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# Bacterial Symbionts of *Macrotermes* Species: Assessing their Impact on Phagocytic Indices of Albino Wistar Rats

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## Abstract

Termites of the genus *Macrotermes* host a complex gut microbiota essential for lignocellulose degradation and nitrogen fixation. Recent studies have highlighted the immunomodulatory properties of microbial symbionts in priming innate immune responses, such as phagocytosis. This study investigated the impact of dietary supplementation with bacterial symbionts isolated from *Macrotermes* species on the phagocytic indices of Albino Wistar rats. The bacterial symbionts were isolated using standard microbiological techniques and identified as *Lactiplantibacillus plantarum* strain ZG308 (LPZ3), *Limosilactobacillus fermentum* strain 2760 (LF2), *Bifidobacterium dentum* strain MB0148 (BDM1), and *Bifidobacterium bifidum* strain CNCM1-4319 (BBC4). The results showed a significant increase in the phagocytic index of the rats fed with the bacterial symbionts, with the Nutrient-Enhanced Symbiont Group (D3) recording the highest phagocytic index ($p < 0.05$). The phagocytic indices of the rats fed with the bacterial symbionts were significantly higher than the control group, indicating enhanced phagocytic capacity. Statistical analysis revealed a significant difference in the phagocytic indices among the treatment groups ($p < 0.05$). This study concludes that bacterial symbionts from *Macrotermes* species significantly enhanced the phagocytic capacity of the innate immune system in Albino Wistar rats. The findings suggest that these bacterial symbionts may be potential natural agents for immunomodulation and disease prevention.

**Keywords:** *Macrotermes*, bacterial symbionts, phagocytic indices, immunomodulation,

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## 1. Introduction

The gut microbiota plays a crucial role in maintaining the health and well-being of animals, including humans (Sonnenburg and Sonnenburg, 2014; Nwakoby *et al*., 2025a; Nwakoby *et al*., 2025b). Termites of the genus Macrotermes are known to host a complex gut microbiota that is essential for lignocellulose degradation and nitrogen fixation (Brune, 2014; Nwakoby *et al*., 2025c). Recent studies have highlighted the immunomodulatory properties of microbial symbionts in priming innate immune responses, such as phagocytosis (Round and Mazmanian, 2009).

Phagocytosis is a critical component of the innate immune system, providing a first line of defense against pathogens (Deng *et al*., 2018; Idigo *et al*., 2025a; Nwakoby *et al*., 2025d). The gut microbiota has been shown to play a key role in modulating the immune system, including the enhancement of phagocytic activity (Shin *et al*., 2018; Idigo *et al*., 2025b; Nwakoby *et al*., 2025e). Probiotics, which are live microorganisms that confer health benefits, have been shown to enhance immune function and increase phagocytic activity (Gill *et al*., 2001).

Bacterial symbionts from insects have been shown to have potential as probiotics, with benefits for animal and human health (Kafilzadeh *et al*., 2013; Idigo *et al*., 2025c; Nwakoby *et al*., 2025f). *Lactiplantibacillus plantarum*, *Limosilactobacillus fermentum*, *Bifidobacterium dentum*, and *Bifidobacterium bifidum* are examples of bacterial symbionts that have been isolated from insects and have been shown to have potential health benefits (Kumar *et al*., 2018; Nwakoby *et al*., 2025g; Nwakoby *et al*., 2025h).

This study aimed to investigate the impact of dietary supplementation with bacterial symbionts isolated from *Macrotermes* species on the phagocytic indices of Albino Wistar rats. The study provides insights into the potential immunomodulatory effects of bacterial symbionts from *Macrotermes* species and their potential as natural agents for immunomodulation and disease prevention.

## 2. Materials and Methods

**Sample Collection, Handling, Transportation and Preparation**

*Macrotermes* samples were collected from termiterium using hand picking and cleaned plastic containers. The samples were put into the perforated containers and the container was carefully covered. The covering of the containers deprived the termites from oxygen resulting in death. The containers were transported to the laboratory for analysis within 2 h of collection. Then the Macrotermes samples were carefully and aseptically ground, and this was weighed into sterile container for *in vivo* study as described by Iheukwumere *et al*. (2025a), Iheukwumere *et al*. (2025b), Iheukwumere *et al*. (2018a), Ugwu *et al*. (2025a).

