

Impact of crude oil-polluted soil on germination and development of *Abelmoschus caillei* (A. Chev.) Stevels seedlings

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ABSTRACT

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Crude oil pollution poses a major problem in many countries of the world, especially in oil-rich nations where it negatively impacts agricultural production. *Abelmoschus caillei* (A. Chev.) Stevels (West African okra), a vital vegetable prized for its high fibre and mineral contents, is widely cultivated in oil-producing regions of Nigeria, yet its response to crude oil-contaminated soil remains poorly understood. The present study examines the effects of crude oil-polluted soil on the germination and seedling development in West African okra, *Abelmoschus caillei* (A. Chev.) Stevels. Five crude oil-contaminated soil treatments denoted as T₁, T₂, T₃, T₄ and T₅ (with 0.1%, 0.5%, 1.0%, 2.5% and 5% v/w crude oil to dried sandy-loam soil) and uncontaminated (control) soil were set up, with each replicated three times. Ten viable seeds of *A. caillei* were planted into the treatment pots in a screen house and observed for germination, growth, chlorophyll content, and biomass of the seedlings. The results showed that seedling emergences started at 6 days after sowing in the crude oil treatments and the control, but the % germination decreased in T₂ to T₅ (with <0.5% crude oil) by 3.3-13.7%. Plant height was markedly reduced under high contamination, with T₅ having the least at 2 WAS (4.00 cm) and 4 WAS (6.76 cm) compared with the control (12.08 cm). Leaf production declined from 3.42 in T₁ to 2.16 in T₅. Chlorophyll *a* decreased significantly in T₅ (6.85 mg g⁻¹) from T₁ (10.87 mg g⁻¹). Fresh weight was significantly highest in T₁ (7.39 g) and lowest in T₅ (3.01 g). Overall, crude oil contamination adversely affected the germination, growth and pigment development of *A. caillei*, although mild contamination elicited a transient stimulatory response.

1.0 Introduction

The seedling stage is a crucial period in the life of plants, serving as the foundation for their entire life history [1]. This crucial stage begins with the germination of the seeds, setting into motion the phase for the development of roots, leaves, and photosynthetic apparatus that ultimately determine the architecture of the plant and preparing the ground for its growth, yield, and adaptive capacity, including response to stresses such as pollutants [2, 3].

Soil pollution imposes stress conditions that adversely affect plant growth and development, especially at the seedling stage when the plant tissues are tender and extremely sensitive. Among the soil pollutants, crude oil pollution poses a major problem in many countries of the world, especially in oil-rich nations like Nigeria, where oil spillage accounts for over 80% of pollution scenarios [4].

Crude oil is a complex, homogenous mixture consisting mainly of hydrocarbons such as paraffins, naphthenes, and aromatics, and with trace amounts of non-hydrocarbons (such as

chemicals containing nitrogen, sulphur, and oxygen), resin, and asphaltene [5]. Crude oil contamination of the soil has gained attention at both local and global levels due to the serious threat to agricultural output, which in turn leads to widespread poverty and hunger [6-8].

Crude oil pollution affects plants by smothering the soil, obstructing air passage into soil pores, and thus lowering soil aeration, and creating anaerobic conditions that reduce microbial populations and plant growth [9, 10]. Crude oil also induces hydrophobicity in soils, reducing water infiltration and capillary action [11]. These limit the access of plants to water and nutrients, thereby retarding plant growth, increasing oxidative stress, and sometimes leading to death of plants [12]. The responses of some plants such as okra, tomato, pepper, maize, lettuce, cabbage and some grasses to crude oil pollution have been documented [6, 13-16]. However, the effects of crude oil-polluted soil on West African okra, *Abelmoschus caillei* (A. Chev.) Stevels, a popular vegetable crop grown for its high fibre and mineral content in Nigeria is still poorly understood. The present study assessed the effects of crude oil in the soil on the germination, seedling and chlorophyll development of *A. caillei*.

2.0 Materials and Methods

2.1 Topsoil

The topsoil used for the experiment was collected from a fallow land within the Botanical Garden, University of Ilorin, Ilorin, Kwara State, Nigeria.

2.2 Crude oil

Crude oil (Bonny Light Crude Oil – BLCO) obtained from the Port Harcourt Refining Company, Eleme, Port Harcourt, Nigeria

2.3 *Abelmoschus caillei*

Certified seeds of *Abelmoschus caillei* used for the experiment were obtained from a seed shop at Sango area of Ilorin, Kwara State, Nigeria.

2.4 Acetone

Acetone of analytical grade was a product of British Drug House Chemicals Pvt, Mumbai, India.

2.5 Determination of growth parameters

A potted experiment was conducted in a screen house at the Botanical Garden, University of Ilorin, Ilorin, Kwara State, Nigeria (Lat. 8° 24' N - 8° 36' N; Long. 4° 10' E - 4° 36' E) from 7th January to 18th February, 2022. The soil was generally deep,

well-drained and rich in humus. The physicochemical properties of the soil are as follows: soil texture – sandy loam, pH – 6.87, organic matter – 3.72%, total N content – 0.48%, available P – 8.28 mg kg⁻¹, exchangeable K – 0.34 cmol kg⁻¹, Ca – 7.12 cmol kg⁻¹, Mg – 1.81 cmol kg⁻¹, and acidity – 0.07 cmol kg⁻¹. Soil was air dried to a constant weight, passed through 2 mm mesh, and 5 kg of soil was weighed into each of eighteen (18) pots with dimensions 22.5 cm by 12.8 cm (diameter × depth). Crude oil was added to the soil to produce concentrations of 0.1%, 0.5%, 1.0%, 2.5% and 5% v/w (i.e., 1, 5, 10, 25 and 50 ml crude oil/kg soil designated as T₁, T₂, T₃, T₄ and T₅). Each crude oil treatment was replicated three times. In addition, three uncontaminated pots were prepared and designated as the Control. The quality of BLCO used in the experiment was: American Petroleum Institute (API) gravity – 32.8, specific gravity – 0.84, sulphur – 0.14% (w/w), nitrogen – 1180 ppm, nickel – 4.15 ppm, vanadium – 0.41 ppm, acid number – 0.18 mg KOH/g, asphaltenes – 0.90%, aliphatic hydrocarbons – 66.7%, aromatic hydrocarbons – 21.7%, and polar materials – 4.96%.

