doi:10.14720/aas.2025.121.3.21676 Original research article / izvirni znanstveni članek

Effect of cocoa pod husk-based compost and watering frequencies on *Phytophthora* seedling blight disease suppression and seedling growth of cocoa clones

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Received January 22, 2025; accepted July 21, 2025
Delo je prispelo 22. januar 2025, sprejeto 21. julij 2025

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Abstract: *Phytophthora* Seedling Blight Disease (PSBD) is a significant threat to global cacao production, causing stem and leaf wilting, defoliation, and seedling death within seven days of infection. The persistence of *Phytophthora palmivora* Butler in soil as mycelia and spores complicates its management. Composting, particularly with cocoa pod husks, enriches soil and suppresses plant diseases. Cocoa pod husk compost enhances seedling growth, improving plant height, dry matter, and foliar nitrogen. Cocoa pod husks also present a sustainable substratum for composting, as a substantial amount of it is left unused after bean harvesting. This study investigated the effects of cocoa pod husk-based compost and watering frequencies on PSBD suppression and cocoa seedling performance. Conducted in Prestea Nkwanta, Ghana, the experiment involved three factors: cocoa hybrid genotypes (PA150 and C85), compost ratios (soil alone, compost alone, 9 kg compost + 81 kg soil, and 18 kg compost + 72 kg soil), and watering frequencies (twice or thrice weekly). Disease incidence, growth, and root architecture parameters were analyzed using GenStat. Results showed significantly higher PSBD incidence in soil alone compared to compost-amended soils ($p < 0.05$). Growth parameters also varied significantly among treatments ($p < 0.05$). Cocoa pod husk compost significantly improved cocoa growth and suppressed PSBD, with reduced watering frequency enhancing effectiveness.

Key words: cocoa pod husk compost, cocoa seedling growth, disease suppression, root architecture, soil amendment, cocoa hybrid genotypes

Učinki komposta iz ostankov plodov kakavovca in pogostosti namakanja na zatira nje bolezni na sejankah povzročene od glive iz rodu *Phytophthora* ter na rast sejank klonov kakavovca

Izvleček: Plesen *Phytophthora* Seedling Blight Disease (PSBD) je velika grožnja svetovni pridelavi kakavovca. Povzroča venenje stebel in listov, defoliacijo in propad sejank v času sedem dni po okužbi. Obstoj glive Phytophthora palmivora Butler v tleh v obliki micelija in trosov otežuje njeno zatiranje. Uporaba komposta, še posebno tistega iz ostankov plodov kakavovca, bogati tla in zavira to rastlinsko bolezen. Takšen kompost pospešuje rast sejank kakavovca, povečuje njihovo višino, vsebnost suhe snovi in vsebnost dušika v listih. Tako predstavljajo ostanki plodov kakavovca znaten vir substrata za kompostiranje, ki je trenutno neizrabljen po izluščenju semen. V raziskavi so bili preučevani vplivi tega komposta in pogostosti namakanja na zatiranje zgoraj omenjen glivične bolezni in rast sejank. Poskus je potekal v Prestea Nkwanta, v Gani in je vseboval tri dejavnike: hibridna genotipa kakavovca (PA150 in C85), delež komposta v substratu (samo prst, samo kompost, 9 kg komposta + 81 kg prsti in 18 kg komposta + 72 kg prsti) in pogostost namakanja (dvakrat ali trikrat na teden). Pojav bolezni, rast in arhitekturni parametri korenin so bili analizirani z uporabo GenStat. Rezultati so pokazali značilno večji pojav PSBD bolezni v substratu samo iz prsti v primerjavi s tistimi, kjer je bil dodan kompost ($p < 0.05$). Tudi rastni parametri so bili med obravnavanji značilno različni ($p < 0.05$). Kompost iz ostankov plodov kakavovca je značilno izboljšal rast kakavovca in zavrl pojav PSBD bolezni, zmanjšal je tudi pogostost namakanja, kar je povečalo učinkovitost pridelave.

Ključne besede: kompost iz plodov kakavovca, rast sejank kakavovca, zatiranje bolezni, arhitektura korenin, dodatki k prsti, hibridni genotipi kakavovca

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1 INTRODUCTION

Phytophthora Seedling Blight Disease (PSBD) is economically important in all cocoa-producing areas of the world. Significant factors such as precipitation and extra irrigation are considered to upsurge the severity and the spread of *Phytophthora* diseases. *Phytophthora palmivora* Butler survives in soil as thick-walled resistant spores, making its control challenging (Gregory and Maddison, 1981). These spores are often spread through partially infected seedlings.

To improve the cultivation of upgraded planting materials for sustainable cocoa production, the Seed Production Division (SPD) and Cocoa Health and Extension Division (CHED) of the Ghana Cocoa Board (COCOBOD) were tasked to produce hybrid cocoa seedlings free of charge to cocoa farmers in Ghana for planting every year. Polythene bags are filled with topsoil and irrigated occasionally for 12 to 24 weeks to raise the seedlings before they are transplanted to the farm (Opoku-Ameyaw et al., 2010). Seedlings in nurseries face numerous challenges to survival, including exposure to various diseases, with *Phytophthora* seedling blight being a significant threat.

