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Effect of soil solarization on tomato (*Solanum lycopersicum* L.) growth and impact on native microbial diversity of farm soil in Nigeria

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Abstract

Background Tomato plant leaves can be wilted by the presence of various species of soil-residing bacteria, especially *Ralstonia solanacearum*. Soil solarization has proven to be an environment-friendly method for disease management in various crops. Therefore, this study aimed to evaluate solarization as an effective and non-chemical way to control *R. solanacearum* population in farm soil cultivated with tomato plants. The tomato variety UC 82 was raised on a nursery bedding for 3 weeks, after which four solarization-based treatments were applied to the field plots where tomato plants were cultivated subsequently. Agronomic, pathological, and soil temperature data were recorded from the soil samples, while isolation, Gram staining, morphological, biochemical, and physicochemical analyses were carried out on the same soil samples.

Results The bacterial species identified from the pre-experiment soil included *Enterobacter cloacae*, *Serratia marcescens*, and *Proteus mirabilis*, while for the post-experiment were *Citrobacter freundii*, *Klebsiella pneumoniae*, *P. mirabilis*, *Salmonella* sp., and *Citrobacter diversus*. Occurrences of bacteria and fungi populations in solarized soils were *R. solanacearum, Aspergillus niger*, *Aspergillus flavus*, *Penicillium*, *Rhizopus* spp., *Actinomycetes*, and yeast.

Conclusions The results obtained showed that solarization reduced the native soil microbial populations since the solarized soils had a lower occurrence of bacteria and fungi than the non-solarized soils. Thus, the present study suggests that solarization is effective in reducing the pathogenic bacteria population on farm soils.

Keywords Solarization, *Ralstonia solanacearum*, Bacteria, Tomato, Biological control, Fungi

Background

Food security is an emerging challenge within the twenty-first century, particularly in the developing economies of Africa. The concept of food security has evolved over the recent decades at first, it focused mainly on the availability of food and the production of food (United Nations 1975); then, it had been expanded to include explicitly the accessibility to food (physical, economic, and sociocultural), its utilization (FAO 1996) and, lastly, to incorporate the stability of these dimensions (FAO 2009). Vegetable production can make a big difference to smallholder farmers' income and well-being as a proper mixture of different vegetables in a meal can make up for shortages in animal protein. It contributes to livelihood diversification and employment for farmers, especially during the dry season (Obuobie et al. 2006). As an important source of minerals, vitamins, and healthy acids, tomato is of the *Solanaceae* family grown universally with

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a production of 124.75 million tons (FAO 2007). Tomato (*Solanum lycopersicum* L.) may be considered a popular fruit and an important nutritional and medicinal vegetable recognized worldwide. In the human diet, it forms an important source of micronutrients such as ascorbic acid, vitamin A, minerals (notably potassium), antioxidants, carboxylic acids, and carotenoids (in particular lycopene and phenolic compounds) (Vallverdú-Queralt et al. 2011).

Chemical pesticides have often been used to control or eradicate the populations of pests, insects, and pathogens that negatively affect the growth of farm crops generally, especially vegetables. These chemicals can cause some contamination, which in turn can have hazardous effects on humans that consume the vegetables. Tomato is a commonly used vegetable that is commonly affected by diseases on the farms located in the southwest region of the country. Farmers use these chemicals to reduce the occurrence of diseases. However, this act is greatly abused by local farmers and growers, thus exposing final consumers to hazards that can impact the environment negatively.

Soil solarization may be regarded as a useful practice that has been established as a non-chemical means of pathogen and disease control in several countries of the world (Díaz-Hernández et al. 2017). Despite this success, the method has hardly been put to widespread use in Nigeria by local farm households. This study was therefore carried out to investigate the environmental impact of solarization control in the farm soil, by comparing the effectiveness of solarized and non-solarized methods used on the soil in the control of incidence of *Ralstonia* bacteria, which are common pathogens infesting tomato cultivated soils in southwest Nigeria. The study's specific objectives were to evaluate the microbial diversity of the soil by isolating and identifying native bacterial and fungal populations. The study also assessed the impact of solarization treatment on the agronomic growth parameters of tomato used as test plants to determine the efficacy of the solarized method in controlling pathogenic microbes present in the farm soil.

