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Nutritional composition of different rearing feedstocks influences larval survival of African palm weevil (*Rhynchophorus phoenicis*)

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Abstract

The African palm weevil (*Rhynchophorus phoenicis*) is a major pest of palm trees in the tropics and subtropics. This study examined the efficiency of rearing African palm weevil larvae on various substrates, used singly and in combination, with reference to their proximate compositions. Palm fibre, coconut husk, wet plantain stem and a mixture of the three substrates were used to rear palm weevil larvae. Twenty larvae were introduced per bowl into six bowls for each treatment, and four treatments were evaluated. Larval survival, pupation and adult emergence were recorded. High larval mortality was recorded in week 3 for wet plantain stem substrate (mean: 12.00) and palm trunk fibre (mean: 14.2). The combination of all substrates enhanced larval survival during the early rearing period. Mean pupation was highest with coconut husk in week 3, and mean adult emergence was highest with coconut husk in week 4. The differences were significant ($p < 0.05$). The proximate compositions of the substrates varied, but the differences were not statistically significant ($p > 0.05$). Moisture content was highest in plantain stem fibre. Ash content was highest in the combination of palm trunk fibre, coconut fruit husk and plantain stem fibre. Crude fibre, crude protein and ether extract were highest in the combination of pawpaw trunk fibre, palm trunk fibre, coconut fruit husk and sugarcane stem fibre. Carbohydrate content, measured as nitrogen-free extract (NFE), was highest in sugarcane stem fibre. Coconut husk was the most appropriate substrate for the mass rearing of African palm weevils.

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Keywords: African palm weevil, Larval survival, Adult emergence, Feedstock, Proximate composition

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1. Introduction

The increasing global need for protein, caused by environmental degradation, climate change and rapid population growth, has fuelled the search for sustainable alternatives to conventional animal production [1]. Edible insects have emerged as a possible alternative because of their high nutritional content, high feed-conversion efficiency and small environmental footprint. Among these, the African palm weevil (*Rhynchophorus phoenicis*), native to tropical Africa, stands out for its cultural acceptability and nutritional richness. The larvae are rich in essential minerals, lipids and crude protein, making them suitable for human consumption and for

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inclusion in livestock and aquaculture diets [2–4]. Protein levels can exceed 60% by dry weight, with lipid profiles that contribute substantially to dietary requirements [5]. Palm weevil larvae are a traditional delicacy in many West and Central African cultures and constitute a readily available option for addressing protein-energy deficiency [6]. Beyond their nutritional value, African palm weevil larvae have considerable environmental and economic benefits [7]. Cost-effective rearing involves simple management procedures, low initial investment and minimal space, making it accessible to rural and peri-urban farmers [8, 9]. Increasing market demand and the rapid life cycle provide income-generating opportunities that may reduce poverty and diversify livelihoods [10]. Insect farming is more environmentally friendly than typical livestock farming because it emits fewer greenhouse gases and uses less feed, land and water [11, 12]. Furthermore, palm weevil larvae can be grown on plant residues and agro-industrial by-products, thereby minimizing plantation pests, supporting circular bioeconomy goals and encouraging waste recycling [13]. Their compact rearing procedures are also consistent with peri-urban and urban agricultural development, resulting in viable and efficient protein-production processes [14].

Despite these advantages, commercializing and expanding African palm weevil farming poses significant challenges, particularly in terms of nutritional consistency, feedstock quality and availability. The nutritional qualities of substrates used in rearing directly affect survival rates, biochemical composition and larval growth performance [15]. Suboptimal feed formulations lead to lower productivity, variable yields and reduced economic viability. Nutritional imbalances in feedstocks can result in higher mortality, poor larval growth, uneven product quality and disease susceptibility, which hinder standardization for commercial production [16]. The variability in nutrient composition of commonly used plant-based feed materials is a key challenge for scaling production. Ether extract, crude fibre, moisture content, ash content, NFE and crude protein vary among feedstocks such as palm fibre, sugarcane, pawpaw leaves, mixed plant residues and coconut husk. Mixed substrates, for example, can contain comparatively high crude protein (33–38%) and ether extract (3–4.1%), which promote larval development, whereas palm fibres have higher crude-fibre levels, which may restrict digestion and nutrient assimilation. This diversity makes it difficult to develop uniform diets for efficient mass rearing. In addition, structured and region-specific dietary information on local feed sources and agricultural by-products used in African palm weevil rearing is limited. Feed formulation is largely practical and unpredictable in the absence of comprehensive proximate tests that evaluate crude fibre (CF), NFE, moisture content (MC), crude protein (CP), ash content (AC) and ether extract (EE). Unstable feed costs and periodic scarcity of feed worsen output variability, particularly among small-scale farmers [17]. These constraints hinder the integration of insect farming into conventional food systems and inhibit data-driven policy decisions [18].

