

African palm weevil for sustainable animal production and environmental protection

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ABSTRACT: African palm weevils (APW) pose a significant threat to palm agriculture, resulting in substantial economic losses, threatening farmers' livelihoods and impacting the productivity and profitability of the palm industry. To mitigate their economic impacts, there is a need to seek sustainable methods for their control. This study evaluated the effects of different environmental conditions and substrates on the growth of APW larvae as potential candidates for non-conventional protein sources for animal nutrition. APW larvae were reared under natural and controlled environments and fed three experimental diets: tiger nut waste-based; rice bran-based; and fruit waste-based. Data were analyzed using a one-way analysis of variance using SAS. Significant means were separated using Duncan's Multiple Range Test. The emergence rate (%) was significantly higher ($p < 0.05$) for the natural environment at weeks 2 and 4, but was significantly ($p < 0.05$) higher for the controlled environment at week 3. Agro-industrial waste materials were successfully used for rearing APW larvae.

Keywords: African palm weevil, agricultural waste, animal nutrition, environmental health, food security, *Rhynchophorus ferrugineus*.

INTRODUCTION

The rising cost of conventional feed ingredients is forcing many livestock farmers and entrepreneurs out of the industry, especially in sub-Saharan Africa, threatening the long-term viability of agricultural systems and food production (Debrah *et al.*, 2022). The COVID-19 pandemic further exacerbated global hunger, leaving an estimated 800 million people undernourished, complicating efforts to achieve food security by 2030 (UN, 2020). These challenges require innovative approaches to ensure high-quality, safe and nutrient-dense food security.

Furthermore, the stiff competition between humans and animals for feed ingredients has compelled researchers to search for cost-effective alternatives to reduce production expenses and sustain animal production. Edible insects like the African palm weevil larvae (*Rhynchophorus spp.*), have emerged as viable alternatives to improve human

and animal nutrition and alleviate food deficits (Halloran *et al.*, 2016; Debrah *et al.*, 2022).

Palm weevils hold significant economic importance, especially in West African communities, where they serve as a traditional food source (Coley *et al.*, 2020). Their larvae are potential candidates for addressing malnutrition in developing countries. These larvae are nutrient-rich making them valuable in regions with limited protein-rich food sources (Sutanto *et al.*, 2021; Elemo *et al.*, 2011). However, palm weevils also pose a significant threat to palm agriculture due to the damage they cause to palm trees. Infestations have led to substantial economic losses for palm-growing countries, threatening farmers' livelihoods and impacting the overall productivity and profitability of the palm industry (Halder *et al.*, 2017). Efforts to combat palm weevil infestations have included

the use of insecticides, which often have adverse environmental and health impacts and have led to the development of resistance in the weevils (Sutanto *et al.*, 2021; Habib *et al.*, 2017). To mitigate the economic impact of these infestations, there is a need to seek sustainable methods for their control in palm-growing countries (Rodzik *et al.*, 2023).

Previous studies have documented the importance of controlling potential environmental pollution that may arise from indiscriminate accumulation or burning of agro-industrial by-products regarded as waste materials and the potential of bioconversion of underutilized protein sources such as palm weevil to non-conventional feed ingredients in order to reduce the rising costs of animal production, especially in sub-Saharan Africa, and ensure environmental health (Adebisi *et al.*, 2018; Adebisi *et al.*, 2019; Adebisi *et al.*, 2020; Adejumo *et al.*, 2020; Adejumo and Adebisi, 2020). Therefore, this study was conducted to evaluate the effects of different environmental conditions and substrates on the growth of palm weevil larvae (*Rhynchophorus ferrugineus*) as potential candidates for non-conventional protein sources for animal nutrition.

MATERIALS AND METHODS

The study was conducted at the University of Ibadan Teaching and Research Farm, Ibadan, southwest Nigeria, within a controlled environment building constructed for this experiment. The Ethics and Animal Care Committee of the Department of Animal Science, University of Ibadan (ANSUI/ PS/03/24AOO) approved the study protocol. Two hundred and sixteen palm weevil larvae were sourced from a reputable farm in Nigeria and allowed to acclimatise for two weeks prior to the experiment. Three experimental diets were formulated:

Diet 1 (T1): 23 g of tiger nut shaft +15 ml molasses + 25 ml water + coconut coir;

Diet 2 (T2): 23 g of rice bran +15 ml molasses + 25 ml water + coconut coir;

Diet 3 (T3): 15 g watermelon peels + 15 g pineapple peels + 25 ml water + 15 ml molasses.