In recent years, various management strategies have been formulated and implemented to effectively control the disease. Copper-based fungicides and systemic fungicides are typically applied every three to four weeks to ensure effective disease management. For several months, *Phytophthora palmivora,* the main causal agent of the disease maintains a reservoir of inoculum and thrives in soils and infected debris making the use of fungicides unsustainable (Akrofi, 2015; Ristaino and Gumpertz, 2000). The fungicide use also increases the cost of seedling production and is problematic due to environmental pollution concerns. Biological control can be considered in integrated disease management strategies but getting commercial products is difficult (Guest, 2007).

Composts play a crucial role in agriculture by enriching soil or container media with essential nutrients and helping to control plant diseases. Research indicates that compost derived from cocoa pod husks significantly enhances the growth of cocoa seedlings by increasing plant height, dry matter yield, and foliar nitrogen content (Fidelis and Rao, 2017). Compost made of cocoa pod husk is a good potting medium when amended in smaller fractions with soil for nursing cocoa seedlings (Ofori-Frimpong et al., 2010). Cocoa pod ash consists of plant nutrients such as nitrogen, potassium, phosphorus, calcium, magnesium, and micronutrients and was found to improve tomato production and yield (Odedina et al., 2007; Ayeni et al., 2008). Agele and Agbona (2008) studied the effects of cocoa pod husk-based compost (CPH) amendment on soil and its influence on the composition of leaf and growth of cashew seedlings. They reported that amendments of cocoa pod husk increased soil pH, calcium, organic matter, organic carbon, potassium, nitrogen, and sodium. Typically, however, large amounts of cocoa pod husk are removed after harvesting beans. It is crucial to explore alternative approaches for effectively managing and utilizing the substantial quantities of cocoa pod husks generated as they enhance the fertility of the soil and reduce disease severity of *Phytophthora* seedling blight disease in cocoa. Therefore, the present study was carried out to investigate how cocoa pod husk-based compost and watering frequencies can suppress *Phytophthora* seedling blight disease, and influence cocoa seedling performance and root architecture.

2 MATERIALS AND METHODS

2.1 EXPERIMENTAL DESIGN

The experiment was carried out in Prestea Nkwanta, a cocoa operational area in the Prestea District of Cocoa Health and Extension Division (CHED) in the Western Region of Ghana. The site is situated in a wet equatorial rainforest area located at latitude 4^o 56’ 20” N and longitude 1^o 51’ 33” W. The area experiences a mean annual rainfall of 187.83 mm with 26 ^{o}C to 30 °C average temperatures and 75–80 % humidity.

The plant materials used for the experiment were the hybrid clone PA150 and clone C85. These plant materials grow rapidly, matures early, has a high yield, and can tolerate drought. Fully matured pods were sourced from the Seed Production Division (SPD) of COCOBOD for the study at Huni Valley Cocoa Station in the Western Region.

The experiment was conducted using a Completely Randomized Design (CRD) to ensure unbiased allocation of treatments across the study. The experiment consisted of three factors; genotype type [clone PA150 and clone C85], compost ratio [90 kg soil (control), 90 kg raw compost, 81 kg soil amended with 9 kg compost, and 72 kg soil amended with 18 kg compost] and watering frequencies [2 or 3 times per week, with 20 litres of water]. In total, there were 16 treatments with three replicates for each. The seeds were sown in 12.5 x 15 cm polybags and raised for three months. Each replication of each treatment consisted of ten polybags. The seedlings were kept under 70 % overhead shade.

Following the compost preparation technique by Doungous et al. (2018), the compost was prepared on-station for 3 months. The content of moisture and temperature were periodically monitored. Using V8 juice agar medium, the in vitro detection test showed no growth of fungal spores in the compost. Prior to experimentation, all compost samples underwent a pasteurization treatment designed to substantially reduce the presence of viable microorganisms, particularly fungal spores. This procedure was essential for establishing a controlled experimental baseline, enabling the researchers to evaluate the potential detection and proliferation of *Phytophthora palmivora* under favourable conditions. To assess microbial presence post-pasteurization, aliquots of the treated compost were aseptically transferred onto sterile culture media for in vitro analysis. The absence of observable fungal growth indicated that the pasteurization process effectively eliminated viable fungal propagules under the test conditions. Additionally, to verify the presence or absence of *Phytophthora palmivora*, compost samples were cultured on V8 juice agar, a selective medium commonly used for isolating this pathogen. This step was crucial for ensuring that the compost remained free from *Phytophthora palmivora* contamination during the detection process.

Samples from the various growth substrata were collected and analysed at the Soil Research Institute Kwadaso Kumasi for their chemical properties (Table 2). Observations for *Phytophthora* Seedling Blight Disease (PSDB) incidence and determination of growth parameters and root architecture were done after four weeks of seedling emergence.

2.2 DETERMINATION OF *PHYTOPHTHORA* SEEDLING BLIGHT DISEASE INCIDENCE AND SEVERITY

The identification of *Phytophthora* Seedling Blight Disease (PSDB) was achieved through a combination of field-based symptom analysis and laboratory verification techniques. In the field, initial detection was guided by the presence of distinct, well-documented visual symptoms. These included basal stem lesions exhibiting a water-soaked appearance, progressive wilting, and extensive root decay features consistent with those described by Erwin and Ribeiro (1996).

