



# Entomopathogenic Bacteria-Mediated Management of *Delia radicum*: A Step towards Eco-friendly Pest Control

Idigo, M. A.<sup>1\*</sup>, Iheukwumere, I. H.<sup>2\*</sup>, Iheukwumere, C. M.<sup>3</sup>, Nnaeze, B. C.<sup>4</sup>, Akulue, C. J.<sup>4</sup>, Nwakoby, N. E.<sup>2</sup>, Ezendianefor, J. N.<sup>5</sup>, Ike, V. E.<sup>6</sup>, Nnaeozie, A. O.<sup>2</sup>, Ezekwueche, S. N.<sup>6</sup>, Anagor, I. S.<sup>7</sup>, Aniekwe, C. C.<sup>3</sup>, Ezeoke, F. C.<sup>8</sup>, Okereke, F. O.<sup>9</sup>, Ochibulu, S. C.<sup>2</sup>

<sup>1</sup>Department of Biological Sciences, Faculty of Natural Sciences, Chukwuemeka Odumegwu Ojukwu University, Uli, Campus, Anambra State, Nigeria.

<sup>2</sup>Department of Microbiology, Faculty of Natural Sciences, Chukwuemeka Odumegwu Ojukwu University, Uli, Campus, Anambra State, Nigeria.

<sup>3</sup>Department of Applied Microbiology and Brewing, Faculty of Biosciences, Nnamdi Azikiwe University, Awka, Nigeria.

<sup>4</sup>Department of Medical Microbiology and Public Health, Faculty of Medical Laboratory Sciences, Nnamdi Azikiwe University, Nnewi Campus, Nigeria.

<sup>5</sup>Department of Microbiology, Tansian University, Umunya, Anambra State, Nigeria.



<sup>6</sup>Department of Microbiology, University of Agriculture and Environmental Sciences, Umuagwo, Imo State, Nigeria.

<sup>7</sup>Department of Medical Microbiology and Parasitology, Faculty of Basic Clinical Sciences, Nnamdi Azikiwe University, Nnewi Campus, Nigeria.

<sup>8</sup>Department of Animal Science, Faculty of Agriculture, Chukwuemeka Odumegwu Ojukwu University, Igbariam Campus, Anambra State, Nigeria.

<sup>9</sup>Department of Biological Sciences (Microbiology), Faculty of Natural and Applied Sciences, Spiritan University, Nneochi, Abia State, Nigeria.

\*Corresponding author e-mail address: [digomediatrix@gmail.com](mailto:digomediatrix@gmail.com)/[ik.iheukwumere@coou.edu.ng](mailto:ik.iheukwumere@coou.edu.ng)/[ikpower2007@yahoo.com](mailto:ikpower2007@yahoo.com)

Abstract	Article History
<p>The cabbage root fly, <i>Delia radicum</i>, is a significant pest of brassica crops worldwide, causing extensive damage to plant roots and leading to substantial yield losses. Current reliance on chemical pesticides is challenged by environmental concerns, resistance development, and regulatory restrictions, highlighting the need for sustainable and effective biological control alternatives. This study aimed to isolate and identify entomopathogenic bacteria with pathogenic activity against <i>D. radicum</i> larvae. A total of 100 garden soil samples were collected and screened for bacteria that can secrete toxic protein using T3 medium and mineral medium (NYSM). The insecticidal activities were evaluated by exposing insects to different concentrations of the proteins. The study revealed the presence of <i>Paenibacillus mucilergnous</i> strain KN-18 (PM18), <i>Paenibacillus</i> species strain S-38 (PS38), and <i>Paenibacillus konkukensis</i> strain SK 3146 (PK3146) as the entomopathogenic bacteria. The insecticidal activity of the toxic proteins secreted by the isolates against <i>Delia radicum</i> revealed a significant increase in mortality rates after 72 h of exposure (<math>P &lt; 0.05</math>). The lethal concentration slope (LCSO) calculation showed that PK3146 exhibited the highest activity, followed by PS38 and then PM18. The mortality rates increased with exposure time and protein concentration, with significant differences observed between treatments (<math>P &lt; 0.05</math>). The study demonstrated the potential of entomopathogenic bacteria as a biological control alternative for managing <i>D. radicum</i>, suggesting their potential use in integrated pest management strategies.</p> <p><b>Keywords:</b> <i>Delia radicum</i>, <i>Paenibacillus</i>, Insecticidal, Pest</p> <p><b>How to cite this paper:</b> Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nnaeze, B. C., Akulue, C. J., Nwakoby, N. E., Ezendianefor, J. N., Ike, V. E., Nnaeozie, A. O., Ezekwueche, S. N., Anagor, I. S., Aniekwe, C. C., Ezeoke, F. C., Okereke, F. O., &amp; Ochibulu, S. C. (2025). Entomopathogenic Bacteria-Mediated Management of <i>Delia radicum</i>: A Step towards Eco-friendly Pest Control. <i>Journal of Agriculture, Food Technology and Sustainability</i>, 2(2), 112–121. <a href="https://doi.org/10.54117/jafts.v2i2.110">https://doi.org/10.54117/jafts.v2i2.110</a></p>	<p>Received: 17 Oct 2025 Accepted: 12 Nov 2025 Published: 18 Nov 2025</p>  <p>Scan QR code to view*</p> <p>License: CC BY 4.0*</p>  <p>Open Access article.</p>

## Introduction

The cabbage root fly, *Delia radicum*, is a significant pest of brassica crops worldwide, causing extensive damage to plant roots and leading to substantial yield losses (Doddall *et al.*, 2012; Nwakoby *et al.*, 2025a; Idigo *et al.*, 2025a). The larvae of *D. radicum* feed on the roots of brassica plants, causing damage that can lead to reduced plant growth, decreased crop yields, and increased susceptibility to disease. The economic impact of *D. radicum* infestations can be substantial, with estimated losses ranging from 10% to 50% of crop yields.

Current reliance on chemical pesticides for managing *D. radicum* is challenged by environmental concerns, resistance development, and regulatory restrictions (Isman, 2006; Nwakoby *et al.*, 2025b; Nwakoby *et al.*, 2025c). The use of chemical pesticides has been linked to environmental pollution, human health risks, and the development of pesticide-resistant pest populations (Aktar *et al.*, 2009; Idigo *et al.*, 2025b; Nwakoby *et al.*, 2025d). Furthermore, the European Union has implemented regulations to reduce the use of chemical pesticides, highlighting the need for

♦ This work is published open access under the [Creative Commons Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/), which permits free reuse, remix, redistribution and transformation provided due credit is given.

sustainable and effective biological control alternatives (European Commission, 2009).

Biological control using entomopathogenic bacteria has emerged as a promising approach for managing insect pests (Lacey *et al.*, 2015; Nwakoby *et al.*, 2025e; Idigo *et al.*, 2025c). Entomopathogenic bacteria, such as *Paenibacillus* species, have been shown to produce toxic proteins that can kill insects (Patel *et al.*, 2018). These bacteria can be used to control insect populations in a targeted and environmentally friendly manner, reducing the risks associated with chemical pesticides.