Given these constraints, proximate analysis is essential for evaluating feedstock and optimizing diets. Thorough nutrient assessments allow the identification of balanced substrates that supply adequate protein for physical growth, lipids for energy and carbohydrates for metabolism, while reducing excessive fibre, which may compromise digestion [19]. Scientifically informed feed formulation enhances larval development rates, economic gains, survival and consistency in product quality [20]. Using locally abundant agricultural by-products in optimized feed strategies supports sustainable production systems and reduces ecological footprints [21]. Harvesting palm weevils from the wild can be energy-consuming and stressful because it involves cutting down raffia palms and sometimes destroying raffia palm plantations to obtain sufficient quantities for supply. To overcome current constraints in harvesting African palm weevil, rearing the larvae on locally available feedstocks is necessary. Addressing feedstock nutritional variability through rigorous analysis is therefore important. By generating reliable data on selected feed materials, this study provides insights for developing standardized, cost-effective diets that enhance economic viability, production efficiency and sustainable protein supply in tropical agro-ecosystems.

2. Methodology

2.1. Source and preparation of feedstocks

Plantain stem, coconut fruit husk and palm trunk fibre were sourced from the surroundings of Campus 3, Delta State University, Abraka, Nigeria. The plantain stem fibre was sliced wet into suitable sizes, and the coconut husks and palm trunk fibre were torn into suitable sizes. The feedstocks were boiled to disinfect them and allowed to cool before use as rearing substrates.

2.2. Source of African palm weevil larvae

The African palm weevil larvae (*Rhynchophorus phoenicis*) used for breeding from larvae to adults were obtained from the *Rhynchophorus* Rearing Room, Entomology Unit, Delta State University, Abraka, Nigeria. The larvae were reared in transparent rectangular bowls with tight-fitting covers perforated for ventilation. Five hundred larvae reared on raffia palm fibre were sorted for the experiment.

2.3. Experimental setup

Five hundred larvae were sorted at 20 larvae per bowl into six bowls for each treatment. Each bowl measured 110 cm in length, 55 cm in breadth and 45 cm in height. Four feedstocks were evaluated for their efficiency as alternatives for rearing palm weevils: palm trunk fibre (PTF), coconut fruit husk (CFH), plantain stem fibre (PSF) and a combination of the three feedstocks. The introduced larvae were covered with white silk cloth to prevent predation. No additional feed was provided. Larval survival, larval mortality, pupation and adult emergence were recorded for four weeks.

2.4. Proximate analysis of feedstocks

The nutritional contents of the substrates were tested for ash, moisture, crude fibre, ether extract, carbohydrate and crude protein contents. This was done to determine whether the nutrient composition of the larvae corresponded to the feedstocks. The standard proximate analysis method described by the Association of Official Analytical Chemists was adapted [22].

2.4.1. Moisture content

Moisture content was determined by weighing 2 g of each feedstock with a balance after the analytical crucible had been oven-dried at 103 °C for 30 min. The feedstock in the crucible was placed in the oven for 24 h. Moisture content was measured as a percentage.

2.4.2. Ash content

Ash content of the feedstocks was determined using the dry-ash method. Two grams of each feedstock in a crucible was placed in a muffle furnace at 500 °C for 45–60 min and then allowed to cool at room temperature. Ash content was calculated using the weight of the tared crucible, the weight of the crucible with ash and the weight of the feedstock.

2.4.3. Crude fibre

Crude fibre was determined using the distillation method. An analytical balance was used to measure the weight of the fibre, and crude fibre was calculated as a percentage.

2.4.4. Ether extract

Ether extract was measured using the Soxhlet method. The weight of the Soxhlet flask was measured with an analytical balance. Two grams of each feedstock was weighed, introduced into a thimble and returned to the extractor. Petroleum ether (250 mL) was introduced into the flask containing the sample and extracted for 7 h until the ether portion reached the bottom of the flask. The sample was then transferred to the oven, dried for 24 h and weighed with an analytical balance. Ether extract was calculated as a percentage.

2.4.5. Crude protein

Two grams of each feedstock was weighed and transferred into a Kjeldahl flask, after which 1 g of copper sulphate, 5 g of sodium sulphate and 20–30 mL of concentrated sulphuric acid (H_2SO_4) were added. A few beads as anti-bumping agents and a pinch of selenium powder as a catalyst were added. The mixture was heated on a heating mantle for 30–40 min until the colour changed to greenish blue, after which it was distilled with boric acid and sodium hydroxide and titrated with 0.01 HCl. Crude protein was calculated as a percentage.

