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ORIGINAL ARTICLE - SILVICULTURE

Performance of Organic Waste Containers for *Libidibia Ferrea* Seedling Production

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Abstract

The proper use of agro-industrial waste is a sustainability strategy and can be applied in the forestry chain to replace polypropylene tubes. This study evaluated the performance of three different biodegradable containers (110 cm³), made from malt bagasse, poultry litter, and coconut coir fiber, respectively, in the production of *Libidibia ferrea* seedlings, and compared them with the control container (polypropylene) under nursery conditions. Morphological parameters and the Dickson Quality Index (DQI) were evaluated. Seedlings grown in malt bagasse showed superior growth in all morphological parameters ($p < 0.01$) and the highest DQI (0.23), significantly surpassing the other treatments. Malt bagasse provided total biomass gains (TBM) up to 6 times higher than polypropylene. Poultry litter and coconut coir fiber containers showed comparable performance to polypropylene. It is concluded that malt bagasse is a highly efficient technical and sustainable alternative container for producing *L. ferrea* seedlings.

Keywords: agro-industrial waste, biodegradable containers, sustainability, circular economy, forestry nurseries.

1. INTRODUCTION AND OBJECTIVES

The growing demand for forest inputs, driven by the need to restore degraded ecosystems and expand reforestation programs, has created a pressing need for large-scale production of high-quality seedlings (Da Silva et al., 2017; Di Sacco et al., 2020; Dobrowski et al., 2024). Native species with high ecological potential and multiple uses stand out as strategic components of this production chain. One such species is *Libidibia ferrea* (Mart. ex Tul.) L.P. Queiroz, popularly known as Brazilian ironwood (pau-ferro). Belonging to the family Fabaceae (subfamily Caesalpinioideae), this species is classified as a fast-growing pioneer, native to the Caatinga, Cerrado, and Atlantic Forest biomes, occurring predominantly in seasonally dry tropical forests and xeric areas, though it can also be found in humid forests (Oliveira et al., 2024). It is distinguished by its wide geographic distribution, rapid growth, and functional versatility, which encompasses multiple uses: dense, highly durable timber suitable for construction and tool handles; recognized beekeeping value; medicinal and pharmacological potential, including antibacterial and anti-inflammatory properties; ornamental appeal in urban landscaping; and strategic applications in ecological restoration. Together, these attributes position the species as strategically important for both the recovery of degraded areas and urban landscaping (Carvalho, 2014; Macêdo et al., 2020; Nair et al., 2022; Oliveira et al., 2024).

Seedling quality is a determining factor for planting success in the forestry production chain and is directly related to the characteristics of the growing containers (Romero et al., 1986; Storck et al., 2016). Polypropylene tubes have become the standard in forest nurseries in Brazil due to their practicality, relative low cost, and operational efficiency (Abreu et al., 2015). These containers also offer important advantages for seedling quality: the rigid walls provide physical protection to the root system, while internal ridges guide root growth vertically, preventing root circling and promoting a more organized, well-distributed root architecture with a higher proportion of functional fine roots, advantages over smoothwalled plastic bags (polybags) and some textile containers (Da Silva et al., 2025; Ferraz et al., 2011; Vieira et al., 2019; Haase et al., 2021). Despite these benefits, these containers have significant environmental impacts because they are derived from fossil fuels and have low degradability, particularly due to their difficulty in recycling and the accumulation of plastic waste in the environment (Barnes et al., 2009).

Given this scenario, there is growing interest in alternatives that combine technical performance, economic viability, and environmental sustainability, with emerging options including biodegradable containers made from agro-industrial waste, such as malt bagasse, poultry litter, and coconut coir fiber. Studies have demonstrated the potential of these materials, with sugarcane bagasse blended with starch producing rigid, highly biodegradable containers (Ferreira et al., 2020; Manickaraj et al., 2025), malt bagasse offering high degradation rates and fertilizer potential (Fuentes et al., 2021), and poultry litter combined with straw contributing additional nutrients and improved seedling vigor (Tian et al., 2019; Nascimento et al., 2024). These materials have an organic composition rich in organic matter and essential nutrients, in addition to favorable physical properties, such as high porosity and water retention capacity, which can favor root development and, in turn, form more vigorous seedlings (Silva et al., 2014; Maeda et al., 2007).