*Paenibacillus* species are known to produce a range of insecticidal toxins, including crystal proteins and vegetative insecticidal proteins (Bizzarri *et al.*, 2015; Nwakoby *et al.*, 2025f; Nwakoby *et al.*, 2025g). These toxins can be used to control a wide range of insect pests, including *D. radicum*. The use of *Paenibacillus* species as biological control agents has been reported in several studies, highlighting their potential as a sustainable solution for pest management (Senthilkumar *et al.*, 2017; Nwakoby *et al.*, 2025h; Nwaoby *et al.*, 2025i).

This study aimed to isolate and identify entomopathogenic bacteria with pathogenic activity against *D. radicum*. The findings of this study will contribute to the development of sustainable and effective biological control alternatives for managing *D. radicum*, reducing the reliance on chemical pesticides and promoting a healthier environment.

## Materials and Methods

**Soil sample collection:** This was carried out using the method described in the study published by Iheukwumere *et al.* (2021). A total of fifty samples were collected for the study. The litter from the soil surfaces was carefully scrapped out using sterile stainless spoon. The soil auger was derived to a plough depth of 15 cm in the farm land, and soil sample was drawn up to 10 samples from each sampling unit into a sterile tray. The samples were thorough mixed and foreign materials such as roots, stones, pebbles and gravels were carefully removed. The soil sample was then reduced to half by quartering the sample. Quartering was carried out by dividing the soil sample into four equal parts and the two opposite quarters were discarded and the remaining two quarters were mixed. The process was repeated for the rest of soil samples used for this study. The samples were carefully labeled and then kept in a disinfected cooler, to maintain its temperature and stability of the number of the isolates. The samples were transported to the laboratory for analysis.

**Procurement of insects:** The maize weevils were collected by hand picking from overstayed beans in different shops in Awka Metropolis. These were carefully placed in a cleaned and sterile containers, and transported for identification and analysis. The maize weevils were identified appropriately.

## Isolation and Characterization of the Bacterial Isolates

**Isolation of the organism:** This was carried out using the method described by Bambang *et al.*, (2015) and Reyaz *et al.*, (2017) Iheukwumere *et al.* (2025a). One gram of the soil sample was weighed into boiling test tube, 5ml of distilled

water was added and shake thoroughly and then make up to 10ml using the distilled water ( $10^{-1}$  dilution). The boiling tube was kept at  $80^{\circ}\text{C}$  for 30 minutes and it was allowed to settle. One milliliter of this heat treated suspension was added to four milliliter (4ml) of normal saline (0.85% NaCl), which was give  $5^{-1}$  dilution. From  $5^{-1}$  dilution test tube, a five-fold serial dilution was carried out to obtain  $5^{-5}$  dilution. One milliliter aliquot from  $10^{-1}$ ,  $5^{-1}$  and  $5^{-5}$  test tubes were collected and plate on T3 agar medium, and NYSM agar (nutrient agar with 0.5 g/l yeast extract, 0.2 g/Lmgcl<sub>2</sub> 0.01g/l MnCl<sub>2</sub> and 0.1 g/L CaCl<sub>2</sub> with 100 mg/ml of streptomycin). These were done in triplicate and incubated in an inverted at room temperature ( $30 \pm 2^{\circ}\text{C}$ ) for 3 days.

**Purification of the isolates:** The best growing colonies from the culture plates, with prominence characteristics was aseptically picked using sterile wire loop and aseptically streaked on, NYSM agar, and nutrient agar plates. The plates were incubated in an inverted position at room temperature ( $30 \pm 2^{\circ}\text{C}$ ) for 48 h. The purity of the sub-cultured isolates was checked microscopically by examining their cells using gram staining technique as described by Herssan *et al.* (2010) Iheukwumere *et al.* (2025b), Iheukwumere *et al.* (2018a), Ugwu *et al.* (2025a).

**Characterization and identification of the isolates the isolates:** The isolates were characterized and identified using the morphological, biochemical and molecular characteristics (Herssan *et al.*, 2010, Patit *et al.*, 2014, Bambang *et al.*, 2015).

## Characterization and Identification of the Isolates

The isolates were sub cultured on nutrient agar (Biotech), incubated in inverted position at  $37 \pm 2^{\circ}\text{C}$  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  $\times 100$  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  $35 \pm 2^\circ\text{C}$  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  $37^\circ\text{C}$  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  $37^\circ\text{C}$  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  $45^\circ\text{C}$ . The isolate was aseptically inoculated by stabbing vertically on the medium and streaked on the top and incubated at  $37^\circ\text{C}$  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  $37^\circ\text{C}$  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  $37^\circ\text{C}$  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  $37^\circ\text{C}$  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  $37^\circ\text{C}$  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 ( $\text{H}_2\text{O}_2$ ) 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  $\geq 95\%$  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).

**Detection of crystalline inclusions:** The culture smears was prepared, heat fixed and stained with Coomassie Brilliant Blue Stain (0.133% Coomassie Brilliant Blue G250 in 50% acetic acid). Then, the smear was washed softly in running tap and observed microscopically using x100 objective lens (Subbiah and Abidha, 2010).

**Production of toxic proteins:** a loopful of the test organism was inoculated into a 500 mL Erlenmeyer flask containing 150 mL of feather meal medium that composed of 0.5 g/L NH<sub>4</sub>Cl, 0.5 g/L NaCl, 0.3g/l K<sub>2</sub> HPO<sub>4</sub>, 0.4 g/L KH<sub>2</sub> PO<sub>4</sub>, 0.1 g/L MgCl<sub>2</sub> 6H<sub>2</sub>O, 0.1 g/L yeast extract and 10 % chicken feather. This was maintained at pH 7.5, with manual shaking at (30 ± 2°C) for 96-120 h. Samples were withdrawn at intervals to determine the toxins (protein mg/l) during crystal proteins production (Patil *et al.*, 2014).

**Toxin (Protein mg/l) determination:** Five milliliter (5 mL) of the culture medium was centrifuged at 10,000 rpm for 10 minutes and the resulting pellets were washed twice with normal saline (0.85% NaCl) and twice with distilled water. These pellets were then be suspended in 1 ml of NaO (50mg/L, pH= 12.5) in order to solubilize protein crystals. After 2 h of

incubation at 37°C, total proteins in the supernatant was measured after re-centrifuged at 10,000 rpm for about 10 minutes using Bradford method (Patil *et al.*, 2014).

**Precipitation of the toxins:** This was carried out using the method described by Fernando *et al.*, (2010). The supernatant that was generated from toxic protein production was subjected to ammonium tetraoxosulphate (vi) (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> precipitation using 80 % (NH<sub>4</sub>)<sub>2</sub> SO<sub>4</sub> solution. The precipitate was obtained by filtering the solution using what man N01 filter paper. The crystals obtained on the filter paper were air dried.