To validate these field observations, laboratory procedures were employed, beginning with the isolation of the suspected pathogen. Infected plant tissues, particularly the root systems and basal stems, were carefully surface-sterilized and cultured on V8 juice agar, a selective medium commonly used for isolating *Phytophthora* species. The plates were incubated at 25 °C for a period ranging from three to five days. Post-incubation, fungal colonies exhibiting morphological traits typical of *Phytophthora*, such as coenocytic hyphae, as well as identifiable sporangia and oospores, were examined under a microscope and recorded for further analysis.

To establish the pathogenic potential and confirm the identity of the isolate, a detached leaf assay was conducted. In this bioassay, healthy leaves sourced from the same plant species were excised and positioned on moistened filter paper within sterile Petri dishes. Mycelial plugs obtained from the purified fungal cultures were then applied to the leaf surfaces. Within 72 hours of inoculation, symptoms resembling those observed in the field particularly water-soaked lesions began to manifest, thereby confirming the virulence and identity of the *Phytophthora* isolate.

Observations for *Phytophthora* Seedling Blight Disease (PSDB) incidence were done at four weeks after seedling emergence and at seven-day intervals for sixteen weeks. The disease incidence and severity were estimated as follows: Disease Incidence (DI) was calculated according to Madden et al. (2007) formula:

$$DI\ (\%) = \frac{Number\ of\ infected\ plants}{Total\ number\ of\ plants\ in\ the\ field} \times 100$$

Table 1: Modified Horsfall–Barrat rating scale of Phytopthora blight disease

DSI	Leaf area affected (%)
1	0
2	0-3
3	3-6
4	6-12
5	12-25
6	25-50
7	50-75
8	75-87
9	87-94
10	94-97
11	97-100
12	100

A modified Horsfall-Barrat rating scale of 1-12 (1 = 0 %. 12 = 100 % disease severity) was used to visually estimate the Disease Severity Index (DSI)

2.3 NUMBER OF DAYS TO REACH 50 % EMERGENCE AND GERMINATION RATE

The number of days that it took 50 % of the seeds to emerge from the media was counted for each replication in a treatment. Germination vigour was determined by counting seedlings that emerged per day from seats and for each treatment. Finally, the seed germination rate was estimated according to a formula by Maguire (1962):

$$T_{50} = RSG = \frac{N1}{D1} + \frac{N2}{D2} + \frac{N3}{D3} + \ldots + \frac{Nn}{Dn}$$

Where;
RSG = rate of seed germination, N1, N2, N3…
Nn = number of seedlings that emerged per day, D1, D2, D3…
Dn = days after sowing,

And will be calculated using:

$$T_{50} = t_i + \frac{\left(\left(\frac{N}{2}\right) - n_i\right)(t_j - t_i)}{n_j - n_i}$$

2.4 DETERMINATION OF GROWTH PARAMETERS

Growth performance parameters were measured after two weeks of emergence and it continued biweekly for three months:

(i) Plant height (cm): The height of 10 tagged seedlings was measured from the soil surface to the growing tip of the plant using a metre rule and it was measured in centimetres (cm).

(ii) Growth rate (cm): The rate at which the plants were growing was determined by assessing the difference in height at two-week intervals by using formulae; (S2-S1)/T where S1 represents the first measurement, S2 the second, and T equals the number of days between each.

(iii) Number of leaves: The number of leaves of 10 tagged plants per treatment per replication was counted and recorded. The average number of leaves was calculated for each replication. (iv) Leaf area (cm^2): The length and breadth of 3 randomly selected leaves in each of the 10 tagged plants were measured, and the product was multiplied by the leaf area factor of cocoa (0.75) in cm^2.

(v) Stem girth (mm): A vernier caliper was used to measure the girth of 10 tagged plants from 2 cm above the soil surface.

(vi) Shoot biomass (g): Six plants per treatment were randomly selected on the last day of the experiment. The shoots of the samples were oven-dried at 80 ^{0}C for 48 hours, and the weights recorded.

2.5 DETERMINATION OF ROOT ARCHITECTURE

(i) Taproot length (cm): On the final day of the experiment, three plants were randomly selected from each replicate for every treatment. The plants were carefully uprooted, and the length of the taproot was measured from the base of the stem to the tip using a meter rule.

(ii) Root length density: Three plants were randomly selected from each treatment replicate and uprooted at the end of the experiment. The roots were washed thoroughly to remove all soil. Clean roots were taken to the lab, where images were captured using a digital camera mounted on a tripod, positioned about 40 cm from the roots. The roots were suspended in water during imaging, and the camera was controlled with a remote shutter. The root images were analyzed using ImageJ software (www.imagej.nih.gov/ij) to determine the total root length. Root length density was then calculated using the formula: Root length density = Total root length / Soil volume.

2.6 STATISTICAL ANALYSIS

GenStat Discovery Edition 4 statistical package was used to analyse the data that was collected. The data were analysed using Analysis of Variance (ANOVA), and the Least Significant Difference (LSD) test was applied to

Table 2: Chemical properties of media of compost and compost-amended potted soils.

	Chemical properties			
Growth Medium	pH	N (%)	P (mg kg^{-1})	K ($cmol^{(+)}$ kg^{-1})
Soil	5.72	0.14	15.02	0.24
Raw Compost	7.90	0.45	23.27	7.89

identify significant differences at the 0.05 probability level.

3 RESULTS AND DISCUSSION

3.1 THE EFFECT OF COCOA POD HUSK-BASED COMPOST AND WATERING FREQUENCIES ON *PHYTOPHTHORA* SEEDLING BLIGHT DISEASE SUPPRESSION IN COCOA CLONES PA150 AND C85.