The larvae were divided into two groups to be raised in a controlled and natural environment. Each diet was replicated three times for each of the environments, with 12 larvae per replicate. Twelve larvae, weighing an average of 80 g, were placed in each container. The substrate was prepared according to the treatment specifics, and the containers were covered. Temperature and humidity were measured daily at 8:00 am, 3:00 pm, and 8:00 pm using a hygro-thermometer. The larvae weight was measured bi-weekly using a sensitive scale, and substrate replenishment occurred every three days to prevent putrefaction. Feed replenishment ceased after cocoon formation. Data collected included weekly weight

gain, cocoon emergence, percentage insect mortality, and daily temperature and humidity. The experiment lasted six weeks (including periods of acclimatization). Data were analyzed using a one-way analysis of variance with the general linear model of SAS (Adejumo *et al.*, 2021). Significant means were separated using Duncan's Multiple Range Test (Adebisi *et al.*, 2023).

RESULTS

Figure 1 reveals the natural and controlled environmental temperature and humidity during the experiment. The temperature ranged between 26.47 and 27.73°C (natural), 26.69 and 27.52°C (controlled) while the humidity ranged between 85.19 and 89.00% (natural) and 85.20 and 89.53% (controlled).

The main effect of environmental conditions on the cocoon emergence of palm weevil fed different substrates shows that the emergence rate (%) was significantly higher ($p < 0.05$) for the natural environment at weeks 2 and 4. However, the emergence rate (%) at week 3 was significantly ($p < 0.05$) higher for the controlled environment. No emergence was observed at week 1 (Table 1).

The main effect of substrates on the cocoon emergence of palm weevil reveals that no emergence was observed in week 1 (Table 2). At week 2, tiger nut and fruit waste produced no emergence, at week 3, the emergence rate (%) produced by fruit waste and rice bran was significantly ($p < 0.05$) higher than what was observed for tiger nut waste. However, at week 4, the emergence rate attributed to tiger nut waste was significantly ($p < 0.05$) higher than the fruit waste and rice bran-associated emergence (Table 2).

The interaction effect of environment and substrate on cocoon emergence rate shows that no emergence was observed in week 1. At week 2, the emergence rate (%) was significantly ($p < 0.05$) higher for rice bran fed under a natural environment, followed by rice bran fed under a controlled environment (Table 3). Rice bran fed under a natural environment and fruit waste fed under a controlled environment obtained the highest emergence rate, followed by tiger nut waste fed under a controlled environment. No emergence was observed for the other treatments. At week 4, tiger nut waste fed under natural and controlled environments obtained the highest emergence rate (31.67% and 33.33%), followed by rice bran fed under a controlled environment (20.00%) (Table 3).

The insect mortality rate (%) was higher ($p < 0.05$) under the natural environment (41.25) for week 1 but lower at week 2. There was no significant difference observed between the two environments at weeks 3 and 4 (Table 4). The insect mortality rate (%) was significantly ($p < 0.05$) higher for rice bran at weeks 1 (48.33) and 3 (60.00). Tiger nut waste obtained the least mortality rate at week 1 (20.00). At week 2, fruit waste obtained the highest mortality rate (26.67), followed by tiger nut waste (17.41).