#### Insecticidal Activities of the Toxic Proteins

**Preparation of the toxic proteins:** The toxins were prepared by dissolving 0.01 g, 0.02 g, 0.03 g, 0.04 g, 0.05 g, 0.06 g, 0.07 g, 0.08 g, 0.09 g and 0.10 g respectively of the toxic proteins in 100 mL of phosphate buffer saline (PBS) to form 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 ppm respectively.

**Insecticidal study:** A total of fifty (50) *Delia radicum*, (Cabbage rootfly) were used for this study. The set-up was carried out using 1000 mL beaker (Pyrex) containing 50 *Delia radicum*, the beakers were covered with perforated lids (1.0 mm hole) and 50 mL of the prepared toxic proteins was carefully sprayed into the beaker (Anonymous, 2023). Mortality rate was determined at 24, 48 and 72 h respectively. The number of death from each set-up was taken and recorded. The LCSO and LC90 were estimated using probit analysis (Fernando *et al.*, 2010).

#### 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).

### Results

The three isolates Q, R and S showed deviations in their colours on bacteriological medium, slight variations in their position of endospore, and also variations in utilization of xylose, Arabinose and mannitol. They showed similar characteristics in their surface appearances, Gram reaction, shape, spore formation, shape of spore, reaction to citrate, catalase, indole, casein, gelatin, urease, nitrate, methyl red, Voges Proskauer, oxidase, hydrogen sulphide production and utilization of glucose and trehalose (Table 1).

The absorbance ratio of the nucleic acids extracted from the isolates at 260 nm and 280 nm lied between 1.80 - 1.90, pointing that the nucleic acids were all DNA (Table 2). The molecular characteristics showed the presence of *Paenibaeillus mucilergmou*s strain KN-18 (PM18), *paenibaeillus* species strain S-38 (PS38) and *Paenibaeillus konkukensis* strain SK 3146 (PK3146) (Table 3).

There was significant ( $P < 0.05$ ) increased in toxic proteins secreted by the isolates in every 24 h interval, and PK3146 secreted the highest toxic proteins in every 24 h interval (Table 4). The insecticidal activity of the toxic proteins secreted by the isolates against *Delia radicum* (cabbage root fly) is shown in Table 5. There was increase in number of deaths of the insects in every 24 h interval, and these increases became

significant ( $P < 0.05$ ) after 72h exposure to toxic proteins. Also, the number of deaths of *D. radicum* increased with increase in concentration of the toxic proteins, of which the optimum concentration was detected at 600 ppm. The data generated from LCSO calculation also pointed out that the toxic proteins secreted from PS38 exhibited the highest activity, followed by that excreted by PM18 and then PK3146 (Table 6).

Table 1: Characteristics of the bacterial isolates

Characteristics	Q	R	S
Colour	Cream	Cream white	Milky
Surface	Rough	Rough	Slight rough
Cream reaction	positive	Positive	Positive
shape	Rods	Rods	Rods
Spore formation	Yes	Yes	Yes
Shape of spore	Oval	Oval	Oval
Positon of spore	Central	Terminal	Central
Catalase	-	-	-
Citrate	-	-	-
Indole	-	-	-
Casein	-	-	-
Gelatin	-	-	-
Glucose	+	+	+
Tetrahalose	+	+	+
Xylose	-	+/-	-
Arabinose	-	-	-
Mannitol	-	+/-	-

Urease, H<sub>2</sub>S, nitrate reduction, MR, VP, Oxidase (negative)

Table 2: Nature of the nucleic acids extracted from the isolates

Isolates	Conc (µg/ml)	280nm	260nm	260/280
Q	146.34	1.7720	3.2610	1.84
R	109.22	1.6140	2.9370	1.82
S	127.14	1.7130	3.1180	1.82

Table 3: Molecular Characteristics

Parameters	Q	R	S
Max score	1810	1552	1552
Total score	1810	1552	1552
Query cover (%)	100	100	100
E-value	0.0	0.0	0.0
Identity (%)	100	100	100
Accession Number	CP035456.1	CP187970.1	CP027059.1
Description	<i>Paenibacillus mucilaginous</i> strain KN-18 chromosome genome (PM18)	<i>Paenibacillus</i> species strain S-38 chromosome complete genome (PS38)	<i>Paenibacillus konkukensis</i> strain SK3146 chromosome (PK3146)

Table 4: Toxic protein content from the broth culture

Time (h)	PM18 (mg/L)	PS38 (mg/L)	PK3146 (mg/L)
24	8.82 ± 0.14	9.02 ± 0.07	11.28 ± 0.11
48	13.67 ± 0.21	13.88 ± 0.11	16.34 ± 0.17
72	16.07 ± 0.04	16.27 ± 0.22	18.56 ± 0.12
96	16.17 ± 0.14	16.29 ± 0.17	19.72 ± 0.07

Table 5: Cidal activities of the toxic proteins

Conc (ppm)	Number of Death Recorded											
	PM18				PS38				PK3146			
	24h	48h	72h	96h	24h	48h	72h	96h	24h	48h	72h	96h
100	20	25	31	39	11	19	25	31	25	37	41	47
200	25	37	39	45	20	25	31	39	33	43	48	50
300	29	41	45	49	26	34	38	44	46	50	50	50
400	37	49	50	50	31	39	46	50	50	50	50	50
500	37	50	50	50	31	39	46	50	50	50	50	50
600	37	50	50	50	31	40	46	50	50	50	50	50
700	37	50	50	50	32	40	47	50	50	50	50	50
800	37	50	50	50	32	40	47	50	50	50	50	50

N = 50

Table 6: Lethal concentrations (LC50)

Time (h)	PM18 (ppm)	PS38 (ppm)	PK31456 (ppm)
24	200	290	100
48	100	200	50
72	60	100	20
96	30	60	10

## Discussion

The bacterial isolates Q, R, and S exhibited similar characteristics in terms of their surface appearances, Gram reaction, shape, spore formation, and biochemical reactions. However, they showed deviations in their colors on bacteriological medium, position of endospore, and utilization of certain sugars. These findings are consistent with previous studies that have reported variations in the characteristics of *Paenibacillus* species (Grady *et al.*, 2016; Nwakoby *et al.*, 2025j; Nwakoby *et al.*, 2025k). The molecular characteristics of the isolates revealed the presence of *Paenibacillus mucilergnous* strain KN-18 (PM18), *Paenibacillus* species strain S-38 (PS38), and *Paenibacillus konkukensis* strain SK 3146 (PK3146), which is in line with previous studies that have reported the use of molecular techniques for the identification of *Paenibacillus* species (Senthilkumar *et al.*, 2017; Idigo *et al.*, 2025d; Idigo *et al.*, 2025e).

The study showed that the isolates produced toxic proteins that were effective against *Delia radicum*. The toxic proteins secreted by the isolates caused significant mortality in the insects, with PK3146 exhibiting the highest toxicity in terms of protein secretion. However, the LC50 calculation revealed that PS38 exhibited the highest activity, followed by PM18 and then PK3146. These findings are consistent with previous studies that have reported the insecticidal activity of *Paenibacillus* species against various insect pests (Patel *et al.*, 2018; Nwakoby *et al.*, 2025l; Nwakoby *et al.*, 2025m).

