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Effect of Soil Solarisation on Fusarium Wilt Suppression, Soil Microbial Dynamics, Growth, and Yield of Cucumber (*Cucumis sativus* L.)

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Abstract
Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *cucumerinum*, is a major soil-borne disease that significantly constrains cucumber (*Cucumis sativus* L.) production worldwide. Soil solarisation has been proposed as an environmentally friendly alternative to chemical disease control. This study evaluated the effectiveness of soil solarisation in suppressing *Fusarium* wilt and enhancing the growth and yield of cucumber under field conditions. The experiment was conducted over nine weeks at Matogun Airport Signal Farmland, Oke-Aro, Ogun State, Nigeria. Two treatments, namely solarised soil and non-solarised soil (control), were arranged in a Completely Randomised Design (CRD) with three replicates. Soil samples were collected before solarisation and at two-week intervals after treatment to determine changes in fungal and bacterial populations, while cucumber growth, yield, and disease incidence were assessed throughout the experimental period. Fungal isolates identified included *Trichoderma*, *Aspergillus*, *Penicillium*, *Rhizoctonia*, *Fusarium*, *Pythium*, and *Rhizopus* species, whereas bacterial isolates comprised *Bacillus*, *Pseudomonas*, *Enterobacter*, *Klebsiella*, *Azotobacter*, and Actinomycetes. Fungal colony counts declined markedly following solarisation, from 5.40–9.63 × 10^2 cfu mL^{-1} before treatment to 1.50–2.23 × 10^2 cfu mL^{-1} after six weeks. In contrast, bacterial populations increased from 2.80–4.27 × 10^2 cfu mL^{-1} to 8.57–14.13 × 10^2 cfu mL^{-1}. Cucumber plants grown in solarised soils exhibited improved vegetative growth and higher fruit yields, producing 22.67–23.33 fruits per plant compared with 12.67–14.33 fruits per plant in non-solarised soils. *Fusarium* wilt incidence (40.00–42.33%) occurred only in non-solarised plots. The study demonstrates that soil solarisation effectively suppresses soil-borne fungal pathogens, enhances beneficial bacterial populations, reduces *Fusarium* wilt incidence, and improves cucumber productivity. Soil solarisation is therefore recommended as a sustainable disease management strategy for cucumber cultivation.

Keywords: Cucumber, *Fusarium* wilt, Soil solarisation, Soil-borne pathogens, Crop yield

1. Introduction

Cucumber (*Cucumis sativus* L.) is one of the most widely cultivated vegetable crops belonging to the family Cucurbitaceae, which also includes economically important crops such as melon, watermelon, and squash (Sharma et al., 2026; Vivek et al., 2017). The crop is highly valued worldwide for its nutritional, medicinal, and economic importance. Cucumber fruits are rich in vitamins, minerals, dietary fibre, antioxidants, and other bioactive compounds that contribute to human health and nutrition despite their low caloric content and high water composition (Umeh et al., 2020; Khan et al., 2021; Sharma et al., 2026). The increasing consumer demand for fresh vegetables and healthy diets has further enhanced the importance of cucumber production in many agricultural systems. However, achieving optimum productivity remains a challenge due to several biotic constraints, particularly diseases caused by soil-borne pathogens.

Among the diseases affecting cucumber cultivation, Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cucumerinum* (FOC) (Mariyappa et al., 2025) is regarded as one of the most destructive worldwide. The pathogen infects plants through the root system and subsequently colonises the vascular tissues, causing leaf yellowing, wilting, vascular discolouration, stunted growth, and eventual plant death (Sun et al., 2017). Fusarium wilt is responsible for substantial yield and economic losses in cucumber-producing regions across the globe (Sharma & Shukla, 2021; Imran et al., 2025). The disease is particularly difficult to manage because the pathogen can survive in soil for prolonged periods through resistant propagules, thereby serving as a persistent source of infection even in the absence of susceptible host plants (Orr & Nelson, 2018). Recent studies have further demonstrated the detrimental effects of FOC on plant physiological processes, growth performance, and overall crop productivity (Yang et al., 2023; Yang et al., 2024).

Conventional management of Fusarium wilt has largely depended on the use of chemical fungicides and soil fumigants. Although these approaches can provide short-term disease suppression, their prolonged use has raised concerns regarding environmental

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contamination, human health risks, pathogen resistance, and increased production costs (Lamichhane et al., 2016; McGovern, 2015). Consequently, there is growing interest in environmentally friendly and sustainable disease management practices. Soil solarisation has emerged as one such alternative, involving the covering of moist soil with transparent polyethylene sheets during periods of intense solar radiation to trap solar heat and elevate soil temperatures. The resulting temperatures, often ranging from 40°C to over 60°C, can effectively suppress a wide range of soil-borne pathogens, nematodes, insects, and weed seeds through thermal inactivation (Fernandez-Bayo et al., 2018; Tziros et al., 2024).

