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Evaluation of organo-mineral qualities of combusted compost floor litters in Achalla forest reserve on early growth responses of *Dacryodes edulis* H. J. Lam

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A B S T R A C T

This study evaluated the potential of compost-combusted forest litters as alternative sources of *ex-situ* organo-mineral products to the direct use of controlled fire for enhanced soil nutrients in forest stands. Floor litters from six (6) delineated standing forest patches of *Pterocarpus erinaceus*, *Gmelina arborea*, *Tectona grandis*, *Bambusa vulgaris*, *Ceiba pentandra* and *Mangifera indica* were characterized for N, K, P, Ca and Mg; composted for 3, 6, 9 and 12 days and then uniformly combusted to produce organo-minerals for early growth response of *Dacryodes edulis* in a 6 x 4 split-plot factorial experiment. Analysis of variance was conducted for litter characteristics, calorific values, moisture, ash contents, and germination and growth variables of *Dacryodes edulis* while significant means were separated with DMRT ($p \geq 0.05$). Results showed that Mangifera had the highest P (0.68%) and K (1.15%); Bamboo had the highest N (1.92%). Germination was 6>9>12> 3 days with Bamboo > Ceiba > Teak > Mangifera > Gmelina > Pterocarpus for 6 days organo-minerals, but the highest height (21.56 ± 6.77 cm) by Pterocarpus to implicate litters under microbe-thermal mediation as sustainable organo-mineral *ex-situ* products to combat incidence of forest fire for fertile forest soil. Thus, *in-situ* controlled fire in standing forests is no longer needed for nutrient-rich forest-agriculture.

Keywords: Forest floor litters, Organo-mineral, Compost age, Germination percentage, Ash content

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Introduction

The Forest floor provides a dynamic platform in the terrestrial ecosystem for variegated activities to generate essential energy outputs with an array of products from interactions with the atmosphere and edaphic components, especially at 0-5 cm, to meet various intermediate needs (Hoover and Lunt, 1952; Stephen and Patrick, 2005). Essentially, floor litter, depending on the thickness to permit air-moisture regime in the rhizosphere region, create a relative imbalance that alters underlying temperature (Groen and Savenije, 2006) to supply veritable products for use in the agro and non-allied economy. Decomposition by microbial activities in this unique forest floor layer has been reported as critical to churning out precipitates for the modification and return of litter to the soil (Ochoa-Hueso *et al.*, 2019).

However, microbial activities under different thermal modifications have been observed as effective chemical pathways for bioturbation products in forest ecosystems for replenishing mined soil nutrients often related to extracted woody and non-woody plant resources (Lavelle *et al.*, 1997). This has accounted for the traditional ecological knowledge on the use of fire as a management tool in the grassland and savanna ecosystems often known for nutrient depletion issues as it reportedly releases ash with high quality of K, P, Ca and Mg alongside a proportion of micronutrients (Bougnom *et al.*, 2011). Controlled fire in land preparation as a means of combusting forest floor litters adjusted basic physicochemical soil properties that influenced tree growth characteristics due to the fertilizing capacity on both physical and chemical properties. However, the growing incidences of wrong fire application due to the inability to control the fire under large hectares of forestland as well as the tendency to negatively impact standing vegetation and wildlife, create a major gap in the utilization of direct fire (Thomaz *et al.*, 2014). In other climes, ash application to agricultural fields has been shown to compensate for critical nutrient deficiencies in leached and acidified soils (Saarsalmi *et al.*, 2006) while acting as an anti-fungal agent against leaf spot infections.

In the tropics, high soil fertility due to interactions between environmental factors and standing indigenous forest community has been observed as the attraction, which has continued to endanger its sustainability as the target for the agricultural program (Egwunatum and Ezealisiji, 2020). This situation has accounted for the loss of several hectares of protected forests in southern Nigeria. Shifting cultivation has the fertile high forest as a potential target for agricultural practices. Over 40% of forest reserves in Anambra State have been lost to agriculture, with one-third gradually becoming degraded and encroached for residential purposes after several failures to practice inorganic agriculture due to the search for fertile forest land coupled with the high availability of fertilizers (ICIR, 2021). Therefore, the propensity of agriculture to continually undermine forest reserves due to soil fertility remains a serious bane to conservation and sustainable forest management. The increase in sourcing soil resource from standing forest vegetation for agriculture and landscaping activities represent a new dimension of pressure on forest conservation since it could ultimately undermine the entire terrestrial forest ecosystem. MOE (2015) reported the direct excavation of forest soil resources for agriculture from Atachi and Akehie forest reserves, leading to severe degradation and the creation of large potholes of 50-60 cm average depths that forestalled natural succession and forest reservation over the years.

