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Effect of composting time of *Tithonia diversifolia* biomass on the physicochemical quality of the compost produced and on the growth of *Terminalia superba* (Engler and Diels) forest seedlings in a nursery

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ABSTRACT: Background: Faced with the disappearance and degradation of forests, and with them certain highly prized species of wood, the State of Côte d'Ivoire has taken several measures through a forest reforestation policy to achieve the goal of 20% forest cover by 2030. In this process, *Terminalia superba* is one of the main tree species to be reforested. Aims: The study aims to develop vigorous *Terminalia superba* seedlings in nurseries using Tithonia diversifolia-based substrates for reforestation in real environments. Place and duration of study: The study was conducted between October 2022 and May 2023 during the rainy season on one of the experimental plots of the Regional Directorate of Water and Forests of Duekoué, in the Guémon region, in western Côte d'Ivoire. Methodology: The methodology involved creating a nursery using a Fisher 4-block design. Each block comprises five basic plots in which 12 polyethylene bags containing different substrates are distributed (Tem = blank forest control; Tet = forest control with fresh *Tithonia diversifolia*; Cot1m = 1-month-old *Tithonia diversifolia* compost; Cot2m = 2-month-old *Tithonia diversifolia* compost; Cot3m = *Tithonia diversifolia* compost aged 3 months. In each bag, *Terminalia superba* seeds with high germination capacity were selected and sown directly at a rate of 2 seeds each, then watered. The parameters measured included physico-chemical analysis of Tithonia diversifolia compost and growth parameters of *Terminalia superba*. Results: The results showed that the substrates are porous (total porosity > 50%; aeration porosity > 20% and retention porosity > 30%), have low acidity (6 <pH <8) and are very rich in nutrients (1180<N(mg/g) <2840; 2212<P(mg/g) <9540; 3421<K(mg/g) <15240; 357<Ca(mg/g) <440; 63<Mg(mg/g) <226; 2514<CE (mg/g) <5252; 0.02<Sat(%)<0.26). They induced a germination rate of up to 70% and significantly affected the growth parameters of *Terminalia superba* seedlings, with the best averages for collar diameter (35 to 37 cm), height (34.50 to 43.40 cm), leaf length (7.10 to 8.54 cm), leaf width (3.32 to 4.90 cm), and robustness ratio up to 6.53 after 14 weeks of sowing, especially for 2- to 3-month-old composts. Conclusion: It is noted that composted substrates based on *Tithonia diversifolia* after 2 to 3 months could be a promising alternative to traditional forest soil for producing vigorous nursery plants.

Keywords: *Tithonia diversifolia compost, Terminalia superba seedling production, Reforestation in Côte d'Ivoire*

INTRODUCTION

Due to its geographic location, Côte d'Ivoire encompasses several forest ecoregions, making it one of the most biologically diverse regions in the world and home to numerous endemic animal and plant species (PIF Côte d'Ivoire, 2016). At the beginning of the 20th century, Côte d'Ivoire's dense rainforest covered an estimated 14.9 million hectares (Chevalier, 1909). By the mid-2000s, Côte d'Ivoire's forest area had fallen from 7.85 million hectares in 1986 to 5.09 million hectares and less than 3.6 million hectares in 2015 (SEP-REDD+ and FAO, 2017). This increased deforestation is the result of a choice to focus on agriculture-based economic development since the country gained independence. Today, it is estimated that forests in Côte d'Ivoire cover an area of 2.97 million hectares, including 2.88 million hectares of natural forests and 92,340 hectares of reforested areas (Cuny et al, 2023). Faced with the disappearance and degradation of forests, the State of Côte d'Ivoire has taken several measures through a reforestation policy to achieve a 20% forest cover by 2030, i.e., more than 300,000 hectares of reforested land per year (SNPREF, 2019). This reforestation can only be achieved if there is sufficient capacity to produce high-quality seedlings in large quantities. However, producing forest seedlings requires abundant forest soil, access to which is becoming increasingly difficult. In addition, a mineral substrate is generally used, whose physical and chemical characteristics not only negatively impact plant development but also make forest soil a source of pathogens that adversely affect the growth of nursery-grown plants and their effectiveness in reforestation operations (Lamhamedi, 1997). To remedy this problem, compost is currently being used as an alternative to forest soil in the preparation of growing media. Composting promotes biological decomposition and stabilization of organic matter (Stofella & Kahn, 2001). The transformation of forestry and agricultural residues into compost has produced excellent results in creating substrates for the production of young plants in horticultural and forest nurseries (Rose et al., 1995; Fitzpatrick, 2001).

