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NUTRITIONAL EVALUATION AND GROWTH RESPONSE OF *TENEBRIO MOLITOR* LARVAE FED FRUIT-WASTE BASED DIETS

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ABSTRACT
The study investigates fruit waste–based diets as alternative feed sources for *Tenebrio molitor* (mealworm) larvae, using nutritional composition, cost-effectiveness, and larval growth performance. Pineapple peels (PP) and watermelon rinds (WR) were processed and analyzed for nutritional composition using standard protocols. Five diets were formulated: D1 (control: 100 g wheat bran), D2 (50 g wheat bran + 50 g PP), D3 (50 g wheat bran + 50 g WR), D4 (50 g wheat bran + 25 g PP + 25 g WR), and D5 (50 g PP + 50 g WR). Each group received 100 g of feed over 90 days. PP showed higher moisture, ash, fat, and crude fiber, while WR had higher mineral and energy content. D3 had the highest energy value (2330 kcal/kg). Feed cost decreased progressively from D1 to D5 (14,000 -5760), with D5 being the most cost-effective. Larvae fed D1 showed the best growth and feed efficiency, with an average larval weight of 237.40±31.25, followed by D4 (106.47±0.95), indicating that partial substitution maintained good performance. Complete replacement reduced growth, likely due to lower protein and higher fiber content. This supports the concept of sustainable waste valorization in insect production systems.

Keywords: Cost analysis, Fruit wastes, Growth performance, Nutritional composition, *Tenebrio molitor*

INTRODUCTION
The increasing demand for sustainable protein sources has prompted the growing interest in insect farming, particularly for their application in the food and feed industries. Conventional livestock production faces challenges such as high feed costs, environmental degradation, and competition for arable land, thereby necessitating alternative protein strategies. Thus, insect farming has gained considerable attention for its application in the food and feed industries. Insects are recognized for their high nutritional value in terms of protein and balanced amino acid profiles (Adamu et al., 2021; Papastavropoulou et al., 2021; Adamu et al., 2022). Their efficient feed conversion, low greenhouse gas emissions, and ability to utilize organic side streams further enhance their suitability as sustainable protein sources (Oladunni et al., 2023). Insects such as mealworm (*Tenebrio molitor*) have shown great potential due to their high protein content, high feed conversion efficiency, rapid growth and reproduction cycles, and ability to thrive on a wide variety of agricultural and organic waste substrates (Ruschioni *et al*., 2020; Oladunni *et al*., 2026). The nutritional composition of these waste materials plays a critical role in determining the growth rate, development, and nutritional quality of the insects. Wheat bran has traditionally been considered the standard and most suitable substrate for mass rearing of *T. molitor*. However, according to Harsányi et al. (2020), the increasing cost of wheat bran presents a significant economic constraint to large-scale mealworm production. This limitation prompted the need to identify less expensive and locally available alternative substrates. Considering the diversity of food and organic waste streams generated from numerous crop varieties and their by-products, there appears to be significant potential for exploring the combinations of food wastes and insect rearing to enhance both bioconversion efficiency and insect biomass production. According to Baysal & Ülkü (2022), around a third of the food produced each year is lost or wasted, which is linked to the processing industry. The vegetable and fruit industries are known to be the highest producers of these wastes, revealing 25–30% peels, seeds, skins, shells, pods, cores, pulp, pomace, amongst others (Rifina *et al*. 2021; Trigo *et al*., 2022). The perishable attributes, as well as disposal, are some of the major concerns associated with the waste. Although several studies have explored agro-industrial by-products as substrates for insect rearing, there is limited information regarding the use of pineapple peels and watermelon rinds as alternative substrates for *Tenebrio molitor*. While some fruit wastes have been evaluated individually in insect feeding trials, the specific effects of pineapple peels and watermelon rinds combined on mealworm larval growth remain scarce. Therefore, this study evaluates the effects of substituting wheat bran with Pineapple peels and watermelon rinds individually and in combination on the growth performance of *T. molitor* larvae.

MATERIALS AND METHODS

Sample collection
Peels of pineapple and watermelon rinds were collected from fruit vendors within Lapai, Niger State. A total of three collection batches were obtained over a two-week period from randomly selected vendors within the town. Immediately after collection, the samples were rinsed with clean tap water to remove dirt. The peels were further cut into smaller pieces to facilitate drying. For each peel, samples from the different vendors within the same batch were pooled to obtain a homogeneous composite sample before processing. The samples were air-dried at room temperature (27–30°C) for 21 days until a constant weight was achieved. In order to prevent contamination, the samples were spread on clean trays and covered with a mesh to prevent insect infestation and dust. The samples were checked periodically to ensure uniform drying. After which they were first pulverized using a mortar and pestle to reduce particle size and then ground into fine particles using an electric blender. The resulting powders were stored in airtight containers at room temperature until further analysis and experimental use.

