (T_1–T_8) according to the predefined formulation ratios presented in Table 1.

Table 1. Ingredients used in beef-type akokono sausage formulation.

Ingredients (g)	Treatment							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Akokono	1400	1200	1000	800	600	400	200	0
Beef	600	800	1000	1200	1400	1600	1800	1600
Salt	20	20	20	20	20	20	20	20
Ice	0	0	0	0	0	0	0	400
Total	2020	2020	2020	2020	2020	2020	2020	2020

T_1–T_7 represent beef–type Akokono sausage formulations containing decreasing levels of Akokono (70%, 60%, 50%, 40%, 30%, 20% and 10%, respectively) with corresponding increases in beef proportion, while T_8 serves as the 100% beef control. All quantities are expressed in grams (g) on a formulation basis.

Thermal processing and storage

The sausages were scalded in a temperature-controlled water bath maintained at 80°C until an internal core temperature of approximately 72°C was achieved, as monitored using a calibrated probe-type meat thermometer. This thermal treatment was applied to ensure product safety and uniform heat penetration. Following scalding, the sausages were immediately cooled in cold water, surface-dried, appropriately labelled, and stored under frozen conditions (approximately −18°C) at the Department of Animal Science for subsequent physicochemical, nutritional and quality analyses.

Parameters evaluated

Proximate composition

Proximate composition of farmed Akokono–beef sausage samples was determined using standard methods of the Association of Official Analytical Chemists (AOAC, 2023). Moisture content was determined by oven drying at 105°C to constant weight, ash content by dry ashing at 550°C, crude protein by the Kjeldahl method using a nitrogen-to-protein conversion factor of 6.25, and crude fat by Soxhlet extraction using petroleum ether. Carbohydrate content was calculated by difference. Proximate composition values were expressed on a dry matter (DM) basis, following moisture correction after oven drying.

Mineral analysis

Mineral composition of the Akokono–beef sausage samples was determined using standard analytical procedures (AOAC, 2023). Dried and finely ground samples were dry-ashed and acid-digested to obtain clear solutions for analysis. Concentrations of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and phosphorus (P) were determined and expressed as percentages (%), while iron (Fe) and zinc (Zn) were quantified and expressed as mg/kg. Calcium, magnesium, sodium, potassium, iron and zinc were analyzed using a true Atomic Absorption Spectrophotometer equipped with hollow cathode lamps and an atomization system, *iCE 3000 Series AAS* (Thermo Fisher Scientific, Waltham, MA, USA), whereas phosphorus was determined using a standard colorimetric method. Analytical accuracy and quality control were ensured using reagent blanks, calibration standards, and certified reference materials.

Experimental design and statistical analysis

The experiment was laid out in a completely randomized design (CRD**)** comprising eight treatments (T_1–T_8**)** corresponding to graded levels of Akokono substitution, with three replications per treatment, each replicate consisting of 2 kg of sausage batter. Data generated from the physicochemical, nutritional, and quality analyses were subjected to one-way analysis of variance (ANOVA) using IBM SPSS Statistics (version 27). Differences among treatment means were determined using Duncan's Multiple Range Test, and statistical significance was declared at $p < 0.05$.

Results and Discussion

Proximate composition

As presented in Table 2, Akokono incorporation significantly influenced the proximate composition of beef-type sausages, particularly crude fibre, ash, protein, and fat contents ($p < 0.001$). Increasing levels of Akokono resulted in higher crude fibre (0.76–7.46%) and ash contents (2.86–7.45%), attributable to the chitin content and mineral richness of palm weevil larvae, respectively (Elemo *et al.*, 2011; van Huis *et al.*, 2015; Lisboa *et al.*, 2024). Conversely, crude protein increased with higher beef inclusion, ranging from 52.97% in Akokono-rich formulations to 85.34% in the beef-only control, reflecting differences in protein density between insect biomass and beef (Choi *et al.*, 2017; Kim *et al.*, 2019). The proximate composition values reported in this study were expressed on a dry matter (DM) basis, thereby excluding moisture from the calculations. Consequently, the coexistence of relatively high crude protein and fat contents in Akokono-rich formulations is mathematically consistent. For example, in T_1, crude protein (52.97%), fat (31.77%), fibre (7.46%), and ash (3.88%) collectively account for 96.08% of the dry matter, leaving a small proportion attributable to nitrogen-free extract (carbohydrates by difference). This observation supports the compositional validity of the results and reflects the nutrient-dense nature of palm weevil larvae. Fat content declined markedly from 31.77% to 5.56% with decreasing Akokono levels, consistent with the relatively high lipid content of palm weevil larvae (Elemo *et al.*, 2011; Chamoun *et al.*, 2023). These results indicate that palm weevil larvae can be utilized as a novel agricultural protein resource to modify the nutritional profile of processed meat products.