Methods

Experimental conditions

The experimental field plot was located at the Farm House, Agriculture Program, Bowen University, Iwo (BUI), Nigeria. Bowen University is located at latitude 7 47′ N and longitude 4^{O}33'W with an elevation that varies between 250 and 300 m above sea level (Ipeaiyeda and Dawodu 2014). Field experiments were conducted from February to May 2022. The dimensions of the main experimental field plot measured 10 m by 7 m. Six planting beds were prepared per plot making a total of 18 beds for the experimental field plot. Each main bed measured approximately (1×0.50 m^2). Before the treatments, the soil was tilled manually and watered every other day to field capacity. Transparent polyethylene sheets were laid over randomly selected field beds, and big stones were used to hold the open edges of the polyethylene sheet. Polyethylene sheets were covered from January to March for a total period of 7 weeks.

Experimental design

The experimental plots were arranged in a randomized complete block design (RCBD) comprising five treatments that were replicated across three blocks. The treatments applied were:

(i) T1: Plastic sheet alone (without compost and biological control),
(ii) T2: Plastic sheet and farmyard compost,
(iii) T3: Non-solarized beds and farmyard compost (compost alone),
(iv) T4: Non-solarized beds alone (control).

Seed and soil collection

Seeds of one tomato variety were used for this study. Improved tomato variety UC82 was obtained from National Horticultural Research Institute (NIHORT) in Ibadan, Nigeria. The seeds were carefully kept in seed envelopes and stored in a dry, clean wooden cabinet. A total of 3 soil samples were collected from the field located at the farmhouse of the Agriculture Program, BUI, Nigeria, using a soil auger and placed in sterile ziplock nylon bags. They were then conveyed to the Microbiology laboratory of the Microbiology Program, BUI, for microbial analyses. Soil samples were also conveyed aseptically to the Soil and Pathology Lab of the National Horticultural Research Institute (NIHORT) Ibadan, Nigeria, for microbial analyses in soil. Soil samples were conveyed to the Central University Laboratory, BUI, for physicochemical analyses. These were done at the pre- and post-experimental stages of the experiment.

Nursery and field operations

The UC 82 variety of tomatoes used was sown on raised nursery bedding sheltered with palm leaves. The seeds were watered daily for germination. The UC82 variety took an average of 5 days to sprout. After 3 weeks, the seedlings were transplanted onto the main field plots after the removal of the plastic sheets used for solarization. Interbed spacing was 18–24 inches apart to allow for proper air circulation, 75 cm space was measured at the length and 50 cm space was measured at the breadth. The seedlings were carefully uprooted from the nursery beds and then placed into planting holes of 5 cm depth

prepared on the main soil beds before covering lightly with soil. The plants were immediately lightly watered to ensure full acclimatization and establishment of the young plants on the field plots. Weeding and other necessary cultural operations were done every 3 days on the farm plots to ensure that the plants survived and thrived. Harvesting was done after 11 weeks of sowing when the fruits were ready for harvesting.

Soil measurements

Soil temperature and agronomic readings

Soil temperatures were measured (5 cm) below the top of the bed for each treatment. The temperatures were recorded during the morning and evening by piercing the soil with an electronic thermometer (multi-stem thermometer), and the temperature readings were recorded three times a week (Mondays, Wednesdays, and Fridays) from January to March for 7 weeks. Morning temperature readings were taken at the peak period of 9–10 am each morning, while the evening readings were taken between 4 and 5 pm each evening, respectively. Temperature readings were taken at the same time for the number of days recorded. The following agronomic parameters were taken for all the tomato plants from the different treatments on a fortnight basis (every 2 weeks) till the final harvest of the tomato plants:

i. Stem girth (STMGT),
ii. Plant height (PLTHT),
iii. Number of leaves (NoLvs),
iv. Days to flowering (D2FLW),
v. Days to fruiting (D2FRT),
vi. Disease incidence,
vii. Disease severity,
viii. Number of fruits per plant per plot (NPP),
ix. Fruit weight per plant per plot (FWPP).

Disease incidence was calculated for the tomato plant using the following formula as stated by Rahman et al. (2013):

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

Disease severity was also calculated according to the modified formula of Sethumadhava Rao et al. (2016):

$$\text{Percentage Disease Severity} = \frac{\text{Number of individual ratings}}{\text{Number of plants assessed} \times \text{ Max. scale}} \times 100$$

Disease severity ratings for *R. solanacearum* were done using a scale of 1–5 as adopted by Sethumadhava Rao et al. (2016) which was based on the aerial plant parts (leaves and stems) and calculated as follows: 1–10% = 1, 11–20% = 2, 21–30% = 3, 31–50% = 4, 51–100% = 5.

