Reforestation by direct seeding of Gmelina arborea using seed briquettes: Composition, size and site preparation, and sowing date

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Abstract. Direct seeding is a promising technique for reforestation, but it has been poorly studied in tropical forests. The research aims to assess the briquette composition, size and site preparation, and sowing date on the seedling survival and early growth of Gmelina arborea direct seeding at 12 months in Parung Panjang, Bogor. The briquette was printed using some materials, i.e., soil, compost, charcoal, lime and tapioca as a glue, and tested in a greenhouse to obtain the optimal seed germination. The complete randomized design was used to assess the optimum seed briquette composition on germination parameters in the greenhouse, while a randomized block design was used to assess the eight combinations of briquette sizes and site preparation techniques on the seedling survival and growth. The briquette composition of soil 10%, compost 45%, rice husk charcoal 35%, lime 5%, and tapioca 5% resulted in the best germination capacity (78.5%) and other germination parameters. Gmelina arborea seed briquette, which had the size of diameter 5 cm and thickness 3 cm sowed by land clearing and briquette burial, showed the highest seedling survival (56.8%) and growth (seedling height 120.32 cm and diameter 15.92 mm) compared to other sizes. The sowing date also significantly influenced the survival of direct seeding. The application on the early-middle rainy season (the middle of December) was optimal for direct seeding because of the stable rainy frequency in Parung Panjang, Bogor. This study supports the use of direct seeding of the species being studied, but the methods could be improved to include a more significant number of species.

1. Introduction
Reforestation of degraded lands and forests requires multiple human interventions and the implementation of adequate methods. Predominant methods of tropical forest reforestation use nursery-raised tree seedlings, which has been the most common method applied in Indonesia [1, 2] and many other tropical countries [3-6]. Although this method can be a practical approach for reforestation and land rehabilitation [4, 7, 8], the approach is quite costly and labor-intensive to be adopted in large scale areas [9, 10]. The development of an alternative method with minimal inputs that can be applied to the large-scale areas has become of increasing interest. One potential alternative is to use a direct seeding as it has few cost and labor requirements than other plant establishment methods [4, 11].

Direct seeding is a simple, easily adopted and effective techniques applied for reforestation [12, 13]. However, many factors will influence the efficiency of this method, including species, seed
characteristics, microenvironmental conditions, seed and seedling predator [14 - 17]. The weather conditions following dispersal can also play a critical role in determining the success of seedling establishment and growth [18]. Some studies also stated that the technique is often not reliable [5, 19] and has some obstacles, so it requires some technological inputs, especially for improving seed germination and seedling vigor.

Seed briquette is a technology for improving seed vigor and seedling ability to survive under hard conditions. The seed briquette is developed by mixing some material, such as seed, soil, compost, lime, and other organic materials. It was adopted from seed ball [20], as a method of direct seeding in farming practice. The seed briquettes were found to improve biological control capacity [21] and increase the percentage and speed of germination [22]. The material content of seed briquette reduces the loss of water by increased water potential [23] and helps prevent the foraging of insects and birds on the seeds [20].

The purpose of the research is to assess the briquette composition, size, site preparation, and sowing date on the seedling survival and growth of Gmelina arborea direct seeding at one year of age in Parung Panjang, Bogor. The species is an economic potential fast-growing species that is adaptive to marginal sites. The G. arborea wood is one of the best tropical timbers that have a durability class of IV-V and strength class of III (II-IV). It is useful for particleboard plywood, core stock, pit probes, matches, and sawn timber for light construction, furniture, general carpentry and packaging. This species is light-demanding, tolerant of excessive drought [24], and potential for direct seeding application [25] because it has the large seed size and fast seedling growth for competing with weeds. Large seeded species and greater seed weights tend to result in better germination and establishment rates [16].