However, standing forest patches in protected forests have been reported as notable sources of litter, which can be relied upon for agricultural practices (Tjitrosemito *et al.*, 2011). Whilst the forest is under strict conservation, the effort is at manipulating crucial parameters that aid high soil fertility status in tropical forests to provide basic rich organo-minerals for use in agricultural establishments. Organo-minerals have been reportedly formed by a wide range of biochemical mechanism that involves activities of microbe on accumulated organic matter on the surface horizons of the forest floor layer under varying thermal differentiation, moisture moderation and ambient soil conditions often precipitated by the different rhizosphere qualities of individual trees species (Becker *et al.*, 2015). Therefore, enriching endemic forest floor litters through further microbial actions to break down the woody component thermally represents a simulation of the natural forest floor parchment process for the supply of critical organo-mineral products.

Furthermore, the choice of fertilizer source in agriculture, especially in the face of global climate and health challenges, has necessitated an investigation into inorganic fertilizer application (Egwunatum *et al.*, 2022; Iiahi *et al.*, 2021). This is because, as a pesticide or fertilizer, the inorganic products have been shown to interfere with the human immune system to alter and cause serve mutation in the gene responsible for the different sense organs. Kumar and Devis (2017) reported significant traces of unabated and recalcitrant elements in agricultural produce of inorganic fertilizer origin in humans. These have, therefore overtime led to a severe decline in the consumption of such products with wider attraction for the organic-based fertilizer products in developed countries, mainly as plant roots readily absorb a more significant proportion of vitamin B12, which only microorganisms can synthesize organically primed healthy soils (Goodland, 2001). However, this disparity has not been substantial in the tropics, probably because of the capability of tropical grounds to still counter-act such inorganic fertilizers to decontaminate the presence in agricultural produce. These coupled with the relatively harsh economic situations in developing countries, the loss of forest ecosystems endowed with the potential and the increasing cancer-related diseases, create concern for urgent anticipation and development of alternatives ahead of possible grievous incidents in the tropics. Moreover, the high consumption of *Dacryodes edulis* as a complimentary food product of *Zea mays* annually presents a life-threatening situation to its several populations in the tropics.

In this light, litters of forest remnant parchments in Achalla Forest Reserve were engaged by composting and combustion to produce ex-*situ* organo-mineral materials for use in agro-allied conurbations. This intends to reduce the threat of controlled fire for fertile forest soils under conservation from deforestation and degradation by agriculture, particularly in forest reserves, while at the same time providing healthier food crops to combat growing concerns for toxic-food crop-related issues.

Materials and Methods

Description of the study area

The samples were collected from Achalla Forest Reserve in Awka North Local Government Area in Anambra State. Achalla forest reserve is located on latitude 6°20'39"N and longitude 6°57´43´´E in the South East region of Nigeria. The climate is humid, subtropical, within the tropical rainforest ecological zone and dominated by broad–leaved hardwood trees that form dense, layered stands. The mean annual temperature is approximately 26°C, with minimum 19°C and maximum 34°C (NiMet, 2019).

The natural vegetation is similar to that of tropical lowland rainforest, but heavy anthropogenic alteration over a long period has replaced previous forests with patches of secondary forest (Anyanwu *et al.*, 2016).

Collection and analysis of forest floor litter

A reconnaissance survey was conducted by ground trotting to identify the various vegetation patches within the forest reserve portion that were not highly degraded. This was delineated into six vegetative parts of 50 m x 50 m plot respectively that comprised *Gmelina arborea, Tectona grandis, Ceiba pentandra, Bambusa vulgaris, Pterocarpus erinaceus* and *Mangifera indica*. Fresh forest floor litter were collected from ten quadrants (0.50 m x 0.50 m) in each plot for the six vegetation. Litters were collected from the forest floor layer (0.00-0.05 m depth) that consisted of twigs, barks, leaves and surface soil from the (L and F) layer as described by (Oraon *et al.*, 2018).

