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REVIEW

Nutritional profile, processing potential and food applications of *Macrotermes nigeriensis* powder: A comprehensive review

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Abstract
Macrotermes nigeriensis is increasingly recognized as a nutrient-dense edible insect with significant potential for food and non-food applications. This review synthesizes current evidence on proximate composition, mineral and vitamin content, amino acid and fatty acid profiles, functional properties, and safety considerations of its powder. Existing studies consistently report high levels of protein, essential minerals (Fe, Zn), and vitamin C, together with low concentrations of antinutritional factors. When incorporated into various food matrices (including cakes, biscuits, and fermented cassava beverages) *M. nigeriensis* powder markedly enhances protein density, micronutrient content, and, in some cases, sensory acceptability. Protein isolates exhibit desirable emulsifying and foaming properties, supporting their potential use in food formulation. Beyond nutrition, the species also provides oils that may serve as unconventional feedstock for biodiesel production. Overall, *M. nigeriensis* represents a promising sustainable protein resource, but further multidisciplinary investigation is required to support its large-scale utilization. Future research should focus on: (i) long-term safety and toxicological evaluation, (ii) nutrient bioavailability and digestibility, (iii) detailed lipid profiling and its health implications, (iv) standardization of processing and preservation methods, and (v) consumer acceptance and market feasibility beyond endemic regions.

Keywords: edible insect; functional properties; *Macrotermes nigeriensis* powder; sustainable protein.

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1. Introduction
In the context of the increasingly urgent need to develop sustainable, nutritious, and environmentally friendly food sources, edible insects are attracting great attention from the scientific community and food industry (Abbasi, 2025). Among them, termites of the genus *Macrotermes* stand out due to their high nutritional value, outstanding protein content, and sustainable exploitation ability (Cheseto et al., 2024). In particular, *Macrotermes nigeriensis* – a termite species native to the African region – has been traditionally consumed for generations and is increasingly being researched as a potential novel food source (Anyiam et al., 2022a). Many recent studies have noted that *M. nigeriensis* possesses a high protein content, is rich in essential amino acids, has a significant proportion of unsaturated fatty acids, and is a source of trace minerals such as iron, zinc, copper, and calcium at relatively high levels compared to many common animal sources (Cheseto et al., 2024). In addition to the core nutritional components, termites also contain biological compounds, such as polyphenols and peptides, with antioxidant activity, which contribute to enhancing the functional value of food when applied (Khadijah et al., 2025).
Besides its nutritional value, the potential applications of *M. nigeriensis* in food are also expanding, from alternative protein sources and enriched powder to processed products such as snacks, nutrition bars, and fermented ingredients (Choi et al., 2026). Some initial tests show that termite powder can improve the protein, mineral, and sensory content of the product; at the same time, low production costs and efficient farming and harvesting capabilities contribute to increasing the sustainability of this raw material source (Boulogne et al., 2017). However, to develop it into a commercial food, a comprehensive

safety assessment is needed, including acute and subchronic toxicity and potential allergic reactions, as well as the impact of handling and processing on the biochemical composition.

Therefore, this review aims to systematize and analyze the existing data on *M. nigeriensis*, including nutritional composition (protein, lipid, amino acid, fatty acid, and mineral), safety and toxicity factors, and current and potential applications in the food sector. This synthesis not only helps to clearly identify the value of this termite species but also points out research gaps that need to be further exploited to promote the application of insects as a sustainable food source in the future.

2. Processing methods of *Macrotermes nigeriensis* powder (MNP)

Table 1 showed that the processing of *M. nigeriensis* powder varied significantly across study groups at all steps, from pretreatment to drying, grinding, and storage. This reflects the lack of standardization in the collection and processing of edible insects in Nigeria and suggests that each study optimized the process according to its own objectives. In general, the most common steps were washing, wing–leg separation, low-temperature drying (40 – 45 °C), and grinding to powder, but the details of time, temperature, and preheat treatment (such as blanching) varied widely.

In terms of pretreatment, two studies by Anyiam et al. (2022a; 2023) used a 1 – 2 min blanching step, which is considered a mild heat treatment to reduce microorganisms and inactivate enzymes that may cause discoloration or lipid degradation. In contrast, Ojinnaka et al. (2013) and Igwe et al. (2011b) did not perform blanching, leading to the observed differences in the milled product. In particular, the lack of blanching combined with the lipid-rich nature of *M. nigeriensis* may explain why Ojinnaka et al. (2013) obtained an oily paste instead of a dry powder, suggesting greater oil release during milling. Another different procedure is that of Omotoso et al. (2015), where the sample was subjected to a 4-h cold asphyxiation before drying (a rare method in insect raw material processing) which may reduce postharvest metabolism but increase the processing time.

Regarding drying conditions, most studies used low temperatures (40 – 45 °C) to limit protein denaturation and lipid oxidation. However, drying times varied considerably: Anyiam et al. (2023) reported 8 h, while Anyiam et al. (2022a) required approximately 12 h to reach constant mass, suggesting that the initial moisture content or sample size may have been different. Omotoso et al. (2015) was the only case to use a higher temperature (60 °C for 4 h), which shortened the time but risked affecting heat-sensitive components. The lack of a detailed description of sample size, drying layer thickness, or air circulation rate limits the comparison of drying efficiency between studies.

The grinding and sieving processes also exhibited heterogeneity. Some studies (Anyiam et al., 2022a) explicitly described the sieve size (250 μm), while Anyiam et al. (2023) did not specify the size, making it difficult to assess the true fineness of the powder. Notably, Igwe et al. (2011b) used a hand mill, which may have given a lower degree of homogeneity than an electric mill. Ojinnaka et al. (2013) were unable to form a powder and obtained an oily paste, making the product unsuitable for dry powder applications. Overall, this difference may directly affect the solubility, dispersibility, and subsequent food applications. Compared to *M. bellicosus* in the study of Atowa et al. (2021), their procedure is more standardized and tightly controlled. All samples were dewinged, cleaned with deionized water, drained on perforated trays, and then dried at 65 °C for 12 h, higher and longer than most studies on *M. nigeriensis*.

Table 1
Summary of collection sites and processing methods of *M. nigeriensis*

Collection site & season	Pre-treatment	Drying conditions	Milling & sieving	Notes	References
Umudike, Nigeria; early morning, rainy season	Washed, dewinged & de-legged; blanched 1 min in boiling water	40 °C, 8 h	Milled → sieved (not specified μm)	Produced fine powder	Anyiam et al. (2023)
Umudike, Nigeria; May–June	Washed 3 times; dewinged & de-legged; blanched 2 min	45 °C until constant weight (~12 h)	Milled → sieved 250 μm	Brown fine powder	Anyiam et al. (2022a)
Nigeria; early rainy season (Mar–May)	No blanching reported	40 °C to constant weight	Milled → oily paste	Used to enrich wheat cake (0 – 20%)	Ojinnaka et al. (2013)
Nigeria; early morning, July	Washed; dewinged; no blanching	40 °C to constant weight	Ground (hand mill)	Stored at 4 °C	Igwe et al. (2011b)
Ekiti State, Nigeria	Larvae asphyxiated 4 h (fridge)	60 °C for 4 h	Blended	Stored airtight in refrigerator	Omotoso et al. (2015)

The application of higher temperatures may result in better microbial reduction but also carries the risk of lipid oxidation and greater protein denaturation. In addition, Atowa et al. (2021) clearly described the grinding step using an electric mill and a 200 µm sieve, which resulted in a uniform fine powder thanks to a fully mechanized process. This contrasts with many studies on *M. nigeriensis*, which lack detailed descriptions or use of semi-manual equipment. Overall, the main difference between the two species or between research groups lies in the level of standardization. The protocol of Atowa et al. (2021) for *M. bellicosus* is consistent and controls many important parameters (type of wash, temperature, time of drying, sieve size), while studies on *M. nigeriensis* remain largely at the level of incomplete experimental descriptions and vary considerably between groups, affecting the comparability of nutritional and functional data.