The PSBD incidence was higher and significant ($p <$ 0.05) in the soil alone relative to the compost-amended soils and the compost alone. The incidence was more prevalent in clone C85 (30 %) than in PA150 for all the treatments. Also, PSBD was more prevalent in the 3 times watering frequency (23.8 %) than 2 times watering. Least occurrence of PSBD was recorded in compost alone (0.63 %) for clone C85. Soil alone recorded the greatest occurrence of PSBD (22.44 %) for clone C85. However, there were no significant differences ($p > 0.05$) among the compost-amended soils and between the clones (Table 3). Disease scores on detached leaves collected from the cocoa seedlings showed significant ($p < 0.05$) differences in the level of disease suppression among the compost doses. The scores were significantly different among the treatments ($p < 0.05$). Clone C85 scored higher disease scores in all the treatments (Fig 1).

The compost-amended soil also was able to suppress the disease, with compost alone having the highest disease suppression capacity. Adequate compost amendment can suppress seedling diseases and also improve soil quality and seedling growth for cocoa seedling cultivation. Cocoa pod husks-based compost has the potential to disinfect reservoirs of *Phytophthora* and reduce the severity of the disease in cocoa cultivation (Doungous et al., 2018). Different watering frequencies affected diseased suppression. Three times watering per week was slightly higher than its counterparts under a two times watering frequency. According to Akrofi (2015), the disease tends to be more severe in plantations with high humidity and inadequate drainage.

Moreover, the disease incidence and severity were more prevalent in C85 than in PA150 clones in all the growth media and watering frequencies. The variety of cocoa being cultivated is important in disease protection. Adejumo (2004) reported that crop protection strategies for major diseases of cocoa are affected by the variety of cocoa being grown. Fungal disease in cocoa is found to vary from genotype to genotype (Ofori et al., 2022).

3.2 THE EFFECT OF COCOA POD HUSK-BASED COMPOST (CPHC) AND WATERING FREQUENCIES ON COCOA SEEDLING EMERGENCE AND GROWTH.

There was no statistically significant difference ($p > 0.05$) observed between the growth substrata and watering frequencies and their interactions for emergence percentage (Table 3). However, there were significant ($p < 0.05$) differences among the clones. The emergence rate was 1.051. Among the interaction effects, only the interaction between clones and watering frequencies had a significant influence on the emergence rate ($p <$ 0.05); all other interactions showed no significant effect ($p > 0.05$) (Table 3). The highest emergence rate of 1.195 was recorded for soil + 20 % compost under a 3 times watering frequency. Clone PA150 recorded a 9 % higher emergence rate (1.101) than C85 (1.001).

The high emergence rate and percentage of PA150 in CPHC can be attributed to the genetic factor of the clone. Clone PA150 might be strong and at ease with the conditions of the CPHC that lead to optimum emergence. The present findings also showed an increase in seedling emergence rate with compost-incorporated soils and 3 times watering per week. This increase in emergence rate could be attributed to improvement in nutrient availability, enhanced soil structure, and enhanced water retention (Bahrun et al., 2018). The increased content of nutrients and moisture consequently resulted in an increased emergence rate. Increased compost application can lead to a decreased emergence percentage regime per week may be attributed to the increased bulk density and limited aeration in the treatment. The right amount of compost is therefore needed to be applied to have good seedling emergence and growth. Marjenah et al. (2016) and Bahrun et al. (2018) have stated similar results in cocoa.

Table 3: Disease incidence (%) of Phytophthora seedling blight disease on the compost and compost-amended soils.

	Disease incidence (%) of *Phytophthora* seedling blight disease			
Treatment	2x watering		3x watering	
	Clone		Clone	
	C85	PA150	C85	PA150
Compost	0.63	0.41	1.46	0.83
Soil	19.50	12.60	22.44	14.90
Soil + [10 % Compost]	6.07	4.03	6.48	4.27
Soil + [20 % Compost]	4.16	2.70	5.26	3.40

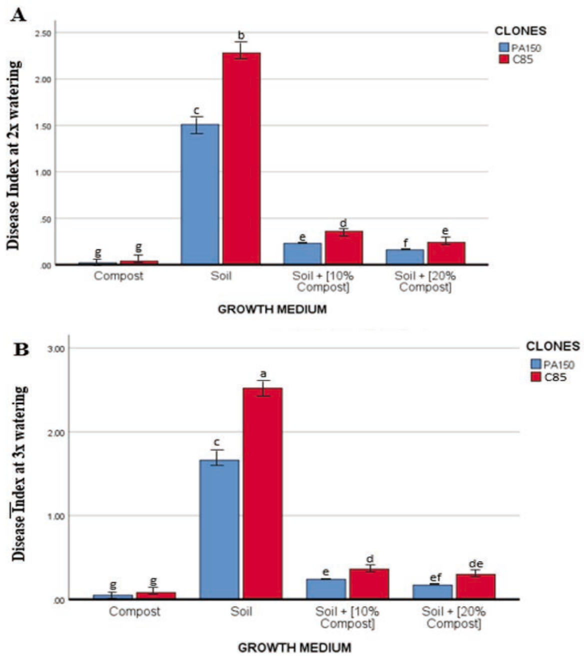

Fig. 1: (A = Disease index under 2x watering frequency; B = Disease index under 3x watering frequency) The effect of cocoa pod husk-based compost and watering frequencies on PSBD. The error bars indicate the standard error of the mean. Values within and between graphs A & B with bars of the same letters are not significantly different. The letters are indicating their homogeneity between the treatments.

