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(Research Article)

Rearing substrate influence on growth performance and nutritional composition of *Rhynchophorus phoenicis* Larvae (Coleoptera: Curculionidae)

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Abstract

The palm weevil, *Rhynchophorus phoenicis*, is recognized as a valuable resource for both human and animal nutrition. Despite its potential, limited research has investigated how the choice of rearing substrate affects its nutritional profile and growth performance. This study sought to assess the influence of three locally available substrates on the growth metrics and nutritional attributes of *R. phoenicis* larvae. Conducted over three months at the Science and Technology Laboratory of Alassane Ouattara University, larvae were raised under controlled conditions in plastic containers with one of three substrates : palm stipe (T1), sugarcane stalk (T2), and maize cobs (T3). Key zootechnical indicators and nutritional parameters were measured. Larvae reared on sugarcane stalks displayed the highest protein content (32.1% dry matter), superior digestibility (82.7%), and a beneficial mineral composition (calcium : 1.8% DM ; iron: 380 mg/kg DM). Those fed on palm stipes showed elevated lipid levels (45.7%) alongside a high survival rate (88.4%). The maize cob substrate provided a well-balanced trade-off between nutritional quality and feed efficiency, evidenced by an optimal feed conversion ratio of 2.5. These findings confirm that the rearing substrate significantly affects both the nutritional quality and growth performance of *R. phoenicis* larvae. Optimizing feeding strategies could thus pave the way for sustainable and cost-effective insect farming systems in Côte d'Ivoire.

Keywords: *Rhynchophorus phoenicis*; Rearing Substrate; Edible Insects; Growth Performance; Nutritional Quality; Insect Farming; Côte d'Ivoire

1. Introduction

Rapid population growth and pressing challenges related to global food security have brought edible insects into the spotlight as a promising and sustainable alternative to traditional animal protein sources, especially in Sub-Saharan Africa where food demand continues to increase [1]. These insects provide significant nutritional benefits while requiring fewer environmental inputs such as water, land, and greenhouse gas emissions, making insect farming an innovative solution in the context of today's agroecological transition. Among these edible insects, the larvae of *Rhynchophorus phoenicis* commonly known as palm weevil larvae hold a significant place in the traditional diets of many West African regions, notably Côte d'Ivoire, due to their rich nutritional content and wide cultural acceptance [2,3]. This longstanding consumption reflects valuable local knowledge that could be further developed and optimized through controlled rearing methods. Insect farming, defined as the controlled breeding of insects, is increasingly recognized as a strategic approach to simultaneously address rising protein demands, enhance the valorization of agricultural by-products, and reduce the environmental impacts linked to conventional livestock production [4,5]. Indeed, this sector facilitates the incorporation of organic waste and by-products into circular production systems, thus reducing waste and supporting sustainability. Multiple studies have shown that insects can be successfully reared on a variety of

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substrates, including agro-industrial residues, without sacrificing the nutritional quality of the resulting products [6,7]. This dietary flexibility enables insect farming to adapt effectively to local conditions, particularly in rural areas where agricultural by-products are plentiful but often underused. Such an approach aligns perfectly with circular economy principles, transforming organic waste into valuable biomass and thereby contributing to improved agricultural income and local food security [8]. Although *R. phoenicis* is mainly harvested from the wild, it has recently attracted growing scientific interest due to its potential for controlled rearing and its ability to utilize diverse substrates [9]. Recent studies conducted in West Africa have demonstrated that the nutritional composition of the larvae varies according to the substrate used, emphasizing the need to identify optimal rearing materials adapted to local agroecological settings [10,11]. However, only a few studies have specifically targeted the valorization of local agricultural residues such as sugarcane stalks and maize cobs, which are abundant in rural areas of Côte d'Ivoire. These by-products are frequently neglected or left unused in the fields, representing an untapped resource that could play a pivotal role in the sustainable development of regional insect farming [12]. This study aims to assess the effects of three local agricultural substrates on the zootechnical performance, digestibility, and chemical, mineral, and lipid nutritional composition of *R. phoenicis* larvae. The goal is to identify the most suitable substrates for sustainable and profitable farming of this species while promoting the valorization of local agricultural residues, thereby contributing to the development of integrated and resilient food systems essential for addressing food security challenges in Sub-Saharan Africa.