Incorporating agro-industrial waste as a raw material for biodegradable containers is part of a broader circular economy perspective, in which byproducts from different production chains are reintroduced into the economic cycle, reducing waste generation, mitigating environmental impacts, and adding value to materials that are difficult to dispose of (Visco et al., 2022; Varghese et al., 2023). The global sustainability challenge requires valorizing agro-industrial waste to reduce environmental impact and promote the circular economy (Assandri et al., 2021; Bianco et al., 2024; Bilal et al., 2020). Malt bagasse is the main byproduct of the brewing industry, accounting for approximately 85% of the co-products generated, with an estimated annual global production of between 38 and 39 million tons (Assandri et al., 2021; Chaves et al., 2021; Girelli et al., 2019). Although the primary reuse of malt bagasse is as animal feed (due to its high fiber and protein content), its high perishability (shelf life of 7 to 10 days) and high moisture content make composting and bioconversion effective and sustainable alternatives for its waste management (Assandri et al., 2021; Bianco et al., 2024). Furthermore, this approach contributes to climate change mitigation by reducing the use of synthetic polymers and promoting more sustainable production practices in forestry.

Given this context, this study aimed to evaluate the performance of three biodegradable containers produced from various organic wastes in the production of *Libidibia ferrea* seedlings, aiming to identify environmentally sustainable and technically efficient alternatives to the polypropylene tubes used in forest nurseries.

2. MATERIALS AND METHODS

The experiment was conducted in a greenhouse installed at the commercial nursery of the company Biovert (Biovert Florestal), located in the municipality of Silva Jardim, RJ (22°29'33" south latitude; 42°30'46" west longitude). The climate in the region is classified as As (tropical rainy with a dry season in winter) (KOTTEK et al., 2006), with an average annual temperature of 26.6°C and an average rainfall of 115 mm (ARAUJO, 2012).

Three types of biodegradable containers, made from poultry litter, coconut coir fiber, and malt bagasse, were used, along with polypropylene tubes as a reference. All containers had a volume of approximately 110 cm^3. The biodegradable containers were manufactured and donated by Toco Engenharia e Inovação Ambiental Ltda. The poultry litter was obtained from commercial poultry farms after six rearing cycles and was used without prior composting, undergoing only homogenization and sieving (4 mm mesh). The coconut coir fiber was purchased from an agricultural supply store and subjected to drying and grinding. The malt bagasse was obtained as a byproduct of the brewing industry and was used in natura (without additional composting), retaining its characteristic high moisture content.

For the biodegradable containers, in addition to the aforementioned raw materials, 30% cellulose, 10% silicon oxide, and 60% modified starch were added to the composition, based on total weight. The water ratio varied between 0.8 and 2.4 kg of solid matter for every 20 to 60 liters of water. A suspension was prepared from the solid components and water, which was then molded using a vacuum press. The container production process involved vacuuming and subsequent oven drying at 65°C for 12 hours. The biodegradable containers had walls 8 mm thick. Commercially known as Biotoco, this biodegradable container has a patent registered in Brazil (No. BR 102020013631-3).

Analyses were conducted to determine the macronutrient and micronutrient contents of the containers according to the Manual of Official Analytical Methods for Correctives and Fertilizers (BRASIL, 2017) (Table 1).

The substrate used to fill the containers consisted of organic sediment collected from a lagoon on the Biovert property. This material, which is produced and processed by the nursery itself, is primarily composed of decomposed plant matter accumulated at the bottom of the lagoon. The substrate was air-dried, homogenized, and used without additional fertilization or mixing with other soil components. Its chemical characterization is presented in Table 2.

Table 1. Chemical composition of organic waste containers with poultry litter, coconut coir fiber, and malt bagasse.