2. Materials and Methods

2.1. Materials

Gmelina arborea seed is orthodox, can be stored for a long time under moisture condition (7%-8%) [26], collected at Nagra Research Station, Bogor (106° 51'27" E, 06° 6'74" S, 280 m asl altitude). The seeds were collected in the forest floor by taking the fresh and mature fruits. Seed processing was conducted at the Forest Tree Seed Laboratory, Forest Tree Seed Technology Research and Development Center (FTSTRDC), Bogor. The seed extraction was carried out using a wet method by breaking the seed shell in the water and cleaning the pulp of fruit manually.

2.2. Location

The seed briquette composition testing was conducted at the greenhouse of FTSTRDC, Bogor (temperature 29-34° C, relative humidity 60-75%) in 2016. The seed briquette size (established in 2016) and sowing date trials (established in 2017-2018) were established at Parung Panjang Forest Research Station, FTSTRDC Bogor, West Java (06°20'42" S, 106°06'15" E, 52 m asl altitude) (Figure 1). The mean annual precipitation of the location was 2,440 mm. The soil at the site has a low level of N, P, K and C-organic with pH 4.8. The planting site is a flat area covered with dense weeds such as Imperata cylindrica, Melastoma malabathricum, Clidemia hirta, which proliferate even after cleaning [27, 28].
2.3. Experimental design and data collection

2.3.1. Seed briquette compositions. Briquetting is the process of enclosing the seed carried out by mixing several materials, i.e., soil, compost, rice husk charcoal, lime and tapioca. Soil, compost, rice husk charcoal, and lime functioned as filler materials, while tapioca had a role as an adhesive material. Seed briquettes were made with different mixing compositions of materials (Table 1) by stirring the ingredients according to the manual composition and printed in a round flattened, formed rectangular plastic with a diameter of 3 cm and thickness of 3 cm. One briquette was filled by one seed. The briquettes were dried under sunlight until dry (for two days, 09.00-14.00), and the seed briquettes were ready to apply in direct seeding.

| Code | The material composition of briquette                                      |
|------|--------------------------------------------------------------------------|
| B-0  | Seed without briquette                                                     |
| B-1  | Compost 45%, rice husk charcoal 30%, lime 20%, tapioca 5%                 |
| B-2  | Soil 10%, compost 45%, rice husk charcoal 35%, lime 5%, tapioca 5%        |
| B-3  | Soil 15%, compost 40%, rice husk charcoal 30%, lime 10%, tapioca 5%       |
| B-4  | Soil 20%, compost 40%, rice husk charcoal 25%, lime 10%, tapioca 5%       |
| B-5  | Soil 25%, compost 35%, rice husk charcoal 25%, lime 10%, tapioca 5%       |
| B-6  | Soil 20%, compost 35%, rice husk charcoal 30%, lime 10%, tapioca 5%       |
| B-7  | Soil 30%, compost 30%, rice husk charcoal 20%, lime 15%, tapioca 5%       |
| B-8  | Soil 35%, compost 30%, rice husk charcoal 15%, lime 15%, tapioca 5%       |
| B-9  | Soil 40%, compost 25%, rice husk charcoal 15%, lime 15%, tapioca 5%       |

The germination test of seed briquette was conducted in a greenhouse with soil medium Forest Seed Laboratory, FTSTRDI Bogor. A complete randomized design with four replications was used in the test. The germination using 100 seed briquettes per replication was made for 60 days and observed every two days. Parameters measured were germination percentage, speed of germination, and mean germination time [29]. The length of hypocotyl and radicle was measured at the end of the observation day (day 60th). The vigor index (total length of sprouts multiplied by germination percentage) was calculated based on [30].