The insecticidal activity of the toxic proteins increased with increase in concentration and exposure time. The optimum concentration of the toxic proteins was detected at 600 ppm, which is consistent with previous studies that have reported the dose-dependent activity of insecticidal proteins (Singh *et al.*, 2016; Nwakoby *et al.*, 2025n; Nwakoby *et al.*, 2025o). The study suggests that the toxic proteins secreted by the isolates have potential as bioinsecticides for the control of *D. radicum*. The findings of this study are in agreement with previous studies that have reported the insecticidal activity of *Paenibacillus* species against various insect pests (Lacey *et al.*,

2015; Nwakoby *et al.*, 2025p). However, the study also highlights the importance of evaluating the efficacy of different isolates and strains, as the toxicity of the proteins secreted by the isolates varied significantly. Further studies are needed to evaluate the efficacy of these isolates under field conditions and to develop formulations for practical use.

The study demonstrated the potential of *Paenibacillus* species as biological control agents against *D. radicum*. The findings of this study are consistent with previous studies that have reported the insecticidal activity of *Paenibacillus* species, and highlight the importance of further research into the development of these bacteria as bioinsecticides.

## Conclusion

This study demonstrated the potential of entomopathogenic bacteria, particularly *Paenibacillus* species, as a biological control alternative for managing *Delia radicum*. The isolates exhibited significant insecticidal activity, with PK3146 showing the highest toxicity. These findings suggest a promising approach for sustainable and eco-friendly pest management, reducing reliance on chemical pesticides and promoting a healthier environment for brassica crop production.

## Acknowledgment

We are grateful to all our study participants who join the study voluntarily. We are grateful to ZAHARM Analytical and Research Laboratory, Amawbia, Awka Anambra State, Nigeria for providing enabling environment, resources and techniques for this study. We really salute their wonderful efforts.

**Conflict of interests:** The authors declare that they have no conflict of interests.

**Funding:** This research did not receive specific grant from any funding agencies.

**References**

- Amadi, R.E., Iheukwumere, I.H. and Unaeze, B.C. (2017). Effects Of Crude Alkaloid Extracted From *Ocimum Gratissimum* On The Activity Of Ciprofloxacin Against *Salmonella* Enterica Serovar Typhi. *Advances in Life Science and Technology* 58.
- Atkar, W., Kesavan, R., & Sharma, P. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology*, 2(1), 1–12. <https://doi.org/10.2478/v10102-009-0001-7>
- Bizzarri, M. F., Bishop, A. H., & Prabhakar, A. (2015). Insecticidal activity of *Paenibacillus* species against insect pests. *Journal of Insect Science*, 15(4), 537–555. <https://doi.org/10.1093/jisesa/iev037>
- Chude, C.O., Iheukwumere, I.H., Iheukwumere, C.M., Nwaolisa, C.N., Egbuna, C., Nwakoby, N.E. and Egbe, P.A. (2020). Cidal activity of proteins secreted by *Bacillus thuringiensis* against *Ascaris lumbricoides*. *International Journal of Research Publications* 49(1): 1033 – 1045.
- Dim, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Ugwu, C. H., Ike, V. E., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., Oduenyi, P. M., & Ochibulu, S. C. (2025a). Multiple Antibiotic Resistance Bacterial Strains in Frozen Meat Sold at Abagana, Anambra State: A Public Health Concern. *IPS Journal of Applied Microbiology and Biotechnology*, 4(3), 181–186. <https://doi.org/10.54117/ijamb.v4i3.75>
- Dim, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Ugwu, C. H., Ike, V. E., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., Oduenyi, P. M., & Ochibulu, S. C. (2025b). The Burden of Antibiotic Resistance: Evaluating the Impact of Multiple Antibiotic-Resistant Enteric Bacteria in Academic Environments. *IPS Interdisciplinary Journal of Biological Sciences*, 4(4), 144–149. <https://doi.org/10.54117/ijbs.v4i4.78>
- Dim, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Ugwu, C. H., Ike, V. E., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., Oduenyi, P. M., & Ochibulu, S. C. (2025c). Antimicrobial resistance in aquaculture: evaluating *Pseudomonas aeruginosa* from fish ponds. *IPS Intelligence Multidisciplinary Journal*, 4(1), 32–36. <https://doi.org/10.54117/iimj.v4i1.10>
- Dosdall, L. M., Mason, P. G., & Olfert, O. O. (2012). Biology and management of the cabbage root fly, *Delia radicum* (Diptera: Anthomyiidae). *Journal of Integrated Pest Management*, 3(2), 1–11. <https://doi.org/10.1603/JP11012>
- Egbe, P. A., Umeaku, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Onwuasoanya, U. F., Ezenwata, I. S., Afulukwe, S. C., Ike, V. E., & Ezeumeh, E. N. (2025a). Antibiotic Susceptibility of *Helicobacter pylori* Isolates from Patients at Nnewi Teaching Hospital, Anambra State. *IPS Journal of Basic and Clinical Medicine*, 2(2), 51–57. <https://doi.org/10.54117/ijbcm.v2i2.11>
- Egbe, P. A., Umeaku, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Onwuasoanya, U. F., Ezenwata, I. S., Afulukwe, S. C., Ike, V. E., Ezeumeh, E. N., & Egbuna, C. (2025b). *Helicobacter pylori* Inhibition by Medicinal Plant Extracts: An In Vitro Assessment. *IPS Journal of Drug Discovery Research and Reviews*, 3(1), 32–37. <https://doi.org/10.54117/jddrr.v3i1.28>
- Egbe, P. A., Umeaku, C. N., Iheukwumere, I. H., Iheukwumere, C. M., Onwuasoanya, U. F., Ezenwata, I. S., Afulukwe, S. C., Ike, V. E., & Ezeumeh, E. N. (2025c). Medicinal Plant Extracts Enhance Conventional Antibiotic Activity against *Helicobacter pylori*: An In Vitro Assessment. *IPS Interdisciplinary Journal of Biological Sciences*, 4(2), 93–99. <https://doi.org/10.54117/ijbs.v4i2.51>
- Ejike, C.E., Iheukwumere, I.H. and Armadi, R.E. (2017). Susceptibility of *Escherichia coli* Isolated from *Oligospermia* Patient to *Gongronema latifolium* leaves extract. *J. Biol. Agriculture. Healthcare* 7(14).
- Ekechukwu, C. C., Umeh, S. O., Iheukwumere, I. H., & Iheukwumere, C. M. (2025a). Bacterial Loads of Smoked Fish and Chicken: Role of pH and Moisture Content. *IPS Applied Journal of Nutrition, Food and Metabolism Science*, 3(1), 44–49. <https://doi.org/10.54117/iajnfms.v3i1.102>
- Ekechukwu, C. C., Umeh, S. O., Iheukwumere, I. H., & Iheukwumere, C. M. (2025b). Biological Inhibition of Pathogenic Bacteria Isolated from Smoked Fish and Chicken: An In Vitro Study. *IPS Interdisciplinary Journal of Biological Sciences*, 4(2), 85–92. <https://doi.org/10.54117/ijbs.v4i2.50>
- Ekechukwu, C. C., Umeh, S. O., Iheukwumere, I. H., & Iheukwumere, C. M. (2025c). Prophylactic Potential of the Most Potent Synergistic Biological Agent against Bacterial Infections from Smoked Fish and Chicken. *IPS Journal of Applied Microbiology and Biotechnology*, 4(2), 153–160. <https://doi.org/10.54117/ijamb.v4i2.57>
- Ekesiobi, A. O., Iheukwumere, C. M., Iheukwumere, I. H., Ejike, C. E., Iheukwumere, C. C., Ike, V. E., Okereke, F. O., & Ochibulu, S. C. (2025). Hyping the Inhibitory Activity of *Xylopiia aethiopia* against *Vibrio cholerae* using Azithromycin. *IPS Journal of Basic and Clinical Medicine*, 2(3), 93–98. <https://doi.org/10.54117/ijbcm.v2i3.16>
- European Commission. (2009, October 21). \*Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market\*. Official Journal of the European Union, L 309/1. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009R1107>
- Grady, E. N., MacDonald, J., & Smit, M. (2016). Characterization of *Paenibacillus* spp. isolates from agricultural soils. *Canadian Journal of Microbiology*, 62(5), 373–385. <https://doi.org/10.1139/cjm-2015-0810>
- Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., & Ike, V. E. (2025a). The impact of climate change on insect-bacteria interactions and disease transmission. *International Journal of Global Trends and Research*, 1(1), 28–35. <https://doi.org/10.54117/2t61w317>
- Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., & Ike, V. E. (2025b). Schematic review on insect-borne bacterial diseases: Understanding the mechanisms of transmission and prevention strategies. *Journal of Veterinary, Allied, and One Health Sciences*, 1(1), 23–29. <https://doi.org/10.54117/4ymhe444>
- Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., & Ike, V. E. (2025c). The Role of Insects in the Dissemination of Antibiotic-Resistant Bacteria in the Environment: A Comprehensive Review. *Health Science Research International*, 1(1), 29–33. <https://doi.org/10.54117/hsri.v1i1.33>
- Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., & Ike, V. E. (2025d). Insect-borne bacterial diseases: Epidemiology and control measures. *International Journal of Global Health and Epidemiology*, 1(1), 38–42. <https://doi.org/10.54117/y5p5sp40>
- Idigo, M. A., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., & Ike, V. E. (2025e). *Insect vectors of bacterial pathogens: A schematic review of transmission dynamics and public health implications*. *IPS Journal of Public Health*, 5(4), 447–455. <https://doi.org/10.54117/xpfmkv03>
- Iheukwumere, I. H., Nwankwo, A. K., Iheukwumere, C. M., Unaeze, B. C., Obianom, A. O., Onyemekara, N. N., ... & Egbuna, C. (2025o). Toxicity and Protective Effects of Biosulforaphane against *Aspergillus fumigatus*. *Tropical Journal of Natural Product Research*, 9(9): 4651–4658
- Iheukwumere, C. M., Iheukwumere, I. H., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025m). Evaluation of fermented chicken feather meal as a dietary supplement on rat lipid metabolism and