Container	N	P_2O_5	K_2O	Ca	Mg	Cu	Mn	Zn	B
	%					ppm			
Poultry litter	1.12	2.08	0.97	1.56	0.32	181	311	306	50
Coconut fiber	0.68	0.72	0.24	0.11	0.05	102	395	150	90
Malt bagasse	3.25	0.88	0.23	0.26	0.06	0.05	245	95	70

Table 2. Chemical characterization of the substrate and cation exchange capacity (CEC).

pH	K	Ca	Mg	Na	Al	CTC	P	S	B	Cu	Fe	Mn	Zn	MO	C
$CaCl_2$	$mmol_c dm^{-3}$							mg dm^{-3}						g dm^{-3}	
4.8	6.9	105	27	1.9	0	181.8	76	17.5	1.2	0.9	72	25	55	34	20

Libidibia ferrea seeds were collected from seedbeds located adjacent to the nursery. The experimental design was completely randomized, with four treatments and 10 replicates. Sowing was done directly into the containers, followed by thinning and transplanting as needed. Irrigation was provided using a micro-sprinkler system according to seedling demand.

The experiment lasted 90 days (November 2021 to February 2022). The morphological parameters evaluated included shoot height (H), diameter at the collection stem (DC), the ratio obtained by dividing H by DC (H:DC), dry matter of shoot (DMS in g seedling^{-1}), dry matter of root (DMR in g seedling^{-1}), and total (TDM in g seedling^{-1}). Shoot height and stem diameter were measured at 90 days using a digital caliper and a tape measure.

All plants were sectioned at the root collar, separating the shoot from the root system in order to determine the DMS and TDM. The root system was carefully washed using a fine sieve to remove the substrate from the roots. The shoot and root system were then placed in paper bags and dried in a forced-air oven at 65°C for 48 hours. Their respective masses were measured using a precision digital scale to three decimal places.

The Dickson Quality Index (DQI) of the sampled seedlings was determined using the following formula (Equation 1):

$$DQI = TDM/ ((H) /DC + DMS/DMR) \quad (Eq.1)$$

In which:
TDM – Total dry matter mass, in g seedling^{-1};
H – Shoot height, in cm;
DC – Diameter at the collection stem in mm;
DMS – Dry matter of shoot, in g seedling^{-1}; and
DMR – Dry matter of root, in g seedling^{-1}.

The data obtained were subjected to statistical analysis using the SISVAR software, which included the Shapiro-Wilk normality test and analysis of variance (ANOVA). When the F-test was significant (calculated F-value (Fc) with probability (p) < 0.05), the Scott-Knott test was performed to compare the means.

3. RESULTS

There was a significant effect of the container type on all morphological variables analyzed: shoot height (H) (Fc = 62.937; p < 0.01), diameter at the collection stem (DC) (Fc = 16.441; p < 0.01), H:DC ratio (Fc = 14.556; p < 0.01), dry matter of shoot (DMS) (Fc = 46.201; p < 0.01), dry matter of root (DMR) (Fc = 6.791; p < 0.01), total dry matter mass (TDM) (Fc = 37.268; p < 0.01) and Dickson Quality Index (DQI) (Fc = 10.732; p < 0.01).

Libidibia ferrea seedlings grown in malt bagasse containers showed remarkably superior performance in height (50.9 cm), reaching values 2.6 times higher than those obtained in polypropylene containers (19.4 cm). Growth in poultry litter containers (28.0 cm) was superior to polypropylene, while coconut coir fiber (19.5 cm) and polypropylene did not differ from each other (Figure 1A).

Diameter at the collection stem (DC) is recognized as a key parameter for forest seedling quality, and plants grown in malt bagasse containers achieved an average of 3.39 mm, which is 64% higher than that obtained in polypropylene tubes (2.07 mm). This treatment also significantly outperformed the poultry litter (2.23 mm) and coconut coir fiber (2.22 mm) containers, whose values did not differ from each other or from polypropylene (Figure 1B).