Soil chemical measurements

A 1:2 ratio of soil to water was used to measure the pH of the soil sample using a Test 2 water-resistant digital pH meter (Hendershot et al. 1993). Electrical Conductivity (EC) was measured using an Electrical Conductivity (EC) Test 2 dual range electrical conductivity meter. The conductivities of the samples were measured in µS/cm at the sampling site after this meter was calibrated using a standard potassium chloride solution at room temperature. The hydrometer method was used to determine the particle size distribution, and sodium hexametaphosphate (Calgon) was used as the dispersing agent (Adepetu et al. 1984). The chromic acid oxidation method was used to calculate the amount of organic carbon (Golterman 1971). The total phosphorus extraction was done by digestion with perchloric acid ($HClO_4$) and fusion with sodium carbonate (Na_2CO_3). Total nitrogen was determined by the macro-Kjeldahl digestion procedure (Bremner 1982), and bulk soil density was measured using the direct method.

Microbiological analysis

Isolation of native bacteria populations in soil was done according to the method employed by Emoghene and Futughe (2011). The bacterial isolates obtained in pure culture were characterized based on their colonial morphology, reaction to Gram staining, and biochemical tests such as citrate utilization test, indole test, methyl red, Voges–Proskauer test (MRVP), and sugar fermentation test. The bacterial wilt pathogen (*R. solanacearum*) was also isolated from soil samples using the methodology described by Popoola et al. (2015), while fungal species isolation was obtained from the soil sample using the method of Ogunmwonyi et al. (2008).

Statistical analysis

All the data generated in the study were subjected to a one-way analysis of variance (ANOVA) using SPSS version 20. Graphs were plotted via GraphPad Prism8 and Microsoft Excel software. Means were separated using Duncan's multiple range test (DMRT) at α-level (0.05).

Results

Soil temperature

Soil temperature readings were recorded on a morning and evening basis for the duration of the solarization process preceding the main planting experiment. The soil temperature ranges for the experiment were recorded from January to March 2022. According to the online *AccuWeather* forecast, the maximum temperature recorded for Iwo, Nigeria, in January 2022 was 36 °C, while the minimum was 21 °C. February 2022 had a maximum temperature value of 36 °C, while the minimum temperature value was 19 °C. In March 2022, the maximum temperature in Iwo was 36 °C, while the minimum temperature was 23 °C (AccuWeather.com 2022). On average, the morning temperature for all the treatments generally followed the same trend across the study period (Fig. 1a). The highest temperature value in the morning period was observed in the treatment with the plastic and compost (T2) with a total mean of 32.5 °C on Day 8, and the lowest temperature was observed in the treatment with compost alone with a total mean of 23.5 °C on Day 6. Thus, soil with plastic and compost had a slightly higher temperature than the other treatments, though non-statistically significant. Evening temperature values followed the same trend of temperature fluctuation readings regardless of treatments (Fig. 1b). The highest temperature in the evening was observed in the treatment with the plastic and compost with a total mean of 40.1 °C on Day 14, and the lowest temperature was observed with a total mean of 29.9 °C on Day 4. These relatively wide variations in evening temperature across the treatments were also observed not to be statistically significant.

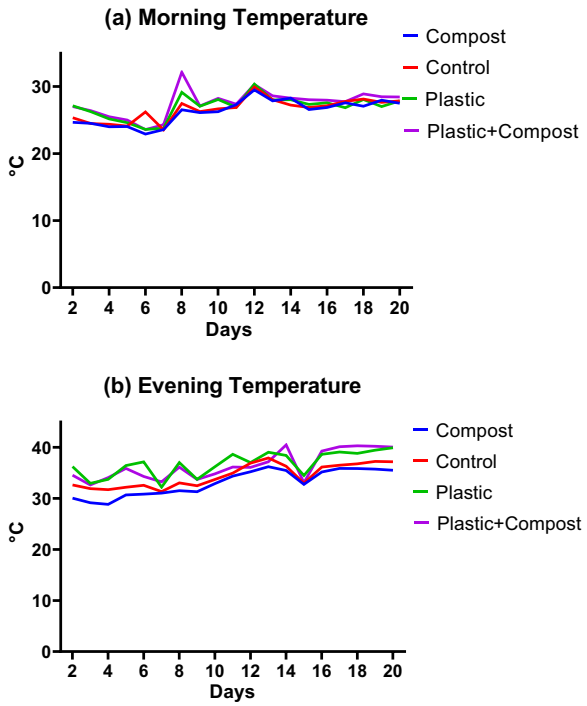

Fig. 1 Temperature variation patterns in solarized soils

Physicochemical soil properties

The results obtained from the pre-experiment physicochemical test carried out on the soil samples are given in Table 1. The pH value of the soil was 8.40 indicating an alkaline soil type. The soil type was classified as loamy soil, with the particle size distribution showing sand (49.80%), clay (9.55%), and silt (40.65%). Electrical conductivity was relatively high at 110µS/cm, while organic matter content and carbon were relatively low, with values of 0.59 and 0.34, respectively. The water percentage for the farm soil employed in this study was also relatively low, with a value of 1.13%.