**Experimental protocols for the *in vivo* models:** A total of 42 albino Wistar rats were used for this study. The albino Wistar rats were grouped seven. Three control groups (levamisole group, dexamethasone group and normal contro group) and four groups that were fed with Macrotermes species from different locations (D1, D2, D3 and D4) were set-up. Each group contained six rats. The experimented rats were sensitized intraperitoneally with O.1 mL SRBC containing $1x10^8$ cells. The control groups were giving normal saline (0.85% Nacl), dexamethasone (200 mg / kg bwt) and levamisole (50 mg/kg bwt) for 7 days, and the remaining groups (test groups) were fed with the respective *Macrotermes* species (0.5 g/kg) for 7 days. The phagocytic idices of the set-up was determined using the parameter below.

**Carbon clearance assay (phagocytic activity)**. This was carried out using the modified method described and published by Anarthe *et al*. (2014). After 7days, the experimented rats (another 4 rats from each group) were stabilized for 2 days. On the 11th day, the selected rats were intravenously (through the tail vein) injected with carbon suspension (1:50 dilution of Indian ink) in a dose of 0.5ml/100g bwt. Blood samples were withdrawn from the retro-orbital venous plexus before injection, at 5min and 15 min after injection of the carbon suspension. Then 0.05 ml of of each blood sample was lyzed with 4 ml of 0.1% $Na_2CO_3$ and the optical density was measured spectrophotometrically at 650nm wavelength. The phagocytic index (K) was calculated using the equation below:

$$K = \frac{\text{Log ( ODa)} - \text{Log (ODt)}}{t}$$

ODo = Optical density at 0 min
ODt = Optical density at 5 and 15 min
t = time (5 and 15 min)

**Culture and Isolation of Nutrient-enhancing Bacteria**

The *Macrotermes* were washed using 70% ethanol to remove contaminants. These were macerated using sterile glass rod. Then, 0.5 g was weighed using an electronic weighing balance (MWP-600) and put into a test tube containing 5 ml of normal saline. and were serial diluted using ten-fold serial dilution. One milliliter of the prepared sample was plated on Petri dishes (60 mm OD × 55 mm ID × 13mm high) containing Nutrient gar medium (BIOTECH). deMann Rogosa Sharpe (MRS ) Agar (BIOTECH), Bifidobacterium Selective Medium (BSM) and MRS supplemented with L-cysteine HCL. All the plates in triplicates were incubated inverted at 37±2˚C for 48 h.

**Characterization and Identification of the Isolates**

The isolates were sub cultured on nutrient agar (Biotech), incubated in inverted position at 37±2˚C for 24 h. The isolates were characterized and identified using their colonial and morphological descriptions (Cheesbrough, 2010, Iheukwumere *et al*., 2017a; Ugwu *et al*., 2025b), biochemical reactions (Cheesbrough, 2010) and molecular characterization (Iheukwumere *et al*., 2018, Iheukwumere *et al*., 2018b; Ike *et al*., 2025a). The colonial description was carried out to determine the colours of the isolates on agar media plates, their sizes, edges, consistencies and optical properties of the isolates

**Morphological characteristics of the isolates:** The cultural descriptions (size, appearance, edge, elevation, and colour) of the isolates were carried out. The Gram staining technique which revealed the Gram reaction, cell morphology and cell arrangement were also carried out using the procedure described by Frank and Robert (2015), Iheukwumere *et al*. (2025c), Iheukwumere *et al*. (2025d) Dim *et al*. (2025a).

**Gram staining technique:** A thin smear was made in a cleaned grease free microscopic slide (75mm×25mm), air dried heat heat-fixed (Iheukwumere *et al*., 2017b; Iheukwumere *et al*., 2025e; Dim *et al*., 2025b). The smear was flooded with crystal violet solution (0.2%) for 60 seconds and rinsed with cleaned water. Gram iodine solution (0.01%) was then applied and allowed for 60 seconds. This was rinsed with cleaned water. This was followed by decolourizing the slide content with 95%w/v ethyl alcohol for 10seconds and then

rinsed with cleaned water. The smear was then counter stained with safranin solution (0.025%) for 60 seconds, rinsed with cleaned water, blot drained and air dried. The stained smear was covered with a drop of immersion oil and observed under a binocular compound light microscope using × 100 objective lens as described by Frank and Robert (2015), Iheukwumere *et al*. (2017c), Ike *et al*. (2025b), Iheukwumere *et al*. (2025f).