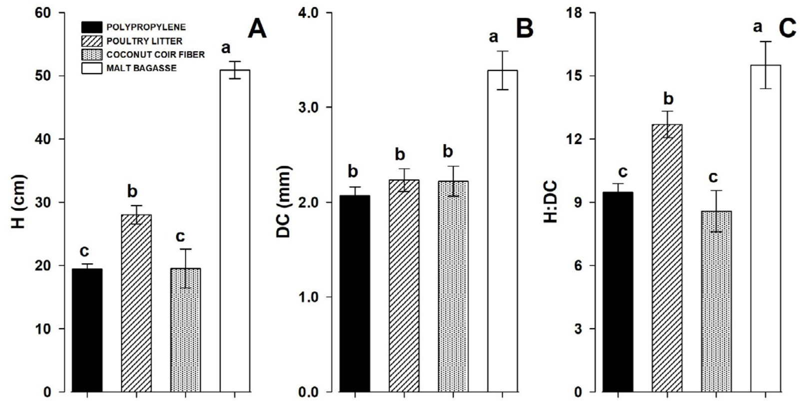

Figure 1. (A) Mean height (H), (B) diameter at the collection stem (DC), and (C) H:DC ratio of Libidibia ferrea seedlings after 90 days of cultivation in polypropylene containers, poultry litter, coconut coir fiber, and malt bagasse. Different letters indicate significant differences according to the Scott-Knott test at 1% significance.

In terms of biomass, seedlings in malt bagasse containers accumulated DMS of 4.17 g seedling^{-1} and TDM of 4.82 g seedling^{-1}, constituting values up to 6 times higher than those recorded in polypropylene (0.70 g and 1.41 g seedling^{-1}, respectively). The poultry litter and coconut coir fiber containers showed intermediate performance, without differing from polypropylene (Figure 2A and 2C).

The DMR of seedlings grown in malt bagasse (0.65 g seedling^{-1}) and polypropylene (0.71 g seedling^{-1}) containers did not differ significantly, but was higher than that of seedlings grown in chicken litter (0.43 g seedling^{-1}) and coconut coir fiber (0.40 g seedling^{-1}) containers (Figure 2B).

The DQI results reflected the observations from the previous variables. Seedlings grown in malt bagasse containers had a higher DQI (0.23) compared to seedlings grown in poultry litter (0.11), coconut coir fiber (0.12), and polypropylene (0.14) containers, which did not show significant differences (Figure 2D).

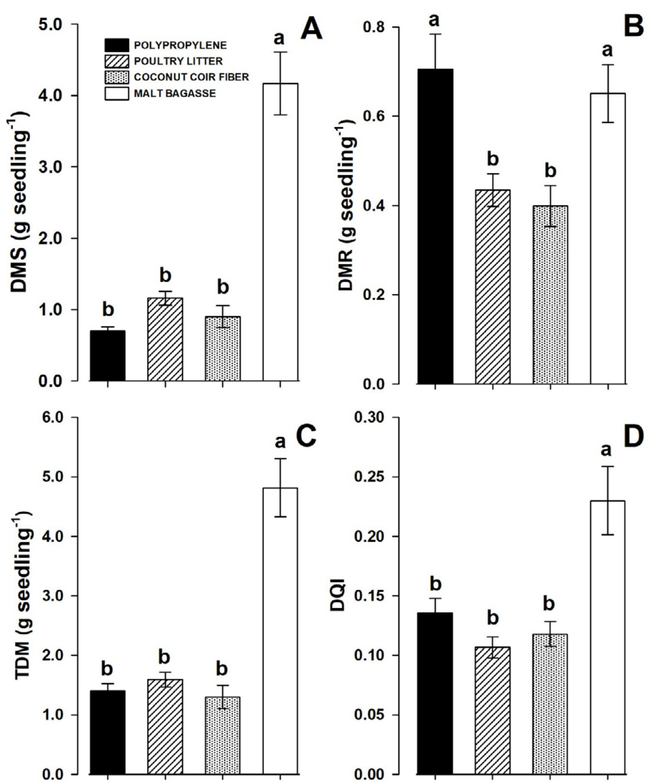

Figure 2. (A) DMS (dry matter of shoot), (B) DMR (dry matter of root), (C) total dry mass (TDM), and (D) Dickson Quality Index (DQI) of *Libidibia ferrea* seedlings after 90 days of cultivation in polypropylene tube containers, poultry litter, coconut coir fiber, and malt bagasse. Significant differences among treatments are indicated by different letters, according to the Scott-Knott mean test at the 1% significance level.