3. Nutrition composition of *M. nigeriensis* powder (MNP)

The nutritional composition of MNP shows marked variation between different regions, reflecting the complex effects of habitat, food sources, termite developmental stages, and post-harvest handling methods (Table 2).

Table 2
Nutrition composition of MNP (%)

	Owerri, Nigeria (Igwe et al., 2011b)	Ekiti State of Nigeria (Omotoso et al., 2015)	Zaria, Nigeria (Muinat and Tariq, 2021)
Moisture	10.78	4.52	3.21
Protein	20.94	37.54	58.99
Lipid	34.23	48.03	18.90
Ash	7.60	3.24	5.32
Crude fibre	5.71	5.00	7.09
Carbohydrate	20.74	2.06	1.48

The moisture content of MNP showed significant differences between locations. Samples collected in Owerri, Nigeria, had the highest moisture content (10.78%), while those from Ekiti, Nigeria (4.52%), and Zaria (3.21%) were significantly drier, suggesting the influence of drying method and environmental conditions at the collection site (Igwe et al., 2011b; Omotoso et al., 2015; Muinat and Tariq, 2021). When compared with other species, the moisture content of *M. subhyalinus* powder at 6.50% was between the above values, while *M. falciger* powder (4.1%) and *M. bellicosus* powder (4.3%) were similar to the samples from Ekiti and Zaria, confirming that processing plays a more important role than species characteristics (Kinyuru et al., 2013; Siulapwa et al., 2014; Adepoju and Omotayo, 2014).

Protein content varied greatly among the three survey areas, with the sample from Zaria, Nigeria, exhibiting a very high value (58.99%), far exceeding the sample from Ekiti, Nigeria (37.54%), and especially the sample from Owerri (20.94%), suggesting nutritional differences in populations due to food sources and habitats (Igwe et al., 2011b; Omotoso et al., 2015; Muinat and Tariq, 2021). When compared between species, the protein value of MNP from Zaria was within or even exceeded that of *M. subhyalinus* powder (39.34%), *M. falciger* powder (43.26%), *M. bellicosus* powder (36.7%), and also the wide range of *M. natalensis* powder (34.39 – 47.73%), emphasizing the potential of Zaria samples as a source of high-quality protein (Kinyuru et al., 2013; Siulapwa et al., 2014; Adepoju and Omotayo, 2014; Musundire et al., 2021).

Lipid composition showed opposite trends to protein, with the Ekiti sample having a very high fat content (48.03%), followed by Owerri (34.23%), while the Zaria sample contained much lower lipid content (18.90%), reflecting the compensation between lipid and protein in insect body composition (Igwe et al., 2011b; Omotoso et al., 2015; Muinat and Tariq, 2021). Compared to other species, the lipid of the Ekiti sample was comparable to *M. subhyalinus* powder (44.82%) and M. falciger powder (43.0%), while *M. bellicosus* powder was also high (34.3%). In contrast, *M. natalensis* powder had much lower lipid content (5.91 – 8.27%), suggesting that ecological diversity strongly influences lipid accumulation (Kinyuru et al., 2013; Siulapwa et al., 2014; Adepoju and Omotayo, 2014; Musundire et al., 2021).

In terms of ash content, the Owerri sample (7.60%) had higher total mineral values than the Zaria (5.32%) and Ekiti (3.24%) samples, reflecting differences in geological features and dietary composition (Igwe et al., 2011b; Omotoso et al., 2015; Muinat and Tariq, 2021). When compared to other *Macrotermes* powders, this content is similar to *M. subhyalinus* powder (7.58%) and *M. falciger* powder (7.3%), and is also in the lower end of the *M. natalensis* powder level (6.53 – 10.33%), while *M. bellicosus* powder has a very low ash content (1.2%), suggesting that the difference may be due to habitat or nest structure (Kinyuru et al., 2013; Siulapwa et al., 2014; Adepoju & Omotayo, 2014; Musundire et al., 2021).

For fiber, levels of samples in the three localities are quite similar (5.00 – 7.09%), with the Zaria sample being the highest and reflecting the chitin content in the cuticle (Igwe et al., 2011b; Omotoso et al., 2015; Muinat & Tariq, 2021). In comparison, *M. subhyalinus* powder (6.37%) had similar values, while *M. natalensis* powder had significantly higher fiber (9.21 – 10.67%), and *M. bellicosus* powder had very low levels (0.3%), suggesting differences in body size and chitin hardening between species (Kinyuru et al., 2013; Musundire et al., 2021; Adepoju & Omotayo, 2014).

Finally, carbohydrates showed the greatest variation, with Owerri samples containing high levels of carbohydrates (20.74%), while Ekiti (2.06%) and Zaria (1.48%) samples had very low levels (Igwe et al., 2011b; Omotoso et al., 2015; Muinat & Tariq, 2021). The high value of the Owerri sample is similar to that of *M. bellicosus* powder (23.2%) and close to that of *M. falciger* powder (32.8%), while the low carbohydrate value of the Ekiti and Zaria samples is consistent with that of *M. subhyalinus* (1.89%) and with that of the sample analyzed by Séré, which was only 0.92% (Kinyuru et al., 2013; Siulapwa et al., 2014; Adepoju & Omotayo, 2014; Séré et al., 2022). This suggests that the carbohydrate composition of MNP is more strongly dependent on ecological and processing conditions than on species specificity.

4. Mineral composition of MNP

The mineral content of MNP shows great variability between locations and species, reflecting the influence of habitat, species characteristics, and even developmental stage (Table 3).

Data from Nigeria show that the local collection of Igwe et al. (2011b) had relatively low calcium and phosphorus levels of 1.00 and 14.90 mg/kg, respectively, while the sample from Ekiti State (Omotoso et al., 2015) recorded significantly higher concentrations, especially calcium at 230.67 mg/kg. However, when compared to other *Macrotermes* species, these values are still significantly different; for example, *M. subhyalinus* powder had calcium at 7.46 mg/kg (Séré et al., 2022), while *M. bellicosus* powder reached an outstanding 2690 – 22650 mg/kg (Adepoju & Omotayo, 2014). This suggests that the intrinsic differences between other *Macrotermes* powders may determine a much stronger mineral accumulation capacity than the local populations of Nigeria. This result suggests the potential for calcium extraction from large *Macrotermes* species such as *M. bellicosus* for mineral supplementation purposes.

Regarding the macronutrients potassium and sodium, according to studies by Igwe et al. (2011b) and Omotoso et al. (2015), MNP ranged from 2757 to 3360 mg/kg and 1120 to 1569 mg/kg, which are much lower than other species. For example, *M. subhyalinus* powders reached potassium levels of 6356.1 mg/kg (Séré et al., 2022), while Musundire et al. (2020) recorded *M. natalensis* levels of 10577 – 12872 mg/kg, which are nearly 3 – 4 times higher than those of Nigerian termites. In contrast, sodium in Nigerian termites (1120 – 1569 mg/kg) was higher than that in *Nasutitermes* spp. powder (1236.1 – 1260.1 mg/kg; Gachihi et al., 2023) but still lower than that in *M. bellicosus* powder (1980 – 9630 mg/kg; Adepoju & Omotayo, 2014).