Beyond its direct suppressive effects on pathogens, soil solarisation has been reported to improve soil fertility and soil biological health. Elevated temperatures can increase the availability of essential nutrients, including nitrogen, phosphorus, and potassium, while also modifying soil microbial communities in favour of beneficial microorganisms (Fernandez-Bayo et al., 2018). Studies have shown that solarisation can significantly reduce populations of pathogenic fungi while promoting beneficial bacteria and other microorganisms that contribute to nutrient cycling, disease suppression, and improved plant growth (Yang et al., 2023; Tziros et al., 2024). Similar findings have been reported in several African countries, where soil solarisation has been used to suppress soil-borne pathogens, weeds, and nematodes in vegetable production systems. In Nigeria, Omotayo and Eegunranti (2023) demonstrated that soil solarisation effectively reduced soil microbial populations associated with bacterial wilt in tomato and improved crop performance under field conditions. Moreover, studies conducted on tomato production in Nigeria have shown that solarisation, either alone or in combination with biological control agents such as *Trichoderma harzianum*, significantly reduced the incidence and severity of soil-borne diseases while enhancing plant growth and yield (Olaoluwa et al., 2024). These findings indicate that soil solarisation is a promising and environmentally sustainable disease-management strategy under tropical conditions. Nevertheless, despite the growing body of evidence supporting its effectiveness in other crops and regions, information on the use of soil solarisation for the management of *Fusarium* wilt in cucumber under southwestern Nigerian conditions remains limited. These combined effects suggest that soil solarisation has the potential not only to reduce disease pressure but also to enhance crop performance and productivity.

Despite the documented benefits of soil solarisation, information on its effectiveness against Fusarium wilt of cucumber under the tropical conditions of Nigeria remains limited. Most previous investigations have been conducted in temperate and Mediterranean regions, leaving a significant knowledge gap regarding its applicability under local environmental conditions. Furthermore, few studies have comprehensively examined the simultaneous effects of soil solarisation on fungal and bacterial populations, disease incidence, plant growth, and yield. Therefore, this study was conducted to evaluate the effectiveness of soil solarisation in controlling Fusarium wilt of cucumber under field conditions in Ogun State, Nigeria, with particular emphasis on its effects on soil microbial communities, disease suppression, plant growth, and fruit yield. The findings are expected to provide scientific evidence supporting the adoption of soil solarisation as a sustainable and environmentally friendly disease management strategy for cucumber production.

2. Materials and Methods

2.1 Study Area

The experiment was conducted under field conditions in a cucumber-producing area during the dry season when solar radiation and ambient temperatures were favourable for soil solarisation. The study evaluated the effects of soil solarisation on rhizosphere microbial populations, Fusarium wilt incidence, and the growth and yield performance of cucumber (*Cucumis sativus* L.).

2.2 Experimental Design

The experiment consisted of two treatments: solarised soil (S) and non-solarised soil (NS). Four plots designated A, B, C, and D served as replicates within each treatment. Each plot measured 2 m × 2 m (4 m²) and was separated by a 0.5 m alley. For the solarised treatment, plots were covered with transparent polyethylene sheets and maintained for six weeks, while the control plots remained uncovered. Soil samples were collected from a depth of 0–15 cm before solarisation (BS) and at two, four, and six weeks after solarisation (ASW2, ASW4, and ASW6). Within each replicate, five soil cores were randomly collected and pooled to form a composite sample for microbial analysis. Following the solarisation period, cucumber seeds were sown at a spacing of 50 cm × 50 cm, giving 16 plants per plot. Growth parameters including plant height, number of leaves, leaf area, and stem girth were measured at regular intervals, while yield parameters such as fruit number, fruit length, fruit weight, and total yield were recorded at harvest. Disease incidence and severity of Fusarium wilt were monitored throughout the experimental period.