The crude oil was mixed thoroughly with the soil in the pots and irrigated with deionised water for two weeks prior to planting. Seed viability was determined for *Abelmoschus caillei* using the flotation method. Seeds that floated in distilled water were considered non-viable and discarded, while the seeds that sank in water were deemed viable and retained for the study. Ten viable seeds were sown into the soil in each pot, and watering was done every three days with deionised water.

The plants were observed for emergent seedlings. The number of emergent seedlings was counted in each pot. The percentage of emergent seedlings was determined from the number of sprouted seeds at days after sowing (DAS). Thereafter, the emergent seedlings in a pot were thinned to two.

The measurement of growth parameters was done at two and four weeks of sowing (2 and 4 WAS). Data were collected on growth parameters (plant height, stem girth, number of leaves, leaf length, and leaf width) at 2 and 4 WAS. Stem length was obtained using measuring tape, while girth was measured using electronic Vernier calliper. Leaves were counted by observation. Leaf length was measured from the point of attachment of the petiole to the tip of the leaf. Leaf width was taken as the longest extension of any two points on the edge of the leaf blade that is perpendicular to the leaf length axis.

2.6 Quantification of chlorophyll

At 4 WAS, chlorophyll content was determined by cutting a 25 mg leaf blade sample and soaking

it in 7 ml of 100% acetone for 72 hours in a dark cupboard. The sample was then centrifuged at 5000 rpm for 5 minutes. The absorbance of the supernatant was read at wavelengths of 645 nm and 662 nm. The chlorophyll a, b and total chlorophyll contents were quantified using the equations highlighted by Lichtenthaler [17] as follows:

$$Chl. a (mg g^{-1} FW) = (11.24 \times A_{662} - 2.04 \times A_{645}) \times V/W$$

..... 1

$$Chl. b (mg g^{-1} FW) = (20.13 \times A_{645} - 4.19 \times A_{663}) \times V/W$$

..... 2

$$T. Chl (mg g^{-1} FW) = Chl. a + Chl. b$$

..... 3

Where *Chl. a* is chlorophyll a content, *Chl. b* is chlorophyll b content, *T. Chl* is total chlorophyll content, A_{645} is the absorbance at 645 nm, A_{663} is the absorbance at 663 nm, V is the volume of supernatant (in litres), and W is the weight (in grammes) of the leaf.

2.7 Quantification of fresh and dried weights

Plants in the pots were uprooted, rinsed to remove soil particles and allowed to drain. Each plant was weighed fresh and dried at 80°C in an oven (BS Model OV-160, Gallenkamp UK) to constant weight to determine the dry weight at 4 WAS.

2.8 Data analysis

Data obtained were tested for normality using the Shapiro–Wilk test at a 95% confidence level. Data that satisfied the assumption of normality were subjected to one-way analysis of variance (ANOVA) to compare differences mean values among crude oil treatments and the control for the measured variables (germination and growth parameters). Where significant differences were detected, means were separated using Duncan’s Multiple Range Test (DMRT) at $p \leq 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 25.0 (IBM Corp., Armonk, NY, USA).

3.0 Results

The result of the percentage of emergent seedlings of *A. caillei* in Figure 1 shows that germination started on the 6th day after sowing (DAS) in the crude oil treatments and the control. Seedling emergence increased progressively with

time across all treatments; however, both the rate and final percentage of emergence decreased with increasing crude oil contamination. By Day 6, emergence ranged from 70.0–76.7%, with lower values evident in the higher contamination treatments (T_4 and T_5). The control reached 100% emergence by Day 7, whereas emergence in contaminated soils remained lower, particularly in T_4 (80.0%) and T_5 (76.7%). By Day 8, the control and T_1 attained 100% emergence, while T_2 and T_3 reached 96.7% and 93.3%, respectively. In contrast, T_4 and T_5 showed persistent reductions (83.3%). The full emergence was achieved by Day 9 in the control, T_1 , and T_2 , while T_3 peaked at 96.7%. At Day 10, the percentage emergence remained highest in the control, T_1 , and T_2 (100%) but was reduced significantly in T_3 (96.7%), T_4 (93.3%), and T_5 (86.7%) accounting for 3.3%, 6.7% and 13.3% decline respectively. Overall, increasing crude oil contamination delayed emergence and reduced final seedling establishment in a concentration-dependent manner.

The result of plant height for *A. caillei* grown in the crude oil-contaminated soils and the control are presented in Table 1. There was a decreasing sequence of the plant height with increasing concentration of crude oil level in the soil. T_5 had the least plant height at 2 WAS (4.00 ± 0.59 cm). The plants in the control were statistically similar in height (7.08 ± 1.17 cm) to those in T_1 (6.56 ± 0.54 cm) and T_2 (6.70 cm) but significantly different ($p < 0.05$) from those of T_3 (5.96 ± 0.77 cm), T_4 (3.90 ± 0.41 cm) and T_5 (4.00 ± 0.59 cm). By 4 WAS, plant height increased across all treatments; however, the negative impact of crude oil contamination remained evident. The control (12.08 ± 1.89 cm), T_1 (11.24 ± 1.09 cm), T_2 (11.48 ± 1.21 cm), and T_3 (11.48 ± 1.64 cm) were statistically similar, suggesting minimal growth suppression at lower contamination levels. In contrast, T_4 (9.40 ± 0.65 cm) and T_5 (6.76 ± 0.53 cm) showed a significant reduction in plant height, and differed significantly from all other treatments. Overall, higher crude oil contamination levels significantly impeded the growth of *A. caillei*, with the strongest