With trace minerals, the differences were even more pronounced. Samples from Nigeria had relatively low levels of zinc and copper (0.97 – 15.50 mg/kg Zn; 0.10 – 0.72 mg/kg Cu), while *M. natalensis* powder exhibited superior levels, especially copper 409.5 – 468.9 mg/kg and zinc 617.3 – 928.0 mg/kg (Musundire et al., 2021). *M. bellicosus* powder also exhibited consistent and high levels of these elements, with zinc ranging from 180 to 313 mg/kg and copper from 190 to 450 mg/kg (Adepoju & Omotayo, 2014). Iron content also showed a similar difference: Nigeria recorded only 9.56–10.59 mg/kg, while Kinyuru et al. (2013) found *M. subhyalinus* powder reached 53.3 mg/kg, and *M. natalensis* powder even spiked to 2020.8 – 4283.0 mg/kg (Musundire et al., 2021). This demonstrates that not all termite species are equal sources of trace minerals, and some species may be particularly important in supplementing mineral-deficient populations.

When comparing species groups, it can be seen that *Macrotermes* powder generally outperforms Nasutitermes powder in most mineral parameters, especially in iron and zinc (*Nasutitermes* spp. only reached iron 7.80 – 8.82 mg/kg and zinc 22.93 – 34.58 mg/kg; Gachihi et al., 2023). However, *Nasutitermes* powder still has relatively high calcium and potassium values, suggesting potential use as an alternative mineral source in areas where *Macrotermes* is not common. Overall, the diversity in mineral composition among species suggests that edible insects, especially termites, can be a rich source of natural micronutrients if the right species are selected and the collection process is standardized. Taken together, mineral analysis of termite species from different regions and sources highlights that many *Macrotermes* powders, especially *M. bellicosus* powder, *M. natalensis* powder, and *M. subhyalinus* powder, possess superior mineral contents, making them potential candidates for the development of natural mineral supplements, as well as strategies to combat micronutrient deficiencies in high-risk areas.

5. Antinutrient composition of MNP

The composition of antinutrients among termite species shows wide variation and is strongly dependent on species and environmental conditions (Table 4). For MNP, data from Omotoso et al. (2015)

and Oibiokpa et al. (2018) showed a relatively low tannin content (0.59 mg/100 g), which is within the range of values commonly found in edible termite species. This is higher than that of *M. falciger* powder, which only reached 0.02 mg/100 g (Kunatsa et al., 2020), but still lower than that of *Nasutitermes* spp. powder, where tannins ranged from 0.72 to 1.69 mg/100 g (Gachihi et al., 2023). For species such as *M. bellicosus* powder and *M. subhyalinus* powder, tannin content was also very low (0.008 mg/100 g in *M. bellicosus* and 0.047 – 0.055 mg/100 g in *M. subhyalinus* powder), suggesting that *Macrotermes* powder is generally a food source with negligible tannin levels.

In terms of phytate, its content in MNP was 15.21 mg/100 g, similar to that observed in M. subhyalinus powder (15.6 – 130 mg/100 g; Ajayi, 2012), but significantly higher than *M. bellicosus* powder, which was only 0.003 mg/100 g (Adepoju & Omotayo, 2014). *Nasutitermes* spp. The lowest phytate levels (0.24 – 0.67 mg/100 g; Gachihi et al., 2023) suggest that this group has a lower risk of interfering with mineral absorption than most *Macrotermes* species. In addition, *M. nigeriensis* powder also contained phytin phosphorus at 4.29 mg/g, suggesting that the extent of mineral binding via phytin complexes may affect micronutrient absorption if consumed in large amounts.

The oxalate content showed more pronounced differences. In MNP, oxalate ranged from 1.03 to 2.03 mg/g, much lower than *M. falciger* powder, which had oxalate levels up to 14.08 mg/g (Kunatsa et al., 2020). *M. bellicosus* powder had intermediate values (8.0 mg/g), while *M. subhyalinus* powder was very low at 0.054 – 0.117 mg/g (Ajayi, 2012). In contrast, *Nasutitermes* spp. also recorded only 0.027–0.788 mg/g (Gachihi et al., 2023), suggesting that this group generally has significantly lower oxalate levels than most *Macrotermes*, thereby reducing the risk of oxalate stone formation if used as food.

The difference is even bigger in the group of saponins and other secondary compounds. MNP contained 0.99 – 1.47 g/100 g of saponins, which is significantly lower than that of *M. falciger* powder (57 g/100 g) and *M. bellicosus* powder (20 g/100 g) (Omotoso et al., 2015; Kunatsa et al., 2020; Adepoju and Omotayo, 2014). These are very high values, far exceeding the range commonly found in many natural food sources, suggesting that dosages should be considered when exploiting these species as food. Additionally, *M. nigeriensis* powder contained 0.32 g/100 g of alkaloids and 0.19 g/100 g of flavonoids, two compounds that have not been reported in most other *Macrotermes* species, suggesting chemical differences and the potential to produce unique bioactivities (Omotoso et al., 2015).

Overall, antinutrient data show that *Macrotermes* species are generally low in tannins, but phytate and oxalate levels vary widely by species. MNP have an intermediate antinutrient profile, while *Nasutitermes* spp. generally have the lowest levels of nutritional inhibition. Species such as *M. falciger* and *M. bellicosus* require further evaluation for heat treatment or processing to reduce saponins and oxalates before use. Due to this chemical diversity, termites are not only a remarkable source of protein and minerals but also have the potential to be developed into functional foods if processing is optimized to limit antinutrients.

6. Vitamin composition of MNP

According to Table 5, the vitamin composition of *Macrotermes* powders shows significant variation between studies and geographical areas, reflecting differences in species, sampling period, and environmental conditions.

Table 5
Vitamin composition of MNP and other powder (mg/100 g)

	MNP (Igwe et al., 2011b)	*Marcrotermes bellicosus* (Adepoju & Omotayo, 2014)	*Cirina forda* (Atowa et al., 2021)
Vitamin A	0.35	0.01 – 0.33	6.89
Vitamin C	17.76	0.97 – 3.58	9.13
Riboflavin	1.56	0.01 – 0.32	5.31
Thiamin	0.67	0.09 – 0.87	0.64
Niacin	2.74	0.85 – 1.59	1.08

For MNP, data from Igwe et al. (2011b) showed that vitamin A content was 0.35 mg/100 g, which is in the average range compared to *M. bellicosus* powder in Adepoju & Omotayo (2014), where values ranged from 0.01 to 0.33 mg/100 g. However, when compared to *Cirina forda* powder in Atowa et al. (2021), vitamin A content was significantly higher at 6.89 mg/100 g, suggesting that this species has the potential to be a significantly better source of provitamin A micronutrients depending on ecological conditions and postharvest handling. The vitamin C content of MNP is 17.76 mg/100 g, which was much higher than the 0.97 – 3.58 mg/100 g of *M. bellicosus* powder reported by Adepoju & Omotayo (2014). This was even significantly higher than the 9.13 mg/100 g in Atowa et al. (2021). This suggests that *M. nigeriensis* powder may be one of the richest in vitamin C among the *Macrotermes* powders, which could contribute significantly to the antioxidant capacity if used as food.