4. DISCUSSION

The use of malt bagasse as a container component resulted in superior growth performance for Libidibia ferrea seedlings compared to coconut coir fiber, poultry litter, and the control (polypropylene). This performance is associated with its nutrient content, particularly nitrogen, and its relatively low C/N ratio, typically reported between 10:1 and 15:1 (Kebede et al., 2020; Assandri et al., 2020, 2021; Tschoeke et al., 2023). Poultry litter also presents a low but variable C/N ratio, generally ranging from 6:1 to 25:1 (Nahm, 2005; Masud et al., 2020), whereas coconut coir fiber has a high C/N ratio, often between 80:1 and 100:1, due to its high lignin content and low nitrogen content (Nair et al., 2022; Bera et al., 2025). Importantly, the low C/N ratio alone does not explain the superior performance of malt bagasse, since poultry litter presented a similar C/N range but resulted in only intermediate seedling growth.

Residues with low C/N ratios generally promote higher nitrogen availability and faster mineralization rates (Chaves et al., 2021; Trevisan et al., 2023). However, the lignocellulosic structure of malt bagasse likely promotes a more gradual decomposition and nutrient release (Gao et al., 2024; Hodson et al., 1984; Kirui et al., 2022), whereas poultry litter is more susceptible to nitrogen losses through volatilization and leaching (Masud et al., 2020; Sikder et al., 2018; Bohara et al., 2018). In contrast, the high C/N ratio of coconut coir fiber can lead to nitrogen immobilization and reduced nutrient availability (Bera et al., 2025; Nair et al., 2022). Therefore, the superior performance of malt bagasse is likely related to the combined effect of adequate nitrogen availability, gradual nutrient release, and favorable physical properties such as porosity and water retention, which together promote better root development and seedling growth. These factors are reflected in the significant accumulation of shoot biomass and the significant increases in height (H) and stem diameter (DC) observed in malt bagasse-grown seedlings (Figure 1), consistent with studies highlighting nitrogen fertilization as a key determinant of dry matter accumulation and quality in forest seedlings (Mussatto et al., 2006; Fernandes et al., 2019).

The superior performance of malt bagasse containers is also justified by morphological quality criteria. The Dickson Quality Index (DQI) is widely accepted as the most complete indicator, as it integrates robustness and balanced biomass distribution (Binotto et al., 2010; Eloy et al., 2012). Our results demonstrated that seedlings in malt bagasse achieved the highest DQI (0.23) and the largest stem diameter (DC) (3.39 mm). DC is considered the most appropriate non-destructive parameter to indicate seedling quality due to its strong correlation with DQI and root dry mass (DMR) (Binotto et al., 2010; Rossa et al., 2013). Achieving a DC of 3.39 mm exceeds minimum quality standards (often above 2 mm), and the robustness conferred by this growth predicts better survival and establishment under field conditions (Eloy et al., 2012; Melo et al., 2018). The fact that malt bagasse led *L. ferrea* seedlings to reach superior quality standards in just 90 days suggests anticipation of the production cycle, which is highly advantageous for productivity in forest nurseries, reducing the residence time of seedlings, increasing turnover, and consequently increasing the overall productivity of the system (Davide and Botelho, 2015; Binotto et al., 2010; Fonseca et al., 2002; Gomes et al., 2002).

In addition to the chemical advantages, the physical characteristics of organic waste-based substrates can be relevant for enhancing seedling quality. Studies using processed malt bagasse substrates (compost and vermicompost) in vegetable crops (lettuce) observed superior root development in the nursery phase compared to chemical fertilizers (Bianco et al., 2024). This early root vigor is a strong predictor of transplanting success and reduced post-planting stress. The composition of malt bagasse is rich in protein and, especially, in lignocellulosic fibers, which account for approximately 70% of its dry matter, conferring favorable porosity and surface area. This characteristic, common to lignocellulosic residues, makes it a promising support material for biotechnological applications (Bilal et al., 2020; Chaves et al., 2021; Girelli et al., 2019).