The result of stem girth of *A. caillei* grown in varying concentrations of crude oil-contaminated soils are presented in Table 2. The stem girth of *A. caillei* was not significantly affected by crude oil contamination at either 2 or 4 WAS, as all treatments and the control were statistically similar ($p \leq 0.05$). The stem girth ranged between 2.60 ± 0.64 mm and 3.02 ± 0.12 mm at 2 WAS while all the plants attained 4.00 mm at 4 WAS, except the control and T_1 with a stem girth of 4.02 ± 0.20 mm and 4.02 ± 0.18 mm respectively.

The number of leaves on *A. caillei* grown in varying concentrations of crude oil contaminated

soils and the control soil are presented in Table 3. The number of leaves was the same (2.00 ± 0.00) for all the stands at 2 WAS. Aside from the control plants, by 4 WAS, the treatment effects became evident as the number of leaves decreased with increasing crude oil contamination in the soil. Plants grown in T₁ produced the highest number of leaves (3.42 ± 0.46), which was significantly higher ($p < 0.05$) than the control (2.92 ± 0.25), and higher crude oil-contaminated treatments. Plants in T₂ had number of leaves (3.08 ± 0.35) that was statistically comparable to T₁ (3.42 ± 0.46), T₃ (2.82 ± 0.24) and the control (2.92 ± 0.25). In contrast, plants exposed to higher crude oil concentrations showed reduced leaf production, with T₄ and T₅ showing the significantly lowest values (2.30 ± 0.25 and 2.16 ± 0.13 , respectively). Overall, leaf number decreased with increasing crude oil contamination, indicating that higher contamination levels adversely affected leaf development at later growth stages.

The length of the leaves of *A. caillei* grown in varying concentrations of crude oil-contaminated soils and the control are presented in Table 4. The control, T₁, T₂, and T₃ had leaf lengths ranging from 18.40 mm to 19.40 mm that were statistically similar ($p \geq 0.05$), but significantly different ($p < 0.05$) from T₄ and T₅ (15.00 ± 1.60 mm and 15.20 ± 1.30 mm respectively) at 2 WAS. By 4 WAS, T₁ showed the significantly highest ($p < 0.05$) leaf length (40.00 ± 0.10 mm) and was different from the control (36.00 ± 5.52 mm) and all other crude oil treatments (T₂ to T₅). Treatments T₂, T₃, T₄, and T₅ all had significantly ($p < 0.05$) shorter leaf lengths (in the range of 28.05 mm to 30.00 mm) compared to the control (Table 4).

The leaf width of *A. caillei* varied significantly across treatments and over time (Table 5). At 2 WAS, the control (20.00 ± 0.71 mm), T₁ (19.80 ± 1.60 mm), and T₂ (21.80 ± 1.80 mm) were statistically similar ($p \geq 0.05$), indicating that low to moderate crude oil contamination did not significantly affect early leaf width. Treatments T₃ (17.20 ± 3.09 mm), T₄ (15.00 ± 1.21 mm), and T₅ (16.10 ± 1.58 mm) showed significantly narrower leaf width, suggesting early inhibitory effects at higher contamination levels. By 4 WAS, T₁ (32.78 ± 4.12 mm) had plants with the widest leaves, comparable to the control (29.80 ± 3.31 mm) and T₂ (29.60 ± 4.60 mm), indicating that low contamination may not impair leaf development over time. Treatments T₄ (22.60 ± 2.62 mm) and T₅ (20.81 ± 2.91 mm) showed significant reductions in leaf width, demonstrating a clear inhibitory effect of the high crude oil concentrations in soil. T₃ (30.00 ± 1.40 mm) was not significantly different from the control, suggesting that intermediate contamination levels may have less pronounced effects as plants mature. (Table 5).

The concentrations of chlorophyll a (Chl. a), chlorophyll b (Chl. b), total chlorophyll (Total Chl. i.e. Chl. a + b), and the Chl. a/b ratio in *A. caillei* were affected by crude oil contamination at 4 WAS (Table 6). The Chl. a values ranged from 6.85 ± 1.12 mg/g FW in T₅ to 10.87 ± 1.55 mg/g FW in T₁. Statistical analysis revealed that T₁ and T₃ had the highest Chl. a, similar to the control (10.30 ± 1.68 mg/g FW), whereas T₅ had the lowest value (6.85 ± 1.12 mg/g FW), which was significantly lower than the control and T₁ ($p \leq 0.05$). The Chl. b concentrations did not differ significantly among treatments (1.40 – 2.93 mg/g FW; $p > 0.05$), indicating relative stability of Chl. b under crude oil stress. The total chlorophyll followed the same trend as Chl. a, with T₁ (13.80 ± 2.52 mg/g FW) and the control (13.14 ± 1.57 mg/g FW) showing the highest values, while T₅ (8.25 ± 1.69 mg/g FW) was the lowest. The Chl. a/b ratio increased progressively with contamination, ranging from 3.63 in the control to 4.06 in T₅, suggesting that Chl. a was more sensitive to crude oil stress than Chl. b. Overall, higher crude oil concentrations (T₄ and T₅) resulted in reduced chlorophyll content, particularly Chl. a and total chlorophyll, whereas low to moderate contamination levels (T₁–T₃) maintained chlorophyll levels similar to the control (Table 6).