2.3 Soil Preparation and Solarisation

The experimental field was cleared of weeds and plant debris before land preparation. The soil was tilled to a fine tilth and irrigated to field capacity. Moist soil was covered with transparent polyethylene sheets and the edges were buried to prevent heat loss and maintain a sealed environment. The plastic mulch remained in place for six weeks during the period of maximum solar radiation. Soil moisture was maintained throughout the solarisation period by periodic irrigation where necessary. The non-solarised control plots received the same agronomic practices but were

left uncovered. Soil solarisation was carried out following the principles described by Katan and DeVay (2024) and Stapleton and DeVay (1986), whereby transparent polyethylene mulch traps solar energy, increasing soil temperature and suppressing soil-borne pathogens and pests through hydrothermal disinfestation. Solarisation has been widely reported to reduce fungal inoculum densities while promoting beneficial microbial communities and enhancing crop growth. A limitation of the present study is that soil temperature was not directly monitored during the solarisation period; therefore, the extent of temperature elevation achieved under the polyethylene mulch was inferred from the observed biological responses and from temperature ranges reported in previous solarisation studies

2.4 Soil Sampling

Composite soil samples were collected from the rhizosphere zone using a sterile soil auger at a depth of approximately 0–15 cm. Samples were collected before solarisation and subsequently at two-week intervals following treatment. Soil samples were transferred into sterile polyethylene bags, labelled appropriately, and transported to the laboratory for microbiological analysis.

2.5 Isolation and Enumeration of Fungal Populations

Ten grams of soil from each sample were suspended in 90 mL of sterile distilled water and homogenised thoroughly. Serial ten-fold dilutions were prepared up to an appropriate dilution level. Aliquots (0.1 mL) from selected dilutions were plated onto Potato Dextrose Agar (PDA) supplemented with streptomycin to suppress bacterial growth. The inoculated plates were incubated at 28 ± 2°C for 5–7 days. Emerging fungal colonies were counted and expressed as colony-forming units (CFU mL^{-1}). Distinct colonies were sub-cultured repeatedly to obtain pure cultures for identification.

2.6 Identification of Fungal Isolates

Fungal isolates were identified based on colony morphology, pigmentation, growth characteristics, and microscopic examination of reproductive structures. Lactophenol cotton blue staining was used to examine hyphae, conidiophores, conidia, and other diagnostic structures under a compound microscope. Identification was carried out using standard fungal identification manuals and taxonomic keys.

2.7 Isolation and Enumeration of Bacterial Populations

Bacterial populations were determined using the serial dilution plate count technique. Soil suspensions were prepared as described for fungal analysis. Aliquots from appropriate dilutions were inoculated onto Nutrient Agar (NA) plates using the spread-plate method. Plates were incubated at 37°C for 24–48 h, after which visible colonies were counted and expressed as CFU mL^{-1}. Representative colonies were purified through repeated streaking to obtain pure cultures.

2.8 Identification of Bacterial Isolates

Bacterial isolates were characterised using colony morphology, Gram staining, cell morphology, and standard biochemical tests including catalase, oxidase, citrate utilisation, indole production, methyl red, Voges–Proskauer, and carbohydrate fermentation reactions. Identification was based on standard bacteriological procedures and reference manuals.

2.9 Assessment of Fungal and Bacterial Diversity

The occurrence of fungal and bacterial species in solarised and non-solarised soils was recorded throughout the study period. The frequency of occurrence of each isolate was calculated as:

$$\text{Frequency of Occurrence (\%)} = \frac{\text{Number of samples in which an organism occurred}}{\text{Total number of samples examined}} \times 100$$

2.10 Raising of Cucumber Plants

Seeds of cucumber (*Cucumis sativus* L.) were obtained from a certified seed source and sown directly into prepared plots following completion of the solarisation period. Standard agronomic practices including irrigation, weeding, and pest management were uniformly applied to all plots throughout the experiment.

2.11 Assessment of Vegetative Growth

Vegetative growth was assessed by counting the number of leaves produced per plant. Measurements were taken at two, four, and six weeks after planting. Mean leaf numbers were calculated from sampled plants within each replicate plot.

2.12 Assessment of Fruit Yield

Fruit yield was determined by counting the number of fruits produced per plant at four, six, and eight weeks after planting. Harvested fruits from individual plants within each treatment were counted and averaged to obtain mean fruit yield values.

2.13 Assessment of Fusarium Wilt Incidence

Plants were monitored regularly for symptoms of Fusarium wilt, including leaf yellowing, wilting, vascular discoloration, and eventual plant collapse. Disease incidence was calculated using:

$$\text{Disease Incidence (\%)} = \frac{\text{Number of infected plants}}{\text{Total number of plants assessed}} \times 100.$$

Disease assessments were conducted at two, four, and six weeks after planting.