2.4.6. Carbohydrate content

The subtraction method described by BeMiller was used to determine the carbohydrate content of the feedstocks [23]. The remaining value obtained after subtracting moisture content, ash content, crude fibre, ether extract and crude protein from the total weight of feedstock was assumed to be the carbohydrate content. Carbohydrate content was calculated using Eq. (1):

$$\text{Carbohydrate content (\%)} = 100 - (\text{sum of protein weight, ether extract, and ash content measured in 100 grams}). \quad (1)$$

2.5. Data analysis

Data for proximate analysis, larval survival, mortality, pupation and emergence were entered into Microsoft Excel 2016. Results were presented in bar charts and tables. Analysis of variance (ANOVA) was used to test for significance in proximate analysis, larval survival, mortality, pupation and adult emergence of palm weevils. All analyses were carried out using XLSTAT 2025.

3. Results

3.1. Larval mortality and survival

The mean larval mortality and survival of African palm weevils reared in different substrates are shown in Table 1. Mortality increased with weeks as survival decreased with increasing weeks (Figures 1 and 2). African palm weevil larval mortality was highest when palm fibre was used as the breeding substrate in week 3 (mean mortality: 14.2). This was closely followed by larval mortality in plantain stem substrate in week 3 (mean: 12.0). The lowest mortality was recorded in coconut husk substrate in week 4 (mean: 0.4). The difference in larval mortality among substrates was highly significant ($F = 4.50$; $p = 0.0038$). Larval survival of palm weevils reared with different substrates is also shown in Table 1. Larval survival was 0 for plantain stem and combined substrates at week 4. The difference in larval survival among the different substrates was significant ($F = 32.66$; $p < 0.0001$).

Table 1: Mean larval mortality and survival of African palm weevils reared in different substrates.

Week	Substrate	Mean larval mortality	Mean larval survival
1	Palm fibre	0.6 ± 0.4	19.4 ± 0.4
	Coconut husk	2.2 ± 0.5	17.8 ± 0.5
	Plantain stem	0.2 ± 0.2	19.8 ± 0.2
	Palm fibre + coconut husk + plantain stem fibre	5.4 ± 1.4	14.6 ± 1.4
2	Palm fibre	1.4 ± 0.7	18.0 ± 0.4
	Coconut husk	2.2 ± 0.2	15.4 ± 0.6
	Plantain stem	4.4 ± 0.9	15.4 ± 0.8
	Palm fibre + coconut husk + plantain stem fibre	6.0 ± 1.6	8.8 ± 3.0
3	Palm fibre	14.2 ± 2.0	2.4 ± 1.5
	Coconut husk	0.6 ± 0.4	6.2 ± 1.0
	Plantain stem	12.0 ± 0.9	2.0 ± 0.6
	Palm fibre + coconut husk + plantain stem fibre	5.6 ± 2.1	3.4 ± 1.1
4	Palm fibre	1.4 ± 0.9	0.2 ± 0.2
	Coconut husk	0.4 ± 0.4	2.6 ± 1.1
	Plantain stem	2.0 ± 0.5	0.0 ± 0.0
	Palm fibre + coconut husk + plantain stem fibre	1.4 ± 0.8	0.0 ± 0.0