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The analyses conducted were proximate compositions (moisture, crude protein, ash, fat, crude fiber, and carbohydrate) and mineral analyses (calcium, iron, magnesium, manganese, phosphorus, potassium, and sodium). Analyses were conducted based on the method of the Association of Official Analytical Chemists (AOAC, 2019), and the results were expressed on a dry matter basis. Moisture content was measured using AOAC 934.01 by oven-drying samples at 105 °C until a constant weight was achieved. Crude protein was determined using AOAC 990.03, based on total nitrogen content measured via the Kjeldahl method and converted to protein using a factor of N × 6.25. Ash content was assessed according to AOAC 942.05 by incinerating samples in a muffle furnace at 550 °C until all organic matter was burned off. Fat (ether extract) was measured using AOAC 920.39 through Soxhlet extraction with petroleum ether. Crude fiber was analyzed by AOAC 978.10, which involves sequential acid and alkali digestion to remove soluble substances, with the remaining residue quantified. Total carbohydrate content was calculated by difference. Mineral composition of the samples was determined using the wet digestion of the samples and quantified using the Atomic Absorption Spectrophotometer (AAS). While the energy contents of the samples were calculated using the Atwater conversion factors:

Protein: 17kj/g (or 4kcal/g) ………………………………… (i)
Fat: 37kj/g (or 9kcal/g) …………………………………… (ii)
Carbohydrate: 17kj/g (or 4kcal/g) ……………………… (iii)

Diet preparation
The feed ingredients used for diet preparation comprised pineapple peels (PP), watermelon rinds (WR), and wheat bran (WB), while carrot served as a moisture source. The feed formulation is presented in Table 1.

Table 1: Ingredients' composition of formulated *T. molitor* diets

Feed source	Experimental diet				
	D1	D2	D3	D4	D5
Wheat bran (WB)	100	50	50	50	-
Pineapple peels (PP)	-	50	-	25	50
Watermelon rind (WR)	-	-	50	25	50
Total	100%	100%	100%	100%	100%

The formulated diets were subjected to proximate (moisture, crude protein, ash, fat, crude fiber, and carbohydrate) and mineral (calcium, iron, magnesium, manganese, phosphorus, potassium, and sodium) composition analysis using the AOAC (2019) standard protocol. While the energy contents of the samples were calculated using the Atwater conversion factors in equations i to iii.

Cost analysis of the prepared fruit-waste diets
The Cost of feed (cost per kg diet) was calculated based on the prevailing cost of ingredients at the time the experiment was conducted. The cost component includes the cost of purchasing the feed materials (wheat bran, pineapple peels, watermelon rinds, and carrots) and the cost of processing. All costs were calculated in Naira (₦) using the formula below (Langston *et al*., 2023, and Ewane *et al*., 2024);

i. $\text{Cost per kg of the larvae} = \frac{\text{Cost per kilogram of the substrate}}{\text{Average weight of the larvae}}$ …………… (iv)
ii. Cost differential = cost/kg weight gain of the control diet – cost/kg weight gain of the test diet- ……………. (v)
iii. $\text{Relative cost advantage (\%)} = \frac{\text{cost differential}}{\text{cost/kg weight gain of the control}} \times 100$ ……….. (vi)

Collection of *T. molitor* larvae
One hundred adult mealworm (beetles) were purchased from a commercial insect breeder in Kwara State and transported in plastic containers to the laboratory. In order to obtain newly emerged larvae, adults were allowed to oviposit for 14 days in egg crates and fed 20g of wheat bran, which served as both substrate and feed. The eggs were not manually removed but were left to hatch inside the substrate. Slices of carrot were provided to adults as a moisture source. After the 14-day interval. Adults were separated from the newly emerged larvae using a sieve. The newly emerged larvae were left to feed on the experimental diet for 14 days prior to the start of the experiments.