Table 3
Mineral composition of MNP and other powder (mg/kg)

Minerals	*M. nigeriensis* Nigeria (Igwe et al., 2011b)	*M. nigeriensis* Ekiti State, Nigeria (Omotoso et al., 2015)	*M. subhyalinus* (Kinyuru et al., 2013)	*M. falciger* (Siulapwa et al., 2014)	*M. natalensis* (Musundire et al., 2021)	*M. subhyalinus* (Séré et al., 2022)	*M. bellicosus* (Adepoju & Omotayo, 2014)	*Nasutitermes* spp (Gachihi et al., 2023)
Calcium	1.00	230.67	5.87	7.8	-	7.46	2690 – 22650	562.8 – 1285.0
Phosphorus	14.90	103.47	-	-	1446.7 – 2466.4	-	14630 – 35850	-
Magnesium	60.96	125.0	-	490	-	49.86	1070 – 2360	-
Potassium	3360.00	2757.0	-	1270	10577 – 12872	6356.1	7510 – 16250	2446.1 – 2601.0
Sodium	1120.00	1569.0	-	1270	2475.5 – 3380.3	748.2	1980 – 9630	1236.1 – 1260.1
Cobalt	0.20	-	-	-	-	-	-	-
Selenium	0.04	-	-	-	-	-	-	-
Chromium	0.25	-	-	-	-	-	-	-
Copper	0.72	0.10	-	7.0	409.5 – 468.9	-	190 – 450	-
Iron	9.56	10.59	53.3	85	2020.8 – 4283.0	11.76	85 – 142	78 – 88.2
Zinc	0.97	15.50	8.1	-	617.3 – 928.0	13.18	180 – 313	229.3 – 345.8
Manganese	0.81	1.26	-	15	-	-	96 – 227	-

Note: "-" not detected.

Table 4
Antinutrient composition of MNP and other powder

	Macrotermes nigeriensis (Omotoso et al., 2015; Oibiokpa et al., 2018)	*Macrotermes facilger* (Kunatsa et al., 2020)	*Marcrotermes bellicosus* (Adepoju & Omotayo, 2014)	*Macrotermes subhyalinus* (Ajayi, 2012)	*Nasutitermes* spp (Gachihi et al., 2023)
Tannin (mg/100 g)	0.59	0.02	0.008	0.047 – 0.055	0.72 – 1.69
Phytate (mg/100 g)	15.21	-	0.003	15.6 – 130	0.24 – 0.67
Phytin phosphorus (mg/g)	4.29	-	-	-	-
Oxalate (mg/g)	1.03 – 2.03	14.08	8.0	0.054 – 0.117	0.027 – 0.788
Saponin (g/100 g)	0.99 – 1.47	57.00	20	-	-
Alkaloids (g/100 g)	0.32	-	-	-	-
Flavonoid (g/100 g)	0.19	-	-	-	-

Note: "-" not detected.

For the B vitamin group, MNP continued to show outstanding values. Riboflavin content was 1.56 mg/100 g, significantly higher than the 0.01 – 0.32 mg/100 g of *M. bellicosus* powder (Adepoju & Omotayo, 2014), and extremely lower than the *Cirina forda* (5.31 mg/100 g) reported by Atowa et al. (2021), although the difference was narrower. On the other hand, thiamin in MNP was 0.67 mg/100 g, similar to some values from *M. bellicosus* powder (0.09 – 0.87 mg/100 g; Adepoju & Omotayo, 2014), and the *Cirina forda* powder 0.64 mg/100 g reported by Atowa et al. (2021). Niacin was recorded at 2.74 mg/100 g, significantly higher than 0.85 – 1.59 mg/100 g (Adepoju & Omotayo, 2014) and far exceeding 1.08 mg/100 g of Atowa et al. (2021). These results suggest that MNP is a species with a relatively higher content of B vitamins than *M. bellicosus* powder in many studies, especially for riboflavin and niacin.

Overall, analysis of Table 5 shows that MNP stands out with higher levels of vitamin A, C, and B vitamins than some other species of the genus, while *M. bellicosus* powder shows strong variability from study to study. These differences again reflect the importance of environmental conditions, sample source, and post-harvest handling methods. Thanks to its high and stable vitamin content in many parameters, MNP shows significant potential for development as a source of micronutrient supplements or ingredients in nutritionally enhanced products.

7. Fatty acid of MNP

Table 6, the fatty acid profile of MNP shows a clear predominance of unsaturated fatty acids, of which oleic acid (C18:1) has the highest proportion at 52.45% (Igwe et al., 2011b). This value far exceeds that of *M. bellicosus* powder in the study of Atowa et al. (2021), which only reached 23.89%, and is also in the same range as other *Macrotermes* species rich in oleic acid, such as *M. subhyalinus* powder, reaching 48.60-50.04% (Séré et al., 2022; Kinyuru et al., 2013). This suggests that *M. nigeriensis* powder tends to be rich in MUFA, which is considered beneficial for the cardiovascular system and lipid metabolism. Regarding linoleic acid (C18:2), an essential PUFA, MNP recorded a level of 7.57%, which is much lower than *M. bellicosus* powder (19.92%; Atowa et al., 2021) and even lower than *M. subhyalinus* (7.01 - 10.75%; Kinyuru et al., 2013; Séré et al., 2022), suggesting that *Macrotermes* species can be divided into two groups: those rich in PUFA (e.g., *M. bellicosus* powder) and those rich in MUFA (monounsaturated lipids) (e.g., *M. nigeriensis*, *M. subhyalinus* powder).

Although the PUFA content of *M. nigeriensis* is not high, the balance between oleic and linoleic acid still provides a lipid profile beneficial to health. Saturated fatty acids (SFA) in MNP were relatively high, mainly due to palmitic acid (31.39%), but still within the typical range for the *Macrotermitinae* family. In comparison, *M. bellicosus* had only 9.27% palmitic acid (Atowa et al., 2021), indicating a large variation between studies and possibly due to diet or collection period. Meanwhile, *M. subhyalinus* powder (27.26% - 27.65%; Kinyuru et al., 2013; Séré et al., 2022) had values closer to MNP, suggesting a more stable trend within the *Macrotermes* group regarding palmitic acid.

The stearic acid content of *M. nigeriensis* (7.14%) was also similar to other species, such as *M. subhyalinus* (6.34 - 11.93%). The TUFA content of MNP was 60.64%, higher than the TSFA (39.35%), indicating the predominance of cardioprotective lipids. This structure is also similar to *M. subhyalinus*, which has a total unsaturated content of up to 64.95% (Kinyuru et al., 2013; Séré et al., 2022).

In contrast, *M. bellicosus* in the study of Atowa et al. (2021) has a very high PUFA content (26.69%), but significantly lower MUFA, resulting in a distinct lipid profile that clearly reflects the intrinsic nutritional diversity among the species

Table 6
Fatty acid of MNP and other powder (%)

	MNP (Igwe et al., 2011b)	*M. bellicosus* (Atowa et al., 2021)	*M. subhyalinus* (Kinyuru et al., 2013; Séré et al., 2022)
Lauric acid (C12:0)	0.20	-	0.07
Myristic (C14:0)	0.62	8.01	0.38 – 1.06
Palmitic acid (C16:0)	31.39	9.27	27.26 – 27.65
Palmitoleic acid (C16:1)	0.62	7.89	1.19 – 4.17
Stearic acid (C18:0)	7.14	5.29	6.34 – 11.93
Oleic acid (C18:1)	52.45	23.89	48.60 – 50.04
Linoleic acid (C18:2)	7.57	19.92	7.01 – 10.75
Total unsaturated fatty acid (TUFA)	60.64	-	35.05 – 40.96
Monounsaturated fatty acid (MUFA)	53.07	36.57	64.95
Polyunsaturated fatty acid (PUFA)	7.57	26.69	51.75 – 52.77
Total saturated fatty acid (TSFA)	39.35	36.57	7.26 – 12.18

Note: "-" not shown.