2.3.2. Seed briquette size and site preparation. The best seed briquette compositions from the previous study were used for direct seeding applications at Parung Panjang Forest Research Station. A
randomized block design with four blocks and eight treatments (a combination of briquette size and site preparation) was established at Parung Panjang Forest Research Station to test the seedling survival and early growth. The eight combination treatments were: 1) seed with site cleaned, 2) seed with site cleaned and the seed was buried, 3) small seed briquette (diameter 3 cm, thickness 3 cm) with site cleaned, 4) small seed briquette (diameter 3 cm, thickness 3 cm) with site cleaned. Seed briquette was buried, 5) medium seed briquette (diameter 4 cm, thickness 3 cm) with site cleaned, 6) medium seed briquette (diameter 4 cm, thickness 3 cm) with site cleaned. Seed briquette was buried, 7) big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned, 8) big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned and seed briquette was buried. The seed and seed briquettes were sown at circle plots with a diameter of 30 cm at the spacing of 2 m x 1 m. The circle plots were cleared by removing the scrubs, grasses and litter layer. In each circle plot, four seeds or seed briquettes were sown. The total of seeds and seed briquettes sowed was 400 seeds/seed briquettes per block. After seeds were sowed and seedlings were planted, no management was performed around the plots or seedlings because the seed and seedling performance under natural conditions will be evaluated.

Survival, height and diameter were measured at the 12 months old seedlings. The survival uses the term proportion of live seedlings as the number of seedlings emerged per some seeds/seed briquette sown. Height was measured as the distance between the soil surface and the apical meristem, while diameter was measured at the collar diameter.

2.3.3. Sowing date. The sowing date trial for testing the optimal time for application of direct seeding using seed briquette was carried out at Parung Panjang Forest Research Station on November 2017-November 2018. The best performance of seed briquette from the previous study on seed briquette size and site preparation was used in the trial. Three sowing dates application were tested: 1) application at very early (before) rainy season on November 2017, 2) application at early rainy season (but the frequency was stable) on December 2017, and 3) application near the end of the rainy season on March 2018. Seedling survival was measured at 12 months old seedlings. The survival uses the term proportion of live seedlings as the number of seedlings emerged per some seeds/seed briquette sown.

2.4. Data analysis

The effects of seed briquette composition on seed germination, combined treatment on seed briquette size and site preparation, and sowing date on seedling survival and growth were assessed using SPSS (v22) for analysis of variance (ANOVA) according to complete randomized design and complete randomized block design. Percentage parameters were transformed by arcsine square-root in order to meet assumptions of normality and homogeneity of variances. Duncan's multiple range test (DMRT) was used to determine the seed germination, seedling survival, and growth differences between the treatments.

3. Result and Discussion

3.1. Seed briquette compositions

Results of analysis of variance (ANOVA) showed that germination capacity, germination speed, mean germination time, hypocotyl length, radicle length, and vigor index were significantly affected by the seed briquette compositions. The composition of B-2 (soil 10%, compost 45%, rice husk charcoal 35%, lime 5%, tapioca 5%) revealed the best performance for most of the germination parameters (Table 2).

The B-2 composition had the best five germination and vigor parameters, i.e., germination capacity, germination speed, mean germination time, radicle length and vigor index. The briquette composition without soil (B-1) revealed that the germination was not optimal. On the other hand, too much soil also affected the germination and radicle length because the briquette was more compact, which hampered the seed germination and radicle growth. In this study, optimal lime addition was reached on 5% of the briquette composition. Application of lime on seed pelleting of *Arachis*
**hypogaea** planted in an acid sand clay loam increased seedling emergence, reduced seedling mortality and enhanced plant growth [31]. At the lower pH, the roots were growing under nutrient-limiting conditions. Under such conditions, the roots, at the expense of the shoots, may use up the little available nutrients [32].

The poor germination and seedling growth (hypocotyl and radicle) of seed briquettes treated with more lime addition are difficult to explain, but the result was similar to *Arachis hypogaea*, which pelleted by CaCl₂ [30]. The response of plants to Ca concentrations was even reported that the number of dicotyledons (soybean, lupin, safflower, and sunflower) exhibited large growth responses to increase Ca concentrations up to 1000 µM when CaCl₂ was the source [33].

### 3.2. Size briquette size and site preparation

Site preparation affected micro-site conditions, which required the process of seed germination and early seedling growth [34, 35]. Moreover, seed treatment is also crucial for the success of direct seeding [36]. In this study, the combination of briquette size and site preparation affected the seedling survival significantly, but not yet influenced the early seedling growth (Table 3). SP-8 resulted in the best seedling survival (big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned and seed briquette were buried). The *G. arborea* seeds are categorized as big seeds. If the briquette is too small, it gets breaks up when the seed is germinated, and the seedling gets out of the briquette.