In contrast to the malt bagasse, the poultry litter containers provided intermediate growth, although significantly better than the inert control. Although poultry litter is a source of N and organic matter, the intermediate performance observed herein may be related to its mineralization rate and the stability of the N in the compost. The decomposition of N-rich residues, such as poultry litter, is subject to high ammonification rates, which under high pH conditions (characteristic of many manures) can result in significant N losses through ammonia volatilization (Assandri et al., 2021).

Field studies on the initial growth of forest species often demonstrate that organic fertilizers, such as poultry manure, promote superior performance compared to mineral fertilizers or other compounds, especially for species such as *Schinus terebinthifolius* and *Cedrela odorata* (Souza et al., 2006). However, the high N concentration inherent to this type of residue, combined with its low C/N ratio, can induce adverse physiological effects in some species, particularly osmotic imbalances or ammonium toxicity (Britto and Kronzucker, 2002; Liu and Wirén, 2017; Primo et al., 2024). Although this effect did not drastically limit the growth of L. ferrea, a fast-growing pioneer species with high physiological plasticity, the instability and potential N losses in poultry litter via volatilization, leaching, and N_2O emissions may have reduced the effective N availability over time (Masud et al., 2020; Lin et al., 2022; Sikder et al., 2018; Bohara et al., 2018). In addition, the possible preferential allocation of N to shoots rather than roots, a well-documented response under high N availability that reduces the root-to-shoot ratio and increases aboveground biomass allocation, may further explain why its performance did not surpass the chemical and structural balance offered by malt bagasse (Feng et al., 2023; Tang et al., 2024; Menge et al., 2024).

Coconut coir fiber also showed intermediate growth results comparable to those of polypropylene. This limitation is consistent with its composition, as it is deficient in macronutrients, which naturally limits plant growth. The low calcium content in this substrate may have sometimes contributed to reduced plant height (Ebrahimi et al., 2012; Chaves et al., 2021; Tuckeldoe et al., 2023). However, the importance of coconut coir fiber lies in its exceptional physical properties, offering good drainage and high water retention and aeration capacity, constituting crucial characteristics for healthy root system development and seedling survival and success during transplantation (Tuckeldoe et al., 2023; Silva et al., 2012).

The root dry matter (DMR) assessment revealed that although malt bagasse resulted in massive aerial growth (DMR up to 6 times greater than the control), the DMR did not differ statistically from the polypropylene control. The high porosity and fibrous nature (70% fiber) of malt bagasse induce root growth through the walls. This may have led to underestimating of DMR values during collection and washing, as discussed in studies on organic substrates (Abad et al., 2001; Mathias et al., 2014). Although root penetration through the walls can make measurement difficult, it is indicative of a favorable environment for root expansion, which is a physiological advantage during field establishment.

Total dry mass (TDM) accumulation is intrinsically related to seedling robustness and vigor (Lu et al., 2021). The significantly superior performance of malt bagasse seedlings in DMS and TDM suggests greater resilience and adaptive capacity post-planting, corroborating reports that early biomass gains are good predictors of field performance (Riikonen and Luoranen, 2018).

It should additionally be considered that organic waste containers offer physical benefits in addition to nutritional support. The ability of organic containers to retain water and leached minerals (Iatauro, 2004; Ferraz et al., 2015), as well as light coloration (which can reduce excessive heating of the substrate), constitute complementary attributes that position organic waste as a superior and sustainable solution (Cavalcanti et al., 2019).

5. CONCLUSIONS

Containers made from the three organic wastes showed comparable or superior performance to polypropylene tubes in producing *Libidibia ferrea* seedlings. Malt bagasse was superior, promoting greater stem diameter, shoot and total dry mass, and Dickson Quality Index. Thus, malt bagasse represents a sustainable and technically efficient alternative to plastic containers in forest nurseries. Field studies are recommended to evaluate seedling survival and early development after transplanting, as well as the degradation dynamics of the organic containers in soil.

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Vinicius de Melo Benites: conceptualization (equal), data curation (equal), formal analysis (equal), funding acquisition (lead), investigation (lead), methodology (lead), project administration (lead), resources (equal), supervision (equal), validation (equal), writing – review & editing (equal).
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DATA AVAILABILITY

The dataset supporting the conclusions of this article is publicly available in the Zenodo repository: https://doi.org/10.5281/zenodo.19740844.

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