Table 4: Effect of growth media, watering frequencies, seedling emergence.

Treatment	Mean value (p value)	
	Emergence parameters	
	Seed Emergence percentage	Emergence rate
Growth media	93.75ns	1.051 ns
Watering	92.95ns	1.050*
Clone	92.90 *	1.051*
Interactions		
Growth media x clone	92.10ns	1.051 ns
Growth media x watering	92.91ns	0.982 ns
Clone x watering	92.93ns	1.051 ns
Growth media x watering x clone	93.10ns	1.033 ns
CV %	10.7	16.1

p-value shows significant effects at the 5 % level ANOVA. ns, not significant. * Significant

3.3 GROWTH PERFORMANCE OF COCOA SEEDLINGS AS INFLUENCED BY GROWTH MEDIA AND WATERING FREQUENCIES.

Seedling height was significantly ($p < 0.05$) influenced by growth substrata, watering frequencies, and their interactions (Table 5). The clone C85 recorded higher seedling heights in all the substrata than Clone PA150. Also, plant heights were highest in soil amended with 20 % compost and 10 % compost under 3 watering frequencies (Table 5). There were notable differences ($p < 0.05$) observed in the growth substrata, watering frequencies, clone used, and their interactions for stem girth of the plants (Table 6). The seedlings' girth in compost were about 40 % thicker compared to the seedlings in soil. In several treatments, Clone PA150 recorded thicker stem girth than C85 for all the treatments although not significant ($p > 0.05$) (Table 5). Table 5 indicates that there were notable differences ($p < 0.05$) observed among the growth media for the number of leaves. The watering frequencies and clones and their interactions did not show notable differences ($p < 0.05$) among them for the number of leaves. The number of leaves increased as the amount of compost amendment and watering frequency were raised (Table 5). Tables 4 and 5 indicate a significant effect ($p < 0.05$) of cocoa pod husk compost, clone, and different watering frequencies on the leaf area of the cocoa seedlings. There were notable differences ($p < 0.05$) observed among all the treatments for shoot biomass except for the watering frequencies (Table 6).

There were notable differences ($p < 0.05$) observed among clones and growth media for root biomass. However, no significant ($p > 0.05$) effect was observed among the watering frequencies for root biomass (Table 5, Table 6).

The high mean growth and dry matter of the seedlings in compost-amended soils is a result of nutrient mineralization and availability through watering. Gruhn et al. (2000) reported that the use of compost maintains soil organic matter and increases microbial activities which promoting plant growth. The availability of nutrients such as nitrogen, phosphorus, and potassium from the compost is vital for plant growth and biomass and could have contributed to the significant growth of cocoa seedlings.

Also, the increased mean total dry matter for root and shoot in the compost-amended growth media may be due to the effect of the availability of nutrients to plants that promoted leaf growth for improved plant photosynthetic activity resulting in high dry matter accumulation. The results align with those reported by Ragagnin et al. (2013) who stated increased shoot dry matter and root dry matter with soybean compost fertilization. Quansah

Table 5: Mean values of growth determinants in different growth media and watering frequencies.

Treatment	Mean values						
2 times watering	Clones	Plant height (cm)	Stem girth (mm)	Leaf count	Leaf area (cm^2)	Root biomass (g)	Shoot biomass (g)
Compost	PA150	27.92d	1.56d	12.57b	130.27d	0.55cd	6.66cd
	C85	28.52d	1.58d	13.07b	129.19d	1.04bc	12.42bc
Soil	PA150	20.18e	1.12e	13.03b	92.06e	0.38d	4.64d
	C85	21.03e	1.17e	11.97b	93.36e	0.92bc	10.96c
Soil + 10 % compost	PA150	32.05c	1.78c	16.6ab	150.35b	0.66cd	8.7c
	C85	31.37c	1.74c	15.5ab	144.22c	1.1b	14.93b
Soil + 20% compost	PA150	34.12b	1.90b	15.43ab	174.12a	0.78bc	9.22c
	C85	34.51b	1.92b	16.77ab	144.71c	1.5a	21.1a
3 times watering Compost	PA150	28.17d	1.56d	14.47ab	136.65cd	0.6d	7.94cd
	C85	44.20a	2.46a	13.33b	130.39d	1.13bc	14.2b
Soil	PA150	21.76e	1.2e	14.13ab	94.55e	0.45d	5.06d
	C85	21.65e	1.2e	13.57b	93.80e	0.98cd	11.69bc
Soil + 10 % compost	PA150	31.91c	1.77c	15.23ab	158.76b	0.8c	8.99c
	C85	31.52c	1.75c	14.8ab	145.68bc	1.4b	17.99a
Soil + 20 % compost	PA150	35.21b	1.96b	17.50a	179.9a	0.93c	8.04c
	C85	34.74b	1.93b	16.13ab	155.45b	2.2a	18.93a

This means that the same letters in the column are not significantly different.

Table 6: p-values for the growth media, watering frequencies, and their interrelations on the growth of different cocoa clones.