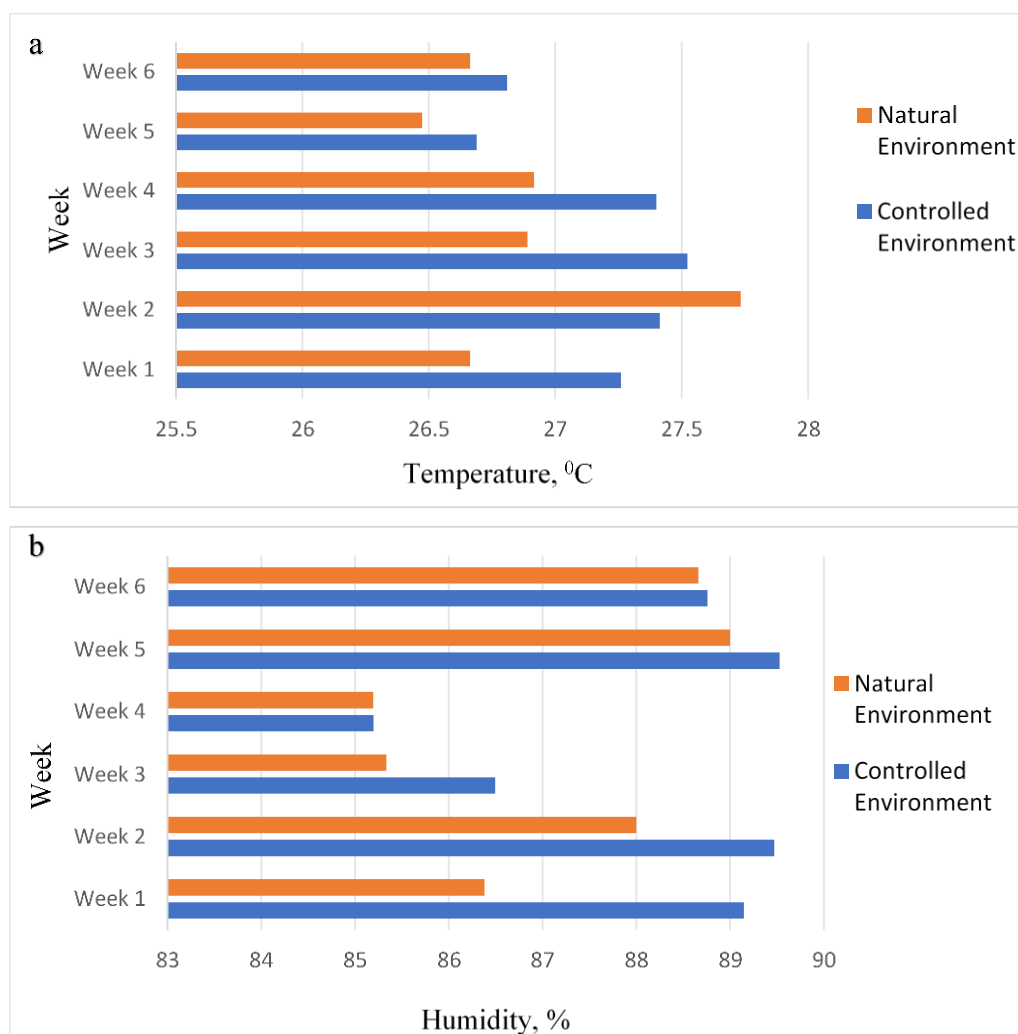


Figure 1. Environment temperature (a) and humidity (b) during the experiment.

Table 1. Main effect of environmental conditions on cocoon emergence of palm weevil fed different substrates.

Effect of environment	Week 1	Week 2	Week 3	Week 4
Natural	0.00	12.50 ^a	2.00 ^b	20.83 ^a
Controlled	0.00	8.33 ^b	6.00 ^a	17.78 ^b
SEM	0.00	2.17	0.66	0.84

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Table 2. Main effect of different substrates on the cocoon emergence of palm weevils fed different substrates under different environments.

Effect of substrate	Week 1	Week 2	Week 3	Week 4
Tiger nut waste	0.00	0.00 ^b	2.50 ^b	32.22 ^a
Fruit	0.00	0.00 ^b	5.00 ^a	6.67 ^c
Rice bran	0.00	31.25 ^a	5.00 ^a	20.00 ^b
SEM	0.00	2.17	0.66	0.84

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Table 3. Interaction effect of feeding different substrates under different environments on cocoon emergence of palm weevil.