Experimental Design and Rearing Conditions of *T. molitor*
A plastic container measuring 29 × 21 cm was used to rear the mealworms. The lid of each container was cut open at the center and replaced with mesh to allow ventilation. The experiment consists of five (5) dietary treatments, each replicated three times, making a total of fifteen (15) plastic containers. Each replicate contained 300 newly emerged larvae with an initial length of 0.3 cm and a weight of 0.005 g. A photoperiod of 12 hours light: 12 hours dark and a temperature range of 20-25°C were maintained throughout the experiment period. Prior to the feeding trial, the larvae were starved for 24 hours to reduce gut content. Thereafter, 100 g of the respective Diets 1, 2, 3, 4, and 5 were administered to the five different groups. Feeding was carried out once every two weeks. The feed residues were weighed before replacement to estimate feed consumption. Fresh carrot slices were provided as a moisture source and replaced every four days to prevent mold growth.

Growth performance of *T. molitor* larvae reared on the prepared experimental diets
Performance of *T. molitor* in growth and feed utilization was determined weekly based on the length gain (LG), weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), and survival rate (Agbo *et al*., 2011; Oonincx *et al*., 2015). An electronic weighing balance (0.0001 g AR224CN Ohaus Corp., Pine Brook, NJ, USA) was used to record larval weight, and a caliper to the nearest 0.1 cm was used to estimate the length. Calculation of each criterion was done based on the formulas below:

i. $\text{Length gain (\%)} = \frac{\text{Final length} - \text{initial length}}{\text{initial length}} \times 100$ …. (vii)
ii. $\text{Weight gain} = \frac{\text{Final weight} - \text{initial weight}}{\text{iinitial weight}} \times 100$ ….. (viii)
iii. $\text{Specific growth rate (\%)} = \frac{(\ln \text{final weight}) - (\ln \text{initial weight})}{\text{total feeding days}} \times 100$ ……………… (ix)
iv. $\text{Feed conversion rate kg/kg} = \frac{\text{Feed intake (g)}}{\text{weight gained}}$……….(x)
v. $\text{Survival rate (\%)} = \frac{\text{initial number} - \text{Number of dead ;arvae}}{\text{initial number}}$ × 100…………………………………………… (xi)

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Data Analysis

Data obtained from the proximate, mineral, and energy composition of the fruit wastes were expressed as mean ± standard error (Mean ± SE) for each treatment (n = 3 replicates per diet). The data were analyzed using one-way analysis of variance (ANOVA), and differences among the means were compared using the Bonferroni multiple comparison test. Microsoft Excel Spreadsheet 2019 was employed to calculate ingredient costs, formulate diets, and analyze cost differential and relative cost advantage. The growth performance of *T. molitor* larvae was also analyzed using one-way ANOVA, with mean comparisons conducted using the Bonferroni test. Differences were considered statistically significant @ $p<0.05$. All statistical analyses and graphical representations were performed using GraphPad Prism version 9.0.

RESULTS

Proximate, mineral, and energy constituents of the selected fruit-wastes

The results of the Proximate, mineral, and energy constituents of the selected fruit wastes is presented in Table 2. The moisture, ash, fat, and crude fiber content were higher in pineapple peels (21.17±0.60; 6.67±0.02; 0.76±0.14; 16.65±0.01) and lower in watermelon rinds (17.77±0.15; 5.59±0.01; 0.47±0.01; 11.19±0.01), while crude protein and carbohydrate contents were higher in watermelon rinds (6.77±0.10; 56.93±0.02) and lower in pineapple peels (3.63±0.10; 49.85±0.01). There were significant ($p<0.05$) differences obtained in the value of both fruits recorded.
The calcium, iron, magnesium, manganese, phosphorous and potassium content was higher in watermelon rinds (1.58±0.02; 8.17±0.05; 0.59±0.01; 2.46±0.01; 1.59±0.01 and 4.30±0.10) and lower in pineapple peels (1.51±0.01; 5.09±0.08; 0.35±0.01; 1.31±0.01; 1.58±0.02 and 2.35±0.01). while sodium was higher in pineapple peels (0.36±0.02) and lower in watermelon rinds (0.35±0.04). There were no significant differences in the calcium, phosphorous and sodium content of the two fruit peels. However, significant differences were observed in the iron, magnesium, manganese, and potassium content of the peels. The energy content was higher in watermelon rinds (2590 kcal/kg), and lower in pineapple peels (2210 kcal/kg).