2.14 Data Analysis

Microbial population densities, leaf production, fruit yield, and disease incidence data were subjected to analysis of variance (ANOVA) using an appropriate

Table 1: Percentage occurrence row (derived from pooled replicates) and frequency (%) of fungal species isolated from cucumber rhizosphere soils under solarised and non-solarised conditions across sampling periods

Fungal species	% Occurrence	BS	ASW2	ASW4	ASW6
Trichoderma sp	56	+	+	+	+
Aspergillus niger	81	+	+	+	+
Aspergillus flavus	19	−	−	+	−
Aspergillus nidulans	63	−	+	+	−
Aspergillus terreus	31	+	+	−	−
Aspergillus versicolor	63	+	−	−	+
Penicillium chrysogenum	25	+	+	+	+
Penicillium italicum	38	+	−	−	+
Rhizoctonia sp.	44	+	−	+	−
Fusarium sp.	44	+	+	+	+
Pythium sp.	31	+	−	+	−
Rhizopus sp.	25	+	−	−	−

BS = Before solarisation; **ASW2** = 2 weeks after solarisation; **ASW4** = 4 weeks after solarisation; **ASW6** = 6 weeks after solarisation.

Table 2: Fungal population density ($\times 10^2$ CFU mL^{-1}) in soil before and after solarisation

Sample	BS	ASW2	ASW4	ASW6
A	7.40 ± 0.05^{b}	2.70 ± 0.05^{b}	2.50 ± 0.06^{c}	2.23 ± 0.03^{b}
B	5.40 ± 0.05^{a}	2.60 ± 0.05^{b}	2.40 ± 0.06^{bc}	1.50 ± 0.10^{a}
C	8.50 ± 0.05^{c}	6.27 ± 0.08^{c}	1.70 ± 0.06^{a}	2.23 ± 0.06^{b}
D	9.63 ± 0.09^{d}	2.10 ± 0.05^{a}	2.18 ± 0.09^{b}	2.23 ± 0.11^{b}

BS = Before solarisation; **ASW2** = 2 weeks after solarisation; **ASW4** = 4 weeks after solarisation; **ASW6** = 6 weeks after solarisation. Values are presented as mean ± standard error (SE). Means within the same column followed by different superscript letters differ significantly according to analysis of variance (ANOVA) followed by Tukey's HSD test at $P \leq 0.05$.

Table 3: Bacterial species occurrence in soil samples

Species	BS-A	BS-B	BS-C	BS-D	ASW2-A	ASW2-B	ASW2-C	ASW2-D	Frequency (%)
Bacillus spp.	−	+	+	+	−	+	+	+	75
Pseudomonas spp.	+	−	−	+	+	+	+	−	75
Klebsiella spp.	+	+	−	−	−	+	−	+	50
Enterobacter spp.	+	+	−	+	+	+	+	+	100
Azotobacter spp.	−	+	−	−	+	−	−	−	25
Actinomyces spp.	+	−	+	+	+	+	+	+	75

BS-A = Before Solarisation Replicate A, BS-B = Before Solarisation Replicate B, BS-C = Before Solarisation Replicate C, BS-D = Before Solarisation Replicate D. ASW2-A = 2 Weeks After Solarisation Replicate A, ASW2-B = 2 Weeks After Solarisation Replicate B, ASW2-C = 2 Weeks After Solarisation Replicate C, ASW2-D = 2 Weeks After Solarisation Replicate D. + = present; − = absent.

statistical package. Treatment means were separated at the 5% probability level ($P \leq 0.05$). Results were expressed as mean ± standard error (SE).

3. Results

3.1 Fungal Species Occurrence in Cucumber Rhizosphere Soil

Thirteen fungal taxa were isolated from cucumber rhizosphere soils during the study period (Table 1). The fungal community comprised species of *Trichoderma*, *Aspergillus*, *Penicillium*, *Rhizoctonia*, *Fusarium*, *Pythium*, and *Rhizopus*. *Aspergillus niger* was the most frequently isolated fungus, occurring in 81% of observations. *Aspergillus nidulans* and *Aspergillus versicolor* each recorded a frequency of 63%, while *Trichoderma* sp. occurred in 56% of observations. Soil-borne pathogenic fungi including *Fusarium* sp. and *Rhizoctonia* sp. each occurred at a frequency of 44%, whereas *Pythium* sp. and *Aspergillus terreus* occurred at 31%. The least frequently isolated fungus was *Aspergillus flavus* (19%). Some species such as *Trichoderma* sp., *Aspergillus niger*, *Penicillium chrysogenum* and *Fusarium* sp. were detected throughout the sampling periods, whereas others showed temporal variation in occurrence.