Soil microbiological properties

Different bacterial groups in the evaluated soil samples (pre- and post-solarized soils) showed varying types of growth, Gram stain reaction, and shape. The bacterial colonies observed were off-white and creamy in color. The bacterial isolates were morphologically and biochemically characterized on the basis of Gram staining and various biochemical tests as shown in Tables 2 and 3. Bacterial groups in the pre-experiment unsolarized soils (without compost) were observed to be all Gram-negative rods. These were identified as *Enterobacter cloacae* (1), *Serratia marcescens* (2), *Proteus mirabilis* (1) for the pre-analysis experiment. Bacterial groups in the post-experiment solarized soils (plastic only) were also observed to be all Gram-negative rods including *Citrobacter freundii* (2), *Klebsiella pneumoniae* (1), *P. mirabilis* (1), *Salmonella* spp. (3), and *Citrobacter diversus* (1). These bacterial groups were identified based on

Table 1 Physico-chemical values of pre-solarized soil

S/N	Physicochemical tests	Soil sample
1	pH	8.40
2	Particle size distribution %	Sand (49.80%)
		Clay (9.55%)
		Silt (40.65%)
3	Electrical conductivity (EC)	110 µS/cm
4	Total nitrogen	0.036 mg/L
5	Total phosphorus determination	25 mg/kg
6	Soil organic matter	0.59
7	Water content percentage (%)	1.13%
8	Soil density (g/cm^3 or mg/cm^3)	0.098 g/cm^3
9	Organic carbon	0.34

identification keys provided in *Microrao* online bacteria identification tool. The highest occurring bacterium species for the pre-experiment unsolarized soil (without compost) was *S. marcescens*. Conversely, the highest occurring bacteria species for the post-experiment solarized soil (plastic only) was *Salmonella* spp. The result obtained from the occurrence of wilt pathogens (bacteria and fungi) and nematode populations in pre-solarized soils is given in Table 4. *Ralstonia solanacearum* as well as the fungus *Aspergillus flavus* was detected in pre-experiment unsolarized soils. In the post-solarized soils as reported in Table 5, it was observed that there was a higher presence of *Ralstonia* recorded in non-solarized soils (6.5×10^3) than the numbers occurring in the plastic-only solarized soils (3.0×10^2).

Agronomic growth parameters of tomato plants

The combined agronomic growth parameters data of tomato plants raised on both solarized treated and unsolarized field beds showing leaf number, plant height, and stem girth are presented in Table 6. The highest number of leaves was observed with the control plants having a

Table 2 Morphological and biochemical characterization of bacteria isolates from pre-solarized soil (without plastic and compost treatments)

S/N	GR	NA	IMVC				Sugar fermentation		Probable organisms
			Ind	MR	VP	CU	Glu	Lac	
							AG	AG	
SB1	– Rod	Cream colony	–	–	+	+	AG	–	*Enterobacter cloacae*
SB2	– Rod	Cream colony	–	–	+	–	–	–	*Serratia marcescens*
SB3	– Rod	Cream Colony	–	–	+	+	AG	–	*Serratia marcescens*
SB4	– Rod	Cream colony	–	+	+	+	AG	–	*Proteus mirabilis*

GR Gram reaction, *NA* Nutrient agar, *Ind* Indole, *MR* Methyl red, *VP* Voges–Proskauer, *CU* Citrate utilization, *Glu* Glucose, *Lac* Lactose, *A* Acid production, *G* Gas production, *SB* Soil bacteria sample

Table 3 Morphological and biochemical characterization of bacteria isolates from solarized soil (plastic only)

S/N	Isolates	GR	NA			IMVC				Sugar fermentation				Probable organisms
				Cat	Mot	Ind	MR	VP	CU	Glu		Lac		
										AG		AG		
1	BS1	– Rod	Cream colony	–	–	–	+	–	+	AG		AG		*Citrobacter freundii*
2	BS2	– Rod	Cream colony	+	+	–	+	+	+	AG		AG		*Klebsiella pneumoniae*
3	BS3	– Rod	Cream colony	+	+	–	+	+	+	AG		–		*Proteus mirabilis*
4	BS4	– Rod	Cream colony	+	–	–	+	–	+	AG		–		*Salmonella* sp.
5	BS5	– Clustered rod	Cream colony	–	+	–	+	–	+	+	+	–	–	*Salmonella* sp.
6	BS6	– Rod	Cream colony	–	–	–	+	–	+	+	+	–	–	*Salmonella* sp.
7	BS7	– Tiny rod	Cream colony	+	+	–	+	–	+	+	+	+	+	*Citrobacter freundii*
8	BS8	– Clustered rod	Cream colony	+	–	+	+	–	+	+	+	+	+	*Citrobacter diversus*