Table 2: Proximate, mineral, and energy composition of the selected fruit wastes

Nutritional composition (%)	Pineapple peels	Watermelon rinds
Moisture	21.17±0.60^{a}	17.77±0.15^{b}
Ash	6.67±0.02^{a}	5.59±0.01^{b}
Fat	0.76±0.14^{a}	0.47±0.01^{b}
Crude fiber	16.65±0.01^{a}	11.19±0.01^{b}
Crude protein	3.63±0.10^{a}	6.77±0.10^{b}
Carbohydrate	49.85±0.01^{a}	56.93±0.02^{b}
Calcium	1.51±0.01^{a}	1.58±0.02^{a}
Iron	5.09±0.08^{a}	8.17±0.05^{b}
Magnesium	0.35±0.01^{a}	0.59±0.01^{b}
Manganese	1.31±0.01^{a}	2.46±0.01^{b}
Phosphorous	1.58±0.02^{a}	1.59±0.01^{a}
Potassium	2.35±0.01^{a}	4.30±0.11^{b}
Sodium	0.36±0.02^{a}	0.35±0.04^{a}
Energy (Kcal/kg)	2210	2590

D1 (wheat bran (90g)) + carrot (10g)); D2 (wheat bran (40g) + PP (50g) + carrot (10g)); D3 (wheat bran (40g) + WR (50g) + carrot (10g)); D4 (wheat bran (40g) + PP (25g) + WR (25g) + carrot (10g)); D5 (PP (45g) + WR (45g) + carrot (10g)). Means with the same superscript on the column are not significantly different at $p<0.05$

Proximate, mineral, and energy composition of the prepared fruit-waste diets

The results of the Proximate, mineral, and energy constituents of the prepared fruit-waste diets are presented in Table 3. The composition of the prepared diets revealed that the moisture content ranged from 12.63±0.01 (D1) to 25.23±0.62 (D5). Ash content ranged from 8.81±0.01 (D1) to 10.87±0.01 (D3). Fat ranged from 1.35±0.16 (D2) to 3.36±0.15 (D1). Crude fiber ranged from 15.55±0.03 (D5) to 26.16±0.01 (D4). Crude protein ranged from 4.28±0.10 (D5) to 9.25±0.05 (D4) while Carbohydrate ranged from 34.98±0.01 (D4) to 46.76±0.01 (D3). There were significant ($p<0.05$) differences in the moisture, ash, crude fiber, protein, and carbohydrate content of all the diets supplemented with fruit wastes compared to the control diet. However, no significant ($p>0.05$) differences were observed in the fat content between D1 and D5.
The calcium content ranged from 1.63±0.02 (D5) to 21.76±0.01 (D4). Iron ranged from 8.69±0.12 (D5) to 10.51±0.01 (D4). Magnesium ranged from 1.06±0.01 (D5) to 8.68±0.00 (D3). Manganese ranged from 2.52±0.03 (D5) to 5.65±0.01 (D4). Phosphorus ranged from 1.76±0.01 (Diet 5) to 20.62±0.02 (D4). Potassium ranged from 3.44±0.01 (D5) to 40.52±0.09 (D4) while sodium ranged from 0.46±0.02 (D5) to 2.83±0.31 (D4), respectively. There were no significant differences in the mineral content of D2, D3, and D4 compared to the control diet (D1). However, significant differences were observed when compared with D5. The highest energy content was recorded in D3 (2330 kcal/kg), while the lowest was in D4 (1980 kcal/kg).

Table 3: Proximate, mineral, and energy composition of the prepared fruit-waste diets

Nutritional composition	Diets				
	D1	D2	D3	D4	D5
Moisture (%)	12.63±0.09^{a}	21.05±0.02^{b}	13.79±0.15^{c}	15.79±0.13^{d}	25.23±0.62^{e}
Ash (%)	8.81±0.01^{a}	9.88±0.01^{b}	10.87±0.01^{c}	10.86±0.03^{c}	9.68±0.05^{b}
Fat (%)	3.36±0.09^{a}	1.35±0.16^{b}	1.58±0.14^{b}	2.28±0.10^{c}	3.27±0.15^{a}
Crude fiber (%)	23.56±0.03^{a}	16.83±0.02^{b}	18.13±0.03^{c}	26.16±0.01^{d}	15.55±0.03^{e}
Crude protein (%)	8.33±0.10^{a}	6.55±0.10^{b}	8.01±0.05^{a}	9.25±0.05^{c}	4.28±0.10^{d}
Carbohydrate (%)	41.98±0.01^{a}	42.93±0.02^{b}	46.76±0.01^{c}	34.98±0.01^{d}	39.89±0.01^{e}
Calcium (mg/kg)	20.60±0.11^{a}	20.63±0.01^{a}	20.62±0.03^{a}	21.76±0.01^{a}	1.63±0.02^{b}
Iron (mg/kg)	10.19±0.05^{a}	10.21±0.01^{a}	10.28±0.02^{a}	10.51±0.01^{a}	8.69±0.12^{b}
Magnesium (mg/kg)	8.59±0.08^{a}	8.61±0.01^{a}	8.68±0.00^{a}	8.62±0.02^{a}	1.06±0.01^{b}
Manganese (mg/kg)	5.08±0.08^{a}	5.21±0.01^{a}	5.27±0.01^{a}	5.65±0.01^{a}	2.52±0.03^{b}