The collected forest floor litter samples were sundried at a screen house temperature of 35-37.5°C for 24 hours. Nitrogen was determined by the Microkjedahl digestion (Bremnar and Mulvaney, 1982). Then samples were dried to ashes at 120°C for 1 hour before extraction with nitric-perchloric acid to determine P, K, Ca and Mg. The P was determined by Vanado molybdate method, while K, Ca and Mg were by EDTA titration (Faithful, 2002).

Preparation of forest floor litter products

The six (6) forest floor litters were composted anaerobically in black litterbags at 3 replicates per litter type for 3, 6, 9 and 12 days under screen house temperature. Harvested composts were then combusted semi-anaerobically for a uniform time of 240 seconds at 45°C.

Emanating combusted-compost litter products were allowed to cool for 24 hours and analyzed for moisture content, ash content and calorific value, respectively. The moisture content was analyzed by heating at 105°C for a period of 60min while the ash content was determined by heating the sample at 600°C for 4 hours (ASTM, 2008).

Then 150 g of each combusted-compost litter was weighed into different troughs with 75 cl of sterilized water. These were allowed to stand for 60 minutes to produce twenty-four (24) different organo-mineral slurries.

Germination trials

Matured seeds of *Dacryodes edulis* were obtained from Eke Awka market in Awka and tested for viability using the floatation method. Four hundred and eighty (480) selected viable seeds were manually de-pulped before sowing in 6 germination troughs measuring 1.50 m x 0.50 m x 0.20 m and containing soils already inoculated with different organo-mineral slurries in a constant ratio of 1:2 at 80 seeds per organo-mineral type. Furthermore, 50 g of each ash type was applied by sprinkling 2 days after sowing to support the efficacies.

Germination was then monitored at two intervals of 1-5 and 5-10 weeks after sowing. Germination recorded was expressed in percentage as the ratio of numbers that germinated to the total number sown per trough multiplied by 100. Then, the growth characteristics of height and collar diameter were measured with steel rule and digital vernier calliper, respectively. At the same time, the number of leaves was estimated by direct counting at 10 weeks after germination.

Results and Discussion

Nutrient element composition of forest floor litter

The nutrient element composition of collected forest floor litter is shown in Table 1. The Bamboo litters had the highest mean N content of 1.92% and differed significantly from other litter types. The least mean N was recorded *Tectona grandis* and Pterocarpus, which were not significantly different. The mean P was relatively low, with Ceiba and *Mangifera indica* litters showing the highest means that were not significantly different. The *Gmelina arborea* litters showed the least mean P value (0.09%).

Mangifera recorded the highest mean K (1.15%) and was significantly different from all other types of litter. There were no significant differences in the mean K between Teak, Pterocarpus, Ceiba, and Gmelina. Pterocarpus recorded the highest mean Ca (1.92%), which differed significantly from other litters, whereas there was no significant difference between the mean Ca of Bamboo and Mangifera and between Ceiba and Teak.

Bamboo litter recorded the highest mean Mg (0.23%), which was not significantly different from Teak (0.19%). There was no significant difference in the mean Mg of Pterocarpus, Gmelina, Ceiba and *Mangifera indica*. The lower moisture contents of Gmelina, Bamboo and Mangifera may not be unconnected with the growth characteristics of these tree species that modified the litter constituents, which decreased with compost age, especially the moisture use efficiency of microbes for the breakdown of vegetative matter. This finding aligns with Brangari *et al.* (2021) that moisture availability decreases with high microbial activity as it is often employed in multiplication for enhanced services.

Table 1. Nutrient element composition (% dry weight) of forest floor litters in Achalla Forest Reserve.

Litter Source/ Type	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Pterocarpus erinaceus	1.58^c	0.25^c	0.28^c	1.92^a	0.03^b
Gmelina arborea	1.18^e	0.09^e	0.16^d	1.16^b	0.08^b
Tectona grandis	1.57^c	0.15^d	0.27^c	0.28^d	0.19^a
Bambusa vulgaris	1.92^a	0.63^b	0.47^b	0.58^c	0.23^a
Ceiba pentandra	1.78^b	0.68^a	0.18^d	0.38^d	0.10^b
Mangifera indica	1.36^d	0.68^a	1.15^a	0.61^c	0.09^b

Mean in the same column with the same superscript are not significantly different ($p \geq 0.05$).