Table 4: Bacterial population density (×10² CFU mL⁻¹) in soil before and after solarisation

Sample	BS	ASW2	ASW4	ASW6
A	3.17 ± 0.12^{ab}	2.73 ± 0.09^{a}	5.70 ± 0.06^{a}	8.57 ± 0.14^{a}
B	3.53 ± 0.12^{b}	2.43 ± 0.09^{a}	11.57 ± 0.14^{c}	14.13 ± 2.43^{ab}
C	4.27 ± 0.07^{c}	3.23 ± 0.09^{b}	12.77 ± 0.09^{d}	12.73 ± 0.09^{b}
D	2.80 ± 0.06^{a}	2.27 ± 0.18^{a}	8.43 ± 0.09^{b}	8.60 ± 0.11^{a}

Values are presented as mean ± standard error (SE). Means within the same column followed by different superscript letters differ significantly according to analysis of variance (ANOVA) at $P \leq 0.05$. **BS** = Before solarisation; **ASW2** = 2 weeks after solarisation; **ASW4** = 4 weeks after solarisation; **ASW6** = 6 weeks after solarisation.

Table 5: Effect of soil solarisation on cucumber leaf production

Sample	Week 2 (S)	Week 2 (NS)	Week 4 (S)	Week 4 (NS)	Week 6 (S)	Week 6 (NS)
A	5.00^{a}	5.33^{a}	11.33^{a}	10.64^{b}	20.33^{a}	20.33^{ab}
B	5.33^{a}	5.00^{a}	11.00^{a}	10.00^{b}	21.00^{a}	19.33^{a}
C	5.00^{a}	5.33^{a}	11.33^{a}	11.00^{b}	20.67^{a}	21.33^{b}
D	5.67^{a}	4.67^{a}	10.67^{a}	9.33^{a}	22.33^{b}	19.33^{a}

BS = Before solarisation equivalent planting baseline condition; **ASW2** = 2 weeks after planting; **ASW4** = 4 weeks after planting; **ASW6** = 6 weeks after planting. Values represent mean number of leaves per plant recorded at different growth stages. Data are presented as mean ± standard error (SE). Treatment means within columns were compared using analysis of variance (ANOVA) at $P \leq 0.05$. S = solarised soil; NS = non-solarised soil.

3.2 Effect of Solarisation on Fungal Population Density

Fungal population density declined markedly following soil solarisation (Table 2). Before solarisation, fungal counts ranged from 5.40 × 10² CFU mL⁻¹ in Sample B to 9.63 × 10² CFU mL⁻¹ in Sample D. Two weeks after solarisation, fungal populations had decreased substantially, with counts ranging from 2.10 × 10² to 6.27 × 10² CFU mL⁻¹. Continued reductions were observed at four and six weeks after solarisation. By week six, fungal counts ranged from 1.50 × 10² to 2.23 × 10² CFU mL⁻¹. Relative to the initial populations, reductions at week six were approximately 69.9%, 72.2%, 73.8% and 76.8% for Samples A, B, C and D, respectively. The greatest reduction occurred in Sample D, indicating a strong suppressive effect of solarisation on fungal populations.

3.3 Bacterial Species Occurrence in Soil Samples

Six bacterial genera were isolated from the soil samples (Table 3). *Enterobacter* spp. were recovered from all samples and recorded the highest frequency of occurrence (100%). *Bacillus* spp., *Pseudomonas* spp. and *Actinomyces* spp. each occurred at a frequency of 75%, while *Klebsiella* spp. occurred in 50% of observations. *Azotobacter* spp. had the lowest frequency of occurrence (25%). The predominance of *Enterobacter*, *Bacillus* and *Pseudomonas* species suggests the presence of a diverse bacterial community capable of surviving under changing soil conditions

3.4 Effect of Solarisation on Bacterial Population Density

Bacterial population density showed a contrasting trend to fungal populations (Table 4). Initial bacterial counts before solarisation ranged from 2.80 × 10² to 4.27 × 10² CFU mL⁻¹. A slight reduction was observed two weeks after solarisation, with counts ranging between 2.27 × 10² and 3.23 × 10² CFU mL⁻¹. Thereafter, bacterial populations increased substantially. At four weeks after solarisation, counts increased to between 5.70 × 10² and 12.77 × 10² CFU mL⁻¹. By six weeks after solarisation, bacterial populations reached their highest levels, ranging from 8.57 × 10² to 14.13 × 10² CFU mL⁻¹. Sample B recorded the highest bacterial population at week six, representing an approximately four-fold increase relative to its initial count.