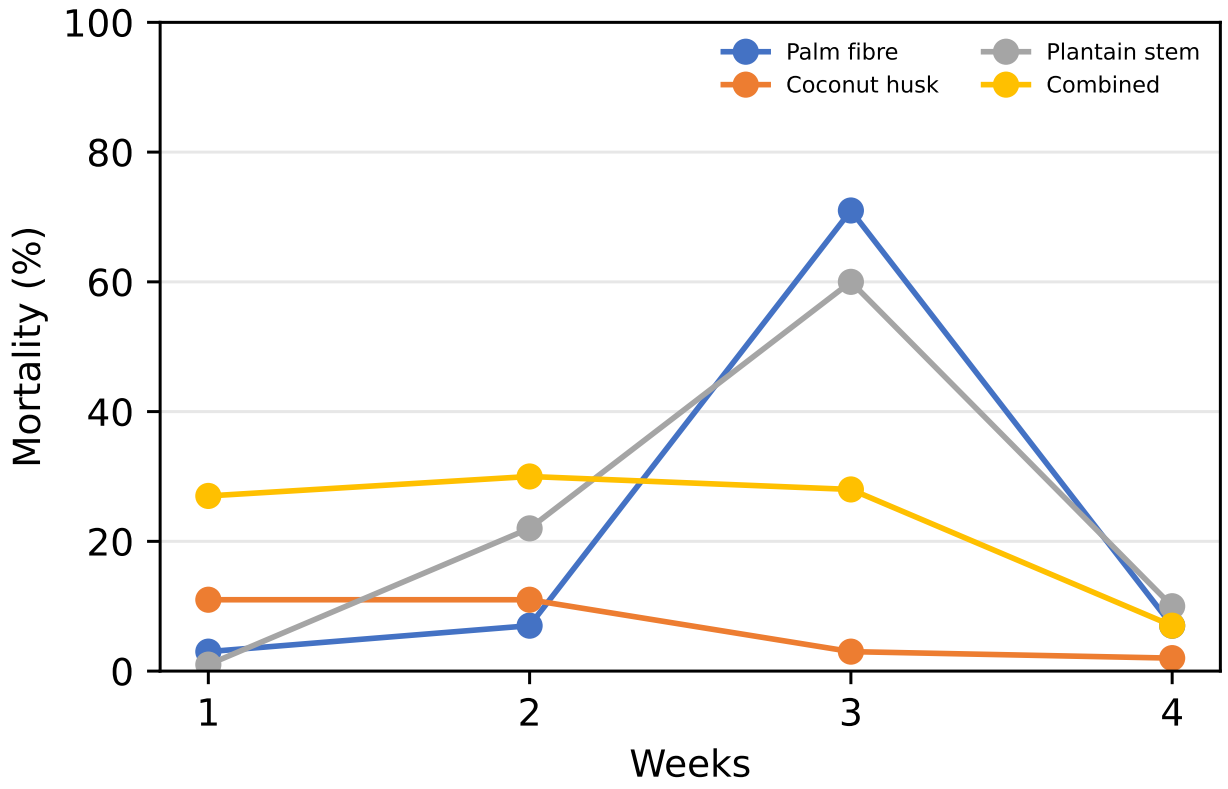

Figure 1: Percentage larval mortality of African palm weevil reared in different substrates ($F_{\text{ANOVA}} = 4.50$, $p = 0.0038$).

3.2. *Pupation and adult emergence*

The mean pupation and adult emergence of African palm weevils reared in different substrates are shown in Table 2. Pupation and adult emergence increased with weeks. Pupation of African palm weevil larvae was highest when coconut husk was used as the breeding substrate in week 3 (mean: 8.6). This was followed by the same coconut husk substrate in week 4 (mean: 3.2). No pupation occurred in plantain fibre or in the combined substrates in week 4. The difference in pupation among substrates was highly significant ($F = 1.56$; $p = 0.201$). Adult emergence was highest in coconut husk at week 4, as shown in Table 2. Palm fibre substrate also recorded adult emergence (mean: 0.6) at week 4. The difference in adult emergence among the different substrates was significant