GR Gram reaction, *NA* Nutrient agar, *Cat* Catalase, *Mot* Motility, *Ind* Indole, *MR* Methyl red, *VP* Voges–Proskauer, *CU* Citrate utilization, *Glu* Glucose, *Lac* Lactose, *A* Acid production, *G* Gas production, *BS* Bacteria soil (sample)

Table 4 Occurrence of wilt pathogens (bacteria and fungi) in pre-solarized soil

Sample	*Ralstonia solanacearum*			*Aspergillus flavus*		
	Load (cfu/g soil)	Score	Rating	Load (cfu/g soil)	Score	Rating
Bacteria	2.65×10^4	+	Mild	–	–	–
Fungi	–	–	–	6.0×10^4	+	Mild

0: Nil, +: Mild, ++: Moderate, +++: Severe

Table 5 Occurrence of wilt pathogens (bacteria and fungi) in post-solarized soil

S/N	Sample	Bacteria species			Fungi species		
		Ralstonia solanacearum (pathogenic species)			*Aspergillus* and yeast species		
		Load (cfu/g soil)	Score	Rating	Load (cfu/g soil)	Score	Rating
1	Plastic sheet alone	3×10^2	+	Mild	2.0×10^2	+	Mild
2	Plastic sheet + compost	0	0	Nil	0	0	Nil
3	Compost alone (non-solarized)	0	0	Nil	0	0	Nil
4	Non-solarized alone (Control)	6.5×10^3	+	Mild	0	0	Nil

0: Nil, +: Mild, ++: Moderate, +++: Severe

Table 6 Agronomic parameters of tomato plants grown in solarized and unsolarized soils

	08 April	22 April	5 May
Number of leaves			
Compost	7 ± 0^a	17 ± 2^a	16 ± 3^a
Control	8 ± 1^a	25 ± 2^a	28 ± 3^a
Plastic	9 ± 1^{ab}	16 ± 1^b	15 ± 3^{ab}
Plastic + Compost	10 ± 1^b	23 ± 1^b	20 ± 3^b
Plant height (cm)			
Compost	20.4 ± 0.8^a	45.1 ± 3.5^a	49.9 ± 7.5^a
Control	22.6 ± 1.2^a	49.9 ± 2^a	66.8 ± 5.8^a
Plastic	27 ± 1.3^a	46.5 ± 3.9^{ab}	42.8 ± 7.1^a
Plastic + Compost	23.5 ± 1^b	57.5 ± 2.1^b	46.8 ± 10.8^a
Stem girth (c)			
Compost	2.8 ± 0.1^a	3 ± 0.1^a	2.8 ± 0.4^a
Control	2.8 ± 0.1^a	4.4 ± 0.6^a	4.9 ± 0.7^a
Plastic	2.9 ± 0.1^a	3 ± 0.1^a	2.7 ± 0.4^a
Plastic + Compost	2.8 ± 0.1^a	2.9 ± 0.2^b	3 ± 0.4^b

Values are Means ± Standard Error of the mean. Different superscripts denote a significant difference ($p < 0.05$) using the Duncan's multiple range test

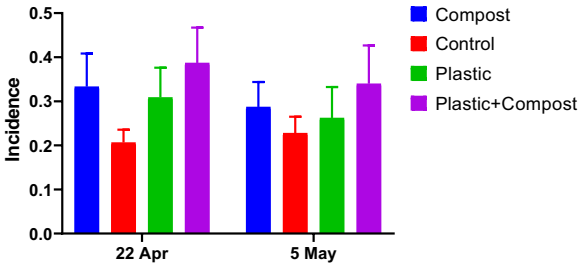

Fig. 2 Disease incidence of tomato plants across treatments

Table 7 Bacterial wilt severity ratings and status of tomato plants in the 11th week after planting

Variety	Severity rating (1–5)	Status
V1(UC82 Variety)		
V1T1	5	Highly susceptible
V1T2	5	Highly susceptible
V1T3	5	Highly susceptible
VIT4	5	Highly susceptible