Data showed that MNP had a TSFA content of 39.35%, which was significantly higher than that of *M. subhyalinus* in two recent studies (12.18% – Kinyuru et al., 2013; 7.26% – Séré et al., 2022), but comparable to *M. bellicosus* (36.57% – Atowa et al., 2021). This relatively high TSFA level was mainly due to palmitic acid (31.39%) and stearic acid (7.14%) contents, reflecting the relatively stable lipid profile of the species. In a nutritional context, not-so-low TSFA levels may mitigate the health advantage over MUFA/PUFA-rich species; but combined with the prominent high MUFA ratio of MNP, the overall fatty acid profile still suggests a fairly balanced lipid quality (Sun et al., 2025). Overall, MNP's TSFA is intermediate to high among *Macrotermes*, reflecting a lipid profile that is stable yet flexible enough to support the nutritional value of this species.

Overall, MNP possesses a fatty acid profile characterized by high MUFA content, with a clear dominance of oleic acid, accompanied by moderate PUFA and stable SFA levels. This balanced distribution not only contributes to the formation of favorable lipid quality but also positions the species as a potential source of lipids for nutritional supplements and functional food products. In particular, in the context of increasing demand for sustainable protein-lipid sources from insects, MNP emerges as a promising candidate due to its high fat content, which increases the energy density of the product.

However, to optimize the application directions, especially in areas such as food, clinical nutrition, or industry, more detailed data on the structure and variation of fatty acid composition, as well as the influence of processing, habitat, and growth stage, are needed. This information will help to more accurately orient the strategies for exploitation and application of lipids from this species.

8. Amino acid of MNP

Based on the data summarized in Table 7, the amino acid profile of MNP exhibits a relatively high and balanced protein quality, suggesting that this species is a potential nutritional source.

The essential amino acid (EAA) contents, such as lysine (2695 mg/100 g), leucine (3395 mg/100 g), valine (2153 mg/100 g), threonine (1838 mg/100 g), and isoleucine (1886 mg/100 g), are at remarkable levels, reflecting the potential to contribute well to human EAA requirements. In particular, leucine (an amino acid important for muscle protein synthesis) is present at relatively high levels compared to many other insect species. In addition, the high glutamic acid and aspartic acid content (5688 and 2984 mg/100 g) suggests a potential for natural umami flavor, which may be useful in applications for developing foods with stronger flavors (Oibiokpa et al., 2018).

When compared to *M. bellicosus* powder (Atowa et al., 2021), this species generally has higher amino acid concentrations than MNP on most parameters. For example, leucine and lysine in *M. bellicosus* powder reached 5307 and 4204 mg/100 g, far exceeding those of MNP. The arginine and glutamic acid content was also more than twice as high. This may be due to differences in sample type, environmental conditions, diet, or life stage, but overall suggests that *M. bellicosus* powder has a superior protein quality within the group.

Table 7
Amino acid of MNP and other powder (mg/100 g)

	M. nigeriensis (Oibiokpa et al., 2018)	*M. bellicosus* * (Atowa et al., 2021)	*M. falciger* (Siulapwa et al., 2014)	*M. subhyalinus* * (Séré et al., 2022)
Lys	2695	4204	-	-
Thr	1838	2927	1950	9176 – 12759
Val	2153	3364	2170	186 – 5610
Met	341	532	820	-
Iso	1886	2982	1890	1465 – 3607
Leu	3395	5307	3160	7817 – 8753
Phe	1956	2879	1970	-
Try	1033	-	350	-
His	1343	2081	2650	1557 – 2078
Arg	2630	4646	3010	686 – 5786
Asp	2984	4672	3730	9159 – 13666
Ser	2231	3446	2080	4432 – 6842
Glu	5688	8878	4680	9492 – 11804
Pro	2581	3800	1930	1604 – 7426
Gly	2630	4156	1890	8447 – 12006
Ala	2595	4045	2740	3440 – 4831
Cys	175	184	130	-
Tyr	2083	3159	3440	-

* Convert from mg/100 g protein to mg/100 g, "-" not detected.

Meanwhile, *M. falciger* powder exhibited a more heterogeneous amino acid profile compared to MNP (Siulapwa et al., 2014). Although many amino acids, such as cysteine and tryptophan, appeared at relatively low levels (ranging from 130 to around 350 mg/100 g), others, particularly tyrosine (3440 mg/100 g) and leucine (3160 mg/100 g) were comparable to or even higher than those in MNP. This reflects a notable variability in protein composition within this species.

In contrast, *M. subhyalinus* showed extremely broad and elevated amino acid ranges, with essential amino acids such as threonine, valine, leucine, and histidine reaching 9176 – 12759, 186 – 5610, 7817 –8753, and 1557 – 2078 mg/100 g, respectively (Séré et al., 2022). Non-essential amino acids, including aspartic acid (9159 – 13666 mg/100 g), glutamic acid (9492 – 11804 mg/100 g), glycine (8447 – 12006 mg/100 g), and serine (4432 – 6842 mg/100 g), were also markedly high. The exceptionally wide ranges reported for this species likely stem from differences in diet, developmental stage, or sample pooling across individuals, emphasizing the substantial nutritional variability within the genus *Macrotermes*.

Taken together, MNP exhibits a complete amino acid profile and is rich in EAA, although lower than *M. bellicosus* and *M. subhyalinus*, but superior to *M. falciger*. This suggests that MNP remains a high-quality protein source, capable of meeting nutritional requirements in protein-fortified foods, dietary supplements, or in the development of new nutritional products. The diversity in amino acid composition among *Macrotermes* species also suggests the potential for optimal species selection for specific nutritional purposes, while reinforcing the role of *Macrotermes* as a sustainable and bioavailable protein source.

9. Biological impact of MNP

Evaluation of nutritional safety and toxicity is a necessary step before expanding the food application of MNP (Figure 1). One of the semi-chronic toxicity studies was conducted on rats to determine the effects of consuming termite powder in the diet. The results showed that supplementation of MNP at a rate of 25% to 75% in the rat diet for 28 days did not cause significant weight gain compared to the control group. However, the concentrations of total cholesterol, free cholesterol in the liver, and high-density lipoprotein cholesterol in the plasma increased gradually with the supplementation dose, while triacylglycerol increased significantly only at 75%. Notably, atherosclerosis risk indicators were not significantly affected. Thus, moderate termite supplementation (≤ 50%) can help maintain stable blood lipids and partially replace animal saturated fat (Igwe et al., 2011a).

In a 28-day experiment on 24 4-week-old male mice, the addition of dried termite powder at 25%, 50%, and 75% to the diet did not cause significant weight gain compared to the control group. Hematological indices such as total blood protein, albumin, hematocrit, hemoglobin, and red blood cell count all increased with the supplemented dose. Notably, liver enzyme activities (ALT, AST) and plasma concentrations of total bilirubin, urea, and creatinine did not change significantly, indicating that the termite-supplemented diet did not cause liver and kidney toxicity. The study results confirmed that the MNP-supplemented diet was safe in terms of liver, kidney, and hematological functions and could be recommended for use as a nutritional supplement in human and animal diets, especially for growing children and lactating mothers, to improve food insecurity and malnutrition (Igwe et al., 2014).