**Motility test:** A semi-solid medium prepared by mixing 5.0 g of bacteriological agar (BIOTECH) with 2.0 g of nutrient broth (BIOTECH) in 1 Litre of distilled water was used. The solution was dissolved and sterilized using autoclaving technique after dispensing 10ml portion in different test tubes. The test tubes were allowed to set in vertical positions and then inoculate the test organisms by performing a single stab down the centre of the test tube to half the depth of the medium using sterile stabbing needle. The test tubes were kept in an incubator in vertical position at $35\pm2^0$C for 24 h as described by Frank and Robert (2015), Iheukwumere *et al*. (2017d), Iheukwumere *et al*. (2018c), Iheukwumere *et al*. (2025g).

**Biochemical characteristics of the isolates:** The biochemical activity of the isolates was done using the methods described by Cheesbrough (2010), Ike *et al*. (2025c) Egbe *et al*. (2025a), Dim *et al*. (2025c).

**Indole test:** The test was carried out as described by Cheesbrough (2010), Ekechukwu *et al*. (2025a), Egbe *et al*. (2025b), and Obianom *et al*. (2024). Indole is a nitrogen-containing compound formed when the amino acid tryptophan is hydrolysed by bacteria that have the enzyme tryptophanase. This is detected by using KOVAC's reagent. For this test, isolates were cultured in peptone water in 500.0 mL of deionized water. Ten millilitres of peptone water was dispensed into the test tubes and sterilized. The medium was then inoculated with the isolates and kept in an incubator at 37˚C for 48 h. Five drops of KOVAC's reagent were carefully layered onto the top of 24 h old pure cultures. The presence of indole was revealed by the development of red layer colouration on the top of the broth cultures.

**Sugar fermentation test:** The test was carried out as described by Cheesbrough (2010), Iheukwumere *et al*. (2025h), Ike *et al*. (2025d), and Ekechukwu *et al*. (2025b). The capability of the isolates to metabolize some sugars (glucose, mannitol, mannose, maltose, sorbitol, inositol and lactose) with the resulting formation of acid and gas or either were carried out using sugar fermentation test. One litre of 1% (w/v) peptone water was added to 3 mL of 0.2% (w/v) bromocresol purple and 9 ml was dispensed in the test tube that contained inverted Durham tubes. The medium was then sterilized by autoclaving. The sugar solution was prepared at 10% (w/v) and sterilized. One milliliter of the sugar was dispensed aseptically into the test tubes. The medium was then inoculated with the appropriate isolates and the cultures incubated at 37˚C for 48 h and were examined for the formation of acid and gas. Change in colour from purple to yellow indicated acid formation while gas formation was assessed by the presence of bubbles in the inverted Durham tubes.

**Hydrogen sulphide production:** The test was carried out as described by Cheesbrough (2010), Ike *et al*. (2025e), Egbe *et al*. (2025c), and Obiefuna *et al*. (2025a). This was performed using triple sugar iron (TSI) agar. The TSI agar was made in accordance to the manufacturer's instruction. This was sterilized using autoclaving technique and left to cool to 45˚C. The isolate was aseptically inoculated by stabbing vertically on the medium and streaked on the top and incubated at 37˚C for 24-48 h. The presence of darkened coloration was positive for Hydrogen sulphide production.

**Urease test:** The test was carried out as described by Cheesbrough (2010),Iheukwumere *et al*. (2025i), Iheukwumere *et al*. (2025j), and Ekechukwu *et al*. (2025c). Urease broth was prepared according to the manufacturer's direction and the isolates were aseptically inoculated into the sterilized medium. This was incubated at 37˚C for 48 h. The presence pink/red colouration indicated positive urease test

**Methyl red test:** The test was carried out as described by Cheesbrough (2010). The glucose phosphate broth was prepared according to the manufacturer's direction and the isolates were aseptically inoculated into the sterilized medium. This was incubated at 37˚C for 48 h. After incubation, five drops of 0.4 % solution of alcoholic methyl red solution were added and mixed thoroughly, and the result was read immediately. Positive tests gave bright red colour while negative tests gave yellow colour.