The fresh and dry weights of *A. caillei* were significantly affected by crude oil contamination at 4 WAS (Table 7). Fresh weight ranged from 3.01 ± 0.96 g in T₅ to 7.39 ± 2.28 g in T₁. T₁ exhibited the highest fresh weight, significantly greater than the control (5.39 ± 1.35 g) and other treatments ($p \leq 0.05$), while T₅ had the lowest value. Fresh weights of T₂, T₃, and T₄ were intermediate and generally lower than the control, with T₃ and T₄ not significantly different from each other ($p > 0.05$). Dry weight followed a similar trend, ranging from 0.46 ± 0.08 g in T₅ to 0.89 ± 0.22 g in T₁. T₁ had the highest dry weight, significantly higher than the control (0.66 ± 0.17 g) and all other crude oil treatments. Although the control and the intermediate crude oil treatments (T₂–T₄) were statistically similar ($p \leq 0.05$), T₅ showed the lowest dry weight, indicating substantial biomass reduction at the highest contamination level. Overall, low crude oil contamination (T₁) resulted in increased biomass accumulation, whereas higher concentrations (T₄, and T₅) led to a significant reduction in both fresh and dry weights, suggesting a dose-dependent effect of crude oil on vegetative growth (Figure 2).

4.0 Discussion

The germination and emergence of *A. caillei* seedlings was delayed and reduced by the crude oil contamination in the soil in a concentration-dependent manner. Low crude oil contamination

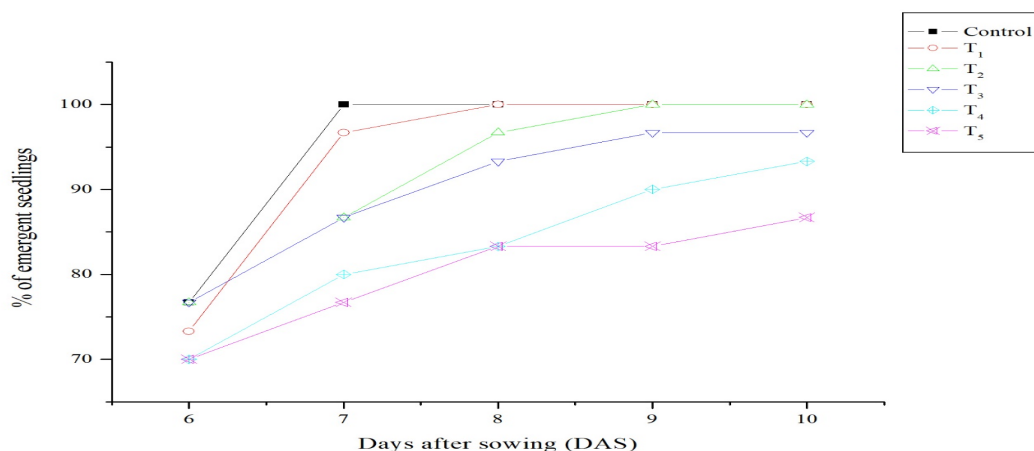


Figure 1: Percentage of germinated seeds of *Abelmoschus caillei* grown in crude oil contaminated soils at days after sowing

Table 1: Plant height of *Abelmoschus caillei* grown in varying concentration of crude oil contaminated soils

Treatment	2 WAS	4 WAS
Control	7.08±1.17 ^a	12.08±1.89 ^a
T ₁	6.56±0.54 ^{ab}	11.24±1.09 ^a
T ₂	6.70±0.58 ^{ab}	11.48±1.21 ^a
T ₃	5.96±0.77 ^b	11.48±1.64 ^a
T ₄	3.90±0.41 ^c	9.40±0.65 ^b
T ₅	4.00±0.59 ^c	6.76±0.53 ^c

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan multiple range test.

Table 2: Stem girth (in mm) of *Abelmoschus caillei* grown in varying concentration of crude oil contaminated soils

Treatment	2 WAS	4 WAS
Control	2.84±0.40 ^a	4.02±0.20 ^a
T ₁	3.02±0.12 ^a	4.02±0.18 ^a
T ₂	3.00±0.18 ^a	4.00±0.22 ^a
T ₃	3.00±0.10 ^a	4.00±0.16 ^a
T ₄	2.64±0.60 ^a	4.00±0.10 ^a
T ₅	2.60±0.64 ^a	4.00±0.12 ^a

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan multiple range test.

Table 3: Number of leaf on *Abelmoschus caillei* grown in varying concentration of crude oil contaminated soils

Treatment	2 WAS	4 WAS
Control	2.00±0.00 ^a	2.92±0.25 ^b
T ₁	2.00±0.00 ^a	3.42±0.46 ^a
T ₂	2.00±0.00 ^a	3.08±0.35 ^{ab}
T ₃	2.00±0.00 ^a	2.82±0.24 ^b
T ₄	2.00±0.00 ^a	2.30±0.25 ^c
T ₅	2.00±0.00 ^a	2.16±0.13 ^c

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan multiple range test.

Table 4: Leaf length (in mm) of *Abelmoschus caillei* grown in varying concentration of crude oil contaminated soils

Treatment	2 WAS	4 WAS
Control	19.40±1.10 ^a	36.00±5.52 ^b
T ₁	19.40±1.30 ^a	40.00±0.10 ^a
T ₂	19.78±1.92 ^a	30.00±0.31 ^c
T ₃	18.40±0.90 ^a	30.00±0.18 ^c
T ₄	15.00±1.60 ^b	30.00±0.15 ^c
T ₅	15.20±1.30 ^b	28.05±4.52 ^c

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan multiple range test

Table 5: Leaf width (in mm) of *Abelmoschus caillei* grown in varying concentrations of crude oil contaminated soils

Treatment	2 WAS	4 WAS
Control	20.00±0.71 ^a	29.80±3.31 ^a
T ₁	19.80±1.60 ^a	32.78±4.12 ^a
T ₂	21.80±1.80 ^a	29.60±4.60 ^a
T ₃	17.20±3.09 ^b	30.00±1.40 ^a
T ₄	15.00±1.21 ^b	22.60±2.62 ^b
T ₅	16.10±1.58 ^b	20.81±2.91 ^b

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan multiple range test.