Compared to direct seeding without briquette, seed briquette resulted in the increase of seedling survival from 3.57% to 56.81% on the best performance (SP-8 treatment, big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned and seed briquette were buried). Seed briquette is able to protect the seeds from seed predators, and also had a role as a delivery system for a biological and chemical treatment to increase seed germination and seedling growth [36, 37]. Other studies have also found that seed pelleted by some materials can increase seed germination as in *Lycopersicon esculentum* seeds and affect the same as priming treatment [38]. The seed treatment with briquette or pellet is also believed to increase the success of direct seeding because the seed briquette is capable of improving the biological control capacity [21], increase the percentage and speed of germination and improve drought resistance [23]. The success of direct seeding is also influenced by micro-site engineering to support the occurrence of optimal germination. Micro-site engineering through land clearing can reduce direct seeding obstacles in the form of competition from weeds [39], precisely the condition of the micro-environment for germination [34, 35, 40].

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**Table 2.** Germination parameter, hypocotyl length, radicle length, and vigor index of *Gmelina arborea* seed briquette composition.

| Briquette composition | Germination capacity (%) | Germination speed (%/etmal) | Mean germination time (days) | Hypocotyl length (cm) | Radicle length (cm) | Vigor index |
|-----------------------|--------------------------|-----------------------------|-----------------------------|----------------------|---------------------|-------------|
| B-0                   | 66.7 bc                  | 4.03 a                      | 26.7 ef                     | 4.67 e               | 2.68 c              | 5.04 d      |
| B-1                   | 40.7 fg                  | 2.13 b                      | 21.2 abc                    | 5.08 e               | 3.92 bc             | 3.66 e      |
| B-2                   | **78.5 a**               | **4.10 a**                  | **18.6 a**                  | 8.45 b               | **7.49 a**          | **12.57 a** |
| B-3                   | 53.5 de                  | 2.60 b                      | 23.9 cd                     | **9.44 a**           | **8.26 a**          | **9.52 b**  |
| B-4                   | 45.5 ef                  | 2.30 b                      | 23.2 bcd                    | 5.86 cd              | 4.96 b              | 4.92 d      |
| B-5                   | 74.0 ab                  | 4.30 a                      | 20.7 ab                     | **9.30 a**           | **8.10 a**          | **12.93 a** |
| B-6                   | 58.0 cd                  | 1.03 c                      | 24.2 de                     | 6.40 c               | 7.44 a              | 6.61 c      |
| B-7                   | 38.2 fg                  | 1.05 c                      | 29.6 g                      | 5.16 de              | 4.22 bc             | 3.57 e      |
| B-8                   | 30.2 g                   | 1.03 c                      | 27.0 f                      | 4.91 e               | 3.90 bc             | 2.69 e      |
| B-9                   | 31.7 g                   | 1.04 c                      | 26.6 ef                     | 8.90 ab              | 5.02 b              | 4.96 d      |
| F-hit                 | 21.51**                  | 9.02**                      | 14.78**                     | 60.34**              | 9.28**              | 105.10**    |

Notes: See Table 1 for the information of briquette compositions; Values followed by the same letter in the same column are not significantly different at 95% confidence level; ** = significantly different at 99%
Table 3. Seedling survival and early growth of direct seeding of *Gmelina arborea* using different sizes of briquette and size preparation at Parung Panjang, Bogor.

| Treatments | Seedling survival (%) | Seedling height (cm) | Seedling root collar diameter (mm) |
|------------|-----------------------|----------------------|-----------------------------------|
| SP-1       | 3.57 d                | 81.25±64.33          | 10.44±9.52                        |
| SP-2       | 15.90 cd              | 88.46±22.39          | 10.63±4.81                        |
| SP-3       | 33.75 b               | 101.29±41.69         | 12.22±7.63                        |
| SP-4       | 28.81 bc              | 93.96±35.76          | 12.18±5.97                        |
| SP-5       | 35.45 b               | 107.03±34.11         | 14.58±7.90                        |
| SP-6       | 38.33 b               | 119.12±148.98        | 12.03±9.07                        |
| SP-7       | 38.63 b               | 103.36±31.21         | 13.65±6.76                        |
| SP-8       | 56.81 a               | 120.32±38.96         | 15.92±8.24                        |