Effect of combustion on compost forest floor litter types of Achalla forest reserve

Table 2 shows that the moisture content in *Tectona grandis* was significantly different ($p > 0.05$) from other forest floor litter types. There were no significant differences between *Pterocarpus erinaceus Ceiba Bombax, Mangifera indica, Bambusa vulgaris* and *Gmelina arborea*. The mean moisture content was *Tectona grandis* (13.99 ± 0.73%) > *Pterocapus erinaceus* (11.70 ± 0.79%) > *Ceiba pentandra* (11.50 ± 0.90%) > *Mangifera indica* (9.65 ± 0.49%) > *Bambusa vulgaris* (8.80 ± 0.51%) > *Gmelina arborea* (8.45 ± 0.44%).

The *Mangifera indica* recorded the highest ash content of 4.47±1.45 compared to *Tectona grandis* (4.30 ± 2.30%) > *Gmelina arborea* (4.24 ± 0.43%) > *Bambusa vulgaris* (3.53 ± 0.18%) > *Ceiba pentandra* (3.17 ± 0.40%) > *Pterocarpus erinaceus* (2.32 ± 0.32%). The *Mangifera indica* recorded the highest calorific value (20.73 ± 0.59 J/kg) > *Ceiba pentandra* (19.44 ± 0.90 J/kg) > *Bambusa vulgaris* (18.60 ± 0.85 J/kg) > *Tectona grandis* (14.78 ± 2.30 J/kg) > *Gmelina arborea* (11.99 ± 0.43 J/kg) > *Pterocarpus erinaceus/Gmelina arborea* (8.45 ± 0.40 J/kg). The ash content notably increased with the age of composting, whereas compost efficiency declined, probably due to a lower microbial population under controlled conditions. The low mean ash content may be due to low organic matter content and high microbial activity that are inversely related. Ash plays a critical role in agricultural practices in adjusting soil acidity towards alkalinity for proper soil nutrient management (Petrovský *et al.*, 2018). This may have underpinned the utilization of forest fires under control as latent ash source for organic agricultural practices in tropical forests to compensate for nutrient losses caused by harvesting, leaching and counter-act soil acidification (Nabatte and Nyombi, 2013; Hannam *et al.*, 2019). Unfortunately, the direct use of fire on soils has a harmful impact on the wider population of resident microbial communities, which could reduce the potential of forest soils to support productive agricultural activities over time.

Table 2. Effects of combustion on composted floor litters in Achalla Forest Reserve.

Litter source/Type	Ash Content (%)	Calorific Value (J/kg)	Moisture Content (%)
Pterocarpus erinaceus	2.32 ± 0.32^{e}	8.45 ± 0.40^{f}	11.70 ± 0.79^{a}
Gmelina arborea	4.24 ± 0.43^{b}	11.99 ± 0.43^{e}	8.45 ± 0.44^{c}
Tectona grandis	4.30 ± 2.30^{b}	14.78 ± 2.30^{d}	12.19 ± 0.73^{a}
Bambusa vulgaris	3.53 ± 0.18^{bc}	18.60 ± 0.85^{c}	8.80 ± 0.51^{c}
Ceiba pentandra	3.17 ± 0.40^{d}	19.44 ± 0.90^{b}	11.50 ± 0.90^{a}
Mangifera indica	4.47 ± 1.45^{a}	20.73 ± 0.59^{a}	9.65 ± 0.49^{b}

Means ±std error in the same column with the same superscript are not significantly different (p ≥ 0.05).

Effect of compost age on combustion

The mean moisture content of compost floor litters at 3 days differed significantly from other ages (Table 3). There was no significant difference in the moisture contents of combusted floor litter at ages 6, 9 and 12 days. The highest moisture content of 10.12 ± 1.51% was recorded by the 6days age forest floor litters while the others were 3 days < 9 days (9.60 ± 1.54 %) < 12 days (8.91 ± 0.32%)

There were significant differences in the ash contents of the forest floor litters at different composted ages. The highest ash content was produced by the 12 days aged compost litters (4.45 ± 1.35%) and the least 2.95 ± 0.45% at 3 days. The 6- and 9 days aged compost produced ash contents of 3.53 ± 0.87% and 3.77 ± 0.94%, respectively.

There were significant differences between the calorific values of different ages of composted forest floor litters at combustion. The highest calorific value was produced by the 12 days aged (16.76 ± 4.61 J/kg) and the least by 3 days aged (14.73 ± 4.42 J/kg). The 9 and 6-day-old forest floor litters recorded calorific values of 16.21 ± 4.69 J/kg and 14.95 ± 4.45 J/kg, respectively, which were significantly different ($p < 0.05$).