V1T1 Plastic alone, *V1T2* Plastic plus farmyard compost, *V1T3* Farmyard compost alone, *V1T4* Control

total mean number of 61 leaves, while the lowest number of leaves were observed in the compost-alone-treated plants and with plants treated with compost alone and plastic sheet alone, respectively, having a mean number of 40 leaves after 12 weeks of transplanting. The plastic plus compost treatment (T2) had a total mean of 53 leaves. Overall, nonsignificant differences in the number of leaves of plants in the compost, control, and plastic treatments. However, the combination of plastic and compost significantly increased the number of leaves throughout the study. The combination of plastic and compost produced a significant difference in the height of the test plants from April 8 to 22. Plants under the other experimental treatments during this period, including the control, did not differ significantly in their height. At the end of the study, on May 5, non-statistical differences were observed across all experimental units. On April 8, the stem girth of the tested plants was similar across treatment groups. Toward the end of the experiment, the plants grown in the control treatment were observed to possess the largest stem girth values, though not significantly different from other treatments in the study.

Disease incidence and severity ratings of tomato plants

Disease incidence and severity values were recorded for the tomato plants subject to all treatments as shown in Fig. 2 and Table 7, respectively. The highest disease incidence across the treatments was observed in the plastic and compost treatment. The lowest incidence was found in the control-treated plants (Fig. 2). The disease severity on all treatments for the UC82 variety was high, each having a severity rating of 5 which were all highly susceptible.

Discussion

The beneficial roles of soil microorganisms in agricultural soils cannot be overemphasized. Healthy soils usually contain a vast number of bacteria, fungi, and free-living nematodes. The result obtained from this study revealed that the heterotrophic bacteria populations isolated from the agricultural soil before solarization were identified to be *E. cloacae*, *S. marcescens*, *P. mirabilis,* and *R. solanacearum* which are all Gram-negative. This study agrees with a similar study by Emoghene and Futughe (2011), who isolated *E. cloacae*, *Bacillus subtilis*, *Pseudomonas* sp., and *Micrococcus varians* from pre-solarized agricultural soil. The heterotrophic bacteria population isolated from the post-solarization were identified to be *C. freundii*, *K. pneumoniae*, *P. mirabilis*, *R. solanacearum*, *Salmonella* spp., and *C. diversus* which are Gram-negative. This study is in agreement with Ogunmwonyi et al. (2008), who isolated *Proteus* spp., *R. solanacearum,* and *Micrococcus varians* from agricultural soil samples. Bacterial wilt pathogen *(R. solanacearum*) is one of the major threats to the production of solanaceous crops such as tomato and thus the production of crops like tomato should be avoided on such pieces of land according to Popoola et al. (2015). In this study, a mild load of *Ralstonia* (2.65×10^4 cfu/g) was found in pre-solarized soil, which after solarization, was still observed to still occur at mild levels in post-solarized soil (3×10^2 cfu/g). It was observed, however, that there was a high presence of *Ralstonia* recorded in non-solarized soils (6.5×10^3); though still rated mild. It appears that solarization had an attenuating effect on these pathogenic bacteria populations in the soil. This study agreed with Ogunmwonyi et al. (2008), who isolated *R. solanacearum* from different top soils. *R. solanacearum* can reduce soil microbial diversity during invasion (Wei et al. 2018). The decrease in microbial diversity may provide more niches for microbes that are suitable for the rotten root environment (Karim et al. 2016).

In this study, *Aspergillus niger*, *A. flavus*, *Penicillium*, and *Rhizopus* species were isolated from pre-solarization, whereas *Aspergillus* spp., *Actinomycetes*, and yeast species were obtained from post-solarization. Similar results also emanated from Emoghene and Futughe (2011), who isolated *A. niger*, *A. flavus*, *P. notatum*, and *A. fumigatus* from agricultural soil before and after solarization. The maximum fungal count was found in solarized soil (2.0×10^2 cfu/g), whereas the lowest count was found in non-solarized soil, which had no count at all.

Although *A. flavus* isn't thought to be pathogenic in soil, it can become pathogenic when it makes contact with fruits or other harvested produce. Agricultural products may become contaminated at several phases, including pre-harvest, harvest, processing, and handling. The sensory, nutritional, and qualitative changes brought on by *Aspergillus* species can include pigmentation, discoloration, rotting, the development of off-odors, and off-flavors. Perrone et al. (2007) isolated the biodiversity of *Aspergillus* species in some important agricultural products such as grapes and coffee.