2. METHODOLOGY

2-1. Study area

The study was conducted from October 2022 to May 2023, during the heavy rainy season, on one of the experimental plots of the Regional Directorate of Water and Forests of Duekoué, the capital of the Guémon region, in western Côte d'Ivoire (Figure 1). The climate in the Duekoué area is sub-equatorial, mountainous, characterized by annual rainfall of 1,600-2,000 mm and an average annual temperature of around 25°C (Kouassi et al., 2012). The vegetation, consisting of dense rainforests interspersed with grasslands (Brou, 2005), is undergoing deforestation, making the Duekoué area the new "cocoa belt" of Côte d'Ivoire (Brou, 2005). The soils are ferralsoils with medium fertility and cover a large area suitable for agricultural development (Amani et al., 2012).

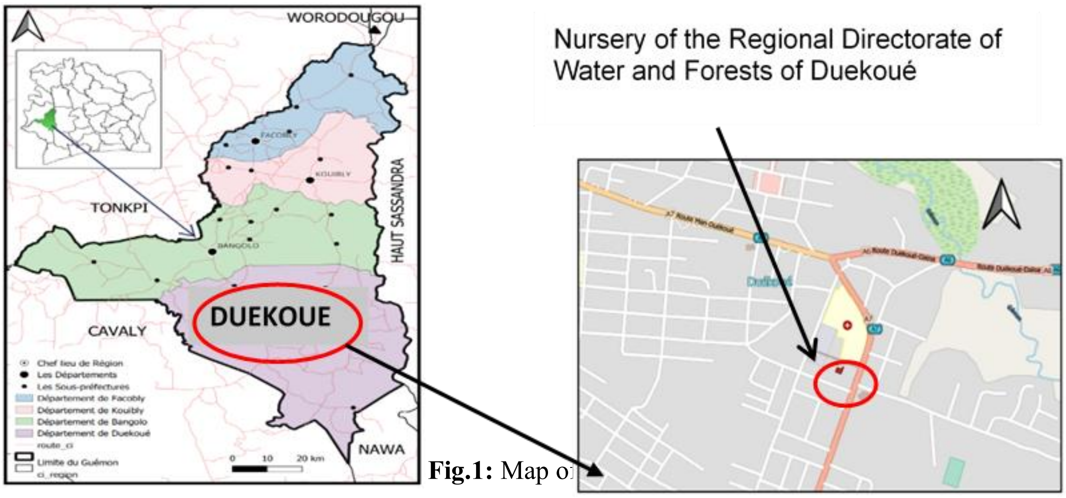

Fig.1: Map o

2-2. Plant material

It consists of *Terminalia superba* seeds (Figure 2A) supplied by the Société de Développement des Forêts (SODEFOR) of Côte d'Ivoire and *Tithonia diversifolia* biomass (Figure 2B) collected from one of the fallow fields in the area. The *Terminalia superba* plant is highly prized for its various uses, particularly in paper production, carpentry, and cabinetmaking (Orwa, 2009), as well as for medicinal purposes (Idu et al., 2010; Akoegninou et al., 2006). In the reforestation process, Côte d'Ivoire uses *Terminalia superba* as one of its main forest species. As for the use of fresh biomass from *Tithonia diversifolia*, which grows on fallow land or sunny open spaces along roadsides (Muoghalu et al., 2005), its value lies in its biofertilizing properties. The choice of this plant is justified by the fact that it is characterized by high nitrogen productivity and therefore its ability to fertilize and improve soil fertility (Pypers et al., 2005). It is locally available and enhances the soil's nutritional potential by providing plants with physically available nutrients for growth, development, and production. The seed of *Terminalia superba* is the main forest species to be developed, while *Tithonia diversifolia* is used as a basic fertilizing substrate for the nursery.