Table 6: Chlorophyll a, b and total chlorophyll concentrations (in mg/g FW) in *Abelmoschus caillei* of grown in varying concentrations of crude oil contaminated soils at 4 WAS

Treatment	Chl. a	Chl. b	Total Chl.	Chl. a/b ratio
Control	10.30±1.68 ^a	2.84±0.57 ^a	13.14±1.57 ^a	3.63
T ₁	10.87±1.55 ^a	2.93±0.97 ^a	13.80±2.52 ^a	3.71
T ₂	9.83±1.67 ^{ab}	2.59±1.62 ^a	12.42±2.15 ^a	3.80
T ₃	9.87±2.05 ^a	2.62±1.35 ^a	12.49±0.98 ^a	3.77
T ₄	8.72±1.81 ^{ab}	2.20±0.96 ^a	10.92±1.43 ^{ab}	3.96
T ₅	6.85±1.12 ^b	1.40±0.87 ^a	8.25±1.69 ^b	4.06

Values with the same superscripted letter(s) along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan's multiple range test. Chl. – chlorophyll

Table 7: Fresh and dry weights (in g) of *Abelmoschus caillei* grown in varying concentrations of crude oil contaminated soils at 4 WAS

Treatment	Fresh weight	Dry weight
Control	5.39±1.35 ^b	0.66±0.17 ^b
T ₁	7.39±2.28 ^a	0.89±0.22 ^a
T ₂	5.32±0.94 ^b	0.63±0.09 ^b
T ₃	4.70±0.61 ^{bc}	0.55±0.07 ^b
T ₄	3.98±0.90 ^{bc}	0.53±0.11 ^b
T ₅	3.01±0.96 ^c	0.46±0.08 ^b

Values with the same superscripted along the same column indicate that they are not statistically different from each other at $p \leq 0.05$ using Duncan's multiple range test.

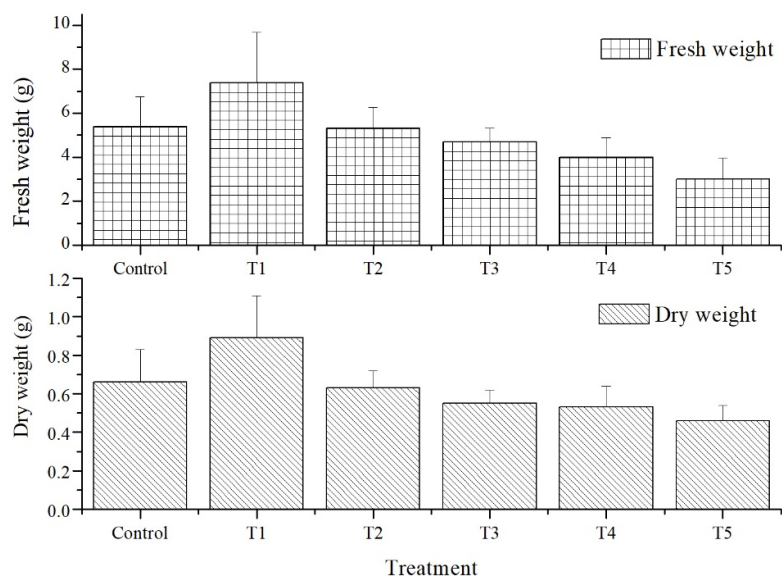


Figure 2: Fresh and dry weights (in g) of *Abelmoschus caillei* seedlings grown in varying concentrations of crude oil contaminated soils at 4 WAS

contamination level (T_1) caused only minor delays in emergence and ultimately resulted in 100% emergence, similar to the control. In contrast, higher contamination levels (T_3 to T_5) led to sustained reductions in both the rate and final percentage of seedling emergence. These findings indicate that crude oil contamination primarily impairs early seedling establishment rather than entirely inhibiting germination. Recent studies have consistently demonstrated that petroleum hydrocarbons impair seed imbibition, restrict oxygen diffusion, and inhibit enzymatic activities essential for rapid germination, resulting in delayed emergence and reduced final stand density [18, 19]. The observed progressive decline at higher contamination levels is likely due to increased soil hydrophobicity and diminished nutrient availability, which together create adverse conditions for radicle protrusion and seedling emergence [20].

The eventual attainment of full emergence in T_1 and T_2 indicates that *A. caillei* possesses a degree of tolerance to low levels of crude oil contamination, possibly through delayed but successful mobilization of seed reserves or adaptive physiological responses. However, the consistently lower emergence in T_4 and T_5 even at 10 days after sowing highlights the inhibitory effects of higher hydrocarbon concentrations, which have been linked to phytotoxic compounds and altered soil microbial activity. The result of the present study

on germination also confirms earlier report on germination reduction by crude oil pollution for okra [6, 21].

Plant growth parameters are influenced by the genetic make-up and environmental conditions prevalent in the growing periods [22]. The present study confirms the negative effect of crude oil contamination on the vertical growth (height) of *A. caillei* in the weeks after sowing. Crude oil impacted on the plant in the highly contaminated crude oil treatment, accounting for a 77% and 78.7% reduction in height relative to the control plants at 2 and 4 WAS respectively. Oyedeji et al. [6] and Ikhajiagbe et al. [23] had similarly reported the reducing effect of crude oil and spent engine oil on the growth of *A. esculentus*.

Soil contamination by oils has been reported to escalate hydrophobicity, thereby reducing the soil's ability to absorb, retain and transport water. The problem of imbalance in the air-water regime due to air displacement is also heightened [24, 25]. These effects of hydrophobicity in oil-polluted soils impact root development as well as water and nutrient transport up along the stem.