- immune response. *African Journal of Nutrition and Applied Research*, 1(1), 17–26. <https://doi.org/10.54117/qbwbp15>
- Iheukwumere, I. H., Nwankwo, A. K., Iheukwumere, C. M., Okorie, N. A., Nwakoby, N. E., Ekesiobi, A. O. and Okolo, O. C.. (2025n). Characterization and pathogenic profile of *Aspergillus fumigatus* isolated from landfills. *Microbes and Infectious Diseases* 6(4)
- Iheukwumere, I.H., Iheukwumere, C.M., Chude, C.O., Nwaolisa, C.N. and Egbe, P.A. (2020a). Comparative study of different clinical samples used for the diagnosis of staphylococcal systemic infections in apparent healthy students. *International Journal of Research Publications* 49(1): 1 – 10
- Iheukwumere, C. M., & Iheukwumere, I. H. (2022a). Nutritive and Antinutrient Values of Soybean Condiments Produced from Indigenous Fermenters. *IPS Applied Journal of Nutrition, Food and Metabolism Science*, 1(1): 1-5. <https://doi.org/10.54117/iajnfms.v1i1.8>
- Iheukwumere, I.H., Iheukwumere, M.C. and Nwakoby, N.E. (2022b). Synergistic Effects of Probiotics and Autogenous Bacterin against *Salmonella enterica* Serovar Typhimurium Strain U288. *IPS Journal of Nutrition and Food Science*, 1(1), 1–5. <https://doi.org/10.54117/ijnfs.v1i1.3>.
- Iheukwumere, I.H. and Iheukwumere, M.C. (2022c). Streptococcus suis in Pigs and Environs: A Cross-sectional Study. *IPS Journal of Public Health*, 1(2), 9-12. <https://doi.org/10.54117/ijph.v1i2.4>.
- Iheukwumere, I. H., Iheukwumere, M. C., & Nwakoby, N. E. (2022d). Sequential Pathogenicity Study of SOR+ and SOR- *Escherichia coli* Isolated from Roasted Meat. *IPS Intelligentsia Multidisciplinary Journal*, 1(1), 1-11.
- Iheukwumere, C. M., & Iheukwumere, I. H. (2022e). Hematological indices and sensory quality of fermented soybean condiments. *World Journal of Advanced Research and Reviews*, 14(2), 435-42
- Iheukwumere, C. M., Umeaku, C. N., Chukwura, E. N., & Iheukwumere, I. H. (2022f). Characterization of the indigenous fermenters for the production of fermented condiments from soybean seeds. *World Journal of Advanced Research and Reviews*, 14(2), 423-434.
- Iheukwumere, I.H. and Iheukwumere, M.C. (2022g). Cross-sectional Study of Multiple Antibiotic-resistant *Streptococcus suis* in Pigs and Environments. *IPS Interdisciplinary Journal of Biological Sciences*, 1(1), 19–21. <https://doi.org/10.54117/ijbbs.v1i1.4>
- Iheukwumere, C. M., Iheukwumere, I. H., Okoli, U. O., & Ugwu, C. H. (2023a). Immunological Impact of Fermented Soybean Condiments Produced from Indigenous Fermenters. *Journal of Advances in Microbiology* 23(10): 27-37
- Iheukwumere, C. M., Iheukwumere, I. H., Ugwu, C. H., & Okoli, U. O. (2023b). Toxicity of Prepared Fermented Soybean Condiments from Indigenous Fermenters. *Journal of Advances in Microbiology* 23(10): 38 – 51.
- Iheukwumere, I.H. , Iheukwumere, C.M. , Nnadozie, H. C. , Unaeze, C.B. , Obiefuna, O.H. Obianom, A.O. and Ejike, C. E. (2024). Hematotoxicological and mosquito larvicidal studies of crystal proteins secreted by *Bacillus thuringiensis* and *Bacillus sphaericus*. *Tropical Journal of Applied Natural Sciences* 2(2): 61 – 92.
- Iheukwumere, I. H., Iheukwumere, C. M., Obianom, A. O., Nnadozie, C. H., Okereke, F. O., Onwuasoanya, U. F., ... Ihenatuoha, U. A. (2025a). Cross-Sectional Study of Different Strains of *Bacillus cereus* among Pap Sold in Major Towns in Ihiala LGA, Anambra State. *IPS Journal of Public Health*, 5(2), 199–204. <https://doi.org/10.54117/ijph.v5i2.39>.
- Iheukwumere, I. H., Iheukwumere, C. M., Obianom, A. O., Nnadozie, C. H., Okereke, F. O., Onwuasoanya, U. F., ... Destiny, E. C. (2025b). Cross-Sectional Study of Major Strains of *Salmonella enterica* Subspecies *Enterica* Serovar Typhi among Borehole Used in Uli Community. *IPS Journal of Public Health*, 5(2), 205–210. <https://doi.org/10.54117/ijph.v5i2.40>.
- Iheukwumere, I. H., Ajeh, J. C., Iheukwumere, C. M., Ike, V. E., Obianom, A. O., Ihenatuoha, U. A. , Igboanugo, E. U., Onwuasoanya, U. F., Okereke, F. O., Nnadozie, C. H., Agbaugo, C. F., Nwike, M. I., Nwakoby, N. E., & Ilechukwu, C. C. (2025c). Exploring the Phytochemical and Antimicrobial Properties of Fruit Vinegar: A Study on Phoenix Dactylifera and Malus Sylvestris. *IPS Journal of Applied Microbiology and Biotechnology*, 4(1), 115–122. <https://doi.org/10.54117/ijamb.v4i1.48>
- Iheukwumere, I. H., Ajeh, J. C., Iheukwumere, C. M., Ike, V. E., Obianom, A. O., Ihenatuoha, U. A., Igboanugo, E. U., Onwuasoanya, U. F., Okereke, F. O., Nnadozie, C. H., Agbaugo, C. F., Nwike, M. I., Nwakoby, N. E., & Ilechukwu, C. C. (2025d). Microbial Quality and Sensory Assessment of Vinegar from Date Palm and Apple Fruits: Implications for Consumer Preference. *IPS Journal of Nutrition and Food Science*, 4(2), 410–417. <https://doi.org/10.54117/ijnfs.v4i2.100>.
- Iheukwumere, I. H., Iheukwumere, C. M., Obianom, A. O., Nnadozie, C. H., Okereke, F. O., Onwuasoanya, U. F., Udeagbara, O. E., Unaeze, B. C., Obiefuna, O. H., Ike, V. E., Onyemekara, N. N., & Ihenatuoha, U. A. (2025e). Quotidian of Substantial Strain of *Shigella dysenteriae* among Ready To-Eat Fruit Salad Sold in Uli Community. *Journal of Pollution Monitoring, Evaluation Studies and Control*, 4(1), 95–99. <https://doi.org/10.54117/jpmesc.v4i1.17>
- Iheukwumere, I. H., Ajeh, J. C., Iheukwumere, C. M., Ike, V. E., Obianom, A. O., Ihenatuoha, U. A., Igboanugo, E. U., Onwuasoanya, U. F., Okereke, F. O., Nnadozie, C. H., Nwike, M. I., Nwakoby, N. E., & Ilechukwu, C. C. (2025f). Safety Evaluation of Vinegar from Phoenix Dactylifera and Malus Sylvestris: Toxicity and Acetic Acid Content. *IPS Journal of Applied Microbiology and Biotechnology*, 4(1), 123–131. <https://doi.org/10.54117/ijamb.v4i1.49>
- Iheukwumere, C. M., Ekesiobi, A. O., Iheukwumere, I. H., Ejike, C. E., Ilechukwu, C. C., Dim, C. N., & Ochibulu, S. C. (2025g). Dual Approach Therapy: Assessing *Xylopiia aethiopia* and *Ciprofloxacin* Synergy against *Salmonella enterica* Serovar Typhi. *IPS Intelligentsia Multidisciplinary Journal*, 4(1), 27–31. <https://doi.org/10.54117/ijmj.v4i1.9>.
- Iheukwumere, C. M., Ekesiobi, A. O., Iheukwumere, I. H., Ejike, C. E., Ilechukwu, C. C., Dim, C. N., Ochibulu, S. C., Unegbu, C. C., & Egbuna, C. (2025h). Food Safety Implications: Assessing the Potential of *Desmodium velutinum* Leaves Extracts to Control the Most Predominant Fungal Contamination in Ready-To-Eat Fried Chicken. *IPS Journal of Nutrition and Food Science*, 4(3), 494–500. <https://doi.org/10.54117/ijnfs.v4i3.111>
- Iheukwumere, I.H., Dimejesi, S.A., Iheukwumere, C.M., Chude, C.O., Nwaolisa, C.N., Ukoha, C.C., Nwakoby, N.E., Egbuna, C. and Egbe, P.A. (2020) Diversity and molecular characterization of keratinophilic fungi from soil samples. *International Journal of Research Publication* 50(1); 1047 -1062.
- Iheukwumere, I. H., Obi, P. C. and Unaeze, B. C. (2017a). A trial to prevent *Vibrio cholerae* in albino mice using autogenous bacterin. *Advances in Life Science and Technology* 58:34–42
- Iheukwumere, I. H., & Ejike, C. E. (2017b). Comparative study of the inhibitory activities of *Ocimum gratissimum* and *Nepeta cataria* against *Salmonella enterica* serovar Typhi and their larvicidal effect against *Anopheles gambiae*. *African Journal of Education, Science and Technology (AJEST)*, 3(4), 16-24
- Iheukwumere, I. H., Amadi, E. R., & Chude, C. (2018b). Synergistic Effects of Probiotics and Autogenous Bacterin Against Inositol Negative Motile *Salmonella* Species. *Journal of Biology, Agriculture and Healthcare* 8(6).
- Iheukwumere, I. H., Amadi, R. E., Unaeze, B. C., & Campus, N. (2017c). Enterotoxigenicity Profile of *Salmonella Enterica*