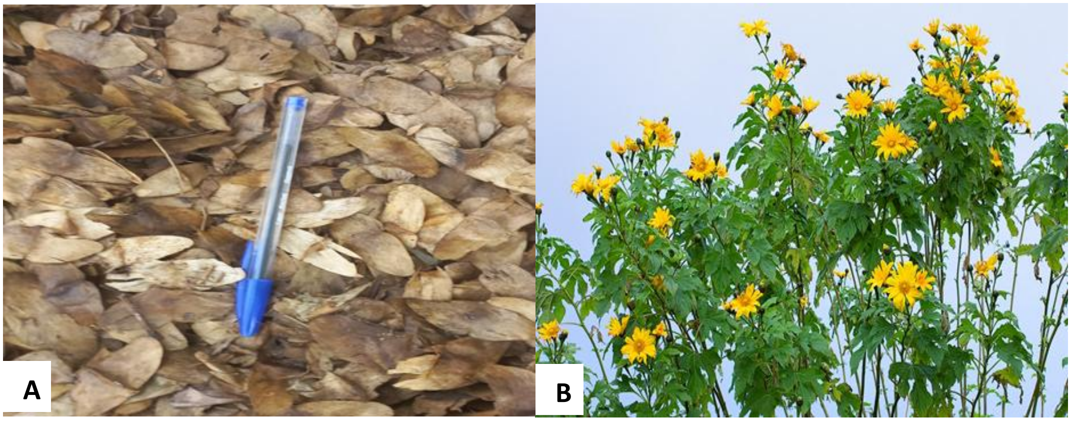

Fig. 2: (A): *Terminalia superba* seed and (B): *Tithonia diversifolia* biomass

2-3. Collection and composting process for fresh *Tithonia diversifolia* biomass

Fresh *Tithonia diversifolia* biomass was harvested from fallow land surrounding the town of Duekoué, cut into pieces, and divided into three 20 kg piles of *Tithonia diversifolia* biomass to be composted at different times (T1 = 1 month, T2 = 2 months, and T3 = 3 months) compared to a control without composting or simply forest soil taken from the experimental site. The composting technique used was aerobic composting in piles or windrows. The piles were 3.5 m x 0.6 m x 0.3 m in size, with a volume of 0.63 m3 per pile. After the piles were made, wood ash was added to accelerate the biological activity of microorganisms, and the piles were covered with black plastic sheeting to retain moisture and heat. Every three days, they were watered and turned until maturity, when the compost was collected and dried in the open air for laboratory analysis.

2-4. Experimental setup and sowing of *Terminalia superba* seeds in a nursery

After clearing an 80 m2 fallow plot and removing plant debris, the nursery was set up in a four-block Fisher system held together by a 1.5 m aisle. Each block comprises five 5m × 3m plots, spaced 1m apart, in which 12 polyethylene bags measuring 25cm x 15m containing the different treatments or substrates are distributed: Tem = Blank control or forest soil; Tet = Control or forest soil with fresh *Tithonia diversifolia*; Cot1m = 1-month-old *Tithonia diversifolia* compost; Cot2m = 2-month-old *Tithonia diversifolia* compost; Cot3m = 3-month-old *Tithonia diversifolia* compost. Before sowing, a germination test was carried out by immersing *Terminalia superba* seeds in tap water at room temperature for 24 hours. At the same time, the polyethylene bags filled with the different substrates were lightly watered to ensure optimal conditions for seed germination. Seeds with good germination potential were selected for direct sowing in each bag at a rate of 2 *Terminalia superba* seeds, to a depth of 2 to 3 cm, then the bags were closed and watered. The polyethylene bags were placed vertically under 0.5 m high shade structures. The plots were labeled with the block and type of substrate specified. Maintenance and care of the seedlings consisted mainly of daily watering in the evening, weed removal as needed, and thinning after germination. No plant protection products were applied during the experiment.

2-5. Data collection

2-5-1. Laboratory analysis of Tithonia diversifolia compost

For laboratory analysis, 1 kg of *Tithonia diversifolia* compost was collected at each composting period, dried, and evaluated to determine its initial fertility status. The analyses were carried out at the Laboratory of the Oceanological Research Center (ORC) in Abidjan, Côte d'Ivoire, and focused on:

-The total porosity (Pt), aeration (Pa), and retention (Pr) of each substrate after the composting period were determined using the standard porosity test developed by Bembli & M'Sadak (2017), where:

-Total porosity (Pt): Pt (%) = (VA/VT) x 100 ***(1)***

- Aeration porosity (Pa): Pa (%) = (VR/VT) x 100 ***(2)***

-Retention porosity (Pr): Pr (%) = Pt - Pa ***(3)***

where: VT: Total volume (mL); VA: Pore volume (mL): VR: Gas phase volume (mL).