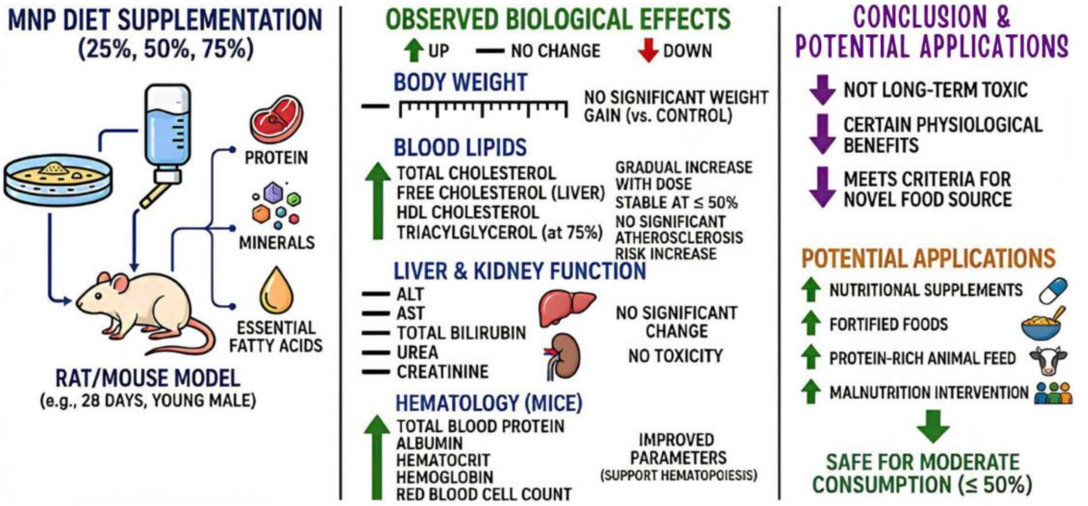

Figure 1. Biological impacts of *M. nigeriensis*.

The combination of existing evidence suggests that MNP is not only safe for long-term use but may also provide certain physiological benefits due to its high protein, mineral, and essential fatty acid content. The lack of liver and kidney damage, no changes in body weight, and no impact on cardiovascular risk factors at moderate levels of consumption suggest that this termite species meets the criteria for a novel food source.

In addition, modest improvement in hematological parameters suggests its ability to support hematopoiesis, which is particularly important for populations prone to micronutrient deficiencies. These data, when viewed in the context of the need for sustainable and affordable protein sources in developing countries, suggest that MNP is a potential candidate for nutritional supplements, fortified foods, protein-rich animal feed, or intervention strategies against malnutrition. However, to expand its application on an industrial scale, further studies are needed to evaluate chronic toxicity, metabolic interactions, effects on intestinal microflora, and stability of the biochemical composition during storage and processing.

10. Applications of MNP

In addition to its nutritional value and chemical composition, MNP has also been extensively investigated for its potential applications in a variety of food products. Recent studies have focused on evaluating the role of termite meals as a nutritional enhancer, a substitute for traditional ingredients, and a protein-lipid source capable of improving the formulation quality and functional value of products. Table 8 shows that MNP is a highly versatile ingredient in the food and non-food industries, with both nutritional and technological effects being prominent. First, when used as a substitute for wheat powder in cakes and biscuits, termite meals significantly increase protein content (up to almost double at 20%), while improving essential minerals such as magnesium, potassium, and phosphorus, while maintaining low levels of anti-nutritional factors. However, the optimum inclusion level is only around 5%, as this is the highest sensory acceptability in both cakes and biscuits, while higher levels reduce the textural quality (Ojinnaka et al., 2013; Ogunlakin et al., 2018).

Table 8
Food and functional applications of MNP in various products

Application	Product / Matrix	Inclusion Level	Main Outcomes	References
Wheat powder substitution in cakes	Cake	0 – 20% termite powder	• Highest sensory acceptability at 5%, comparable to control ($p < 0.05$). • Protein increased from 10.04% → 19.57% (at 20%). • Mg, K, P increased significantly. • Antinutrients (tannin, phytate, saponin, oxalate) remained low. → Suitable for protein-enriched bakery products.	Ojinnaka et al. (2013)
Biscuits enrichment	Biscuits	0 – 20% termite powder	• Protein increased 9.80% → 17.07%; fat, fiber, ash and moisture increased. • Carbohydrate and caloric value decreased. • Spread ratio increased (8.55→11.00), break strength decreased (283→259 g). • 5% had highest acceptability (color, aroma, overall liking).	Ogunlakin et al. (2018)
Nutrient enhancement of fermented cassava mahewu	Mahewu (fermented cassava beverage)	0 – 40% termite powder	• Protein increased from 1.35→32.65 g/100 g; fat and fiber also increased. • Fe, Zn, vitamin C, riboflavin increased notably. • Carbohydrates reduced 84.90→15.65 g/100 g. • 30% inclusion had best sensory acceptance. → Strong potential for combating micronutrient deficiencies.	Anyiam et al. (2022a)
Contribution to recommended nutrient intake (RNI)	Mahewu fortified with 30% termite powder (MECM)	30%	• RNI contribution greatly improved for children 6–9 years: protein (46.4%), Fe (72.7%), Zn (45.4%), vitamin C (87.1%). • Similar trends for children 10–15 years. • Ca remained low (1.98–1.06%). → Effective vehicle for improving protein and micronutrient intake in children.	Anyiam et al. (2022b)
Effect of fermentation time on MECM quality	30% termite–fortified cassava mahewu	Fermenta-tion: 0 – 48 h	• pH decreased (6.45→3.65); titratable acidity increased (0.10→0.38%). • At 42 h: protein (21.02%), Fe (52.69%), Zn (69.46%), vitamin C (125.71%) improved; protein digestibility 62.42%. • At 48 h: largest reductions in antinutrients (phytate ↓64%, oxalate ↓76%, tannin ↓41%).	Anyiam et al. (2023)
Protein extraction and functional properties	Termite protein isolates	Alkali extraction (pH 10) and salt extraction (0.5 M)	• Extraction yield: 62.1% (alkali) and 68% (salt). • Highest protein content: salt extract (68.68 g/100 g). • Best emulsifying activity/stability at pH 10; best foaming capacity/stability at 6% salt. → Functional properties suitable for food formulation and alternative protein development.	Anyiam et al. (2024)

Another valuable application is the nutritional fortification of mahewu from fermented cassava. A 30% MNP inclusion level significantly improved protein, fiber, vitamin C, riboflavin, and minerals, while reducing carbohydrates, creating a more balanced nutritional profile. Notably, MECM (mahewu fortified with 30% MNP) met the high levels of the recommended intake (RNI) for children 6 – 15 years of age, especially for protein, iron, and zinc, showing great potential for reducing micronutrient deficiencies and improving food security (Anyiam et al., 2022b). In addition, fermentation lasting up to 42 – 48 h further improved the nutritional value, increased protein digestibility, and significantly reduced antinutrients, confirming the role of fermentation in optimizing product quality (Anyiam et al., 2023).

In terms of functional properties of proteins, protein extraction from termites showed high yields (62–68%), with good foaming and emulsifying properties, especially at alkaline pH or when salt was added. This opens the way for the development of functional protein ingredients for applications in protein-rich foods or meat substitutes (Anyiam et al., 2024). In addition to food, oil from *M. nigeriensis* has also been noted to have potential as a biofeedstock for biodiesel production, suggesting a potential expansion into the sustainable energy sector (Kalu-Uka et al., 2021).