Contrary to the varying effects of crude oil on plant height, the result for stem girth of *A. caillei* plants in the oil-contaminated treatments and the control were statistically similar. This attests to the fact that the crude oil pollution impacted plant growth parameters differently. The lack of significant variation in stem girth of *Abelmoschus*

caillei across crude oil-contaminated soils at both 2 and 4 WAS indicates that radial stem growth is comparatively tolerant to petroleum-induced stress during early development. The result of stem girth in the present study differed from earlier observations by Ikhajiagbe *et al.* [23] for *A. esculentus*, where a significant decrease in the stem girth was recorded for plants grown in oil-polluted soils. The smaller stem girth of *A. caillei* for the control when compared with the range (11.30-16.20 mm) reported for *A. esculentus* genotypes in Nigeria by Okoli [26] affirms differences in the attributes of growth of both plant species.

Plant leaf is an important regulator of growth, as leaf size and shape influence photosynthetic efficiency, nutrient supply, yield, quality and resistance to environmental stresses [27]. The decrease in the number of leaves with increasing crude oil level in the soil is indicative of the crude oil pollution impact on leaf production. The high number of leaves in T₁ compared to the unpolluted soil could be due to the presence of growth-promoting substances in the crude oil. Agbogidi *et al.* [28] and Seeger *et al.* [29] reported that crude oil can improve the soil content of some nutrient elements such as magnesium, potassium, sodium and phosphorus. These elements are vital for plant growth and development, especially under stress [30-33]. The uptake of these essential minerals in the crude oil could be impeded at higher pollution concentrations due to the formation of hydrophobic layers in the soil, which limit the uptake of moisture and nutrients [34].

Similar to the number of leaves, the leaf length of *A. caillei* plants in T₁ was comparatively higher than the control plants, confirming an earlier assertion that crude oil is likely to contain growth-promoting substances that is effective in the low-concentration treatments. This is in line with an earlier report by Balogun *et al.* [35] that crude oil has a promoting effect on leaf area in *Musa paradisiaca*. Inhibitory effect of crude oil was observed at 4 WAS in treatment T₂ to T₅ for leaf length and T₄ to T₅ for leaf width. Reduction in the length and width of the leaves in the crude oil treatment may be attributed to water stress induced by the hydrophobicity of oil. Leaf area reduction in water-stressed conditions results from a decrease in mitotic activity of the epidermal cells, which causes a reduction in the total number of cells per leaf and leaf blade area [36]. Olanont *et al.* [37] have also reported the declining effect of crude oil contamination on the leaf length and leaf width in *Ipomoea pes-caprae*.

The reductions in chlorophyll content at higher crude oil concentrations are indicative of photosynthetic impairment due to hydrocarbon-induced stress. Petroleum hydrocarbons in soil can alter nutrient availability, reduce water uptake, and

generate oxidative stress, all of which can damage chloroplast structure and inhibit chlorophyll biosynthesis. The result of chlorophyll a was within the range of 5.43 to 14.38 mg/g FW reported by Ayub *et al.* [38] for *A. esculentus* under stressed condition. Contrarily, chlorophyll b and total chlorophyll contents in the present study were lower than the ranges of 13.51-24.42 mg/g FW and 18.94-38.80 mg/g FW reported by the author. Generally, there was a decline in the chlorophyll a, b and total chlorophyll contents with increasing crude oil pollution, while the trend of the Chl. a/b ratio was the reverse. The progressive increase in the Chl. a/b ratio with higher contamination suggests a relative decrease in Chl. b stability compared to Chl. a, which may reflect selective sensitivity of chlorophyll types under stress conditions. Adenipekun *et al.* [21] reported a decrease in chlorophyll content in *A. esculentus* with increasing oil pollution in the soil. Chlorophyll content has been reported to decrease in response to environmental stresses such as limiting moisture, pollution, and nitrogen deficiency [21, 38, 39]. These conditions often result in the inability to take up water and nutrients needed for the synthesis of chlorophyll. The Chl a/b ratio is known to increase with decreasing foliar N and chlorophyll under stress conditions [39]. This is due to prioritization of the Chl. a formation (the reaction centres) for sustain core photochemistry while reducing investment in Chl. b – the peripheral light-harvesting complexes [40]. The crude oil in soil causes hydrophobicity, which increases water repellence and decreases infiltration and moisture availability as well as inducing toxicity at higher concentration due to the high levels of polycyclic aromatic hydrocarbons [41]. These could impose stresses in the tender okra plants, and affect the growth and development.

The lowest crude oil treatment (0.1% v/w) significantly improved carbon assimilation in *A. caillei*, even surpassing the plants in uncontaminated soil. The evidential decrease in the fresh weight of plants in T₅ (5% v/w crude oil treatment) could be due to reduced moisture in tissues of the plant, since the dry weight was comparable to those of plants in the control and other crude oil treatments, except T₁. Similar observations on fresh weight reduction in rye grown on crude oil-polluted soil had been reported by Skrypnick *et al.* [42]. Low moisture conditions in plants could be triggered by air displacement from soil pore spaces by crude oil, which reduces the water available to the plants [43].

In conclusion, this study revealed that crude oil contamination exerts a significant, concentration-dependent effect on the germination, growth, physiological performance, and biomass

accumulation of *A. caillei*. As crude oil levels increased, seedling emergence was progressively delayed and reduced, indicating that petroleum hydrocarbons compromise early establishment by altering soil conditions necessary for successful germination. Vegetative growth responses showed that *A. caillei* tolerates low contamination levels with minimal or transient growth stimulation, whereas higher contamination levels markedly suppressed plant height, leaf development, chlorophyll content, and biomass production.