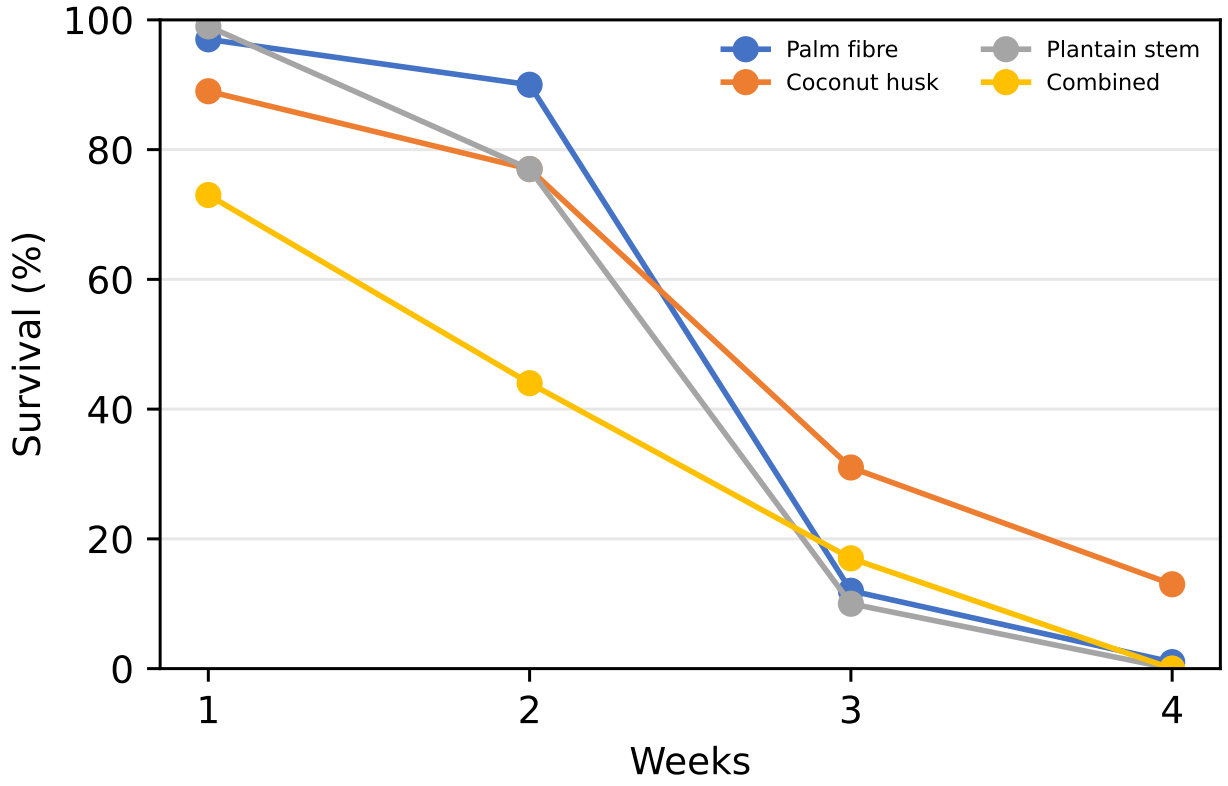

Figure 2: Percentage larval survival of African palm weevil reared in different substrates ($F_{\text{ANOVA}} = 32.66$, $p < 0.0001$).

Table 2: Mean pupation and adult emergence of African palm weevils reared in different substrates.

Week	Substrate	Mean pupation	Mean adult emergence
3	Palm fibre	1.4 ± 0.7	0.0 ± 0.0
	Coconut husk	8.6 ± 1.0	0.0 ± 0.0
	Plantain stem	1.4 ± 0.9	0.0 ± 0.0
	Palm fibre + coconut husk + plantain stem fibre	0.0 ± 0.0	0.0 ± 0.0
4	Palm fibre	2.2 ± 1.1	0.6 ± 0.4
	Coconut husk	3.2 ± 1.5	2.0 ± 0.6
	Plantain stem	0.0 ± 0.0	0.0 ± 0.0
	Palm fibre + coconut husk + plantain stem fibre	0.0 ± 0.0	0.0 ± 0.0

($F = 1.253$; $p = 0.341$). The percentage pupation and adult emergence patterns are shown in Figures 3 and 4.

3.3. Proximate analysis of feedstock

Mean proximate compositions of the feedstocks used in palm weevil rearing are shown in Table 3. Moisture content was higher in plantain stem fibre than in the other feedstocks, either singly or in combination. Ash content was higher in the combination of palm trunk fibre, coconut fruit husk and plantain stem fibre than in the other feedstocks. Crude fibre, crude protein and ether extract were higher in the combination of pawpaw trunk fibre, palm trunk fibre, coconut fruit husk and sugarcane stem fibre than in the other feedstocks. Carbohydrate content, measured as NFE, was higher in sugarcane stem fibre than in the other feedstocks. The differences between the proximate compositions of the feedstocks were not significant ($p > 0.05$).

4. Discussion

This study indicated that the substrate used for rearing palm weevil larvae to adults substantially affects survival and mortality rates of African palm weevil (*Rhynchophorus phoenicis*) larvae and their development into adults. Over the four-week evaluation period, larval mortality increased while survival decreased, suggesting that substrate suitability changed as the larvae advanced