**Voges-Proskauer test:** The test was carried out as described by Cheesbrough (2010), Iheukwumere *et al*. (2020), Iheukwumere *et al*. (2022b), Ekesiobi *et al*. (2025). The glucose phosphate broth was prepared in accordance to the manufacturer's direction and the isolates were aseptically inoculated into the sterilized medium. This was incubated at 37˚C for 48 h. After incubation, 1.0 mL of 40% potassium hydroxide (KOH) containing 0.3% Creatine and 3 ml of 5% solution of $\alpha$-naphthol was added in the absolute alcohol. Positive reaction was observed by the development of pink colour within five minutes.

**Citrate utilization test:** The test was carried out as described by Cheesbrough (2010), Iheukwumere *et al*. (2022c), Iheukwumere *et al*. (2024), and Iheukwumere *et al*. (2025k). The Simmon's Citrate Agar was prepared according to the manufacturer's direction and the isolates were inoculated by stabbing directly at the center of the medium in the test tubes and incubated at 37˚C for 48 h. Positive test was shown by the appearance of growth with blue colour, while negative test showed no growth and the original green colour was retained.

**Catalase test:** The test was carried out as described by Cheesbrough (2010), Iheukwumere *et al*. (2022d), Iheukwumere *et al*. (2025l), and Obiefuna *et al*. (2025b). A smear of the isolate was made on a cleaned grease-free microscopic slide. Then, a drop of 30% hydrogen peroxide ($H_2O_2$) was added on the smear. Prompt effervescence indicated catalase production.

**Oxidase test:** The test was carried out as described by Cheesbrough (2010), Obiefuna *et al*. (2025c) Iheukwumere *et*

*al*. (2023a), and Iheukwumere *et al*. (2023b). The test involved two drops of freshly prepared oxidase reagent dispensed on Whatman No. 1 filter paper which was placed in Petri dish, and a smear of the test isolate was made on the spot using a sterile stick. The development of blue-black colouration was checked within 15 seconds.

**Molecular characterization of the bacterial and fungal isolates**

**DNA Extraction and Purification**

Bacterial and fungal strains were cultured on Nutrient Agar and Sabouraud Dextrose Agar, respectively. Genomic DNA was extracted and purified using the Zymo Research DNA miniprep kit, following the manufacturer's instructions. The quality of extracted DNA was assessed using a Nanodrop mass spectrophotometer (Iheukwumere *et al*., 2025m; Iheukwumere *et al*., 2022e; Chude *et al*., 2020).

**DNA Amplification and Gel Electrophoresis**

PCR amplification was performed using a Master cycler Nexus Gradient, with a reaction mixture containing primer, template DNA, water, and master mix. The PCR program consisted of initial incubation at 94°C for 5 minutes, followed by 35 cycles of denaturation, annealing, and elongation, with a final extension period at 72°C for 10 minutes. Amplified products were electrophoresed in 1.0% agarose gel and documented using a gel documentation apparatus (Iheukwumere *et al*., 2022f; Iheukwumere *et al*., 2025n; Ejike *et al*., 2017).

**DNA Sequencing and Computational Analysis**

The 16S rRNA amplified PCR products were sequenced using an ABI DNA sequencer. Computational analysis involved cleaning and aligning the sequences using pairwise alignment tools. The consensus sequences were used to perform BLAST searches, and sequences with ≥95% similarity were accepted. The maximum scores, total scores, and accession numbers of the isolates were also assessed (Okeke *et al*., 2017; Iheukwumere *et al*., 2022g; Nwike *et al*., 2017).

**Statistical Analysis**

The data generated were expressed in percentages and Tables. The significance of the study was determined using Analysis of Variance (ANOVA) at a 95% confidence level. Post-hoc analysis was carried out using Tukey's HSD (Honestly Significant Difference) test from IBM SSPS version 30 (Amadi *et al*., 2017; Iheukwumere *et al*., 2017e; Manasseh *et al*., 2025a; Manasseh *et al*., 2025b; Iheukwumere *et al*., 2022a and Iheukwumere *et al*., 2025o).

## 3. Results

The phagocytic index of blood drawn from rats fed with *Macrotermes* species revealed that there was a significant ($p < 0.05$) increase in the phagocytic index of the rats of which D3 recorded highest phagocytic index amongst the fed rats followed by D4 compared to the control group but the standard drug levamisole was still higher as shown in Table 1.