Parameter	Growth media	Watering	Clone	GM × Clone	GM × Watering	Clone × Watering
Plant height	< 0.001	0.089	< 0.001	0.009	0.279	0.903
Stem girth	< 0.001	0.095	< 0.001	< 0.001	0.167	0.111
Leaf count	< 0.001	0.058	0.330	0.713	0.418	0.658
Leaf area	< 0.001	0.007	< 0.001	< 0.001	0.513	0.476
Root biomass	< 0.001	0.011	0.884	0.122	0.606	0.930
Shoot biomass	< 0.001	0.089	< 0.001	0.009	0.279	0.903

Treatment has a significant influence on the parameters at $p \leq 0.05$

(2021) found that the addition of 5 % compost to soil notably improved all plant growth parameters, except for root dry mass and root volume. Mensah (2021) reported that foliar amendments at the nursery increased cocoa seedling's stem diameter, number of leaves, plant height, and root and shoot mass. Both Sun et al. (2019) and Bass et al. (2016) observed a decline in seedling growth and biomass yield as biochar application rates increased. Similarly, Bahrun et al. (2018) found that cocoa seedling growth rates decreased when biochar was applied at rates exceeding 9 g of cocoa pod husk-based compost per 1 kg of soil. This reduction in growth may be attributed to significant changes in bulk density, increased soil moisture, and diminished soil aeration (Bahrun et al., 2018).

3.4 THE EFFECT OF COCOA POD HUSK-BASED COMPOST (CPHC) AND WATERING FREQUENCIES ON COCOA ROOT ARCHITECTURE.

Root architecture refers to the three-dimensional arrangement of roots within the soil, which is defined by factors such as root length density, diameter, length, and the development of root air spaces. This architecture plays a crucial role in how plants explore and utilize the soil for water and nutrient absorption, influencing overall plant growth and performance (Pandey and Bennet, 2019). The results of the root architecture are presented in Table 7, Fig 2, and Fig 3. Growth media and clone significantly ($p < 0.05$) impacted the root length and root density (Table 7). The root length and density increased with increased compost quantities in the soil. A root density of 0.06 cm cm^{-3} was recorded for clone PA150 in 10 % amended soil and 0.065 cm cm^{-3} in 20 % in amended soil under both 2 and 3 times watering frequency (Fig 2). The lowest root density of 0.05 cm cm^{-3} for clone PA150 was recorded in soil under the 3 times watering frequency, while the highest (11.88 cm) was recorded in 20 % compost-amended soil under the 3 times watering frequency (Fig 2). The lowest root density of 0.043 cm cm^{-3} for PA150 was recorded in soil alone under 2 times watering while the highest root length (5.2 cm) was in soil under 2 times watering (Fig 3).

Table 7: Average values of the effect of the growth substrata and the different watering frequencies on cocoa root architecture.

	Average value Root density (cm cm^{-3})	Average value Root length (cm)
Growth medium	0.0650*	7.67*
Clone	0.0652*	7.68*
Watering frequency	0.0650ns	7.68ns
Growth medium x clone	0.0653ns	7.65ns
Growth medium x watering frequency	0.0650ns	7.68ns
Clone x watering frequency	0.0652ns	7.67ns
Clone x watering frequency x clone	0.0652ns	7.68ns

* Treatment has a significant influence on the parameters at p ≤ 0.05. ns, not significant.

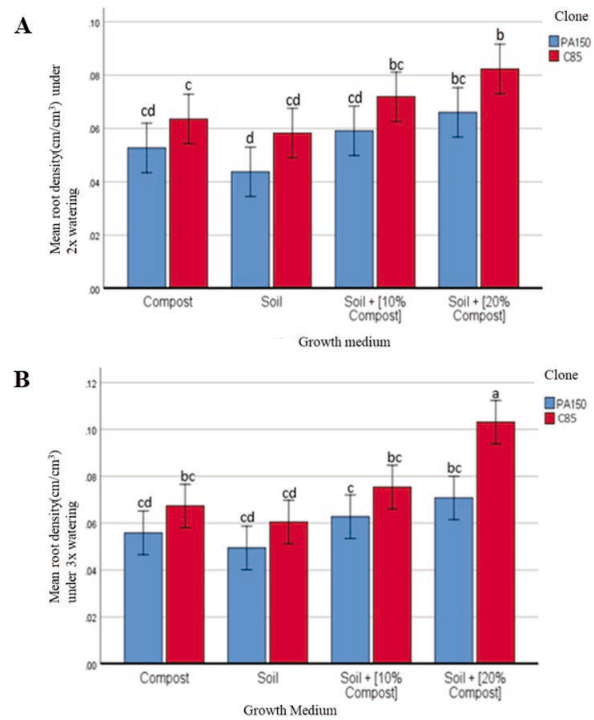

Fig. 2: Root density of cocoa due to CPHC and different watering frequencies. Values followed by the same letters on each bar are not significantly different at *p*-value < 0.05 LSD. The letters are indicating their homogeneity between the treatments.

The root system is essential for plant growth and development performing diverse roles including nutrient and water uptake, offering mechanical support, developing beneficial microbial association, and involving in the manufacturing of growth substances and hormones. (Smith and De Smet, 2012).

In this study, compost and compost-amended soils enhanced the rooting system of the cocoa plants, while soil alone showed poor root architecture. The use of compost as soil amendment improves the stability of soil aggregate in binding and retaining nutrients for plant use (Gruhn et al., 2000). The analysis of the chemical properties of the growth media showed an improvement in total nitrogen, phosphorus, and potassium in the compost.