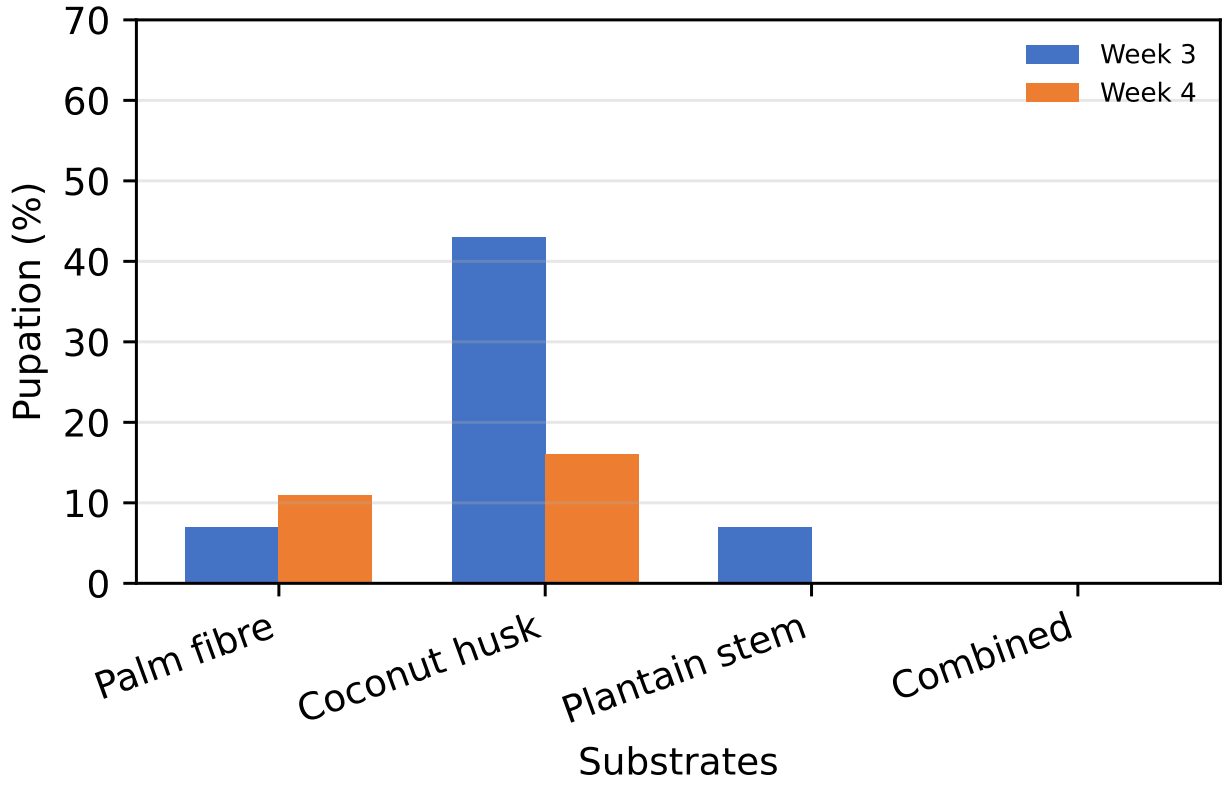

Figure 3: Mean pupal development of African palm weevil reared in different substrates ($F_{\text{ANOVA}} = 1.56$, $p = 0.201$).

Table 3: Mean proximate composition (%) of feedstocks used in rearing African palm weevils.

Feedstock	Status	MC	AC	CF	EE	CP	NFE
Pawpaw trunk fibre	NT	5.76 ± 1.38	7.02 ± 0.13	21.09 ± 0.44	2.00 ± 0.01	23.19 ± 2.63	40.94 ± 0.94
Palm trunk fibre	T	1.55 ± 0.90	4.19 ± 0.01	32.94 ± 3.11	0.80 ± 0.40	10.48 ± 0.02	50.05 ± 3.64
Coconut fruit husk	T	0.55 ± 0.30	5.44 ± 0.36	25.27 ± 0.47	0.69 ± 0.49	19.77 ± 0.77	46.80 ± 1.26
Sugarcane stem fibre	NT	0.24 ± 0.11	3.16 ± 0.56	25.14 ± 0.05	1.23 ± 0.03	5.02 ± 0.24	65.22 ± 0.57
Plantain stem fibre	NT	11.47 ± 1.75	7.11 ± 1.28	18.35 ± 0.41	0.83 ± 0.35	9.20 ± 0.13	58.43 ± 0.84
Palm fibre + coconut husk + plantain fibre	T	9.36 ± 1.22	8.14 ± 0.62	29.47 ± 3.15	0.72 ± 0.24	31.08 ± 3.26	13.76 ± 0.55
Pawpaw fibre + palm fibre + coconut husk + sugarcane fibre	NT	5.54 ± 0.06	7.03 ± 0.66	33.74 ± 2.77	3.66 ± 0.47	35.60 ± 2.50	14.42 ± 0.02
p value		0.997	0.898	0.958	0.505	0.787	0.863

Note: MC, moisture content; AC, ash content; CF, crude fibre; EE, ether extract; CP, crude protein; NFE, carbohydrate; NT, not tested; T, tested. Values are mean ± SE.

through developmental stages. Similar temporal patterns have been observed in insect rearing systems, where substrate quality and nutrient depletion affect larval performance over time [15]. The gradual rise in mortality seen in this study may be due to the gradual decline in substrate quality during the rearing period. In week 3, palm fibre had the highest mortality rate; this may be ascribed to the declining quality of the substrates over time. Larval mortality in the third week was also high in plantain stem. Mortality associated with the plantain substrate was probably due to water contained in the substrate, which could have drowned the larvae. Mortality decreased when substrates were combined. It is possible that water released from the fresh plantain stem into the rearing setup was absorbed, limiting the chances of larval drowning. Water absorbed by palm fibre and coconut husk could have made the fibre moist and influenced larval growth beyond the initial developmental phases. Insect larvae require substrates with appropriate nutrients, moisture levels and texture for survival. Fibrous substrates have been reported to be suitable for larval survival [9]. The growth performance of *Rhynchophorus phoenicis* larvae is closely related to the physical structure and nutritional quality of the substrate on which they are reared [24]. Coconut husk consistently promoted enhanced larval survival and exhibited the lowest mortality rates, especially in week 4. Coconut husk is fibrous and moderately porous, which may support aeration and moisture retention. Adequate aeration limits excessive fermentation, whereas moderate moisture ensures that larvae can feed