3.5 Effect of Soil Solarisation on Cucumber Leaf Production

Soil solarisation enhanced vegetative growth of cucumber plants as reflected by leaf production (Table 5). At week two, plants grown in solarised soil produced between 5.00 and 5.67 leaves per plant compared with 4.67–5.33 leaves per plant in non-solarised soil. By week four, leaf numbers increased to 10.67–11.33 in solarised treatments and 9.33–11.00 in non-solarised treatments. At week six, cucumber plants in solarised soils produced between 20.33 and 22.33 leaves per plant, whereas plants in non-solarised soils produced 19.33–21.33 leaves per plant. Although differences were relatively small, solarised treatments consistently recorded higher leaf numbers across sampling periods.

3.6 Effect of Soil Solarisation on Cucumber Fruit Yield

Fruit yield was markedly improved by soil solarisation (Table 6). At week four, fruit production in solarised soils ranged from 10.67 to 12.33 fruits per plant,

Table 6: Effect of soil solarisation on cucumber fruit yield

Sample	Week 4 (S)	Week 4 (NS)	Week 6 (S)	Week 6 (NS)	Week 8 (S)	Week 8 (NS)
A	10.67^{a}	6.33^{a}	16.67^{a}	11.00^{a}	22.67^{a}	14.33^{a}
B	12.33^{b}	6.00^{a}	18.00^{b}	10.33^{a}	22.67^{a}	12.67^{a}
C	10.67^{a}	6.33^{a}	16.67^{a}	11.00^{a}	23.33^{a}	14.00^{a}
D	10.67^{a}	6.67^{a}	17.00^{ab}	11.00^{a}	23.00^{a}	13.67^{a}

Values represent mean number of fruits per plant recorded at different growth stages. Data are presented as mean ± standard error (SE). Treatment means within columns were compared using analysis of variance (ANOVA) at $P \leq 0.05$. **BS** = Baseline condition; **ASW2** = 2 weeks after planting; **ASW4** = 4 weeks after planting; **ASW6** = 6 weeks after planting. S = solarised soil; NS = non-solarised soil.

Table 7: Incidence of Fusarium wilt in cucumber plants (non-solarised soil)

Sample	Week 2	Week 4	Week 6
A	40.67 ± 1.45^{a}	40.00 ± 1.73^{a}	41.00 ± 1.52^{a}
B	41.67 ± 1.85^{a}	41.33 ± 1.66^{a}	41.00 ± 2.08^{a}
C	40.67 ± 1.45^{a}	40.67 ± 1.45^{a}	40.33 ± 2.18^{a}
D	40.67 ± 0.88^{a}	41.33 ± 0.33^{a}	42.33 ± 0.66^{a}

Values represent percentage incidence of Fusarium wilt in cucumber plants. Data are presented as mean ± standard error (SE). Means within columns were compared using analysis of variance (ANOVA) at $P \leq 0.05$. **BS** = Before solarisation; **ASW2** = 2 weeks after solarisation; **ASW4** = 4 weeks after solarisation; **ASW6** = 6 weeks after solarisation.

compared with 6.00–6.67 fruits per plant in non-solarised soils. Yield continued to increase throughout the study period. At week six, solarised treatments produced between 16.67 and 18.00 fruits per plant, while non-solarised treatments produced 10.33–11.00 fruits per plant. By week eight, fruit production reached 22.67–23.33 fruits per plant in solarised soils compared with 12.67–14.33 fruits per plant in non-solarised soils. Across all sampling periods, fruit yield in solarised plots exceeded that of non-solarised plots by approximately 60–90%.

3.7 Incidence of Fusarium Wilt

No symptoms of Fusarium wilt were observed in cucumber plants grown in solarised soil throughout the experimental period; consequently, disease incidence remained 0% in all solarised replicates. In contrast, Fusarium wilt incidence remained consistently high in non-solarised soils throughout the study period (Table 7). Disease incidence ranged from 40.67–41.67% at week two, 40.00–41.33% at week four and 40.33–42.33% at week six. The highest incidence (42.33%) was recorded in Sample D at week six. The persistence of disease across all observation periods indicates continued survival and activity of the pathogen in untreated soils.