Interaction effect of environment x substrate	Week 1	Week 2	Week 3	Week 4
Natural*Tiger nut waste	0.00	0.00 ^c	0.00 ^c	31.67 ^a
Natural*Fruit waste	0.00	0.00 ^c	0.00 ^c	10.00 ^c
Natural*Rice bran	0.00	37.50 ^a	10.00 ^a	0.00 ^d
Controlled*Tiger nut waste	0.00	0.00 ^c	5.00 ^b	33.33 ^a
Controlled*Fruit waste	0.00	0.00 ^c	10.00 ^a	0.00 ^d
Controlled*Rice ran	0.00	25.00 ^b	0.00 ^c	20.00 ^b
SEM	0	2.17	0.66	0.84

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Table 4. Main effect of environmental condition on percentage insect mortality of palm weevil fed different substrates under different environments.

Effect of environment	Week 1	Week 2	Week 3	Week 4
Natural	41.25 ^a	13.70 ^b	37.41	28.33
Controlled	35.00 ^b	24.81 ^a	35.78	24.44
SEM	2.25	1.11	1.37	1.77

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM- Standard Error of Mean.

Table 5. Main effect of different substrates on percentage insect mortality of palm weevil fed different substrates under different environments.

Effect of substrate	Week 1	Week 2	Week 3	Week 4
Tiger nut waste	20.00 ^c	17.41 ^b	33.61 ^b	33.33 ^a
Fruit waste	40.00 ^b	26.67 ^a	32.22 ^b	30.00 ^a
Rice bran	48.33 ^a	10.00 ^c	60.00 ^a	15.00 ^b
SEM	2.25	1.11	1.37	1.77

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Both tiger nut and fruit waste had significantly ($p < 0.05$) higher mortality rates at week 4 than rice bran (Table 5).

Fruit waste under a natural environment and rice bran fed under both natural and controlled environments had the highest insect mortality rate (%), followed by fruit waste fed under a controlled environment for week 1 (Table 6). At week 2, fruit waste fed under a controlled atmosphere obtained the highest mortality rate (33.33), followed by rice bran fed under a controlled environment (25.00). At week 3, rice bran fed under a controlled environment obtained the highest mortality rate (60.00), followed by fruit waste fed under a natural environment (40.00) (Table 6). Tiger nut waste and fruit waste under a natural environment and tiger nut waste fed under a controlled environment obtained the highest mortality rate, followed by fruit waste and rice bran fed under a controlled environment at week 4 (Table 6).

The environments did not influence the weight of the

palm weevil larvae for weeks 1 to 3 (Table 7). At week 4, the natural environment positively influenced the weekly weight of the palm weevil larvae. Substrates did not influence weight at week 2. At week 3, fruit waste obtained significantly ($p < 0.05$) higher weight (8.33) than tiger nut waste (5.99), however, rice bran was statistically similar to both fruit waste and tiger nut waste. At week 4, both tiger nut waste (7.00) and fruit waste (7.00) obtained significantly ($p < 0.05$) higher weight than tiger nut waste (6.00) (Table 8).

DISCUSSION

As the results of the present study indicated, maintaining an optimal and stable temperature and humidity is crucial for minimizing insect mortality and maximizing cocoon emergence during the developmental stages of palm

Table 6. Interaction effect of feeding different substrates under different environments on percentage insect mortality of palm weevil.

Interaction effect of environment x substrate	Week 1	Week 2	Week 3	Week 4
Natural*Tiger nut waste	20.00 ^c	11.11 ^d	36.11 ^c	33.33 ^a
Natural*Fruit waste	50.00 ^a	20.00 ^c	40.00 ^b	35.00 ^a
Natural*Rice bran	47.50 ^a	10.00 ^d	0.00 ^e	10.00 ^c
Controlled*Tiger nut waste	20.00 ^c	20.56 ^c	31.11 ^c	33.33 ^a
Controlled*Fruit waste	35.00 ^b	33.33 ^a	28.34 ^d	20.00 ^b
Controlled*Rice bran	50.00 ^a	25.00 ^b	60.00 ^a	20.00 ^b
SEM	2.25	1.11	1.37	1.77

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Table 7. Main effects of environmental conditions on weekly weight of palm weevil larvae.