Overall, the data demonstrates that *M. nigeriensis* is not only a valuable source of protein and micronutrients for nutritionally fortified foods but also a promising technological raw material due to its superior functional properties. This reinforces the feasibility of exploiting termites as a valuable and multipurpose bioresource.

11. Potential and challenges of MNP

MNPs exhibit great application potential due to their superior nutritional value and versatility in processing (Figure 2). Studies have shown that the addition of termite powder to baked goods, biscuits, and mahewu significantly increases the protein content, essential amino acids, iron, zinc, and vitamin C, while maintaining low levels of antinutrients (Ojinnaka et al., 2013; Ogunlakin et al., 2018). At the same time, termite protein isolates also show good emulsifying and foaming properties, opening up opportunities for applications in the development of formulated foods and novel protein-rich products (Anyiam et al., 2024). In addition to food, termite oil has also been identified as a potential non-traditional lipid feedstock for biodiesel production (Kalu-Uka et al., 2021). This evidence suggests that this species could become a promising alternative protein source, especially in the context of increasing demand for sustainable nutritional ingredients.

However, the exploitation and application of MNP still face many challenges. Seasonal characteristics make it difficult to maintain a stable source of raw materials, while the collection and processing process still relies mainly on manual methods, increasing fluctuations in product quality. Some risks related to food safety, such as microbial contamination, parasites, or heavy metal accumulation, have not been systematically assessed. In addition, the level of consumer acceptance of insect foods, although improved, remains a major obstacle in many regions outside West Africa. The lack of standardization in drying, grinding, preservation, and processing of raw materials also makes commercialization difficult.

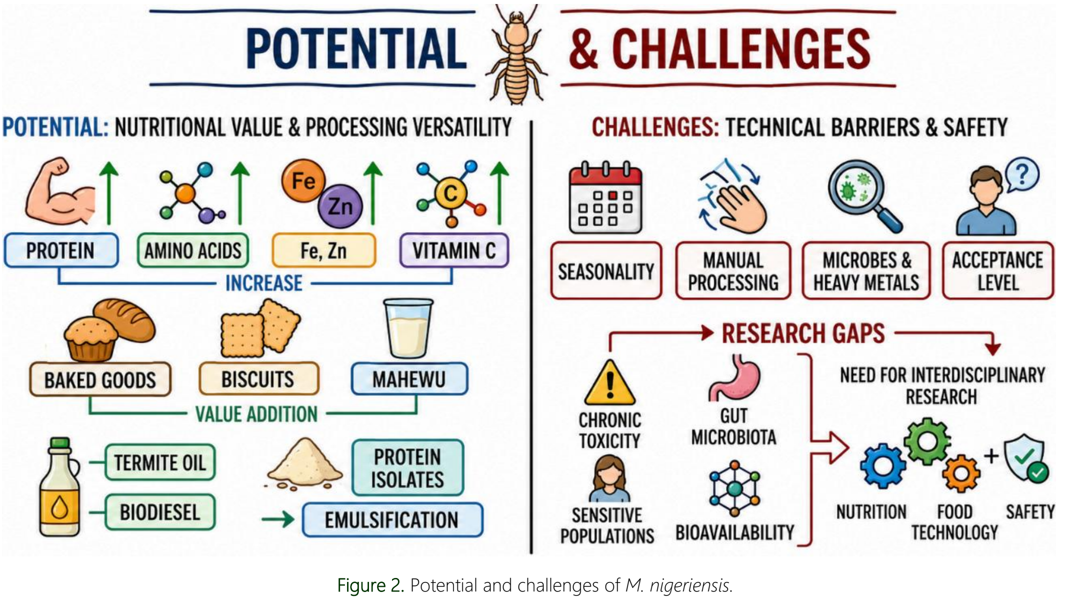

Figure 2. Potential and challenges of *M. nigeriensis*.

Although existing data indicate that *M. nigeriensis* is safe in short-term toxicity tests (Igwe et al., 2011b; Igwe et al., 2014), there are still many gaps that need to be further investigated to support industrial-scale product development. Specifically, there has been no assessment of chronic toxicity, effects on the gut microbiota, or potential effects on sensitive populations such as young children and pregnant women. The lipid composition, fatty acid profile, mineral bioavailability, and nutritional improvement mechanisms of fermentation with cassava have also not been thoroughly analyzed. Therefore, interdisciplinary research integrating nutrition, food technology, and food safety is needed to fully exploit the potential of this termite species while overcoming existing challenges and promoting sustainable commercialization in the future.

12. Conclusions

Macrotermes nigeriensis is a nutrient-dense edible insect with notable potential for food and non-food applications. Current evidence highlights its high-quality protein, essential minerals and vitamins, favorable fatty acid composition, and functional protein properties suitable for product development. Its successful incorporation into bakery items and fermented beverages further demonstrates its value in improving protein density and micronutrient intake. Despite these advantages, wider utilization remains constrained by seasonal availability, lack of standardized processing, limited toxicological and bioavailability data, and low consumer acceptance outside of local areas. Future studies should focus on safety evaluation, optimization of processing methods, and assessment of long-term nutritional benefits. Overall, *M. nigeriensis* represents a promising sustainable protein source, but more scientific evidence and technological developments are needed to support large-scale applications.

Conflicts of interest

The authors declare no conflict of interest.

Ethical statement

Not applicable.

Contribution of the authors

L. P. T. Quoc and P. M. Hao: Conceptualization, investigation, and writing original draft. N. H. D. Thuan and P. T. Quyen: Supervision, visualization. L. P. T. Quoc: Writing, review, and editing.

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References

Abbasi, E. (2025). Edible insects as a sustainable and innovative approach to addressing global food security and environmental challenges: a comprehensive review. *Journal of Insects as Food and Feed*, *11*(13), 2255-2266.

Adepoju, O. T., & Omotayo, O. A. (2014). Nutrient composition and potential contribution of winged termites (*Macrotermes bellicosus* Smeathman) to micronutrient intake of consumers in Nigeria. *British Journal of Applied Science & Technology*, *4*(7), 1149–1158.

Ajayi, O. E. (2012). Biochemical analysis and nutrition content of four castes of subterranean termites, *Macrotermes subhyalinus* (Rambur)(Isoptera: Termitidae): differences in digestibility and anti-nutrient contents among castes. *International Journal of Biology*, *4*(4), 54. https://doi.org/10.5539/ijb.v4n4p54

Anyiam, P. N., Nwuke, C. P., Adimuko, G. C., Nwamadi, C. P., Salvador, E. M., Ajibade, G. F., & Maxwell, E. C. (2022a). Inclusion of African winged termites (*Macrotermes nigeriensis*) improves the nutrients and quality of fermented cassava mahewu. *African Journal of Biotechnology*, *21*(2), 46–54. https://doi.org/10.5897/AJB2021.17444

Anyiam, P. N., Nwuke, C. P., Onyeabo, C., Uche, P. C., Adimuko, G. C., Guibunda, F. A., & Ononogbu, E. C. (2022b). Potential contribution of *Macrotermes nigeriensis*-improved fermented cassava mahewu to nutrient intake adequacy of school children in Umudike, Nigeria. *Food Chemistry Advances*, *1*, 100062. https://doi.org/10.1016/j.focha.2022.100062

Anyiam, P. N., Nwuke, C. P., Uhuo, E. N., Ajah, O., Uche, C. P., Dike, O. G., & Onyemuchara, T. C. (2024). Influence of pH and salt conditions on extraction efficiency and functional properties of *Macrotermes nigeriensis* protein concentrate for food applications. *Discover Food*, *4*(1), 100. https://doi.org/10.1007/s44187-024-00181-w