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None

Authors Contributions

SO – Conceptualization, Resources, Formal analysis, Methodology, Supervision, Writing – original draft; GTA - Data curation; JMF - Writing – original draft; KSO - Writing – review & editing; POF – Conceptualization, Resources and Supervision, Writing – review & editing.

References

- Hanley, M. E., Fenner, M., Whibley, H., & Darvill, B. (2004). Early plant growth: identifying the end point of the seedling phase. *New Phytologist*, 163(1), 61-66.
- Obroucheva, N. V. (1981). Development of the mature root growth pattern in the course of seed germination. In: Brouwer, R., Gašpariková, O., Kolek, J., & Loughman, B. C. (eds): Structure and Function of Plant Roots. Developments in Plant and Soil Sciences, vol 4. Springer, Dordrecht.
- Sharma, G., Prajapati, D., Devi, K. A., Pal, A., Saharan, V. (2022). Chitosan nanomaterials for delivery of micronutrients in plants. In Kumar, S., & Madihally, S. V. (eds), Nanomaterial-plant interactions: role of chitosan and chitosan-based nanomaterials in plant sciences, Academic Press, pp. 239-253.
- Odu, C. T. I. (1997). Microbiology of soils contaminated with petroleum hydrocarbons: natural rehabilitation and reclamation of soil affected. *Institute of Petroleum Technology Pub*, 1, 77-105.
- Zhang, J. H., Feng, Z. H., Fang, W., Qiuli, H., Kun, Z., JingKun, L. I., HuaSen, Z., & Bowei, Z. (2014). Crude-oil hydrocarbon composition characteristics and oil viscosity prediction in the northern Songliao basin. *Science China Earth Sciences*, 57, 297-312.
- Oyedeji, A., Adebisi, A., Omotoyinbo, M., & Ogunkunle, C. (2012). Effect of crude oil-contaminated soil on germination and growth performance of *Abelmoschus esculentus* L. Moench—a widely cultivated vegetable crop in Nigeria. *American Journal of Plant Science*, 3(10), 1451-1454.
- Adekunle, A. A., & Adeniyi, A. O. (2015). Biodegradation of petroleum oil by fungi isolated from *Treculia africana* (Dec'ne) seeds in Nigeria. *African Journal of Environmental Science & Technology*, 9(2), 126-135.
- Steliga, T., & Kluk, D. (2020). Application of *Festuca arundinacea* in phytoremediation of soils contaminated with Pb, Ni, Cd and petroleum hydrocarbons. *Ecotoxicology & Environmental Safety*, 194(3), 110409. <https://doi.org/10.1016/j.ecoenv.2020.110409>
- Ewetola, E. A. (2013). Effect of crude oil pollution on some soil physical properties. *International Organisation of Scientific Research Journal of Agriculture & Veterinary Science*, 6(3), 14-17.
- Sutton, N. B., Maphosa, F., Morillo, J. A., Al-Soud, W. A., Alette, A. M. L., Grotenhuis, T., Huub, H. M. R., & Hauke, S. (2013). Impact of long-term diesel contamination on soil microbial community structure. *Applied Environmental Microbiology*, 79(2), 619-630.
- Aislabie, J. M., Balks, M. R., Foght, J. M., & Waterhouse, E. J. (2004). Hydrocarbon spills on Antarctic soils: effects and management. *Environmental Science & Technology*, 38(5), 1265-1274.
- Al-Joumaa, K. (2009). Effect of pollution with petroleum on some soil characteristics and plant growth. *Arabian University Journal of Agricultural Science*, 17(1), 267-275.
- Kuhn, W., Gambino, R., Al-Awadhi, N., Balba, M. T., & Dragun, J. (1998). Growth of tomato plants in soil contaminated with Kuwait crude oil. *Journal of Soil Contamination*, 7(6), 801–806.
- Amakiri, J. O., & Onofeghara, F.A. (1983). Effect of crude oil pollution on the growth of *Zea mays*, *Abelmoschus esculentus* and *Capsicum frutescens*. *Oil & Petrochemical Pollution*, 1(3),199-205.
- Odukoya, J., Lambert, R., & Sakrabani, R. (2019). Impact of crude oil on yield and phytochemical composition of selected green leafy vegetables. *International Journal of Vegetation Science*, 25(6), 554-570.