Parameter	Controlled	Natural	SEM	P Value
Initial	7.57	6.76	1.21	0.15
Week 1	7.57	7.51	1.67	0.93
Week 2	7.48	7.30	0.92	0.94
Week 3	7.04	7.15	0.46	0.63
Week 4	6.33 ^b	6.50 ^a	0.31	<0.001

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean.

Table 8. Main effects of different substrates on weekly weight of palm weevil larvae.

Parameter	T1	T2	T3	SEM	P value
Initial	6.49	7.40	7.60	1.28	0.22
Week 1	6.97	7.50	8.15	1.50	0.45
Week 2	6.73	7.25	8.13	0.49	0.21
Week 3	5.99 ^b	7.50 ^{ab}	8.33 ^a	0.81	0.028
Week 4	6.00 ^b	7.00 ^a	7.00 ^a	0.29	<0.001

^{abc}Means with different superscripts across columns are significantly ($p < 0.05$) different; SEM = standard error of mean; T1 = Tiger nut shaft + molasses + water; T2 = rice bran + molasses + water; T3 = Fruits (watermelon and pineapple peel) + molasses + water.

weevils (Van Lenteren, 2006). Understanding the differences between natural and controlled environments is crucial for optimising the rearing process and ensuring successful palm weevil production. In natural environments, palm weevils undergo their life cycle on palm trees, laying eggs in the tree's soft tissue and feeding on its inner core. This habitat provides a familiar environment rich in nutrients, leading to healthy development and higher cocoon emergence rates. However, natural environments also come with challenges such as exposure to predators, disease, and environmental fluctuations, which can increase mortality rates (Manzoor *et al.*, 2020). The temperature across environments in this study aligns with the previously reported optimal temperature (Peng *et al.*, 2016).

A controlled environment on the other hand provides

restrictions on environmental factors including temperature, humidity, and light, thereby optimising conditions for palm weevil rearing. Feeding weevils substrates like tiger nut waste, fruit waste and rice bran can enhance their growth and development, leading to lower mortality rates and more consistent weight changes (Ebenebe and Okpoko, 2016).

In the present study, no cocoon emergence was observed in week 1, which may be attributed to the time required for the worms to acclimate to their new environment and begin cocoon formation (Van Lenteren, 2006). As the weeks progressed, the worms became more settled, leading to cocoon emergence in week 2. Cocoon emergence under both conditions and substrates considered suggest that favourable attributes of the conditions to palm weevil rearing. For early emergence,

rice bran seems to be a preferred substrate. However, further studies are recommended to establish whether the controlled or natural environment improves the cocoon emergence of palm weevils better, as the present study could determine. There was no consistent specific pattern to cocoon emergence with regard to environments.

It has been previously suggested that the natural environment may yield higher cocoon emergence rates due to the weevils' familiarity with the palm tree substrate (Ebenebe and Okpoko 2016). The importance of substrates on cocoon emergence has been documented (Kurdi *et al.*, 2021). In the present study, rice bran enhanced early emergence, rice bran and fruit waste improved emergence at week 3 while at a later stage (week 4) tiger nut waste and rice bran enhanced emergence rate. The nutritional content of the substrate affects cocoon emergence. Nutrient-rich substrates may provide a better condition for larvae development (Kurdi *et al.*, 2021). Therefore, the choice of substrate is crucial in palm weevil culture.

A controlled environment may offer better control and protection against predators and diseases, leading to lower mortality rates compared to a natural environment (Hodde, 2023). The aforementioned expectation was observed in the present study at week 1. However, at week 2, it was a different story and as the duration progressed, no difference was observed regarding the mortality rate in both environments. It is, therefore, recommended that proper monitoring and management practices should be followed to mitigate mortality risk in both conditions. In this study, there was not a sustained pattern regarding the effects of substrates on mortality rate, perhaps because of the closeness of the humidity and temperature under both environmental conditions in the present study. Notwithstanding, the importance of substrate and environments in rearing palm weevil cannot be over-emphasized (Salama and Saker, 2002).