- pH measurement using the electronic glass pH meter method in a soil/solution ratio of 1/2.5 (Diack & Loum 2014). The principle is to immerse the glass electrode of the pH meter in the soil mixture and read the pH value directly from the pH meter dial after stabilization.

- Determination of total nitrogen content using the modified Kjeldahl method (Murphy & Riley, 1962). The principle consists of converting organic nitrogen compounds into ammonium sulfate $SO_4(NH_4)_2$ in an acidic environment, in the presence of concentrated sulfuric acid (H_2SO_2), at high temperature, and a mixture of catalysts (K_2SO_4 and $CuSO_4$). The ammonia thus formed is displaced from its compounds by concentrated sodium hydroxide (NaOH), distilled by steam stripping, collected in a boric acid (H_3BO_3) solution, and titrated with sulfuric acid.

Determination of the assimilable phosphorus content using the Olsen-Dabin method described by Olsen & Sommers (1982). The assimilable phosphorus in the soil is extracted using a sodium bicarbonate solution (NaHCO3; 0.5N), pH 8.5, on an autoanalyzer, by measuring the intensity of the blue phosphomolybdic complex.
- Exchangeable bases (Ca++, Mg++, and K+) are determined by atomic absorption spectrophotometry and K+ by flame photometry in the percolate, as are trace metal elements (Zn++ and Fe++).

2-5-2. Germination parameters of Terminalia superba seeds
The seed germination parameters determined were seed dormancy, germination time, and germination rate. These parameters were determined using the following calculation methods:
- Dormancy (in days) = Date of first germination - Date of sowing ***(4)***
- Germination time (days) = Date of last germination - Date of first germination ***(5)***
- Germination rate (%) = (Number of germinated plants /Total number of seeds sown) x100 ***(6)***

2-5-3. Seedling growth parameters
During the growth of *Terminalia superba* seedlings, the following parameters were measured:
-diameter at the collar using an electronic caliper;
-height of the plants, length and width of the third leaf emerging on the plant using a tape measure;
-robustness ratio (cm/mm) by dividing the height by the diameter at the collar

2-6. Statistical analysis
To compare the different treatments, R software version 4.3.2 was used for analysis of variance (ANOVA). Tukey's multiple-comparison test was used to classify the treatments into homogeneous groups at a 5% significance level (P-value). Thus, significance is expressed when the P-value is less than 0.05.

3. RESULTS AND DISCUSSION

3-1. Results
3-1-1. Physicochemical quality of substrates
3-1-1-1. Porosity of the substrates studied
Porosity parameters varied across substrates (Table 1). For total porosity, the Cot1m, Cot2m, and Cot3m substrates had the highest total porosity (Pt) values (Pt ≥ 50%) compared to the controls, which recorded low total porosities (Pt ≤ 50%) with the blank control (Tem = 36.42%) and the *Tithonia diversifolia* control (Tet = 44.99%). In terms of aeration porosity, the highest values were obtained by the Cot1m (29.51%), Cot2m (28.72%), Tet (18.48%), Cot3m (14.80%) and Tem (11.80%) substrates, in descending order. Retention porosity also varied, with the lowest values for the control (24.53%), the control with *Tithonia diversifolia* (26.51%), Cot1m (25.89%), Cot2m (27.81%) and Cot3m (35.84%) in ascending order of values relative to the standard.

Table 1: Porosity rates of substrates

Porosity Parameters (%)	Substrates					Porosity standard (%)
	Tem	Tet	Cot1m	Cot2m	Cot3m	
Total porosity	36.42	44.99	56.40	51.53	50.64	50
Aeration porosity	11.89	18.48	29.51	28.72	14.80	20
Retention porosity	24.53	26.51	26.89	27.81	35.84	30

Tem = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia*

3-1-1-2. Chemical content of substrates
Analysis of the chemical content of the substrates showed a pH ranging from 6.51 for the blank control to 8.25 for the Tithonia diversifolia compost after three months of composting. Specifically, the Cot1m, Cot2m, and Cot3m recorded basic acidity of 8.77 for Cot1m, 8.02 for Cot2m, and 8.25 for Cot3m, compared to low acidity for the controls (Tem = 6.51) and almost neutral for the