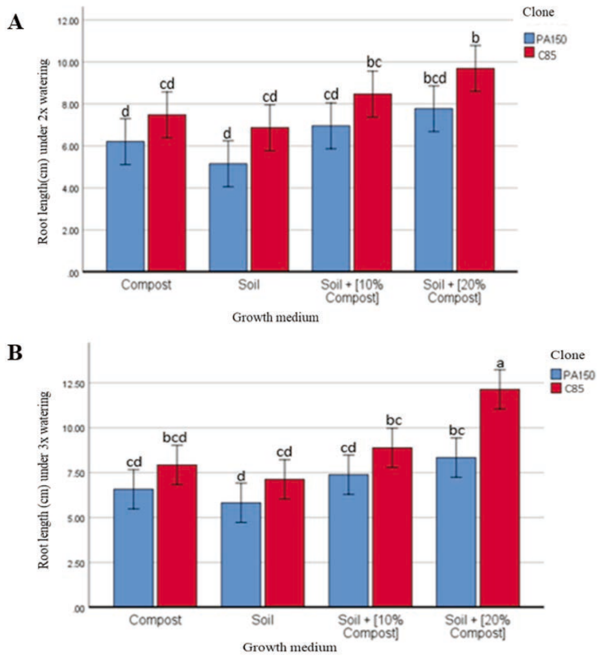

Fig. 3: Root length of cocoa due to CPHC and different watering frequencies. Values followed by the same letters on each bar are not significantly different at p-value < 0.05 LSD. The letters are indicating their homogeneity between the treatments.

These available nutrients may contribute to good development of the rooting system of the seedlings.

Increased watering frequency increased both root length and root density. Root length density is found to respond positively to the amount of water available for use in the soil (Kou et al, 2022). Root length and density increase the response to water sufficiency and vice versa. Also, the water uptake by roots is found to be proportional to root density (Zhang et al, 2020). Therefore, providing enough watering for cocoa seedlings is important to develop good root architecture for water uptake in deeper layers of the soil.

4 CONCLUSIONS AND RECOMMENDATIONS

The study concludes that the disease suppression level was higher in compost than in soil alone and varied with compost doses. The higher the amount of compost, the greater the suppression of PSBD. Moreover, increasing the number of times of watering per week increases the disease incidence. *Phytophthora* seedling blight disease was found to be more prevalent in cocoa clone C85 than in PA150. The comparison of PA150 and C85 indicates that C85 is optimal for better growth performance but more susceptible to *Phytophthora* seedling blight disease. The seedling height, stem girth, leaf count, leaf size, dry matter, and root architecture were all significantly affected by the incorporation of the cocoa pod husk-based compost.

The study suggests that incorporating 20 % compost amendment and watering seedlings three times per week can enhance soil quality and promote better growth in cocoa seedlings. Clone C85 should be selected for areas with low *Phytophthora* incidence, while clonePA150 should be considered in PSBD prevalent areas for its relative resistance. When using compost to suppress *Phytophthora* seedling blight disease, the frequency of watering should be reduced for effective results. Further investigations of the cocoa pod husk-based compost should be conducted on other crops especially crops that are inter-planted with cocoa and further research should be conducted on the same experimental sites to assess the residual effect of the compost on the subsequent raising of cocoa seedlings.

Data Availability

Data analysed during the study are included in this article.

Acknowledgment

I am deeply grateful to the seed production Division of Ghana Cocoa Board for the supply of the clones used in the research.

Conflicts of Interest

No conflicts of interest.

Financial support and sponsorship

None.

5 REFERENCES

Adejumo, T. O. (2004). Crop protection strategies for major diseases of cocoa, coffee, and cashew in Nigeria. *African Journal of Biotechnology*, *4*(2), 143–150. https://doi.org/10.5897/AJB2005.000-3029

Agele, S. O., & Agbona, A. I. (2008). Effects of cocoa pod husk amendment on soil and leaf chemical composition and growth of cashew (*Anacardium occidentale* L.) seedlings in the nursery. *American-Eurasian Journal of Sustainable Agriculture*, *2*(3), 219–224.

Akrofi, A. Y. (2015). *Phytophthora megakarya*: A review on its status as a pathogen on cacao in West Africa. *African Crop Science Journal*, *23*, 67–87. https://doi.org/10.4314/acsj.v23i1

Ayeni, L. S. (2008). Integrated application of cocoa pod ash and NPK fertilizer on soil chemical properties and yield of tomato. *American-Eurasian Journal of Sustainable Agriculture*, *2*(3), 333–336.