2. Materials and Methods

2.1. Study Site

The experiment was conducted at the Alassane Ouattara University of Bouaké (Côte d'Ivoire), within the Laboratory of Science and Technology, located at 7°41′ N and 5°02′ W. The region features a tropical savanna climate characterized by an average annual temperature of 27 °C and two distinct seasons.

2.2. Biological Material

The study focused on 10-day-old larvae of *Rhynchophorus phoenicis* collected and reared at the Laboratory of Animal Biology and Physiology. These larvae were reared on three different local agricultural substrates: T1: palm stipe, T2: sugarcane stalk, and T3 : maize bran. These substrates were selected based on their local availability and potential nutritional value for larval rearing.

2.3. Technical Material

Larvae were housed in plastic containers measuring 40 cm × 30 cm × 25 cm. Each container was equipped with perforations on the lid covered by a fine mesh to ensure adequate ventilation, prevent excessive moisture accumulation, and avoid larval escape. The containers were placed in a laboratory room maintained at 28 ± 2 °C and 70 ± 5 % relative humidity. Each container contained only one type of substrate (palm stipe, sugarcane stalk, or maize bran) to evaluate the effect of substrate type on larval growth and nutritional composition. For analyses, precision scales, drying ovens, an electric grinder (Tecnal TE-650), and standard laboratory equipment (glassware, spatulas, funnels) were used.

2.4. Experimental Procedures

2.4.1. Rearing of R. phoenicis Larvae

Approximately 10-day-old larvae were collected from felled palm trees in the Sakassou area (Gbêkê region). Healthy, active larvae with an initial weight of approximately 1 g each were selected and randomly distributed into plastic rearing containers (50 × 30 × 30 cm) with perforated lids for ventilation. Each substrate was tested on three independent batches of 100 larvae each. The containers were kept under a ventilated shelter with controlled temperature (28 ± 2 °C) and relative humidity (70 %). Substrates were renewed every five days, and dead larvae were removed daily. After 30 days, surviving larvae were harvested, rinsed with distilled water, killed by freezing at –20 °C, then dried at 60 °C for 48 hours before being ground into powder using a mechanical grinder. The resulting powder was used for subsequent analyses.

2.4.2. Nutritional Composition Analyses

Moisture content was determined by drying samples at 105 °C in a ventilated oven until constant weight. Protein content was measured by the Kjeldahl method : digestion of samples in concentrated sulfuric acid with catalysts ($CuSO_4$ + K_2SO_4), distillation of released ammonia, and titration with 0.1 N hydrochloric acid. Lipid content was extracted continuously for six hours using a Soxhlet apparatus with petroleum ether. Ash content was determined after incineration in a muffle furnace at 550 °C for six hours. Fatty acid profiles were analyzed by transesterification of extracted lipids to methyl esters, followed by gas chromatography with flame ionization detection. Amino acid profiles were established after protein hydrolysis (6 N HCl, 110 °C, 24 h under nitrogen atmosphere), filtration, and injection into an HPLC system equipped with an ion exchange column and UV detector. Minerals (calcium, iron, zinc) were quantified by atomic absorption spectrophotometry after dissolving ash in 2 N hydrochloric acid.

2.4.3. In vitro digestibility

Digestibility of larval flour was assessed by incubating 1 g of sample in pepsin solution (pH 2.0) at 39 °C for two hours, followed by pancreatin digestion (pH 7.0) for four hours. Undigested residue was separated and weighed. Digestibility (%) was calculated as:

Digestibility (%) = [(Initial matter – Undigested residue) / Initial matter] × 100

2.5. Rearing performance parameters

Survival rate was calculated as :

Survival rate (%) = (Number of surviving larvae / Initial number of larvae) × 100

The feed conversion ratio (FCR) was determined by :

FCR = Total mass of substrate consumed / Total mass of larvae produced

2.6. Statistical analysis

Data were subjected to one-way analysis of variance (ANOVA) to assess the effect of substrate type on measured parameters. When significant differences were detected, means were compared using Tukey's HSD test at a 5% significance level ($p < 0.05$). All measurements were performed in triplicate, and results are presented as mean ± standard deviation.