Tithonia diversifolia control (Tet = 6.90), as shown in Table 2. The Cot1m, Cot3m, and Cot2m substrates have the highest electrical conductivity (EC) values in descending order: Cot1m = 5252, Cot3m = 3414, and Cot2m = 3209 µs/cm, compared to the other substrates. The lowest conductivity value is found in the control substrate (Tem = 661 µs/cm). The substrates containing Tithonia diversifolia recorded the highest conductivity. This observation applies to the values for iron (Fe), magnesium (Mg), potassium (K), and phosphorus (P). Nitrogen (N), calcium (Ca), and zinc (Zn) had intermediate values.

Table 2: Chemical content of different composts

Substrates	**Nutrient content of compost produced**									
	pH	**N (mg/Kg)**	**P (mg/Kg)**	**K (mg/Kg)**	**Ca (mg/Kg)**	**Mg (mg/Kg)**	**Zn (mg/Kg)**	**Fe (mg/Kg)**	**CE (µs/cm)**	**Sal (%)**
Tem	6.51	1020	2310	231	132	78	63	23	661	0.03
Tet	6.90	2210	2212	3421	423	63	23	38	2514	0.12
Cot1m	8.77	2610	6060	15240	357	162	54	207	5252	0.26
Cot2m	8.02	2840	2940	11340	440	226	70	272	3209	0.16
Cot3m	8.25	1180	9540	12530	360	139	35	139	3414	0.17

Tem = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia*

3-1-2. Effect of different substrates on the germination of *Terminalia superba* seeds

The germination parameters of *Terminalia superba* seeds evaluated across substrates are presented in Table 3. It should be noted that dormancy, which is the germination waiting period or latency period (in days) between the sowing date and the date of the first germination, is shorter for Cot2m (10 days) and Cot3m (10 days), while Cot1m (12 days) and Tem (12 days) recorded the longest dormancy period, with Cot1m (11days) recording an intermediate dormancy period. Furthermore, the germination time (in days), i.e., the time between the first and last seeds to germinate, is identical at 31 days for Tem, Tet, and Cot1m, whereas Cot2m and Cot3m show 30 days, one day less than Tem, Tet, and Cot1m, respectively.

The germination rate was very high for Cot2m (76%) and Cot3m (74%), high for Cot1m (62%) and Tet (61%), and finally average for Tem (50%).

Table 3: Germination of *Terminalia superba* seeds according to substrate germination parameters

	Substrates				
Germination parameters	**Tem**	**Tet**	**Cot1m**	**Cot2m**	**Cot3m**
Dormancy (days)	12	11	12	10	10
Germination time (days)	31	31	31	30	30
Germination rate (%)	50	61	62	76	74

Tem = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia*

3-1-3. Effect of different substrates on the growth of *Terminalia superba* seedlings

3-1-3-1. Collar diameter of seedlings

The collar diameter of *Terminalia superba* seedlings was significantly affected ($p<0.05$) by the different substrates, regardless of composting time, with values ranging from 0.24 cm (Tet) to 0.54 cm (Cot3m) on average after 14 weeks of sowing, compared to 0.15 cm for the control (Table 4). However, the Cot2m (0.37 cm), Cot3m (0.35 cm), and Cot1m (0.32 cm) substrates promoted an increase in the collar diameter of Terminalia superba plants, in descending order, more effectively than Tet compost (0.24 cm). The *Tithomia diversifolia* compost substrate composted after 2 weeks (Cot2m = 0.37 cm) significantly impacted the collar diameter of Terminalia superba plants more than the other composting times after 14 days of sowing.