16. Oyedeji, S., Raimi, I. O., & Odiwe, A. I. (2013). A comparative assessment of the crude oil-remediating potential of *Cynodon dactylon* and *Eleusine indica*. *Environmental & Experimental Botany*, 11(3), 145-150.
17. Lichtenthaler, H. K. (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. *Methods in Enzymology*, 148, 350-382.
18. Njoku, K. L., Okporuanefe, F. O., & Ude, E. O. (2018). Responses of accessions of *Zea mays* to crude oil pollution using growth indices and enzyme activities as markers. *Pollution*, 4(1), 183-193.
19. Sorana, I. T., Mihăilescu, S., Strat, D., & Florentina, G. I. (2020). Effects of oil pollution on seed germination and seedling emergence toxicity. *Romanian Biotechnological Letters*, 25(1), 1194-1201.
20. Gheorghe, I. F., & Strat, D. (2024). Effect of crude oil and petroleum products on the plants propagation and growth. Generis Publishing, Miron, Republic of Moldova, 308 pp.
21. Adenipekun, C. O., Oyetunji, O. J., & Kassim, L. Q. (2009). Screening of *Abelmoschus esculentus* L. Moench for tolerance to spent engine oil. *Journal of Applied Bioscience*, 20, 1131 – 1137.
22. Tiamiyu, R. A., Ahmed, H. G., & Muhammad, A. S. (2012). Effect of sources of organic manure on growth and yields of okra (*Abelmoschus esculentus*) in Sokoto, Nigeria. *Nigerian Journal of Basic & Applied Science*, 20(3): 213-216.
23. Ikhajiagbe, B., Omoregie, G., Ekhaton, P., & Mshelmbula, B. P. (2017). Growth and yield responses of okra (*Abelmoschus esculentus*) in a petroleum hydrocarbon-polluted soil after substrate amendment. *Ethiopian Journal of Environmental Studies & Management*, 10, 866-876.
24. Adams, R. H., Guzmán Osorio, F. J., & Zavala Cruz, J. (2008). Water repellency in oil contaminated sandy and clayey soils. *International Journal of Environmental Science & Technology*, 5(4), 445–454.
25. Asadi, T., Najafi, P., Chavoshi, E., & Hoodaji, M. (2025). The impact of oil contamination on soil hydrophobicity and physico-chemical properties around Bandar Abbas oil refinery, Hormozgan Province, Iran. *Environmental Health Engineering and Management Journal*, 12, 1420. [https://doi: 10.34172/EHEM.1420](https://doi.org/10.34172/EHEM.1420)
26. Okoli, E. E. (2021). Agronomic attributes of five okra landraces selected for okra production in Oyi Local Government Area of Anambra state, Nigeria. *International Journal of Scientific Advances*, 2(1), 35-38.
27. Zhang, L., Du, J., Ge, X., Cao, D., & Hu, J. (2021). Leaf size development differences and comparative transcriptome analyses of two poplar genotypes. *Genes (Basel)*, 12(11), 1775. [https://doi: 10.3390/genes12111775](https://doi.org/10.3390/genes12111775)
28. Agbogidi, O. M., Eruotor, P. G., Akparobi, S. O., & Nnaji, G. U. (2007). Evaluation of crude oil contaminated soil on the mineral nutrient elements of maize (*Zea mays* L.). *Journal of Agronomy*, 6, 188-193.
29. Seeger, T. S., Muller, E. I., Mesko, M. F., & Duarte, F. A. (2019). Magnesium and calcium determination in desalted crude oil by direct sampling graphite furnace atomic absorption spectrometry. *Fuel*, 236, 1483-1488.
30. Frans, J., & Maathuis, M. (2014). Sodium in plants: perception, signalling, and regulation of sodium fluxes. *Journal of Experimental Botany*, 65(3), 849–858.
31. Sardans, J., & Peñuelas, J. (2021). Potassium control of plant functions: ecological and agricultural implications. *Plants (Basel)*, 10(2), 419. <https://doi.org/10.3390/plants10020419>
32. Ishfaq, M., Wang, Y., Yan, M., Wang, Z., Wu, L., Li, C., & Li, X. (2022). Physiological essence of magnesium in plants and its widespread deficiency in the farming system of China. *Frontiers in Plant Science*, 13, 802274. <https://doi.org/10.3389/fpls.2022.802274>
33. Khan, F., Siddique, A.B., Shabala, S., Zhou, M., Zhao, C. (2023). Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. *Plants (Basel)* 12(15): 2861.
34. Gordon, G., Stavi, I., Shavit, U., & Rosenzweig, R. (2018). Oil spill effects on soil hydrophobicity and related properties in a hyper-arid region. *Geoderma* 312, 114-120.
35. Balogun, K.P., Aborisade, A.T., Odiyi, B.O. (2022). Effect of crude oil pollution of soil on the vegetative growth of plantain (*Musa paradisiaca*). *J Glob Ecol Environ*. 16(4): 183–194.
36. Ekpo, I. A., Agbor, R. B., Okpako, E. C. & Ekanem, E. B. (2012). Effect of crude oil polluted soil on germination and growth of soybean (*Glycine max*). *Annals of Biological Research*, 3(6), 3049-3054.
37. Olaranont, Y., Stewart, A.B., Traiperm, P. (2021). Effects of crude oil on plant growth and leaf anatomical structures in a common coastal plant. *International Journal of Phytoremediation*, 23(2), 162-170.
38. Ayub, Q., Khan, S. M., Hussain, I., Naveed, K., Ali, S., Mehmood, A., Khan, M. J., Haq, N. U., & Shehzad, Q. (2021). Responses of different okra (*Abelmoschus esculentus*) cultivars to water deficit

- conditions. *Journal of Horticultural Sciences*, 16(1), 53-63.
39. Kitajima, K, Hogan K. P. (2003). Increases of chlorophyll a/b ratios during acclimation of tropical woody seedlings to nitrogen limitation and high light. *Plant Cell & Environment*, 26(6), 857-865.
 40. Nisbett, K. I., Alokozai, A., Ko, S. H. E., Mott, G. A., & Brown, J. C. L. (2024). Degradation and resynthesis of chlorophyll during increased oxidative stress and prolonged darkness differ between annual and perennial flax (*Linum L.*). *Oil Crop Science*, 9(2), 121-130.
 41. Ola, I., Drebenstedt, C., Burgess, R. M., Mensah, M., Hoth, N., Okoroafor, P., & Kulls, C. (2024). Assessing petroleum contamination in parts of the Niger Delta based on a sub-catchment delineated field assessment. *Environmental Monitor Assess.*, 196, 585. doi.org/10.1007/s10661-024-12743-7
 42. Skrypnik, L., Maslennikov, P., Novikova, A., & Kozhikin, M. (2021). Effect of crude oil on growth, oxidative stress and response of antioxidative system of two rye (*Secale cereale L.*) varieties. *Plants (Basel)*, 10, 157. doi: [10.3390/plants10010157](https://doi.org/10.3390/plants10010157)
 43. Athar, H. R., Ambreen, S., Javed, M., Hina, M., Rasul, S., Zafar, Z. U., Manzoor, H., Ogbaga, C. C., Afzal, M., Al-Qurainy, F., & Asharaf, M. (2016). Influence of sub-lethal crude oil concentration on growth, water relations and photosynthetic capacity of maize (*Zea mays L.*) plants. *Environmental Science Pollution Research International*, 23(18), 18320–18331.