3. Results

The nutritional composition analysis of *Rhynchophorus phoenicis* larval flour reared on the three tested substrates revealed statistically significant differences ($p < 0.05$) among treatments for most evaluated parameters. Variations were particularly observed in protein, lipid, ash, and dry matter contents, highlighting the influence of substrate type on the nutritional quality of the produced larvae. The findings suggest that certain locally available agricultural by-products may be more suitable for optimizing larval nutritive value.

3.1. Overall chemical composition of larvae

Statistical analysis indicated significant differences ($p < 0.05$) between larvae reared on the different substrates. Larvae reared on oil palm trunk tissues exhibited the highest lipid content, reaching 45.7 % of dry matter, whereas their protein content was lower (28.4 %). In contrast, larvae reared on sugarcane stems displayed the highest protein level (32.1 %) and the greatest ash content (4.1 %), indicating a notable mineral richness. Larvae reared on maize cobs showed intermediate values, with protein and lipid contents of 30.0 % and 40.5 %, respectively, thus presenting a balanced nutritional profile (Table 1).

Table 1 Effect of rearing substrate on the biochemical composition of R. phoenicis larvae (percentage of dry matter)

Rearing substrate	Protein (%)	Lipid (%)	Ash (%)
Palm trunk	28.4 ± 1.2^{b}	45.7 ± 1.0^{a}	3.5 ± 0.3^{b}
Sugarcane stem	32.1 ± 1.5^{a}	38.3 ± 1.1^{c}	4.1 ± 0.4^{a}
Maize cobs	30.0 ± 1.0^{ab}	40.5 ± 0.9^{b}	3.9 ± 0.2^{ab}

Different superscript letters (a, b, c) indicate significant differences ($p < 0.05$) between means within the same column.

3.2. Mineral composition

Statistical analysis revealed significant differences ($p < 0.05$) in the mineral content of larvae depending on the rearing substrate. Larvae reared on sugarcane stalks showed higher calcium (1.8 % DM) and iron (380 mg/kg DM) levels. Those from maize cobs displayed average values for all minerals, while larvae reared on palm trunks exhibited the lowest mineral values, particularly for zinc (45 mg/kg DM).

Table 2 Effect of rearing substrate on the mineral content of *R. phoenicis* larvae.

Rearing substrate	Calcium (%)	Iron (mg/kg DM)	Zinc (mg/kg DM)
Palm trunk	1.2 ± 0.1^{c}	280 ± 15^{c}	45 ± 5^{c}
Sugarcane stalk	1.8 ± 0.1^{a}	380 ± 18^{a}	65 ± 6^{b}
Maize cobs	1.5 ± 0.1^{b}	340 ± 12^{b}	70 ± 7^{a}

Different superscript letters (a, b, c) indicate significant differences ($p < 0.05$) between means in the same column.

3.3. Fatty acid profile

Chromatographic analysis of the lipid extracts from the different *Rhynchophorus phoenicis* larval flours revealed a predominance of unsaturated fatty acids in all samples. Larvae reared on maize cob substrate showed the highest linoleic acid (C18 : 2) content, representing 28.4 % of the total lipid fraction. Those from sugarcane stalk substrate were distinguished by a higher concentration of oleic acid (C18 : 1), reaching 30.1 %. In contrast, larvae fed with palm trunks displayed an intermediate lipid profile, characterized by moderate proportions of the two dominant fatty acids.

Table 3 Effect of rearing substrate on the fatty acid profile of R. phoenicis larvae

Rearing Substrate	Palmitic Acid C16:0 (%)	Oleic Acid C18:1 (%)	Linoleic Acid C18:2 (%)
Oil palm stipe	26.0 ± 1.1^{a}	28.5 ± 1.2^{b}	24.3 ± 0.9^{b}
Sugarcane stalk	24.5 ± 1.0^{b}	30.1 ± 1.3^{a}	25.0 ± 1.0^{b}
Maize cobs	25.2 ± 1.2^{ab}	27.9 ± 1.1^{b}	28.4 ± 1.4^{a}

Different superscript letters (a, b, c) indicate significant differences ($p < 0.05$) between means within the same column.