Table 4: Effect of *Tithonia diversifolia* composting time on the collar diameter of *Terminalia superba* plants

Substrates	Average collar diameters (cm)				
	6 Week.AS	**8 Week.AS**	**10 Week.AS**	**12 Week.AS**	**14 Week.AS**
Tem	0.9±0.01c	0.10±0.02c	0.12±0.04c	0.13±0.06c	0.15±0.09c
Tet	0.14±0.02b	0.16±0.02b	0.19±0.04b	0.20±0.05b	0.24±0.07b
Cot1m	0.18±0.01a	0.21±0.02a	0.25±0.04a	0.29±0.06a	0.32±0.09a
Cot2m	0.18±0.02a	0.22±0.05a	0.27±0.08a	0.32±0.10a	0.37±0.14a
Cot3m	0.18±0.01a	0.20±0.02a	0.24±0.04a	0.30±0.06a	0.35±0.05a
P-value	<0.00049	<0.00039	<0.00054	<0.00025	<0.0032

Values followed by the same letter in each column are statistically identical at the 5% threshold **Tem** = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia ; **Week.AS** :* week after sowing

3-1-3-2. Plant height

No significant difference (p >0.05) in the height of *Terminalia superba* plants was observed until the eighth week after sowing for all substrates (Table 5). However, between the 10th and 14th day after sowing, the height of Terminalia superba seedlings was significantly affected (p<0.05) by the substrates, with values ranging from 12.80 (Tem at 10 weeks.AS) to 43.40 cm (Cot2m to 14 weeks.AS) on average (Table 5). More specifically, on the 14th day after sowing, the size of *Terminalia superba* plants was greater with the Cot2m (43.40 cm) and Cot3m (34.50 cm) substrates, while the Cot1m (22.10 cm) and Tet (17.10 cm) substrates showed intermediate values compared to the blank control.

Table 5: Effect of *Tithonia diversifolia* composting time on the height of Terminalia superba plants

Substrates	Average plant heights (cm)				
	6 Week.AS	**8 Week.AS**	**10 Week.AS**	**12 Week.AS**	**14 Week.AS**
Tem	9.30±1.17a	10.00±1.68a	10.90±2.15c	11.70±1.95c	12.10±3.47c
Tet	9.48±0.21a	11.00±0.34a	12.80±0.50b	14.50±1.22b	17.10±1.48b
Cot1m	9.52±0.27a	11.80±0.44a	13.20±0.57b	15.70±1.27b	22.10±1.08ab
Cot2m	10.80±0.44a	12.14±0.59a	22.90±0.89a	35.00±1.80a	43.40±2.33a
Cot3m	10.66±0.22a	11.70±0.75a	20.24±0.77a	29.76±0.43a	34.50±0.61a
P-value	0.1057	0.1322	<0.00021	<0.00057	<0.00049

Values followed by the same letter in each column are statistically identical at the 5% threshold **Tem** = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia ; **Week.AS** :* week after sowing

3-1-3-3. Length of the third emerged leaf on Terminalia superba seedlings

Table 6 shows that the length of the third emerged leaf on *Terminalia superba* seedlings was significantly affected (p<0.05) by the substrates only between the 10th and 14th day after sowing and varied between 5 cm (Tet at 10 days after sowing) and 8.54 cm (Cot3m at 14 days after sowing). More specifically, on the 14th day after sowing, the length of Terminalia superba plants was greater with the Cot3m (8.54 cm) and Cot3m (7.10 cm) substrates, while the Cot1m (6.98 cm) and Tet (6.20 cm) substrates showed intermediate values compared to the blank control (5 cm).

Table 6 Effect of *Tithonia diversifolia* composting time on the length of the 3rd width of the third emerged leaf on *Terminalia superba* seedlings.

Substrates	Width of the third leaf of the plant (cm)				
	6 Week.AS	**8 Week.AS**	**10 Week.AS**	**12 Week.AS**	**14 Week.AS**
Tem	0.94±0.29b	1.20±0.72b	1.22±0.77c	1.88±1.17c	2.01±1.25c
Tet	1.10±0.22a	1.26±0.26ab	1.65±0.15b	1.90±0.17b	2.96±0.59ab
Cot1m	1.36±0.22a	2.00±0.26a	2.36±0.36b	2.96±0.17b	3.00±0.59b
Cot2m	1.88±0.22a	2.00±0.38a	2.70±0.41a	3.04±0.48ab	3.32±0.38b
Cot3m	2.16±0.26a	2.99±0.44a	3.90±1.04a	4.40±1.08a	4.90±0.80a
P-value	<0.0001	<0.0012	<0.0001	<0.0018	<0.0002

Values followed by the same letter in each column are statistically identical at the 5% threshold **Tem** = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia ; **Week.AS** :* week after sowing