In this study, the temperature of the solarized soil varied from 22.5 to 31.5 °C in the morning and from 32.0 to 40.7 °C in the evening. During the early stages of solarization, soil temperature ranges were observed as the highest in the soil covered by plastic mulching film. The highest temperature recorded in the non-solarized soils was 36.6 °C, compared to the plastic solarized soil's maximum temperature value of 40.7 °C. This is consistent with findings from Di Mola et al. (2021), who reported that soil temperatures ranged between 30.8, 31.1, and 30.9 °C at their low points and reached a maximum of 43.2 and 41.9 °C at their high point. According to Efath et al. (2018), whose observations also agree with the results of this study, the highest soil temperature recorded in solarized plots was 51.4 °C, while the lowest one recorded in solarized plots was 36.2 °C. The highest soil temperature recorded in non-solarized plots was 40.8 °C, while the lowest one was 23.7 °C during a similar period. The physicochemical results of the agricultural soil employed in this study showed that the pH value of 8.40, favored the growth of the bacteria in the soil which grew well at the pH value. The soil type was classified as loamy soil, with the particle size distribution showing sand (49.80%), clay (9.55%), and silt (40.65%), and water content (1.13%) which indicated that the soil had a good amount of water and was good for planting. The organic matter content of the soil was low at 0.59, though several studies have shown that low levels of organic matter present in solarized soils are usually not affected and also present in a stabilized and recalcitrant form that is not susceptible to a rapid decomposition after soil heating by solarization (Di Mola et al. 2021).

The agronomic data in this study showed that the tallest plant across the treatments was observed in the non-solarized treatment (T5) with an average height of (139.3 cm), while the shortest height was observed in the compost (T4) with a mean of (115.4 cm). In this study, it was observed that the non-solarized treatment (T5) did better in increment of plant height than the solarized treatment (T1). This is in contrast with Emoghene and Futughe (2011) who reported that the plant height in the non-solarized soils, *Amaranthus viridis* showed the least mean height of (36.60 cm) at the end of the experiment. This result also does not agree with that of Sabatino et al. (2019), who reported a higher plant growth in solarized soil compared to non-solarized soil.

The highest level of disease incidence across the treatments was observed in plastic and compost-treated tomato plants with the total mean incidence being 0.73 and a severity percentage of 100%, while the lowest level of incidence was observed in control tomato plants with the total mean incidence being 0.44 and severity rate of 100%. The results are, however, in contrast to those of Kamaludeen and Sobita (2013) who reported that a minimum percent of disease severity was recorded in plants treated by soil solarization. The observations from this study showed that the presence of solarization treatments did not significantly reduce the incidence and severity of disease induced by the pathogenic bacteria during the period of the study. This observation was probably due to the low quality of polythene plastic sheets used for the solarization experiments and perhaps makes the case for the need for repeated cycles of solarization to effectively control soil-borne pathogens in tropical agricultural soils. The greatest effectiveness of solarization may also be achieved by exploiting different time frames to determine which time frame works best for effective treatment and has the least impact on the native microbial community parameters.

Conclusion

Solarization has been demonstrated through this study as a valid, non-chemical, and environmentally friendly approach to the control of soil-based plant pathogens such as *R. solanacearum*. This study's findings suggested that solarization impacted native soil microbial populations since the solarized soils had lower counts of bacteria, fungi, and nematodes than the non-solarized soils. Both the solarized and non-solarized were shown to have a favorable impact on the agronomic parameters; however, the non-solarized had a stronger influence as shown in the study. This study demonstrates that soil solarization had little or no risks to human health or safety, and the crops grown under solarization-based systems are pesticide-free. Therefore, the use of solarization is recommended in modern agriculture, especially in developing world nations like Nigeria, as the technique will likely gain further prominence and relevance as the world commits to a greener future and will surely help to reduce environmentally related problems.

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Author contributions
OEO contributed to conceptualization, visualization, project administration, supervision, writing—review and editing; AE contributed to investigation, methodology, formal analysis, writing—original draft, and resources. Both authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