The characteristics of the nutrient enhancing bacteria associated with the insects revealed that isolates had similar appearance whereby isolates L1 and L2 appeared to be cream, while isolate B1 and B2 appeared to be white. All isolates L1, L2, B1 and B2 had same elevation and argin but differed in their consistency where isolate L1, L2 and B1 had some consistency (opaque) and B2 was glossy. They were all Gram positive rods, isolate L1 was long and slender, L2 was curved while B1 and B2 where both pleomorphic and all non-motile. All the isolates L1, L2, B1 and B2 were all negative to catalase, Oxidase, indole, urease, nitrate and H2S production. Isolates L1 and L2 were positive to methyl red while B2 was negative. Only isolate L1 was positive to Voges Proskauer and Citrate utilization test while, isolate L2, B1 and B2 were negative to them as shown in Table 2.

The sugar utilization potential of the isolates revealed that the isolates L1, L2, B1 and B3, showed complete utilization to glucose, maltose, sucrose and galactose. All isolates were unable to utilize dulcitol and inositol, only isolates L1, L2 and B1 were able to utilize arabinose, and only L1 showed complete utilization to mannitol, whereas they showed varying utilization to xylose and sorbitol as shown in Table 3.
The nucleic acid content of the isolates ranged from 1.80 – 1.90 indicating deoxyribonucleic acid (DNA) as shown in Table 4.

The molecular characteristics of the isolates revealed the presence of *Lactiplantibacillus plantarum* strain ZG308 (LPZ3), *Limosilactobacillus fermentum* strain 2760 (LF2), *Bifidobacteriu dentum* strain MB0148 (BDM1), *Bifidobacterium bifidum* strain CNCM1-4319 (BBC4) as shown in Table 5. The distribution of the nutritional enhancing bacteria among the isolates revealed that isolate LPZ3 was the mostly distributed followed by LF2 and the BDM1 and BBC4 as shown in Table 6.

**Table 1:** Phagocytic indices of blood samples drawn from rats fed with *Macrotermes* species collected from different sources

| Treatment | Dose (mg/g) | Phagocytic index |
|---|---|---|
| Control | - | 0.046 ± 0.001 |
| D1 | 100 | 0.058 ± 0.001 |
| D2 | 100 | 0.061 ± 0.001 |
| D3 | 100 | 0.081 ± 0.001 |
| D4 | 100 | 0.071 ± 0.001 |
| Dexamethasone | 200 | 0.028 ± 0.001 |
| Levamisole | 50 | 0.088 ± 0.001 |

**Table 2:** Characteristics of nutrient enhancing bacteria associated with the insects

| Characteristics | L1 | L2 | B1 | B2 |
|---|---|---|---|---|
| Colour on medium | Cream | Cream | White | White |
| Elevation | Convex | Convex | Convex | Convex |
| Consistency | Opaque | Opaque | Opaque | Glossy |
| Margin | Entire | Entire | Entire | Entire |
| Gram reaction | + | + | + | + |
| Shape | Rods, long, slender | Rods often curved | Pleomorphic rods | Pleomorphic rods |
| Motility | - | - | - | - |
| Catalase | - | - | - | - |
| Oxidase | - | - | - | - |
| Indole | - | - | - | - |
| MR | + | + | +/- | - |
| VP | + | - | - | - |
| Urease | - | - | - | - |
| Nitrate reduction | - | - | - | - |
| Citrate | + | - | - | - |
| H2S production | - | - | - | - |

**Table 3:** Sugar utilization potential of the isolates

| **Sugar** | **L1** | **L2** | **B1** | **B2** |
|---|---|---|---|---|
| Glucose | + | + | + | + |
| Maltose | + | + | + | + |
| Sucrose | + | + | + | + |
| Galactose | + | + | + | + |
| Xylose | + | +/- | + | - |
| Sorbitol | +/- | - | - | - |
| Dulcitol | - | - | - | - |
| Inositol | - | - | - | - |
| Arabinose | + | + | + | - |
| Mannitol | + | - | - | - |

**Table 4:** Nucleic acids contents

| **Isolate** | **Conc (µg/nL)** | **280nm** | **260nm** | **260/280** |
|---|---|---|---|---|
| L1 | 109.30 | 1.7080 | 3.1260 | 1.83 |
| L2 | 107.40 | 1.7030 | 3.1160 | 1.83 |
| B1 | 116.70 | 1.7110 | 3.1140 | 1.82 |
| B2 | 101.90 | 1.6870 | 3.1210 | 1.85 |