3.4. Digestibility and Rearing Performance

In vitro digestibility was significantly influenced by the rearing substrate. Flours obtained from larvae reared on sugarcane stems showed the highest digestibility (82.7%), followed by those reared on maize cobs (81.0%) and finally those reared on palm trunks (78.2%). In terms of zootechnical performance, larvae fed on palm trunks achieved the highest survival rate (88.4%), while those reared on maize cobs displayed the best feed conversion ratio (FCR), reaching 2.5, indicating greater substrate utilization efficiency. Larvae reared on sugarcane also showed a good compromise, with an FCR of 2.6 and a survival rate of 81.2% (Table 2).

Table 4 Effect of rearing substrate on digestibility, survival, and feed conversion ratio (FCR) of *R. phoenicis* larvae.

Rearing substrate	Digestibility (%)	Larval survival rate (%)	FCR
Palm trunk	78.2 ± 1.3^{b}	88.4 ± 2.0^{a}	3.1 ± 0.1^{a}
Sugarcane stem	82.7 ± 1.4^{a}	81.2 ± 1.5^{b}	2.6 ± 0.1^{b}
Maize cobs	81.0 ± 1.2^{ab}	85.0 ± 1.8^{ab}	2.5 ± 0.1^{b}

Different superscript letters (a, b, c) indicate significant differences ($p < 0.05$) between means within the same column.

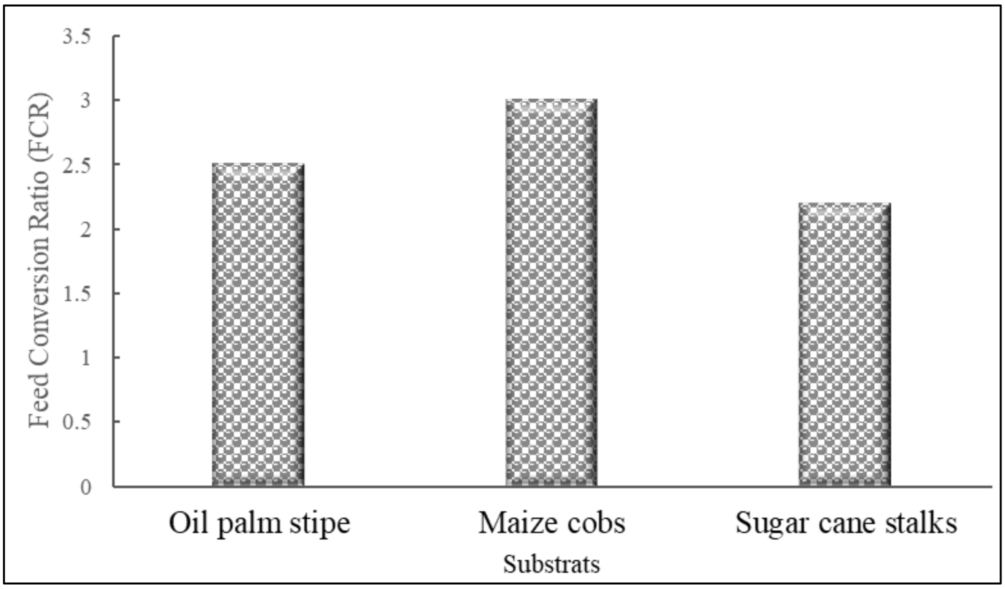

Figure 1 Feed Conversion Ratio (FCR) of *R. phoenicis* larvae on the three rearing substrates