4. Discussion

The present study demonstrated that soil solarisation substantially influenced the soil microbial community, reduced fungal populations, enhanced bacterial abundance, improved cucumber vegetative growth and fruit yield, and was associated with a lower occurrence of *Fusarium* wilt. A total of thirteen fungal taxa and six bacterial genera were recovered from the experimental soils. Fungal population densities declined progressively throughout the solarisation period, with reductions of approximately 70–77% after six weeks. In contrast, bacterial populations initially decreased slightly following solarisation but subsequently increased markedly, reaching levels two to four times higher than their pre-solarisation populations. Cucumber plants grown in solarised soils consistently produced more leaves and fruits than those grown in non-solarised soils. Fruit yield advantages became particularly pronounced at later growth stages. Furthermore, *Fusarium* wilt incidence remained consistently high in non-solarised soils, whereas solarisation was associated with effective disease suppression. Collectively, these findings indicate that soil solarisation altered the soil microbial ecosystem in favour of beneficial microorganisms while reducing pathogen pressure, resulting in enhanced cucumber productivity.

The fungal community isolated from the cucumber rhizosphere consisted predominantly of species belonging to *Aspergillus*, *Penicillium*, *Trichoderma*, *Rhizoctonia*, *Fusarium*, *Pythium*, and *Rhizopus*. The high frequency of occurrence of *Aspergillus niger* (81%) suggests that it is well adapted to the prevailing soil conditions and possesses considerable ecological competitiveness within the rhizosphere environment. Similar observations have been reported by Domsch et al. (2007), who noted that species of *Aspergillus* are among the most abundant fungi in agricultural soils because of their ability to tolerate environmental fluctuations and utilise diverse organic substrates. The occurrence of *Fusarium*, *Rhizoctonia*, and *Pythium* species is of particular importance because these fungi are recognised worldwide as major soil-borne pathogens responsible for root rot, damping-off, and

vascular wilt diseases in cucurbit crops (Agrios, 2005). Their presence prior to treatment indicates that the soil possessed a substantial pathogen reservoir capable of negatively affecting cucumber growth and productivity.

One of the most significant findings of this study was the progressive decline in fungal population density following soil solarisation. Fungal colony counts decreased substantially over the six-week solarisation period, suggesting that the treatment created conditions that were unfavourable for the survival and proliferation of several soil-borne fungal species. Similar reductions in fungal populations have been reported in previous solarisation studies, where the treatment was associated with suppression of pathogenic fungi and a reduction in soil inoculum levels (Katan & DeVay, 1991; Katan, 2017; Stapleton, 2000). Although soil temperature was not monitored in the present study, the observed decline in fungal populations is consistent with the general effects of soil solarisation reported in the literature. Therefore, the reduction in fungal density observed in this study may be attributed to the combined physical and biological changes commonly associated with solarisation, although the specific mechanisms involved could not be directly verified. Elevated temperatures disrupt fungal cellular structures, denature proteins, damage nucleic acids, and reduce spore viability, thereby decreasing inoculum density in the soil (Stapleton, 2000). Similar reductions in fungal populations following solarisation have been reported in tomato, pepper, cucumber, and melon production systems, where solar heating significantly reduced populations of *Fusarium oxysporum*, *Rhizoctonia solani*, and *Pythium* species (Gamliel & Katan, 2012). The substantial reduction in fungal abundance observed in this study may also reflect indirect ecological effects of solarisation. Beyond direct thermal killing, solarisation modifies soil biological interactions by altering nutrient availability and changing microbial competition patterns. According to Katan (1981), heat-induced mortality among susceptible microorganisms releases nutrients into the soil, creating conditions that favour recolonisation by beneficial microbes while limiting pathogen recovery. The decline in fungal populations observed throughout the six-week solarisation period therefore likely resulted from both direct thermal suppression and subsequent ecological restructuring of the rhizosphere environment.

Unlike fungal populations, bacterial communities exhibited a recovery response following solarisation. Although bacterial populations declined slightly during the first two weeks after treatment, they increased markedly thereafter, reaching maximum densities at six weeks after solarisation. This trend supports previous observations that many bacterial groups are more resilient to elevated soil temperatures than fungi and can rapidly recolonise solarised soils once favourable conditions return (Stapleton & DeVay, 1986). Heat-tolerant bacterial species often survive solarisation through the formation of resistant structures such as endospores or through physiological adaptations that confer thermal tolerance (Katan & DeVay, 2024). Consequently, once fungal competitors are reduced, bacterial populations can proliferate rapidly and occupy newly available ecological niches. The bacterial community recovered from the soil was dominated by *Enterobacter* spp., which occurred in all samples, while *Bacillus* spp., *Pseudomonas* spp., and *Actinomyces* spp. were also frequently isolated. These microorganisms are widely recognised as plant-growth-promoting rhizobacteria (PGPR) and play critical roles in maintaining soil fertility and plant health. Species of *Bacillus* and *Pseudomonas* are known to produce antibiotics, siderophores, phytohormones, and lytic enzymes capable of suppressing soil-borne pathogens while simultaneously enhancing nutrient uptake and root development (Compant et al., 2005; Lugtenberg & Kamilova, 2009). The increased abundance of these beneficial bacteria following solarisation suggests that the treatment may have contributed to the establishment of a more disease-suppressive soil environment. Similar findings have been reported by Kokalis-Burelle et al. (2017), who observed increased populations of beneficial rhizobacteria in solarised soils accompanied by improved disease control and crop performance.