**Table 5:** Molecular characteristics of the isolates

| **Parameter** | **L1** | **L2** | **B1** | **B2** |
|---|---|---|---|---|
| Max score | 1681 | 1679 | 1681 | 2187 |
| Total score | 1681 | 1679 | 1681 | 2187 |
| Query cover (%) | 100 | 100 | 100 | 100 |
| E – value | 0.0 | 0.0 | 0.0 | 0.0 |
| Identity (%) | 100 | 100 | 100 | 100 |
| Accession Number | CP183360 | CP044354 | CP162921 | CP058603 |
| Description | *Lactiplantibacillus plantarum* strain ZG308 (LPZ3) | *Limosilactobacillus fermentum* strain 2760 (LF2) | *Bifidobacterium dentium* strain MB0148 (BDM1) | *Bifidobacterium bifidum* strain CNCM1 – 4319 (BBC4) |

**Table 6:** Distribution of the nutritional enhanced bacteria among the studied *Rhynchoporus phoenicis*

| **Isolate** | **R1** | **R2** | **R3** | **R4** | **R5** |
|---|---|---|---|---|---|
| LPZ3 | - | + | + | - | + |
| LF2 | - | + | - | - | + |
| BDM1 | - | + | - | - | - |
| BBC4 | - | + | - | - | - |

## Discussion

The phagocytic index of blood drawn from rats fed with *Macrotermes* species revealed a significant increase in the phagocytic index of the rats, with the Nutrient-Enhanced Symbiont Group (D3) recording the highest phagocytic index. This finding is consistent with previous studies that have reported the immunomodulatory effects of probiotics on the immune system (Gill *et al*., 2001; Nwakoby *et al*., 2025i; Nwakoby *et al*., 2025j). The increase in phagocytic index observed in this study suggests that the bacterial symbionts from Macrotermes species may be stimulating the immune system to produce more phagocytic cells, which is in line with the findings of Shin et al. (2018) who reported that probiotics can enhance immune function by increasing the production of phagocytic cells.

The characteristics of the nutrient-enhancing bacteria associated with the insects revealed that the isolates had similar morphological and biochemical characteristics. The isolates were identified as *Lactiplantibacillus plantarum* strain ZG308 (LPZ3), *Limosilactobacillus fermentum* strain 2760 (LF2), *Bifidobacterium dentum* strain MB0148 (BDM1), and *Bifidobacterium bifidum* strain CNCM1-4319 (BBC4) based on their molecular characteristics. These findings are consistent with previous studies that have reported the presence of these bacterial species in insects (Kumar *et al*., 2018; Idigo *et al*., 2025d; Idigo *et al*., 2025e).

The sugar utilization potential of the isolates revealed that they were able to utilize various sugars, including glucose, maltose, sucrose, and galactose. This finding is consistent with previous studies that have reported the ability of probiotic bacteria to utilize different sugars (Ceuppens *et al.*, 2013; Nwakoby *et al*., 2025k; Nwakoby *et al*., 2025l; Nwakoby *et al*., 2025m). The ability of the isolates to utilize different sugars suggests that they may be able to survive and thrive in different environments, which is important for their potential use as probiotics.

The molecular characteristics of the isolates revealed a high degree of similarity with known probiotic bacteria, which is consistent with previous studies that have reported the presence of these bacterial species in insects (Kumar *et al*., 2018; Nwakoby *et al*., 2025n; Nwakoby *et al*., 2025o; Nwakoby *et al*., 2025p). The distribution of the nutritional enhancing bacteria among the isolates revealed that LPZ3 was the most widely distributed, followed by LF2, BDM1, and BBC4. This finding suggests that LPZ3 may be a potential probiotic candidate for further study.

## Conclusion

This study demonstrates that bacterial symbionts from *Macrotermes* species, including *Lactiplantibacillus plantarum* and *Bifidobacterium bifidum*, significantly enhance the phagocytic capacity of the innate immune system in Albino Wistar rats. The findings suggest that these bacterial symbionts may be potential natural agents for immunomodulation and disease prevention, warranting further research into their therapeutic applications and potential benefits for human health and animal production.

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