Phosphorous (mg/kg)	20.18±0.03 [a]	20.09±0.01 [a]	20.31±0.01 [a]	20.62±0.02 [a]	1.76±0.01 [b]
Potassium (mg/kg)	40.12±0.03 [a]	40.05±0.05 [a]	40.17±0.01 [a]	40.52±0.09 [a]	3.44±0.01 [b]
Sodium (mg/kg)	2.54±0.03 [a]	2.51±0.01 [a]	2.57±0.01 [a]	2.83±0.31 [a]	0.46±0.02 [b]
Energy (Kcal/kg)	2270	2100	2330	1980	2060

D1 (wheat bran (90g)) + carrot (10g)); D2 (wheat bran (40g) + PP (50g) + carrot (10g)); D3 (wheat bran (40g) + WR (50g) + carrot (10g)); D4 (wheat bran (40g) + PP (25g) + WR (25g) + carrot (10g)); D5 (PP (45g) + WR (45g) + carrot (10g)). Means with the same superscript on the column are not significantly different at p<0.05.

Cost analysis of the prepared fruit-waste diet

The cost analysis of the prepared fruit-waste diet shows a decrease in the total feed cost as the diet progressed from 1-5 (Table 4). D1 reported the highest total feed cost of 14,000 naira, while D5 reported the lowest price of 5,760 naira. The highest and positive cost differential and relative cost advantage was recorded in D5 (1.78 and 3.01%), while the least was recorded in D2 (-22.35 and -37.90%), as shown in Table 5.

Table 4: Cost analysis of the prepared fruit-waste diet

Cost parameters	Diet				
	D1	D2	D3	D4	D5
Total feed (kg)	1.8	1.8	1.8	1.8	1.8
Total feed cost (₦)	14,000	8,260	8,260	8,260	5,760
Cost per kg weight gain (₦/kg)	58.97	81.32	79.90	77.58	57.19
Cost differential (per kg of diet)		-22.35	-20.93	-18.61	1.78
Relative cost advantage (%)		-37.90	-35.49	-31.55	3.01
Total production cost	38,800	33,060	33,060	33,060	30,590

D1 (wheat bran (90g)) + carrot (10g)); D2 (wheat bran (40g) + PP (50g) + carrot (10g)); D3 (wheat bran (40g) + WR (50g) + carrot (10g)); D4 (wheat bran (40g) + PP (25g) + WR (25g) + carrot (10g)); D5 (PP (45g) + WR (45g) + carrot (10g)).

Growth performance of T. molitor larvae reared on the prepared fruit-waste diets

The highest larval length was attained in D1 (2.80±0.09) followed by in D4 (2.43±0.06), while the least was recorded in D5 (1.87±0.06). Similarly, the larval weight was highest in D1 (237.40±31.25), followed by D4 (106.47±0.95). while the least was recorded in D5 (100.70±0.71) as shown in Table 5, respectively. There were significant differences (p<0.05) in larval length and weight of larvae reared on the control diet (D1) compared to D2, D3, D4, and D5.

Specific growth rate (SGR) was higher in D1 (4.28±0.15), followed by D4 (3.40±0.01), while the lowest value was attained in D5 (3.34±0.02). Feed conversion rate (FCR) decreased as the weeks went by. The highest FCR was attained in D2 and D5 (0.98±0.01) followed by D3 (0.97±0.01). while the least was observed in D1 (0.42±0.05), and the survival rate was higher in D1 (87.33%), followed by D4 (84.93%). The least was recorded in D3 (81.20%), as shown in Table 5. There were significant differences (p>0.05) observed in the SGR, FCR, and survival rates of larvae reared on the control diet (D1) compared to other diets.