Improved vegetative growth was evident from the consistently higher leaf numbers recorded in cucumber plants grown in solarised soils. Although the differences between treatments were relatively modest, the trend remained consistent throughout the study period. Enhanced vegetative growth following solarisation has frequently been attributed to improved soil physical, chemical, and biological properties. Solarisation can increase the availability of mineral nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium through accelerated decomposition and mineralisation of organic matter (Chen & Katan, 1980). Increased nutrient availability promotes root development and photosynthetic activity, thereby stimulating leaf production and overall plant growth. Additionally, reduced pathogen pressure allows plants to allocate more resources towards growth rather than defence responses, further enhancing vegetative performance.

The most economically important outcome of the study was the substantial increase in cucumber fruit yield in solarised soils. Fruit production in solarised treatments exceeded that of non-solarised treatments throughout the experiment, with differences becoming increasingly pronounced at later growth stages. By week eight, solarised plants produced approximately 65–80% more fruits than plants grown in non-solarised soil. This finding agrees with numerous reports demonstrating that soil solarisation can significantly improve crop yield by reducing disease incidence, increasing nutrient availability, and promoting beneficial microbial activity (Stapleton, 2000; Gamliel & Katan, 2012). Yield improvements following

solarisation have been documented in several vegetable crops including cucumber, tomato, pepper, eggplant, and melon, particularly in tropical and subtropical environments where high solar radiation facilitates effective soil heating. The observed increase in fruit yield may also be linked to the enhanced bacterial populations recorded in solarised soils. Beneficial bacteria can improve plant growth through several mechanisms, including biological nitrogen fixation, phosphate solubilisation, production of indole-3-acetic acid, and suppression of phytopathogens (Vessey, 2003). The increased abundance of *Bacillus*, *Pseudomonas*, and *Enterobacter* species observed after solarisation may therefore have contributed indirectly to the improved productivity of cucumber plants by enhancing nutrient acquisition and maintaining healthier root systems. A limitation of this study is that soil physicochemical properties, such as pH, organic matter content, total nitrogen, available phosphorus, and exchangeable potassium, were not assessed before and after solarisation. Consequently, the effects of solarisation on soil fertility could not be directly quantified. Future studies should integrate physicochemical analyses with microbial assessments to provide a more comprehensive understanding of the mechanisms through which soil solarisation influences soil health and cucumber productivity.

The persistence of Fusarium wilt in non-solarised plots further highlights the effectiveness of solarisation as a disease-management strategy. Disease incidence remained above 40% throughout the assessment period in untreated soils, indicating the continued survival and infectivity of the pathogen. Fusarium wilt, primarily caused by *Fusarium oxysporum* f. sp. *cucumerinum*, is one of the most destructive diseases affecting cucumber production worldwide because the pathogen can survive in soil for many years through resistant chlamydospores (Agrios, 2005). The marked reduction in fungal populations observed after solarisation, coupled with improved plant performance, suggests that solar heating substantially reduced pathogen inoculum levels and disease pressure. Previous studies have consistently reported that soil temperatures achieved during solarisation are sufficient to reduce populations of *Fusarium* propagules and suppress wilt development in susceptible crops (Katan & DeVay, 1991; Stapleton, 2000).

Finally, findings from this study support the concept that soil solarisation functions not merely as a physical method of pathogen suppression but also as an ecological management tool that restructures the soil microbial community. The treatment reduced populations of potentially harmful fungi while promoting the proliferation of beneficial bacterial groups associated with nutrient cycling, biological control, and plant growth promotion. These microbial changes were accompanied by enhanced vegetative growth, increased fruit yield, and reduced disease pressure. Consequently, soil solarisation represents an effective, environmentally friendly, and sustainable alternative to chemical soil fumigants for the management of soil-borne diseases and the improvement of cucumber productivity in tropical agroecosystems.

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