Bahrun, A., Fahimuddin, M. Y., & Rakian, T. C. (2018). Cocoa pod husk biochar reduces watering frequency and increases cocoa seedlings growth. *International Journal of Environment, Agriculture and Biotechnology*, *3*(5), 264–446. http://dx.doi.org/10.22161/ijeab/3.5.9

Bass, A. M., Bird, M. I., Kay, G., & Muirhead, B. (2016). Soil properties, greenhouse gas emissions and crop yield under compost, biochar, and co-composted biochar in two tropical agronomic systems. *Science of the Total Environment*, *550*, 459–470. https://doi.org/10.1016/j.scitotenv.2016.01.143

Doungous, O., Minyaka, E., Longue, E. A. M., & Nkengafac, N. J. (2018). Potentials of cocoa pod husk-based compost on *Phytophthora* pod rot disease suppression, soil fertility, and *Theobroma cacao* L. growth. *Environmental Science and Pollution Research International*, *25*(25), 25327–25335. https://doi.org/10.1007/s11356-018-2591-0

Fidelis, C., & Rajashekhar Rao, B. K. (2017). Enriched cocoa pod composts and their fertilizing effects on hybrid cocoa seedlings. *International Journal of Recycling of Organic Waste in Agriculture*, *6*, 99–106. https://doi.org/10.1007/s40093-017-0156-8

Gregory, P. H., & Maddison, A. C. (1981). Epidemiology of *Phytophthora* on cocoa in Nigeria. *Phytopathological Paper*, *25*, 23–26. https://librarysearch.adelaide.edu.au/discovery/fulldisplay/alma9911103101811/61ADELAIDE_INST:UOFA

Gruhn, P., Golleti, F., & Yudelman, M. (2000). *Integrated nutrient management, soil fertility and sustainable agriculture: Current issues and future challenges*. Washington, D.C. http://hdl.handle.net/10919/65343

Guest, D. (2007). Black pod: Diverse pathogens with a global impact on cocoa yield. *Phytopathology*, *97*, 1650–1653. https://doi.org/10.1094/phyto-97-12-1650

Kou, X., Han, W., & Kang, J. (2022). Responses of root system architecture to water stress at multiple levels: A meta-analysis of trials under controlled conditions. *Plant Abiotic Stress*, *13*. https://doi.org/10.3389/fpls.2022.1085409

Marjenah, M., Kiswanto, K., Purwanti, S., & Sofyan, F. P. M. (2016). The effect of biochar, cocopeat and sawdust compost on the growth of two dipterocarps seedlings. *Nusantara Bioscience*, *8*(1). https://doi.org/10.13057/nusbiosci/n080108

Mensah, A. D. (2021). Growth of cocoa seedlings with soil and foliar amendments at the nursery in Akim Tafo in the Eastern Region of Ghana. *University of Cape Coast*. https://ir.ucc.edu.gh/xmlui

Odedina, S. A., Ojeniyi, S. O., & Awodun, M. A. (2007). Effect of agro-industrial wastes on nutrient status and performance of tomato. *Global Journal of Environmental Research*, *1*, 18–21.

Ofori, A., Padi, F. K., & Ameyaw, G. A. (2022). Field evaluation of the impact of cocoa swollen shoot virus disease infection on yield traits of different cocoa (*Theobroma cacao* L.) clones in Ghana. *PLOS ONE*, *17*(1), e0262461. http://doi.org/10.1371/journal.pone.0262461

Ofori-Frimpong, K., Afrifa, A. A., & Acquaye, S. (2010). Relative efficacy of cocoa pod husk-based compost on growth and nutrient uptake of cocoa seedlings in the nursery. *Ghana Journal of Agricultural Science*, *43*(1), 55–59.

Opoku-Ameyaw, K., Baah, F., Gyedu-Akoto, E., & Anchirinah, V. (2010). *Cocoa manual: A source book on cocoa production* (1st ed.). Cocoa Research Institute of Ghana, Akim-Tafo, 14–19. https://www.researchgate.net/publication/283018115

Pandit, N. R., Mulder, J., Hale, S., Martinsen, V., Schmidt, H. J., & Cornelissen, G. (2018). Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low input Nepalese soil. *Science of the Total Environment*, *625*, 1380–1388. http://dx.doi.org/10.1016/j.scitotenv.2018.01.022

Quansah, E. (2021). The quality of cocoa pod husk biochar produced with the "Kon-Tiki" kiln technology, and its effect as a soil enhancer on the growth rate of cocoa seedlings. *Norwegian University of Life Sciences*, 57p. https://hdl.handle.net/10568/121038

Ragagnin, V. A., Sena Júnior, D. G. de, Dias, D. S., Braga, W. F., & Nogueira, P. D. M. (2013). Growth and nodulation of soybean plants fertilized with poultry litter. *Ciência e Agrotecnologia*, *37*(1), 17–24. http://dx.doi.org/10.1590/S1413-70542013000100002

Ristaino, J. B., & Gumpertz, M. L. (2000). New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. *Annual Review of Phytopathology*, *38*, 541–576. http://dx.doi.org/10.1146/annurev.phyto.38.1.541

Smith, S., & De Smet, I. (2012). Root system architecture: Insights from *Arabidopsis* and cereal crops. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1595), 1441–1452. https://doi.org/10.1098/rstb.2011.0234

Sun, H., Shi, W., Zhou, M., Ma, X., & Zhang, H. (2019). Effect of biochar on nitrogen use efficiency, grain yield and amino acid content of wheat cultivated on saline soil. *Plant, Soil and Environment*, *65*(2), 83–89. https://doi.org/10.17221/525/2018-PSE

Zhang, X. X., Whalley, P. A., Ashton, R. W., Evans, J., Hawkesford, M. J., Griffiths, S., Huang, Z. D., Zhou, H., Mooney, S. J., & Whalley, W. R. (2020). A comparison between water uptake and root length density in winter wheat: Effects of root density and rhizosphere properties. *Plant and Soil*, *451*(1), 345–356. https://doi.org/10.1007/s11104-020-04530-3