F test:
- Treatment: 9.271**
- Block: 0.687ns

Notes: SP-1 = seed with site cleaned; SP-2 = seed with site cleaned and the seed were buried; SP-3 = small seed briquette (diameter 3 cm, thickness 3 cm) with site cleaned; SP-4 = small seed briquette (diameter 3 cm, thickness 3 cm) with site cleaned and seed briquette was buried; SP-5 = medium seed briquette (diameter 4 cm, thickness 3 cm) with site cleaned; SP-6 = medium seed briquette (diameter 4 cm, thickness 3 cm) with site cleaned and seed briquette was buried; SP-7 = big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned; SP-8 = big seed briquette (diameter 5 cm, thickness 3 cm) with site cleaned and seed briquette were buried; Values followed by the same letter in the same column are not significantly different at 95% confidence level; ** = significantly different at 99%; * = significantly different at 95%, ns = not significantly different.

3.3. Sowing date of seed briquette

Seed germination and seedling growth are uncertain stages in the plant life cycle [41]. The mortality at the stage can be caused by different factors, such as seed predation, competition, and abiotic factors (extreme temperatures, frost, drought, and sun scorch). The time of seeding is one crucial factor that affects the abiotic factor for optimal germination [42, 43]. In this research, the optimal sowing date at Parung Panjang Forest Research Station was in the middle of December when the precipitation intensity was stable. Direct seeding using seed briquette on time resulted in the seedling survival of 58%. Seeding should occur when site environmental conditions are the least stressful [44]. The best time for seeding is when they have the best chance of germination, which means plentiful moisture, optimum temperature, minimal weed competition, and a potentially favorable growing season before exposure to stressful environmental conditions [45].

Previous researches have indicated that sowing time resulted in the differences in germination and survival among the different sowing times on *Acacia pycnantha*, *A. acinacea*, and *Eucalyptus microcarpa* [46], *Pinus palustris* [47] and *Quercus* spp. [48]. Ultimately, the sowing date of direct seeding is dictated by the time of year, providing the best chance of maintaining consistently the optimum environmental conditions that once seeds germinate, young seedlings avoid planting stress and become established. In the tropical dry forests planting seeds when the soil has enough moisture in the rainy season can increase seedling establishment [38]. Just like planted seedlings, young seedlings from direct seeding need to grow a root system into the soil to achieve a proper water balance as they become coupled with the hydrologic cycle of the planting site [49, 50].
Figure 2. Precipitation pattern and its effect on the seedling survival of *Gmelina arborea* direct seeding after 12 months after sowing.
4. Conclusion
Seed briquette can be an important complementary technology that can eliminate the risks associated with direct seeding practices. Seed briquette combination which gave the optimal germination was composed of soil 10%, compost 45%, rice husk charcoal 35%, lime 5%, and tapioca 5%, resulted in the seed germination of 78.5%. Seed briquette size and site preparation affected seedling survival and early growth (seedling height and collar diameter) of *G. arborea*. The combination treatments of big seed briquette (diameter 5 cm, thickness 3 cm) and site preparation (site clearing and seed briquette were buried) resulted in the best performance of the direct seeding of *G. arborea*. Considering the success of direct seeding is related to seed mass, that sowing date is suggested to be conducted on stable precipitation intensity, not in the very early rainy season or late rainy season. In Parung Panjang, Bogor, the optimum sowing date is in the middle of December. Future research should determine how the effect of microorganisms (arbuscular mycorrhiza (AM fungi) and endophyte fungi) on the success of direct seeding. Finally, this experiment was conducted for only 12 months, which is a relatively short time in the life of a forest. Long-term trials should be conducted to improve further understanding of how direct seeding using seed briquette can contribute to forest regeneration.

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