The calorific value of compost floor litters increased with compost age to attain the highest mean (16.76 ± 4.61 J/kg) at 12 days and implicate longer composting period may enhance the calorific value of forest floor litters, which essentially justified the need for composting before combustion. Materials with low calorific values have been reported to demonstrate poor thermal properties and may not function effectively as substitutes for energy products (ASTMD, 2013). Consequently, the 12 days compost combusted forest product, and *Mangifera indica* tree species may have better potential as alternative energy products that could substitute fuelwood to avert forest degradation. In contrast, its other aged product with lower calorific value constitute innovative organo-mineral products for application in agriculture due to the higher ash content.

Table 3. Effects of compost age on floor litter quality in Achalla Forest Reserve.

Compost Age (Days)	Moisture Content (%)	Ash Content (%)	Calorific value (J/kg)
3.00	9.92 ± 2.62[b]	2.95 ± 0.45[d]	14.73 ± 4.42[d]
6.00	10.12 ± 1.51[a]	3.53 ± 0.87[c]	14.95 ± 4.45[c]
9.00	9.60 ± 1.54[b]	3.77 ± 0.94[b]	16.21 ± 4.69[b]
12.00	8.91 ± 0.32[c]	4.45 ± 1.35[a]	16.76 ± 4.61[a]

Means ±standard errors in the same column with the same superscript are not significantly different (p ≥ 0.05)

Effect of compost on germination of Dacryodes edulis

The effect of various litter compost types on the germination of *Dacryode edulis* is shown in Figure 1. The highest and least germination percentages during the first interval of 1-5 weeks were recorded by the 6 and 12 days compost litters, respectively. Bamboo (BB) organo-mineral products recorded the highest (50.5%), while the Gmelina (GM) and Pterocarpus (PE) recorded the least (10%). The percentage germination at 5-10 weeks interval showed that the 6 days organo-mineral products and Bamboo had the highest germination percentage (87.5%). The Ceiba (CB), Teak (TK) and Mangifera (MG) organo-mineral products recorded 85%, 68.75% and 42.5%, respectively, in the 6 days. The Bamboo organo-mineral product recorded the highest germination (71.25%) while Ceiba and Teak was 60% with the 9days organo-mineral product.

The fantastic germination shown by the 6 and 9 days organo-minerals products, especially the Bamboo, Teak and Ceiba implied the likelihood of better forest *ex-situ* products. These may have readily improved critical edaphic parameters such as soil structure and capacity to retain water as well as nutrients for essentially faster protoplasmic activities to initiate and complete germination (Atere and Olayinka, 2012). Even though a uniform combustion time and temperature were employed, the inherent qualities of individual floor litters may have presented significant variations in the emanating organo-mineral products under the different composting ages to influence water availability and uptake of *Dacryodes edulis* seed (Huang *et al.*, 2020). The 12days Bamboo organo-mineral product, which was higher at the 1-5weeks but later declined in the last 5-10 weeks, may not be unconnected with nutrient exhaustion probably due to prolonged composting and high moisture content of the ash with consequent higher adsorption capacity on soil particles for faster mineralization at the earlier phase. But the Ceiba and Mangifera showed higher germination percentages with the 12days organo-mineral products in the last 5-10weeks to reveal a likely incremental release of nutrients for enhanced germination probably as a result of lower moisture content of the ash through improved water holding capacity (Perez-Cruzado *et al.*, 2011; Domes *et al.*, 2018).