Table 2. Proximate composition of beef-type kokono sausages

Parameters	Treatment								SEM	p-value
	T 1	T 2	T 3	T4	T 5	T 6	T7	T8		
Fiber	7.46^{g}	2.53^{c}	5.06^{e}	6.35^{f}	4.50^{d}	1.83^{b}	0.76^{a}	0.87^{a}	0.49	<0.001
Ash	3.88^{b}	4.85^{c}	7.03^{g}	5.06^{d}	2.86^{a}	5.62^{e}	7.45^{g}	6.55^{f}	0.30	<0.001
Protein	52.97^{a}	54.05^{b}	59.95^{c}	68.50^{d}	69.40^{e}	72.61^{f}	81.55^{g}	85.34^{h}	2.32	<0.001
Fat	31.77^{h}	25.66^{g}	23.19^{f}	19.09^{e}	17.51^{d}	15.76c	6.72^{b}	5.56^{a}	1.75	<0.001

[abcdefgh]Means in the same row with different superscripts are significantly different (p<0.001); T_1= 70% kokono + 30% beef; T_2= 60% kokono + 40% beef; T_3= 50% kokono + 50% beef; T_4= 40% kokono+ 60% beef; T_5 = 30% kokono + 70% beef; T_6 = 20% kokono + 80% beef; T_7 =10% kokono + 90% beef, T_8= 0% kokono + 100% beef; SEM= standard error of means.

Mineral composition of sausages

Table 3 presents the mineral composition of beef-type Akokono sausages across the eight formulations (T_1–T_8). Significant differences ($p < 0.05$) were observed among treatments for all minerals analyzed, indicating that Akokono inclusion level substantially influenced mineral composition. Phosphorus, magnesium, sodium, calcium, potassium, zinc, and iron contents varied across formulations, reflecting differences in the proportion of Akokono relative to beef. In general, formulations containing higher proportions of Akokono exhibited elevated concentrations of both macro- and micro-minerals, consistent with the mineral-rich nature of palm weevil larvae.

The observed mineral profiles align with previous reports that identify palm weevil larvae as valuable sources of essential minerals, including iron, zinc, calcium, potassium, and phosphorus (Adobeze *et al.*, 2022; Rumpold and Schlüter, 2013).

Table 3. Mineral composition of sausages

Parameter (%)	Treatment								SEM	p-value
	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8		
P	0.94^{c}	0.84^{a}	1.06^{d}	1.11^{f}	1.09^{e}	1.19^{g}	0.93^{c}	0.91^{b}	0.02	<0.001
Mg	0.24^{e}	0.18^{bc}	0.19^{d}	0.18^{bc}	0.17^{b}	0.18^{bc}	0.16^{a}	0.16^{a}	0.26	<0.001
Na	0.06^{b}	0.05^{a}	0.07^{d}	0.08^{e}	0.08^{e}	0.09^{g}	0.08^{e}	0.07^{c}	0.02	<0.001
Ca	0.44^{f}	0.38^{b}	0.41^{c}	0.38^{b}	0.43^{g}	0.42^{d}	0.43^{e}	0.33^{a}	0.07	<0.001
K	1.30^{b}	1.17^{a}	1.65^{d}	2.00^{f}	1.86^{e}	2.18^{g}	1.85^{e}	1.53^{c}	0.06	<0.001
Zn (mg/kg)	13.16^{ab}	10.68^{a}	20.20^{cd}	20.55^{cd}	21.68^{d}	26.64^{e}	22.65^{d}	16.61^{bc}	1.08	<0.001
Fe(mg/kg)	18.54^{b}	15.04^{a}	24.58^{d}	28.48^{e}	22.59^{c}	30.68^{f}	22.91^{c}	18.70^{b}	1.01	<0.001

[abcdefg]Means in the same row with different superscripts are significantly different (p<0.001); T_1= 70% kokono + 30% beef; T_2= 60% kokono + 40% beef; T_3= 50% kokono + 50% beef; T_4= 40% kokono+ 60% beef; T_5 = 30% kokono + 70% beef; T_6 = 20% kokono + 80% beef; T_7 =10% kokono + 90% beef; T_8= 0% kokono + 100% beef; SEM= standard error of means.

Phosphorus and magnesium levels were within ranges reported for processed meat and insect-enriched food systems (Espinales *et al.*, 2024), while sodium levels remained relatively low and within recommended limits for healthier meat products (WHO, 2012). Calcium and potassium contents were comparable to values reported for conventional and insect-based foods (Zhou *et al.*, 2022). Zinc and iron concentrations were within ranges typically reported for fresh and processed meats (Bohrer, 2017), suggesting that Akokono-enriched sausages can contribute meaningfully to dietary micronutrient intake (Lim *et al.*, 2013). Overall, Akokono incorporation enhanced the mineral profile of beef-type sausages, with moderate inclusion levels providing a balanced and nutritionally advantageous mineral composition suitable for product optimization

Conclusions and Recommendations

The results of this study demonstrate that palm weevil larvae (*Rhynchophorus phoenicis*) can be successfully incorporated into beef-type sausages, significantly influencing their nutritional composition. Akokono inclusion increased fibre, ash, fat, and mineral contents, while beef-dominant formulations exhibited higher protein and moisture levels. The presence of chitin enhanced dietary fibre, and the incorporation of Akokono markedly improved the mineral profile of the sausages, particularly iron, zinc, potassium, calcium, magnesium, and phosphorus, without excessive sodium levels. Overall, sausages containing moderate levels of Akokono provided a balanced nutritional profile, combining improved micronutrient content with acceptable protein levels. It is therefore recommended that Akokono be incorporated at moderate substitution levels in beef-type sausages to maximize nutritional benefits**.** Further studies should explore shelf stability, mineral bioavailability, consumer perception at scale, and the optimization of processing techniques to support commercial adoption. These findings highlight palm weevil larvae as a nutritionally valuable and innovative agricultural protein resource with strong potential for value addition, product diversification, and sustainable meat product development.

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