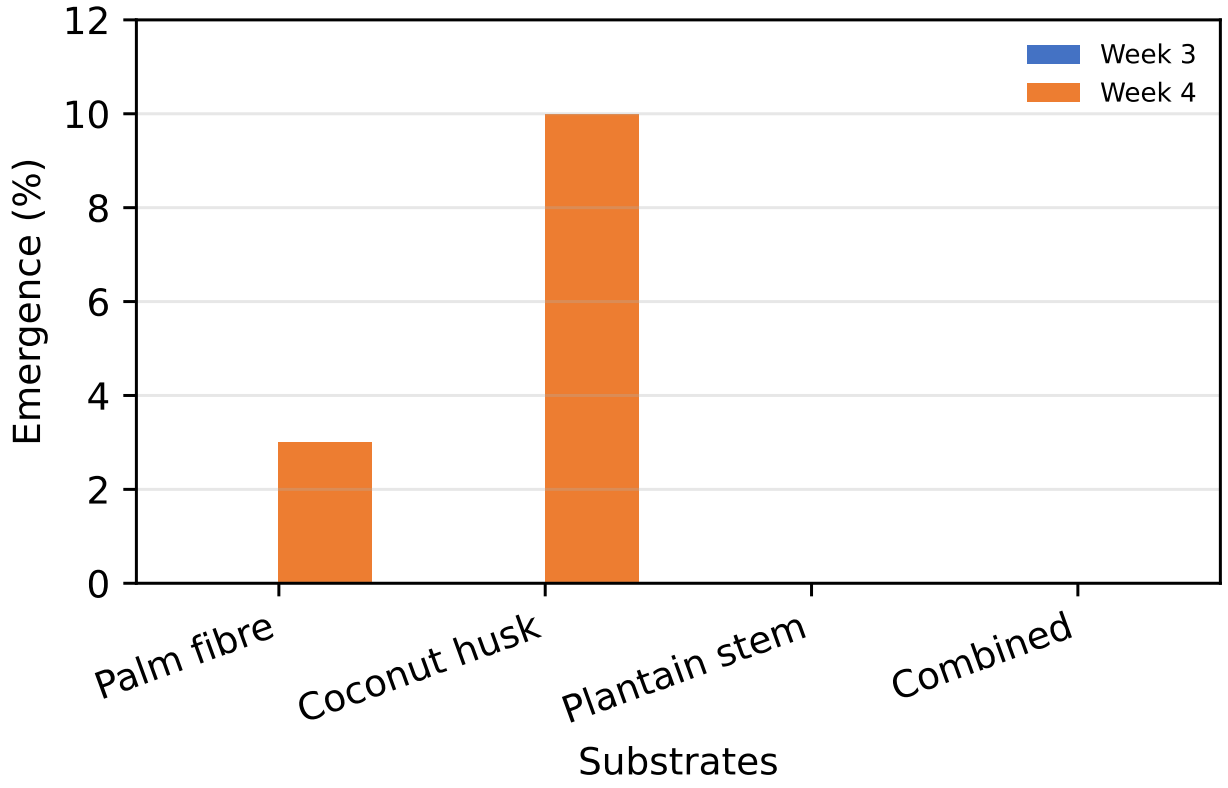

Figure 4: Percentage adult emergence of African palm weevil reared in different substrates ($F_{\text{ANOVA}} = 1.253$, $p = 0.341$).

without becoming dehydrated or suffocated. These traits probably contributed to the higher survival rates observed in coconut husk substrates. This finding corroborates previous studies showing that insect development and viability are significantly influenced by substrate quality and nutritional equilibrium [20]. Therefore, choosing appropriate rearing substrates is important for optimizing larval production and minimizing mortality in controlled rearing systems.