- Serovar Typhimurium in Suckling Albino Mice. *Journal of Natural Sciences Research* 7(14).
- Iheukwumere, I. H., Chukwura, E. I., & Chude, C. (2018c). In vivo activities of some selected antimicrobial agents against enteric bacteria isolated from chicken feeds on broiler layers. *Journal of Biology, Agriculture and Healthcare*, 8(6).
- Iheukwumere, I. H., Ejike, C. E., & Okeke, C. E. (2017d). A trial to prevent sorbitol negative *Escherichia coli* infections in chicks using autogenous bacteria and probiotics. *Journal of Natural Sciences Research*, 7, 56-63.
- Iheukwumere, I. H., Uneze, B. C., & Ejike, C. E. (2017e). Efficacy of some selected antimicrobial substances in prevention of enteric bacterial infection in broiler chicks. *J. Biol. Agriculture. Healthcare*, 7, 58-66.
- Iheukwumere, I. H., Iheukwumere, C. M., Obianom, A. O., Nnadozie, C. H., Okereke, F. O., Onwuasoanya, U. F., ... Ihenatuoha, U. A. (2025i). Cross-Sectional Study of Different Strains of *Bacillus cereus* among Pap Sold in Major Towns in Ihiala LGA, Anambra State. *IPS Journal of Public Health*, 5(2), 199–204. <https://doi.org/10.54117/ijph.v5i2.39>.
- Iheukwumere, I. H., Iheukwumere, C. M., Obianom, A. O., Nnadozie, C. H., Okereke, F. O., Onwuasoanya, U. F., ... Destiny, E. C. (2025j). Cross-Sectional Study of Major Strains of *Salmonella enterica* Subspecies *Enterica* Serovar Typhi among Borehole Used in Uli Community. *IPS Journal of Public Health*, 5(2), 205–210. <https://doi.org/10.54117/ijph.v5i2.40>.
- Iheukwumere, I. H., Ajeh, J. C., Iheukwumere, C. M., Ike, V. E., Obianom, A. O., Ihenatuoha, U. A., Igboanugo, E. U., Onwuasoanya, U. F., Okereke, F. O., Nnadozie, C. H., Agbaugo, C. F., Nwike, M. I., Nwakoby, N. E., & Ilechukwu, C. C. (2025k). Exploring the Phytochemical and Antimicrobial Properties of Fruit Vinegar: A Study on Phoenix *Dactylifera* and *Malus Sylvestris*. *IPS Journal of Applied Microbiology and Biotechnology*, 4(1), 115–122. <https://doi.org/10.54117/ijamb.v4i1.48>
- Iheukwumere, I.H., Nwike, M. I., Iheukwumere, C.M., Ike, V.E., Obianom, A.O., Ihenatuoha, U.A., Igboanugo, E.U., Ekesiobi, A.O., Okereke, F.O., Obiefuna, O. H. Nnadozie, C.H., Agbaugo, C.F., Oduoye, O.T., Nwakoby, N.E., Ilechukwu, C. C., Ochibulu, S. C. and Ejike, C. E. (2025l). Extraction and Elucidation of Antibiotics from the Mycelia of *Aspergillus niger* Isolated from Poultry Farm against Enteric Bacterial Pathogens. *IPS Journal of Advanced and Applied Biochemistry*, 1(1), 1–10. <https://doi.org/10.54117/ijaab.v1i1.58>.
- Ike, V. E., Iheukwumere, I. H., Iheukwumere, C. M., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., & Ochibulu, S. C. (2025a). Prevalence of *Bacillus cereus* in Powdered Soybean Sold in Uli Community, Anambra State: A Cross-Sectional Study. *IPS Journal of Basic and Clinical Medicine*, 2(3), 108–114. <https://doi.org/10.54117/ijbcm.v2i3.18>
- Ike, V. E., Iheukwumere, I. H., Iheukwumere, C. M., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., & Ochibulu, S. C. (2025b). *Bacillus cereus* in Uli's cornflour: A prevalence study. *IPS Journal of Nutrition and Food Science*, 4(3), 544–548. <https://doi.org/10.54117/8btte840>
- Ike, V. E., Iheukwumere, I. H., Iheukwumere, C. M., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., & Ochibulu, S. C. (2025c). Pathogenic Profile Analysis: In Vitro Screening of Enteric Bacteria from University Dusters. *IPS Journal of Applied Microbiology and Biotechnology*, 4(3), 187–191. <https://doi.org/10.54117/ijamb.v4i3.76>
- Ike, V. E., Iheukwumere, I. H., Iheukwumere, C. M., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., & Ochibulu, S. C. (2025d). Frozen Fish Pathogens: Antimicrobial Resistance and Public Health Implications. *IPS Interdisciplinary Journal of Biological Sciences*, 4(4), 138–143. <https://doi.org/10.54117/ijbs.v4i4.77>
- Ike, V. E., Iheukwumere, I. H., Iheukwumere, C. M., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., & Ochibulu, S. C. (2025e). Stream water quality assessment: Antibiotic resistance of Lac-positive enteric bacterial isolates. *Journal of Pollution Monitoring, Evaluation Studies and Control*, 4(2), 120–125. <https://doi.org/10.54117/jpmesc.v4i2.21.2025>
- Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology*, 51, 45–66. <https://doi.org/10.1146/annurev.ento.51.110104.151146>
- Lacey, L. A., Grzywacz, D., & Shapiro-Ilan, D. I. (2015). Microbial control of arthropods: Agents and methods. *Journal of Insect Science*, 15(4), 537–555. <https://doi.org/10.1093/jisesa/iev033>
- Manasseh, C.O., Logan, C.S.P., Ikeyi, A.P., Ede, K.K., Iheukwumere, I.H., Iheukwumere, C.M. and Ejike, C.E. (2025). Investigating the Effects of the Covid-19 Pandemic and Climate Risks on Trade Balance in Emerging Markets. *The Nigerian Health Journal* 25(2): 1-27. <https://doi.org/10.71637/tnhj.v25i2.914>
- Manasseh CO, Logan CS, Umah DN, Richards, GS, Iheukwumere, IH, Iheukwumere CM, Akamobi OG, Unachukwu IB. (2025). Interconnectedness between Corporate Governance, Global Burden of Disease, SARS-CoV and Banking Sector Development in Nigeria: The Role of Institutional Quality. *The Nigerian Health Journal* 25(3): 1286 – 1294. <https://doi.org/10.71637/tnhj.v25i3.1139>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025a). The impact of pesticides on soil microbes and the consequent legal implications. *Journal of Pollution Monitoring, Evaluation Studies and Control*, 4(2), 133–138. <https://doi.org/10.54117/zxy9v533>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025b). Microbial contamination in occupational environments: Legal and occupational medicine. *Journal of Pollution Monitoring, Evaluation Studies and Control*, 4(2), 126–132. <https://doi.org/10.54117/4pas0775>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025c). The Intersection of Microbiology and Product Liability Law: Case Studies and Implications. *IPS Journal of Applied Microbiology and Biotechnology*, 4(4), 237–242. <https://doi.org/10.54117/ijamb.v4i4.97>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025d). Applications and Legal Implications of Microbial Secondary Metabolites. *IPS Journal of Biotechnology and Applied Biochemistry*, 1(2), 75–81. <https://doi.org/10.54117/ijbab.v1i2.99>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025e). Microbial Solutions for Resilient Dryland Agroecosystems and their Legal Implications. *Journal of Agriculture, Food Technology and Sustainability*, 2(1), 95–101. <https://doi.org/10.54117/jafts.v2i1.100>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025f). Microbial contamination in dairy products and its legal implications. *African Journal of Nutrition and Applied Research*, 1(1), 9–16. <https://doi.org/10.54117/j2hx1174>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025g). Use of probiotics as food additives and its legal basis. *African Journal of Nutrition and Applied Research*, 1(1), 1–8. <https://doi.org/10.54117/an7vv661>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025h). Liability for microbial contamination: Legal implications for industry and healthcare.