AccuWeather Forecast (2022). Retrieved online from accuweather.com/en/ng/iwo/255022/January-March/255022?year=2022 on December 20, 2022, 3.45 pm
Adepetu JA, Obi AO, Amusan AA (1984) Soil science laboratory manual. Department of Soil Science, University of Ife, Ile-Ife, Nigeria, p 206
Bremner JM, Mulvaney CS (1982) Nitrogen – total. In: Page AL, Miller RH, Keeney DR (eds) Methods of Soil Analysis Part 2. 2nd edn. Agronomy Monogram 9. American Society of Agronomy, Madison, WI, pp 575–624
Di Mola I, Valeria V, Eugenio C, Lucia O, Ida R, Luigi GD, Olimpia P, Mauro M (2021) Biodegradable mulching vs traditional polyethylene film for sustainable solarization: chemical properties and microbial community response to soil management. Appl Soil Ecol 163:1–9. https://doi.org/10.1016/j.apsoil.2021.103921
Díaz-Hernández S, Gallo-Llobet L, Domínguez-Correa P, Rodríguez A (2017) Effect of repeated cycles of soil solarization and biosolarization on corky root, weeds and fruit yield in screen-house tomatoes under subtropical climate conditions in the Canary Islands. Crop Prot 94:20–27
Efath S, Razdan VK, Saba B (2018) Effect of soil solarization on the growth of onion (*Allium cepa* L.) and onion blight disease. J Pharmacogn Phytochem 7(2):417–421
Emoghene AO, Futughe EA (2011) Effect of soil solarization on *Amaranthus viridis* shoot disease caused by *Choanephora cucurbitarum*. Niger Ann Nat Sci 11(1):33–40
FAO (1996) rome declaration on food security and world food summit plan of action. FAO, Rome
FAO (2007) Production Year Book, Food and Agriculture Organization, Rome, Italy
FAO (2009) Declaration of the world food summit on food security. FAO, Rome
Golterman HL (1971) Methods for chemical analysis of freshwaters. (ed) I. B. P. handbook no. 8, Blackwell, Oxford and Edinburg
Hendershot WH, Lalande H, Duquette M (1993) Soil reaction and exchangeable acidity. Soil sampling and methods of analysis
Ipeaiyeda AR, Dawodu M (2014) Assessment of toxic metal pollution in soil, leaves, and tree barks: bio-indicators of atmospheric particulate deposition within a university community in Nigeria. AES Bioflux 6(2):101–110
Kamaludeen, Sobita S (2013) Effect of soil solarization, bio-agents and organic composts on blast of paddy. Int J Bot Res 3(4):21–28
Karim NFA, Mohd M, Nor NM, Zakaria L (2016) Saprophytic and potentially pathogenic *Fusarium* species from peat soil in Perak and Pahang. Trop Life Sci Res 27:1
Obuobie E, Keraita B, Danso G, Amoah P, Cofie OO, Raschid-Sally L, Drechsel P (2006) Irrigated urban vegetable production in Ghana: characteristics and risks. IWMI-RUAF-CPWF, Accra, Ghana

Ogunmwonyi IN, Igbinosa OE, Aiyegoro OA, Odjadjare EE (2008) Microbial analysis of different topsoil samples of selected site in Obafemi Awolowo University, Nigeria. Sci Res Essay 3(3):120–124
Perrone G, Susca A, Cozzi G, Ehrlich K, Varga J, Frisvad JC, Meijer M, Noonim P, Mahakarnchanakul W, Samson RA (2007) Biodiversity of *Aspergillus* species in some important agricultural products. Stud Mycol 59:53–66
Popoola AR, Ganiyu SA, Enikuomehin OA, Bodunde JG, Adedibu OB, Durosomo HA, Karunwi OA (2015) Isolation and Characterization of *Ralstonia solanacearum* causing bacterial wilt of tomato in Nigeria. Nig J Biotech 29:1–10
Rahman MM, Ali MA, Ahmad MU, Dey TK (2013) Effect of tuber-borne inoculum of *Rhizoctonia solani* on the development of stem canker and black scurf of potato. Bangladesh J Plant Pathol 29:29–32
Sabatino L, D'Anna F, Prinzivalli C, Iapichino G (2019) Soil solarization and calcium cyanamide affect plant vigor, yield, nutritional traits, and nutraceutical compounds of strawberries grown in a protected cultivation system. Agronomy 9(9):513
Sethumadhava Rao SD, Keflemariam S, Tesfagergish H, Tesfamariam R, Habtemariam T (2016) Pathological survey on disease incidence and severity of major diseases on Tomato and Chilli crops grown in Sub Zoba Hamelmalo, Eritrea. Int J Res Stud Agric Sciences 2(1):13–24
United Nations (1975) Report of the world food conference, Rome, November 1974. UN,New York, pp 5–16
Vallverdú-Queralt A, Medina-Remón A, Andres-Lacueva C, Lamuela-Rayentos RM (2011) Changes in phenolic profile and antioxidant activity during production of diced tomato. J Food Chem 126(4):1700–1707
Wei Z, Hu J, Gu Y, Yin S, Xu Y, Jousset A, Shen Q, Friman VP (2018) *Ralstonia solanacearum* pathogen disrupts bacterial rhizosphere microbiome during an invasion. Soil Biol Biochem 118:8–17

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