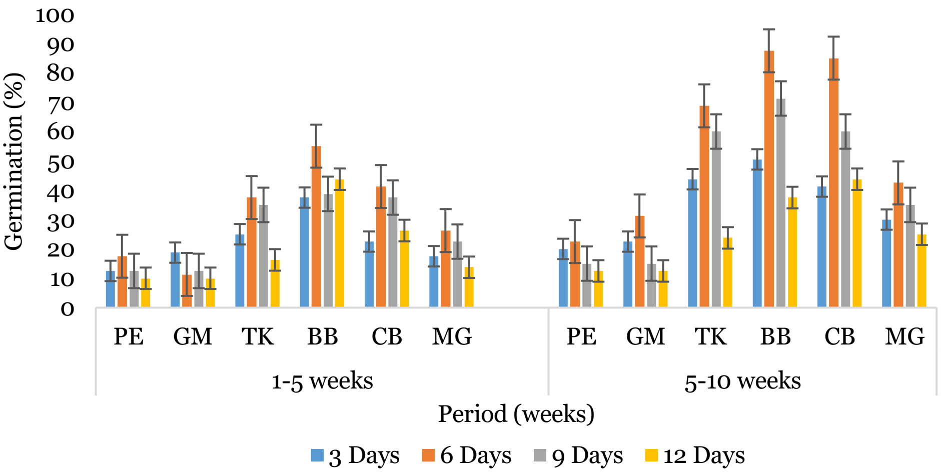

Figure 1. Effect of forest floor litter compost types and age on germination of *Dacryodes edulis*.

Effect of organo-mineral products on growth characteristics of *D. edulis*

There were significant differences in growth characteristics (Figure 2). There was no significant difference in the effect of Teak and Gmelina organo-mineral products ($p > 0.05$). Still, they differed from the others, especially *Pterocapus* and *Mangifera,* which recorded the highest and least plant heights, respectively. There were no significant differences between Bamboo, Gmelina and Teak collar diameters and Bombax and Pterocarpus, respectively. The highest collar diameter was recorded by 6 days of the organo-mineral product of Pterocarpus. There was no significant difference between the Mangifera, Gmelina and Teak leaf count and between Bombax and Pterocarpus organo-mineral products. However, Bamboo differed significantly from every other.

The initial high N and P-contents of Bamboo and Ceiba floor litters may have contributed equally, especially during composting, to the organo-mineral potential to account for the highest germination of *D. edulis*. This is because nitrogen promotes seed germination as a signalling molecule in addition to functioning as a nutrient (Yan *et al.*, 2016) alongside P, which has been reported to positively correlate and facilitate mass litter loss across the various stages of decomposition to enrich the soil with inherent nutrients (Hättenschwiler, 2011).

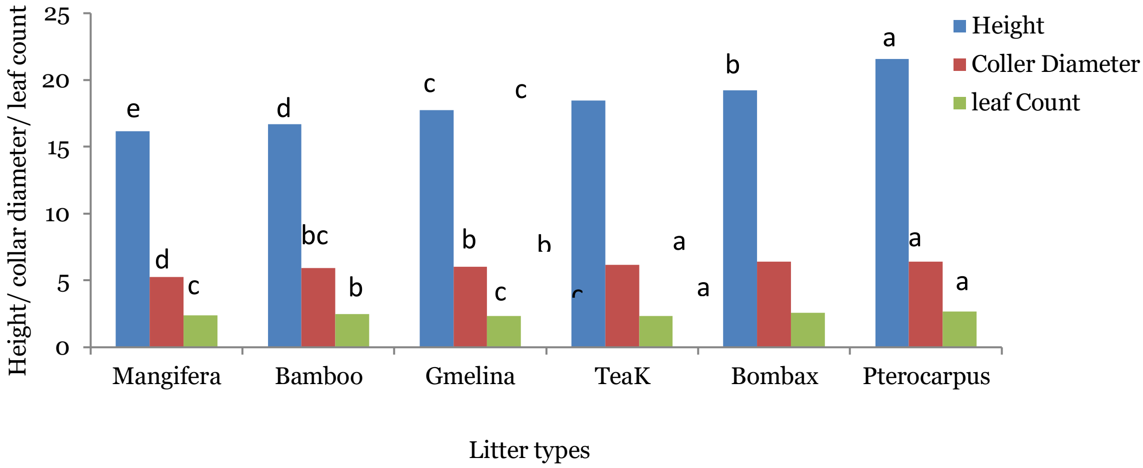

Figure 2. Effect of different combusted compost forest floor litters on growth characteristics of *Dacryodes edulis* (Mean of respective growth characteristics with the same alphabet are not significantly different at 5% probability level using DMRT).

Conclusion

This study indicated that forest floor litter types in Achalla Forest Reserve present various organo-mineral-rich products with proportionate microbial and ash contents as a result of the differentials in calorific value for *ex-situ* soil enrichment to manage competition for the fertile forest soil of standing forest by agriculture to enhance ecological services. Thereby ensuring agriculture without forest degradation and deforestation, especially in the tropics where the fire is annually employed as a unique tool in eliciting component nutrients amidst standing forest in the already degraded forest reserve.

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