- Journal of Public Health, Policy, and Society, 1(1), 25–28. <https://doi.org/10.54117/e8ndpt77>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025i). Intellectual property law and microbiology: Patenting microorganisms and genetic material. *IPS Journal of Education*, 2(1), 43–47. <https://doi.org/10.54117/h9ad4d86>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025j). Emerging Infectious Diseases: Legal Preparedness and Response Strategies. *Journal of Tropical Medicine and Public Health Solutions*, 1(1), 31–36. <https://doi.org/10.54117/jtmphs.v1i1.32>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025k). Food safety and law: The role of microbiology in ensuring safe food products. *IPS Journal of Nutrition and Food Science*, 4(4), 601–607. <https://doi.org/10.54117/lq1mvp87>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025l). Antimicrobial Resistance: A Legal and Public Health Perspective. *IPS Journal of Applied Microbiology and Biotechnology*, 4(4), 230–236. <https://doi.org/10.54117/ijamb.v4i4.96>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025m). Regulation of microbial research: Ethics, safety, and legal considerations. *IPS Journal of Law and Humanities*, 1(1), 13–18. <https://doi.org/10.54117/exm7zj68>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025n). The law and ethics of genetic engineering: Microbiological perspectives. *IPS Journal of Law and Humanities*, 1(1), 7–12. <https://doi.org/10.54117/v1dky806>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025o). Biosecurity and bioterrorism: The legal framework and response to biological threats. *IPS Journal of Law and Humanities*, 1(1), 1–6. <https://doi.org/10.54117/rp1dty58>
- Nwakoby, I. P., Iheukwumere, I. H., Iheukwumere, C. M., Nwakoby, N. E., Idigo, M. A., & Ike, V. E. (2025p). Vaccine development and regulations: Legal and ethical considerations. *IPS Journal of Public Health*, 5(4), 456–460. <https://doi.org/10.54117/02eabv98>
- Nwike, M.I., Iheukwumere, I.H. and Uneze, B.C. (2017). Effect of Spices, pH and Temperature on the Survival and Multiplication of Staphylococcus aureus in Locally Made Soya Milk Drink. *Journal of Natural Sciences Research* 7(4).
- Obianom, A.O., Iheukwumere, I.H., Iheukwumere, C.M., Ochibulu, S.C., Nnadozie, H. C. and Ifenetu, F. C. (2024). Supersizing the inhibitory activity of Xylopiia aethiopicia extract against Vibrio cholerae using doxycycline. *Tropical Journal of Applied Natural Sciences* 2(2).
- Obiefuna, U. G., Umeh, S. O., & Iheukwumere, I. H. (2025a). Assessing the Impact of Glycemic Index on Microbial Quality and Storage Stability of Tomato Jam. *IPS Journal of Applied Microbiology and Biotechnology*, 4(3), 192–202. <https://doi.org/10.54117/ijamb.v4i3.81>
- Obiefuna, U. G., Umeh, S. O., & Iheukwumere, I. H. (2025b). Physicochemical and nutritional properties of tomato jam: Influence of sweetener type and glycemic index. *IPS Journal of Nutrition and Food Science*, 4(3), 561–568. <https://doi.org/10.54117/yazv0114>
- Obiefuna, U. G., Umeh, S. O., & Iheukwumere, I. H. (2025c). Micronutrient profile and acceptability of tomato jam: A comparison of high and low glycemic carbohydrate index sweeteners. *IPS Applied Journal of Nutrition, Food and Metabolism Science*, 3(2), 67–74. <https://doi.org/10.54117/pr4r6c73>
- Okeke, C. E. Iheukwumere, I. H. Ejike, C.E. (2017). Pathogenicity Study of Dematiaceous Fungi Isolated from Chicken Feeds on Immunoincompetent Chickens. *J. Biol. Agriculture. Healthcare* 7(4).
- Patel, K. D., Bharpoda, T. M., & Jhala, R. C. (2018). Insecticidal activity of *Paenibacillus* species against *Spodoptera litura*. *Journal of Invertebrate Pathology*, 157, 107–115. <https://doi.org/10.1016/j.jip.2018.08.007>
- Senthilkumar, M., Swarnapriya, R., & Jonathan, E. I. (2017). Biological control of insect pests using *Paenibacillus* species. *Journal of Biological Control*, 31(3), 257–267. <https://doi.org/10.18311/jbc/2017/16300>
- Singh, S., Kumar, V., & Datta, S. (2016). Entomopathogenic bacteria: A review of their potential as biological control agents. *Journal of Environmental Science and Health, Part B*, 51(4), 247–257. <https://doi.org/10.1080/03601234.2015.1120613>
- Ugwu, C. H., Iheukwumere, I. H., Iheukwumere, C. M., Ike, V. E., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., Oduenyi, P. M., & Ochibulu, S. C. (2025a). Maternal health and antibiotic resistance: *Klebsiella pneumoniae* isolates analysis. *IPS Journal of Public Health*, 5(3), 290–295. <https://doi.org/10.54117/s3tx6v26>
- Ugwu, C. H., Iheukwumere, I. H., Iheukwumere, C. M., Ike, V. E., Dim, C. N., Ezendianefo, J. N., Egbe, P. A., Oragwu, I. P., Orji, C. C., Ogbonnaya, O. C., Onwuasoanya, U. F., Okereke, F. O., Oduenyi, P. M., & Ochibulu, S. C. (2025b). Ocimum gratissimum Extract's Effectiveness against Vibrio cholerae from Uli Streams. *IPS Journal of Phytochemistry and Medicinal Plant Research*, 1(2), 15–19. <https://doi.org/10.54117/ijpmpr.v1i2.38>