4. Discussion

The results clearly indicate that the type of rearing substrate has a significant impact on both the nutritional composition and growth performance of *Rhynchophorus phoenicis* larvae. These findings align well with previous studies conducted on other edible insect species [13,14]. The observed differences in protein, lipid, and ash contents among larvae raised on palm stipes, sugarcane stalks, and maize cobs suggest that the physico-chemical properties of the substrate directly influence larval metabolism [15]. This effect can be attributed to the complex interactions between substrate chemical composition and the digestive physiology of the larvae, which modulate the absorption of essential nutrients. Larvae fed on sugarcane stalks showed higher protein content, indicating better assimilation of nitrogenous nutrients. This elevated protein level likely stems from the abundance of simple sugars in sugarcane stalks, which promote rapid growth and efficient protein conversion [16]. This substrate therefore appears to provide a particularly favorable nutritional environment by combining easily mobilizable energy sources with essential nutrients needed for protein synthesis. This hypothesis is supported by the high digestibility rate (82.7%) observed with this substrate, comparable to values reported for other insects reared on sugary residues [17]. Increased digestibility likely allows larvae to maximize nutrient extraction and optimize their development. Conversely, larvae reared on palm stipes exhibited a higher lipid content (45.7%) but lower protein levels. This lipid profile may be explained by the intrinsic richness of the substrate in residual fats [18]. It is also possible that larvae adjust their metabolism to store more lipids when the substrate is rich in fats, which could serve as an important energy reserve. Such characteristics may be particularly interesting when considering the formulation of foods enriched with fatty acids for animal or human nutrition, as demonstrated by [19]. Regarding mineral profiles, larvae fed on sugarcane stalks had the highest concentrations of calcium and iron—two minerals essential for human health. Zinc was most abundant in larvae grown on maize cobs, confirming that each substrate can influence the biosynthesis or retention of specific minerals [20]. This mineral variability suggests that selecting substrates could help tailor production towards targeted nutritional profiles based on dietary needs. These results are consistent with observations by [21] on the influence of substrate on mineral content in insects. Fatty acid analysis revealed a predominance of unsaturated fatty acids, especially oleic (C18 :1) and linoleic (C18 :2) acids, with concentrations varying by substrate. Larvae raised on maize cobs contained the highest levels of linoleic acid, an essential fatty acid known to help prevent cardiovascular diseases [22]. The ability of larvae to modulate their lipid profile according to substrate demonstrates their metabolic flexibility and highlights their potential value in human or animal diets. Similar lipid profiles have been reported in *Tenebrio molitor* and *Hermetia illucens* reared on plant-based substrates [23, 24] Zootechnical performances were also affected by the substrate type. Palm stipes resulted in a high survival rate (88.4%), indicating good larval adaptation, but came with a less efficient feed conversion ratio (FCR). This may reflect a higher tolerance to substrate conditions, even if feed-to-biomass conversion is reduced. In contrast, maize cobs yielded better substrate utilization efficiency, with an FCR of 2.5, which is advantageous for intensive production systems [25]. These findings suggest that agricultural residues can be selected and used according to production goals—whether prioritizing protein or lipid content, optimizing feed conversion, or enhancing mineral content. Moreover, these substrates are inexpensive and locally available, making their use in insect farming a promising way to reduce production costs while contributing to sustainable agricultural waste management

[26]. This approach fits well within circular economy principles and local resource valorization, supporting the sustainability of production systems. Overall, this study highlights the potential of agricultural by-products as substrates for *Rhynchophorus phoenicis* rearing and opens avenues for developing alternative, sustainable food systems in Sub-Saharan Africa. The larvae's metabolic adaptability and ability to optimize their nutritional composition depending on the substrate represent major advantages for their integration into innovative agro-food strategies.

5. Conclusion

This study highlighted the significant influence of the rearing substrate on the zootechnical performance, digestibility, and nutritional quality of *Rhynchophorus phoenicis* larvae. Sugarcane stalks promoted better digestibility and higher protein content, while maize cobs provided a balanced outcome between growth, feed efficiency, and lipid profile. Although palm oil stipes ensured high survival rates, their nutritional performance was comparatively lower. These results confirm the potential of local agricultural by-products as sustainable substrates in insect farming, while emphasizing the importance of choosing residues based on the targeted objective (nutritional quality, yield, cost). Optimizing the diet of edible insects could thus significantly contribute to valorizing agricultural waste and improving food security in Côte d'Ivoire and Sub-Saharan Africa. Further research focusing on sensory evaluation, post-processing stability, and social acceptability of derived products is necessary to facilitate their integration into local food systems.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest related to this publication. No financial or institutional support influenced the design, execution, analysis, or interpretation of the results of this study.

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