Anyiam, P. N., Nwuke, C. P., Uhuo, E. N., Ije, U. E., Salvador, E. M., Mahumbi, B. M., & Boyiako, B. H. (2023). Effect of fermentation time on nutritional, antinutritional factors and in-vitro protein digestibility of macrotermes *nigeriensis-cassava* mahewu. *Measurement: Food*, *11*, 100096. https://doi.org/10.1016/j.meafoo.2023.100096

Atowa, C. O., Okoro, B. C., Umego, E. C., Atowa, A. O., Emmanuel, O., Ude, V. C., & Ugbogu, E. A. (2021). Nutritional values of *Zonocerus variegatus*, *Macrotermes bellicosus* and *Cirina forda* insects: Mineral composition, fatty acids and amino acid profiles. *Scientific African*, *12*, e00798. https://doi.org/10.1016/j.sciaf.2021.e00798

Boulogne, I., Constantino, R., Amusant, N., Falkowski, M., Rodrigues, A. M., & Houël, E. (2017). Ecology of termites from the genus *Nasutitermes* (Termitidae: *Nasutitermitinae*) and potential for science-based development of sustainable pest management programs. *Journal of Pest Science*, *90*(1), 19–37. https://doi.org/10.1007/s10340-016-0796-x

Cheseto, X., Ochieng, B. O., Subramanian, S., & Tanga, C. M. (2024). Unravelling the nutritional and health benefits of marketable winged termites (*Macrotermes* spp.) as sustainable food sources in Africa. *Scientific Reports*, *14*(1), 9993. https://doi.org/10.1038/s41598-024-60729-9

Choi, Y. S., Lee, J. H., Cha, J. Y., & Kim, Y. J. (2026). Use of Insects and/or Insect-Derived Compounds as Ingredients in Food Formulation. In *Insects for Human Consumption* (pp. 139-177). CRC Press.

Gachihi, A., Tanga, C., Nyambaka, H., & Kimiywe, J. (2023). Effect of processing methods on nutrient and anti-nutrient composition of grasshopper and termites. *CyTA - Journal of Food*, *21*(1), 745–750. https://doi.org/10.1080/19476337.2023.2281984

Igwe, C. U. (2014). Biochemical and Haematologic Effects of Intake of *Macrotermes nigeriensis* Fortified Functional Diet. *Pakistan Journal of Biological Sciences*, *17*(2), 282–286. https://doi.org/10.3923/pjbs.2014.282.286

Igwe, C. U., Onwuliri, V. A., Ojiako, A. O., & Arukwe, J. U. (2011b). Effects of *Macrotermes nigeriensis* based diet on hepatic and serum lipids of albino rats. *Australian Journal of Basic and Applied Sciences*, *5*(7), 906–910.

Igwe, C. U., Ujowundu, C. O., Nwaogu, L. A., & Okwu, G. N. (2011a). Chemical analysis of an edible African termite *Macrotermes nigeriensis*, a potential antidote to food security problem. *Biochemistry and Analytical Biochemistry*, *1*(105). https://doi.org/10.4172/2161-1009.1000105

Kalu-Uka, G. M., Kumar, S., Kalu-Uka, A. C., Vikram, S., Okorafor, O. O., Kigozi, M., Ihekweme, G. O., & Onwualu, A. P. (2021). Prospects for biodiesel production from *Macrotermes nigeriensis*: Process optimization and characterization of biodiesel properties. *Biomass and Bioenergy, 146*, 105980. https://doi.org/10.1016/j.biombioe.2021.105980

Kinyuru, J. N., Konyole, S. O., Roos, N., Onyango, C. A., Owino, V. O., Owuor, B. O., Estambale, B. B., Friis, H., Aagaard-Hansen, J., & Kenji, G. M. (2013). Nutrient composition of four species of winged termites consumed in western Kenya. *Journal of Food Composition and Analysis*, *30*(2), 120–124. https://doi.org/10.1016/j.jfca.2013.02.008

Khadijah, B., Ahmad Khan, A., & Razid Sarbini, S. (2025). Comparative nutritional profile, fatty acid composition and in-vitro antioxidant properties of flour derived from four edible winged termite species from Uganda. *CyTA-Journal of Food*, *23*(1), 2544935.

Kunatsa, Y., Chidewe, C., & Zvidzai, C. J. (2020). Phytochemical and antinutrient composite from selected marginalized Zimbabwean edible insects and vegetables. *Journal of Agriculture and Food Research*, *2*, 100027. https://doi.org/10.1016/j.jafr.2020.100027

Muinat, M. I., & Tariq, A. M. (2021). Evaluation of proximate compositions of some edible insects in Zaria Kaduna State Nigeria. *International Journal of Science for Global Sustainability*, *7*(1), 44–53. https://doi.org/10.57233/ijsgs.v7i1.45

Musundire, R., Chidewe, C., Samende, B. K., Chemura, A., Bangira, C., Andika, O. A., & Chiwona-Karltun, L. (2021). Soil characteristics and nutritional traits of *Mactrotermes natalensis* (Isoptera: *Macrotermitinae*) as indicators of nutritional quality in Zimbabwe. *International Journal of Tropical Insect Science*, *41*(3), 2113–2124. https://doi.org/10.1007/s42690-020-00394-3

Ogunlakin, G. O., Oni, V. T., & Olaniyan, S. A. (2018). Quality evaluation of biscuit fortified with edible termite (*Macrotermes nigeriensis*). *Asian Journal of Biotechnology and Bioresource Technology*, *4*(2), 1–7. https://doi.org/10.9734/AJB2T/2018/43659

Oibiokpa, F. I., Akanya, H. O., Jigam, A. A., Saidu, A. N., & Egwim, E. C. (2018). Protein quality of four indigenous edible insect species in Nigeria. *Food Science and Human Wellness*, *7*(2), 175–183. https://doi.org/10.1016/j.fshw.2018.05.003

Ojinnaka, M. C., Ofoelo, M. U., & Ezenwa, L. I. (2013). Nutritional evaluation of wheat cakes enriched with edible African termites (*Macrotermes nigeriensis*). *Agro-Science*, *12*(3), 35–42.

Omotoso, O. T. (2015). Nutrient composition, mineral analysis and anti-nutrient factors of *Oryctes rhinoceros* L.(Scarabaeidae: Coleoptera) and winged termites, *Macrotermes nigeriensis* Sjostedt (Termitidae: Isoptera). *British Journal of Applied Science & Technology*, *8*(1), 97–106.

Séré, A., Bougma, A., Bazié, B. S. R., Nikièma, P. A., Gnankiné, O., & Bassolé, I. H. N. (2022). Nutritional and functional properties of defatted powder, protein concentrates, and isolates of *Brachytrupes membranaceus* (Orthoptera: Gryllidae) (Drury: 1773) and *Macrotermes subhyalinus* (Isoptera: Blattodea) (Rambur: 1842) from Burkina Faso. *Insects*, *13*(9), 764. https://doi.org/10.3390/insects13090764

Siulapwa, N., Mwambungu, A., Lungu, E., & Sichilima, W. (2014). Nutritional value of four common edible insects in Zambia. *International Journal of Science and Research*, *3*(6), 876–884.

Sun, M., Jiang, D., Long, X., & Chen, X. (2025). The polyunsaturated-to-monounsaturated fatty acid ratio and cardiovascular risk prediction: a prospective cohort study of 183,237 adults. *Lipids in Health and Disease*, *24*, 322. https://doi.org/10.1186/s12944-025-02745-w