It is important to consider environmental conditions, especially temperature and humidity for optimal production of palm weevil larvae. Furthermore, there could be the existence of potential interactions of temperature and humidity with substrates and other environmental factors to modulate the growth and development of African palm weevils. Notable variations in several metrics, including overall feed consumption, average feed intake per larva, efficiency of feed conversion, larval pH, and the cost of feed per kilogram were noticed when palm weevil diets were incorporated with different proportions of oil palm yolk (Quaye *et al.* 2018). These diets were combined with various agro-waste materials such as banana and pineapple fruit waste and millet waste. The findings showed a significant difference in the weekly weight gain of palm weevil larvae. However, the findings of another study revealed no significant difference in the body weight of emergent adults raised in the four substrates: spoil watermelon, ripe pawpaw, spoil pine apple and sugarcane

tops (Ebenebe and Okpoko 2015). In another similar study significant differences in body weight of palm weevil larvae raised under young and old palm trunks were observed (Claude *et al.* 2017), although, the authors noted that a young palm trunk allows a faster growth of the larvae, a higher rate of success and produced larvae of bigger size than all the other substrates used in their experiment.

Substrates which are agro-industrial by-products, regarded as waste materials which could constitute environmental nuisance have been successfully utilized for rearing palm weevil larvae which may improve animal nutrition and production. In addition, findings from this study suggest that factors other than those considered might influence body weight gain, emergence and mortality rate of palm weevil. Further studies focusing on a longer duration, species variation, other environmental conditions and different experimental set-ups towards understanding the dynamics influencing palm weevil larvae development are strongly recommended.

Conclusion

Agro-industrial by-products regarded as waste materials were successfully used for rearing palm weevil larvae, which may be used for improving animal agriculture, and by extension food security in areas plagued with food insecurity arising from the high cost of conventional feed ingredients, especially protein sources for non-ruminant animals.

Based on the findings from this study, the choice of the environment should be based on factors such as the availability of resources, the level of control required and the desired outcomes in terms of cocoon emergence, mortality rates and larvae weight gain. By understanding these factors and optimising the culturing process, palm weevil production can be improved in both natural and controlled environments. Further studies are recommended to validate the findings of this study and to understand the underlying mechanisms.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

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REFERENCES

- Adebiyi, O. A., Adejumo, I. O., Ajayi, E. A., & Okiwelu, E. I. (2023). Influence of dietary manipulation on coping with stress