Table 5: Growth performance of *T. molitor* larvae reared on pineapple and watermelon wastes

Parameter	D1	D2	D3	D4	D5
Length (cm)	2.80±0.09 [a]	1.93±0.06 [b]	2.13±0.12 [c]	2.43±0.06 [d]	1.87±0.06 [b]
Weight (mg)	237.40±31.25 [a]	101.57±1.07 [b]	103.37±0.45 [b]	106.47±0.95 [b]	100.70±0.71 [b]
Specific growth rate (%)	4.28±0.15 [a]	3.35±0.01 [b]	3.37±0.01 [b]	3.40±0.01 [b]	3.34±0.02 [b]
Feed conversion rate (kg)	0.42±0.05 [a]	0.98±0.01 [a]	0.97±0.01 [a]	0.94±0.01 [a]	0.98±0.01 [a]
Survival rate (%)	87.33±1.53 [a]	82.33±0.98 [b]	81.20±1.11 [b]	84.93±0.50 [b]	81.27±2.02 [b]

D1 (wheat bran (90g)) + carrot (10g)); D2 (wheat bran (40g) + PP (50g) + carrot (10g)); D3 (wheat bran (40g) + WR (50g) + carrot (10g)); D4 (wheat bran (40g) + PP (25g) + WR (25g) + carrot (10g)); D5 (PP (45g) + WR (45g) + carrot (10g)). Means with the same superscript on the column are not significantly different at p<0.05

DISCUSSION

The moisture content of pineapple and watermelon rinds obtained in this study was lower than the 82.93% and 80.50% reported by Abarshi *et al.* (2018) and Dias *et al.* (2020). All the diets exhibited higher moisture content than the values (9.55% and 12.7%) reported by Curti *et al.* (2013) and Ghodrat *et al.* (2015). Differences in moisture content between this study and previous studies may be attributed to factors such as the depth of peeling and the drying techniques used. Since moisture content is a key indicator of water activity in food and is commonly used to assess stability and susceptibility to microbial contamination (Ekanem *et al.*, 2019). Although the moisture content of the diets was relatively high, which may predispose them to microbial growth, actual shelf stability would depend on water activity and storage conditions.

The ash content of pineapple peels in this study was comparable to the values reported by Vincent et al. (2016) and Morais *et al.* (2016). Similar observations were made for the ash content of watermelon rind, as the values were comparable to those reported by Sadiq *et al.* (2022) and Ramelle *et al.* (2016). However, the values were higher than the values reported by Kamau *et al.* (2020) and Abhimanyu *et al.* (2013). The ash content of the experimental diets was within the range of 8.1% to 12.7% reported by Curti *et al.* (2013). The ash content reflects the mineral composition of the food material and provides essential minerals for exoskeleton formation and metabolic functions (Gemede *et al.*, 2015). The moderate ash content suggests the presence of mineral

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constituents; however, mineral bioavailability would require further evaluation. Fat is essential for living organisms, particularly humans and animals, where it plays a major role in energy supply, protection of body organs, maintenance of cell membranes, and absorption of fat-soluble vitamins (FAO, 2023). The fat content of pineapple and watermelon wastes was comparable to values reported by Dias et al. (2020), but lower than the values reported by Ramelle *et al*. (2016), Morais *et al*. (2016), Abarshi *et al.* (2018), Rahman *et al.* (2020), Owoeye *et al*. (2022), and Sadiq *et al.* (2022). The low-fat content observed in both peels, as well as their mixtures, aligns with findings from Champagne et al. (2011), who reported that fruits are generally low in fat. The fat content of D1 was similar to that reported by Aderemi & Alabi (2013). However, the high fat content observed in D5 suggests that it could serve as a better source of fat compared to D2, D3, and D4. Differences in fat content across studies may be attributed to variations in plant varieties, geographical factors, and peeling depth.