Table 7: Effect of *Tithonia diversifolia* composting time on the width of the third leaf of Terminalia superba seedlings

Substrates	Length of the third leaf of the plant (cm)				
	6 Week.AS	**8 Week.AS**	**10 Week.AS**	**12 Week.AS**	**14 Week.AS**
Tem	3.40±0.65a	4.64±1.08a	4.70±1.15c	4.96±1.93c	5.00±1.60c
Tet	3.60±0.96a	4.88±0.26a	5.00±0.42b	5.40±0.42b	6.20±0.57b
Cot1m	3.60±0.96a	4.88±0.26a	5.10±0.42b	5.90±0.42ab	6.98±0.57ab
Cot2m	3.90±0.65a	5.02±0.74a	6.00±0.44a	6.86±0.65a	7.10±0.65a
Cot3m	3.68±0.41a	5.08±1.06a	6.12±1.69a	7.70±1.99ba	8.54±1.68a
P-value	0.1695	0.1132	<0.00111	<0.00201	<0.0055

Values followed by the same letter in each column are statistically identical at the 5% threshold **Tem** = Blank control; **Tet**: Control with *Tithonia diversifolia*; **Cot1m**: 1-month-old compost with *Tithonia diversifolia*; **Cot2m:** 2-month-old compost with *Tithonia diversifolia*; **Cot3m**: 3-month-old compost with *Tithonia diversifolia; **Week.AS** :* week after sowing

3-1-3-4. Width of the third emerged leaf on Terminalia superba plants

The width of the third emerged leaf on Terminalia superba seedlings was significantly affected ($p<0.05$) by the different substrates, regardless of composting time, with values ranging from 2. 96 cm (Tet) and 4.90 cm (Cot3m) on average after 14 weeks of sowing, compared to 2.01 cm for the control (Table 7). However, the Cot3m (4.90 cm), Cot2m (3.32 cm), and Cot1m (3.00 cm) substrates promoted the expansion of the third emerged leaf of Terminalia superba seedlings in descending order more effectively than the Tet compost (0.96 cm). The Tithomia diversifolia compost substrate composted after 3 weeks (Cot3m = 4.90 cm) significantly affected the width of Terminalia superba plants, whereas composting times after 14 days of sowing did not.

3-1-3-5. Robustness ratio of Terminalia superba seedlings

The robustness ratio of Terminalia superba seedlings in each substrate ranged from 5.22 cm/mm (Cot1cm) to 6.53 cm/mm (Tet) after 14 weeks of sowing (Figure 3). The minimum value of 5.22 cm/mm was recorded in the Cot1m substrate and the maximum value of 6.53 cm/mm in the Tet substrate.

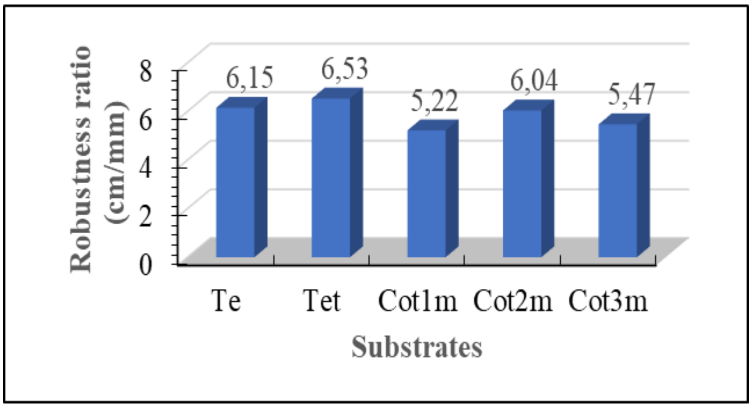

Fig. 3: Robustness ratio of *Terminalia superba* plants

3-2. DISCUSSION

3-2-1. Physicochemical properties of substrates

Regarding the physicochemical quality of Tithonia diversifolia-based substrates, laboratory analysis indicates they are highly porous. This provides them with good capacity for root growth and for the circulation of water, air, and nutrients for plant development. In agriculture, porosity, whether total, aeration, or retention, is a crucial indicator that is important for the physiological life of the plant because it ensures good drainage and irrigation, good soil aeration, good root growth, and a better habitat for microorganisms when the proportions are above 20% (Bembli & M'Sadak, 2017). In nurseries, substrate porosity is an important physical property of the substrate used to assess plant morphological quality, as it directly affects plant root functions, particularly water and mineral absorption (Landis et al., 1990). This porosity is believed to underpin the vigor of Terminalia superba plants observed in nurseries, as reported by M'Sadak et al. (2014). In addition to the physical properties of the substrates, there is also the issue of acidity.