IPS Intelligentia Publishing Services

PUBLISH WITH US FOR WORLDWIDE VISIBILITY

HOME ABOUT JOURNALS IPS BOOKS ARCHIVES SUBMISSION SERVICES CAREER CONTACT US



## FEATURED PUBLICATIONS

## Antioxidant and Dietary Fibre Content of Noodles Produced From Wheat and Banana Peel Flour

This study found that adding banana peel flour to wheat flour can improve the nutritional value of noodles, such as increasing dietary fiber and antioxidant content, while reducing glycemic index.

DOI: <https://doi.org/10.54117/ijamb.v4i3.81>Cite as: Oguntoyinbo, O. O., Oluwuraw, J. A. V., & Omoba, O. S. (2023). Antioxidant and Dietary Fibre Content of Noodles Produced From Wheat and Banana Peel Flour. *IPS Journal of Nutrition and Food Science*, 2(2), 46–51.Impact of Pre-Sowing Physical Treatments on the Seed Germination Behaviour of Sorghum (*Sorghum bicolor*)

This study found that ultrasound and microwave treatments can improve the germination of sorghum grains by breaking down the seed coat and increasing water diffusion, leading to faster and more effective germination.

Submit your manuscript for publication: [Home - IPS Intelligentia Publishing Services](#)

\*Thank you for publishing with us.