The type of rearing substrate also had a substantial effect on *Rhynchophorus phoenicis* pupation and adult emergence. Pupation is an important stage in the insect life cycle, during which larvae change into adults. For pupation to be successful, the substrate must provide adequate protection, moisture balance and structural support. In this study, coconut husk exhibited the highest pupation rate in week 3, possibly because the fibrous nature of the substrate favoured metamorphosis of larvae into pupae. The loose fibrous structure of coconut husk could have made it easier for larvae to build pupal chambers with adequate airflow. Pupating insects are very sensitive to environmental conditions, and substrates that keep moisture and temperature levels stable can support survival and development. Adult emergence followed a pattern similar to pupation, with coconut husk showing the highest adult emergence in week 4. This finding further corroborates the efficacy of coconut husk as a viable rearing substrate for African palm weevil larvae, as previously reported for rearing from adults to larvae and back to adults [9]. Palm fibre supported some pupation and adult emergence, but the values were lower than those recorded for coconut husk. This indicates that palm fibre can aid metamorphosis, although a synergistic effect may be required to improve pupation and emergence. Interestingly, the combined substrate did not support pupation or adult emergence. This result suggests that the combined substrates may have undesirable physical characteristics or chemical constituents that impede larval metamorphosis. The plantain component in the combined substrates could have encouraged microbial growth, which may reduce pupal survival. The absence of pupation in the combined substrate suggests that it may not provide the structural stability required for pupal chamber formation. This finding corroborates a previous study indicating that substrate characteristics significantly affect developmental success and yield [25].

The proximate composition of the rearing substrates could have significantly influenced the growth, metamorphosis and survival of African palm weevils. Plantain stem fibre had the highest moisture content among the substrates. Larvae require optimum moisture for survival. Excess moisture can cause larval mortality and encourage microbial growth in the substrates, which could in turn affect larval survival. This might explain why larvae reared on plantain stem substrates had higher mortality rates. Similar correlations between moisture levels and insect development have been reported in insect production systems [26]. The combined substrates had more ash, crude fibre, crude protein and ether extract than the individual substrates. These nutrients are important for insect growth and metabolism, especially crude protein, which is important for enzymatic action and tissue formation. However, the

combined substrates did not support optimal larval development, even though they had higher nutrient levels. This implies that the physical properties of one substrate may influence the suitability of the others. This finding is consistent with the study of Debrah *et al*. [20], which noted that *Rhynchophorus phoenicis* larval growth and nutrient content are strongly influenced by changes in substrate nutritional composition. The highest carbohydrate content (NFE) was found in sugarcane stem fibre, which may provide a readily accessible energy source for larval metabolism. However, protein is also required for body building and growth. There should be synergy between the physical structure and nutritional composition of substrates to promote optimal larval development. This supports previous findings that nutritional content and substrate quality affect insect development performance [27]. Overall, the proximate composition results highlight the complexity of insect nutrition and suggest that both chemical composition and physical characteristics of substrates must be considered when selecting materials for insect rearing.

The results of this study have significant implications for African palm weevil mass rearing. Coconut husk is a promising material for large-scale production systems because it was the best substrate for promoting larval survival, pupation and adult emergence. Lalander *et al*. [28] demonstrated that agricultural by-products align with circular bioeconomy principles in black soldier fly systems; the findings of the present study extend this framework to palm weevil cultivation by highlighting coconut husk as a locally available, sustainable feedstock. The demand for effective and economical rearing techniques has increased because of growing interest in edible insects as alternative protein sources. African palm weevil larvae are widely consumed across Africa and are known for their high nutritional content, including substantial fat and protein [26, 27]. Consequently, choosing the right substrate can increase output and make insect farming more profitable. Furthermore, using agricultural waste materials as substrates for insect rearing can enhance waste management and environmental sustainability. Insect farming systems can produce high-quality feed and food supplies while lowering environmental pollution by converting organic wastes into profitable insect biomass. This approach advances broader objectives of resource efficiency and sustainable food systems [29, 30]. Overall, this study provides insight into the relationship between substrate composition and developmental performance in *Rhynchophorus phoenicis*. Future studies should investigate other substrate combinations, nutrient supplementation methods and environmental factors that can improve the productivity of African palm weevil production systems. This study did not compare the efficiency of dried and wet feedstocks.

5. Conclusion

This study has shown that rearing substrate has a major impact on African palm weevil larval survival and development. Coconut husk supported the highest larval survival, pupation and adult emergence among the substrates evaluated, demonstrating its suitability for effective larval development. Plantain stem fibre admixed with other substrates impeded metamorphosis. Variations in moisture, fibre and nutrient balance contributed to differences in larval performance. Coconut husk represents a promising, locally available substrate for the sustainable mass rearing of *Rhynchophorus phoenicis*, with potential uses in insect-based protein production and circular bioeconomy systems.

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Declaration of competing interest

The authors confirm that they have no conflicts of interest to declare.

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Data availability

The datasets generated during the current study are not publicly available because the study is ongoing; however, they are available from the corresponding author upon reasonable request.

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