Dietary fiber is known to influence digestion and absorption processes in the small intestine. However, excessive amounts can reduce nutrient absorption and feed efficiency in animals (Singh and Kim, 2021). The crude fiber content was slightly higher than the range of 13.9% to 15.9% for pineapple peels, and lower than 32.3% to 37.4% for watermelon rinds as reported by Morais *et al*. (2016). The fiber content of the experimental diets was higher than the 8.5% reported by Aderemi & Alabi (2013) for wheat bran. While moderate fiber levels may support gut functions, excessive fiber could reduce nutrient digestibility and growth performance (Alagbe, 2020). Protein is not generally known to be higher in fruits, but it plays a primary role in the growth and development of animals, serving as a building block for tissues (Hawkey *et al*., 2020). The lowest protein content was recorded in pineapple peels, but was significantly improved in the mixed diets (D4), where the protein content matched that of pure wheat bran. The protein content of D1 was slightly lower than the range of 9.60% to 18.50% reported by Onipe *et al*. (2015). Similarly, the protein content of D3 was comparable to that of pure wheat bran. These findings suggest that combining wheat bran with pineapple and watermelon peels results in a better source of protein than using the peels alone. Which explains why D4 >D2, D3, and D5 in performance. Carbohydrates play a crucial role in diets, serving as the primary source of energy and being essential for the development of the insect exoskeleton (Campos, 2022). The carbohydrate content of the two fruit peels was relatively high compared to previous studies by Rahman *et al*. (2015), Ramelle *et al*. (2016), and Koffi *et al*. (2021). However, values observed in all the diets was lower than the 60%–75% range reported by Onipe *et al*. (2015). These indicate the presence of natural sugars, fiber, and starch in the peels and the diet, which can thus serve as a valuable source of energy.

Fruits are considered a good source of dietary minerals, playing a key role in various physiological functions, especially in building and regulating processes. Calcium, in particular, is crucial in animals for functions such as development, metamorphosis, reproduction, carbohydrate and lipid metabolism, and diapause (Toprak *et al*., 2021). Studies on the calcium content of pineapple peels and watermelon rinds revealed lower values than previous studies by Morais *et al*. (2016) and Ramelle *et al*. (2016) (4236.2 mg/100g and 9770.9 mg/100g). However, the calcium content observed in the current study was still higher than the 0.18 mg/100g reported by Asaolu *et al*. (2016). All the diets had a lower calcium content compared to the values reported by Li et al. (2023). This shows that the diets would serve as a poor source of calcium. The concentration of iron in both peels was significantly higher compared to previous studies by Ekpete *et al*. (2013) and Morais *et al*. (2016). The iron content in all the diets fell within the range of 1.9 to 34.0 mg/100g, as reported by Onipe *et al*. (2015). This suggests that supplementing both peels with wheat bran can serve as a valuable source of iron for the insect. Analysis of the magnesium content in fruit peels showed that watermelon rinds had slightly higher magnesium content than pineapple peels. However, the values obtained were lower than the values reported by Abhimanyu *et al*. (2013) and Morais *et al*. (2016). In terms of diets, Sadiq *et al*. (2022) reported magnesium values of 8.22 mg/kg, which were similar to those obtained in D1, D2, D3, and D4. This suggests that these diets could serve as a good source of magnesium. A lower value was reported in Diet 5, which could be attributed to the absence of wheat bran in the diet.

The concentration of Mn in pineapple peels was lower than the range of 1.63–4.40 mg/100g reported by Kodagoda & Marapana (2017). Values obtained for watermelon rinds were comparable to those of Yargamji *et al*. (2024), but lower than the values reported by Morais *et al.* (2016). Additionally, the manganese concentration in all diets fell within the range of 0.9–10.1 mg/100g reported by Onipe *et al.* (2015). This suggests that both fruit peels, when supplemented with wheat bran, could serve as a good dietary source of manganese. Sodium was found in all the samples analyzed, although in small quantities. The sodium content in watermelon rinds was lower than the values reported by Morais *et al.* (2017) and Sadiq *et al*. (2022). However, D2, D3, and D4 showed higher sodium levels compared to those studies, though still lower than the values reported by INRAE-CIRAD-AFZ (2020). The variation in sodium levels may be due to differences in soil nutrient availability, organic matter content, topography, and the drying techniques used. The potassium content in pineapple peels was lower than the values reported by Kamau *et al*. (2020). However, higher values were observed in watermelon rinds compared to those reported by Yargamji *et al*. (2024). The potassium content in D2, D3, D4, and D5 was also higher than that reported by the same author, though slightly lower than the values reported by INRAE-CIRAD-AFZ (2020).

The energy composition of pineapple peels reported in this study is in line with the findings of Mallam *et al*. (2023), who reported energy values ranging from 2084.00kcal/kg to 2328.80 kcal/kg. However, the energy content of watermelon rinds was higher than the values reported by Yargamji *et al*. (2024). According to INRAE-CIRAD-AFZ (2020) the energy content of wheat bran ranges between 3930 and 4520 kcal/kg, which is higher than the values obtained in this study. However, values obtained in D3 were higher compared to other diets, which shows that D3 would serve as a better source of energy.