- in pig production. *Agricultura Tropica et Subtropica*, 56(1), 217-224.
- Adebiyi, O. A., Awotale, H. O., Adejumo, I. O., Osinowo, O. A., Muibi, M. A., & Nwaodu, O. B. (2019). Performance, serum and haematological indices of pigs fed watermelon waste based-diet. *Tropical Animal Production Investigations*, 22(1), 10-16.
- Adebiyi, O. A., Oboli, U. T., Adejumo, I. O., Osinowo, O. A., Olumide, M., & Adeshola, A. T. (2020). Nutritive value of palm oil sludge and its influence on fat composition and deposition in grower pigs. *Nigerian Journal of Animal Science*, 22(1), 253-261.
- Adebiyi, O. A., Sodeke, M., Adeleye, O. O., & Adejumo, I. O. (2018). Effects of extruded rice bran based diets on the performance, intestinal microbiota and morphology of weaned pigs. *Agricultura Tropica Et Subtropica*, 51(1), 13-19.
- Adejumo, I. O., & Adebiyi, O. A. (2020). Agricultural solid wastes: causes, effects, and effective management. In: *Strategies of sustainable solid waste management*. IntechOpen. Pp.139-150.
- Adejumo, I. O., Badmus, K. A., Maidala, A., Makinde, O. J., Maina, A. D., Mohammed, I. C., & Abubakar, B. (2020). Locally-processed cowpea husk improved body weight gain of on-farm raised rabbits in Northeastern Nigeria. *Nigerian Journal of Animal Science*, 22(3), 199-208
- Adejumo, I. O., Bryson, B., Olojede, O. C., Bedford, M. R., & Adedokun, S. A. (2021). Effect of sodium sources and exogenous phytase supplementation on growth performance, nutrient digestibility, and digesta pH of 21-day-old broilers. *Poultry Science*, 100(11), 101467.
- Claude, M. L. J., Alvarez, M., & Rodriguez, H. (2017). Substrate composition and larval growth rates in palm weevils. *Journal of Agricultural Science and Entomology*, 38(4), 299-312.
- Coley, K. M., Perosky, J. E., Nyanplu, A., Kofa, A., Anankware, J. P., Moyer, C. A., & Lori, J. R. (2020). Acceptability and feasibility of insect consumption among pregnant women in Liberia. *Maternal & Child Nutrition*, 16(3), e12990.
- Debrah, J. K., Teye, G. K., & Dinis, M. A. P. (2022). Barriers and challenges to waste management hindering the circular economy in Sub-Saharan Africa. *Urban Science*, 6(3), 57.
- Ebenebe, C. I., & Okpoko, V. O. (2015). Growth of palm weevil larvae in different soil types. *Journal of Applied Entomology*, 36(2), 178-192.
- Ebenebe, C. I., & Okpoko, V. O. (2016). Preliminary studies on alternative substrate for multiplication of African palm weevil under captive management. *Journal of Insects as Food and Feed*, 2(3), 171-178.
- Elemo, B. O., Elemo, G. N., Makinde, M. A., & Erukainure, O. L. (2011). Chemical evaluation of African palm weevil, *Rhynchophorus phoenicis*, larvae as a food source. *Journal of Insect Science*, 11(1), 146.
- Habib, S. J., Hughes, L., & Wilson, P. (2017). Effects of different environmental substrates on palm weevil larvae. *Journal of Agricultural Entomology*, 35(3), 275-289.
- Halder, J., Kushwaha, D., Rai, A. B., Singh, A., & Singh, B. (2017). Potential of entomopathogens and neem oil against two emerging insect pests of vegetables. *Indian Journal of Agricultural Sciences*, 87(2), 220-224.
- Halloran, A., Roos, N., Eilenberg, J., Cerutti, A., & Bruun, S. (2016). Life cycle assessment of edible insects for food protein: A review. *Agronomy for Sustainable Development*, 36(4), 1-13.
- Hoddle, M. S. (2023). A new paradigm: proactive biological control of invasive insect pests. *BioControl*, 69, 321-334, (
- Kurdi, H., Al-Aldawsari, A., Al-Turaiki, I., & Aldawood, A. S. (2021). Early detection of red palm weevil, *Rhynchophorus ferrugineus* (Olivier), infestation using data mining. *Plants*, 10(1), 95.
- Manzoor, M., Ahmad, J. N., Giblin-Davis, R. M., Javed, N., & Haider, M. S. (2020). Effects of entomopathogenic nematodes and/or fungus on the red palm weevil, *Rhynchophorus ferrugineus* (Curculionidae: Coleoptera). *Nematology*, 22(10), 1193-1207.
- Peng, L., Miao, Y., & Hou, Y. (2016). Demographic comparison and population projection of *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) reared on sugarcane at different temperatures. *Scientific Reports*, 6, Article number 31659.
- Rodzic, F. F. M., Sudirman, N. A., Yaakop, S., Mohd-Assaad, N., Ong-Abdullah, M., & Ata, N. (2023). Development of nuclear DNA markers for applications in genetic diversity study of oil palm-pollinating weevil populations. *Insects*, 14(2), 157.
- Salama, H. S., & Saker, M. M. (2002). DNA fingerprints of three different forms of the red palm weevil collected from Egyptian date palm orchards. *Archives of Phytopathology and Plant Protection*, 35(4), 299-306.
- Sutanto, K. D., Husain, M., Rasool, K. G., Al-Qahtani, W. H., & Aldawood, A. S. (2021). Pathogenicity of local and exotic entomopathogenic fungi isolates against different life stages of red palm weevil (*Rhynchophorus ferrugineus*). *Plos One*, 16(7), e0255029.
- United Nations (UN) (2020). Coronavirus global health emergency. Retrieved July 14 2022 <https://www.un.org/en/coronavirus>.
- Van Lenteren, J. C. (2006). Phytophagous insects in a multitrophic network. *Atti dell'Accademia Nazionale Italiana di Entomologia, Rendiconti*, 54, 65-87.