Indeed, the analysis showed that the different substrates have low to basic acidity, ranging from pH 6 to 8. This reveals a high content of exchangeable bases in the compost produced. Similar results were obtained in the compost produced by Ngnikam & Tanawa (2000). pH values between 6 and 8 indicate the maturity of compost (Avnimelech et al., 1996) and can strongly influence nutrient uptake by roots, as shown by Ondo (2011) and Ognalaga et al. (2015) for the growth of Terminalia superba seedlings in nurseries. According to Lompo (2009), this tendency towards alkalinity enhances biological properties and makes cations in the substrate available to plants (Temgoua et al., 2012). Furthermore, the results showed that the substrates are rich in macroelements and trace elements, which are thought to be due to the biomass of Tithonia diversifolia, as reported by Kaho et al. (2011), who analyzed the leaves and found them very rich in nutrients.

3-2-2. Germination and growth of Terminalia superba seedlings

Regarding germination, the dormancy of Terminalia superba seeds was broken after only 10 days of sowing in 2- to 3-week-old compost, with a germination time of 30 days and a germination rate of 74-76%. These observations indicate that the substrates are judiciously well chosen and appropriate for influencing germination, as according to the work of SODEFOR (Society for Forest Development) in 2003, a dormancy period of 2 to 4 weeks, a germination time of 30 to 31 days, and a germination rate of 55% are characteristic and suitable for Terminalia superba seeds and forest tree seed sources in nurseries. This high germination rate could be explained, in part, by the seeds' short storage time. In fact, the Terminalia superba seeds used in this study were stored for only one month after harvest and retained all their vitality (Ahoton et al., 2011). On the other hand, the high substrate rates could be explained by substrate maturity, which improves porosity and water retention capacity and helps maintain the substrate's structure. This promotes good root development, which is a prerequisite for emergence (Steward et al., 1997). The various agro-morphological parameters (plant height, collar diameter, leaf length and width) of Terminalia superba plants treated with Tithonia diversifolia were superior to those of plants grown on the control substrate without Tithonia diversifolia. This is explained by the fact that the decomposition of Tithonia diversifolia leaves released the mineral elements necessary for the growth of Terminalia superba plants. Indeed, Kaho et al. (2011) showed that the rate of organic matter decomposition and the increase in yields were closely related to the synchronization between nutrient release and plant assimilation. The same authors state that Tithonia diversifolia contains nitrogen and potassium levels comparable to most species used in agroforestry. The green biomass of Tithonia diversifolia incorporated into the Cot2m, Cot3m, and Cot1m substrates appears to have a suitable decomposition rate, allowing Terminalia superba plants to assimilate a large proportion of the nutrients released during decomposition and achieve better results. Similar results were obtained by Salla et al. (2022) on lettuce production in Côte d'Ivoire. Kalo et al. (2011) and Jama et al. (2000) also reported that corn grain yields were higher on plots with Tithonia diversifolia alone than on plots receiving only chemical fertilizers.

4. CONCLUSION

The objective of this work is to develop vigorous Terminalia superba forest seedlings in nurseries on Tithonia diversifolia-based substrates for reforestation in real environments. This study shows that all organic substrates derived from Tithonia diversifolia have low to alkaline acidity and are very rich in nutrients, capable of inducing vigorous Terminalia superba seedlings for reforestation in real-world environments. Substrates based on Tithonia diversifolia composted for 2 and 3 weeks showed the best physical and chemical properties for the germination and growth of forest seedlings in nurseries.

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Competing Interests

Authors have declared that no competing interests exist.

Authors' Contributions

This work was carried out in collaboration between all the authors. Authors, GROGA Noel, N'GANZOUA K. René, and KOUAME A. Guillaume designed the study and drafted the experimental protocol. Authors, KOUADIO A. Henri-Maurice, YAO K.A. Georges and SORO Dognimeton performed the statistical treatments and interpreted the study results. All authors read and approved the final manuscript.

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