There was a decrease in the feed cost as the diet progressed from Diet 1 to 5. The increase in the cost per kg of D1 is due to the high cost of purchasing wheat bran and carrots. However, D5, which reported the least cost, was because the fruit waste was gotten free and the only cost incurred was for the carrot (moisture source). Thus, the decrease in the feed cost across the diet was due to the inclusion of the fruit wastes across the treatments. According to Aniebo *et al*. (2009), the feed cost reduces with the inclusion of

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alternative feedstuffs. The positive and highest cost differential of 1.78/kg obtained in D5, compared to the negative differentials observed in D2, D3, and D4, indicates that less money is required to produce a kilogram of mealworm using D5 than with the control diet. Additionally, D5 demonstrated the highest and positive relative cost advantage of 3.01% over the control diet. Although D5 had the lowest feed cost and highest relative cost advantage, its reduced growth performance may limit its suitability for commercial production. Therefore, D4 may represent a more balanced compromise between cost and biological efficiency.

The larvae fed solely on wheat bran (D1) showed higher length, weight, and SGR compared to the other larvae that received a mixture of pineapple and watermelon waste supplementation. This differs from the findings of Lopez-Gamez *et al*. (2024), who reported that *T. molitor* larvae fed solely on wheat bran exhibited lower weight than those fed with vegetable waste supplementation. The length of larvae supplemented with fruit wastes was similar, with D4 higher than the other diets supplemented with fruit wastes. The highest final larval weight observed in D1 was greater than the 140.4 mg reported by Bordien *et al*. (2022), where mealworm larvae were reared on 100% wheat bran. However, the larval weight reported by the same authors after rearing on a mixture of wheat bran and chicken feed (136.9 mg and 135.5 mg) was slightly higher than the values reported for larvae reared on wheat bran supplemented with fruit wastes (101.57 mg - 106.47 mg) in the present study. The values obtained in this study were comparable to the 110 mg reported by Liu *et al*. (2020), who reared larvae solely on wheat bran without a water source. Additionally, larvae reared on D4 were both longer and heavier than those fed on each substrate alone. It is possible that the mixed diets balanced the nutritional requirements of the larvae (Morales-Ramos *et al*., 2020). The reduced performance in larvae reared on D5 may be attributed to a lower crude protein level, higher fiber content, mineral imbalance and absence of wheat bran in D5. The larval weight at harvest in the mixed diets aligns with the results obtained when mealworm larvae were fed on dried watermelon rinds (Loh *et al*., 2018), which reached an average weight of 102.26 mg. The differences in performance compared to the literature could be due to factors such as the type of feed used, the water source (or lack of water source), the origin of the strain, and rearing temperature.
The Feed Conversion Ratio (FCR) of the larvae reported in this study was lower compared to previous studies by Van-Broekhoven *et al.* (2015) and Bordien *et al*. (2020), where larvae were reared on 100% chicken feed and wheat bran, and willow leaf sunflower diets. The lower FCR value (0.42 – 0.98) observed in larvae reared on a mixture of diets or solely on wheat bran indicates that the larvae utilized less feed, converting it more efficiently into body mass, which is indicative of better feed conversion (Bordien *et al*., 2022). The survival rate of mealworm larvae was high across treatments, ranging from 81.20% to 87.33%. This survival rate is in line with the range reported by Bordien *et al*. (2022), who observed survival rates of 89.3%, 89.7%, 91.75%, and 92.5% in larvae fed on wheat bran supplemented with chicken feed and vegetables.

Conclusion

Based on the findings of this study, the incorporation of pineapple and watermelon peels into the diet of *Tenebrio molitor* larvae is a viable option, particularly when used as a partial replacement (D4) for wheat bran compared to full replacement (D5), indicating that fruit peels can effectively complement conventional feed ingredients when nutritionally balanced. This also suggests that fruit peels alone may not adequately meet the protein and nutrient requirements necessary for optimal larval development. Therefore, their use is more appropriate as a supplementary feed rather than a sole feed substrate. In addition, utilization of pineapple and watermelon peels, an agro-industrial by-product that is typically discarded, offers potential cost savings in feed formulation while contributing to waste valorization. This approach aligns with circular economy principles by converting low-value organic waste into high-value insect biomass. Further studies should explore the potential of other fruit peels and agricultural by-products as feed for *T. molitor* larvae and other insects. This could lead to a broader application of waste reduction strategies in insect farming

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