The Fabrication and Performance of Plantable Bio-Pots from Thick Sheets of Oil Palm Trunk

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The oil palm trunk contains great nutrients for plant growth, and its supporting cells are mostly parallel to the centerline. This study investigated the fabrication of a plantable bio-pot from 5 mm thick sheets of oil palm trunk. The effects of the three zones in the trunk (outer, middle, and inner) and the pressing mold temperature in the range from 160 °C to 200 °C on characteristics of a bio-pot were evaluated. The results demonstrated that the outer zone of an oil palm trunk with 200 °C molding temperature had the highest ultimate compression load, and the pot shape appeared stable after soaking in water for 24 h, showing 105% water absorption. The changes to oil palm trunk chemistry caused by elevated temperature contributed to the mechanical properties and improved durability. The oil palm trunk plantable bio-pots facilitated germination of chili and eggplant seeds. The leaf number, leaf greenness, plant height, and total dry biomass had no significant difference between using the oil palm trunk bio-pot and a plastic pot for a seedling of either of these plants.

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INTRODUCTION

The interest in eco-friendly planting devices for home gardening has been increasing, along with the demand for biodegradable pots (Folino *et al.* 2020). The biodegradable pots or bio-pots fall into two types: compostable bio-pots and plantable bio-pots. The compostable bio-pots are usually made of bioplastics and have strong walls that prevent the growth of the plant roots, and it is necessary to take the plant seedling out before planting in garden soil. The used pot is then decomposed separately. In contrast, the plantable bio-pot can be transplanted altogether into a larger container or garden soil without disturbing the root system of plant seedling or a young plant, and it returns nutrients to the soil by decomposing, leaving no waste (Sandak *et al.* 2019; Tomadoni *et al.* 2020). Generally, a plantable bio-pot is produced from lignocellulosic materials, such as agro-industrial wastes and agricultural residues. These materials are normally comminuted to particles or fiber bunches before molding to pot shape. The molding can be by cold or hot pressing, depending on the binder type used. The kinds of raw materials used to make plantable bio-containers influence the mechanical strength of the pot and the plant's growth (Saffian *et al.* 2016; Zhang *et al.* 2019; Juanga-Labayen and Yuan 2021).

The felled oil palm trunk is raw material available in large quantities from oil palm plantations, with a good nutrient reserve for plant growth, especially of potassium and nitrogen. Previous studies have reported that the nutrient concentration in the felled oil palm trunk includes 1.86% potassium, 0.58% nitrogen, 0.06% phosphorus, 0.38% calcium, and 0.15% magnesium based on dry weight (Khalid *et al.* 2000; Uke *et al.* 2021). Those contents in oil palm trunk are similar to the nutrient contents in typical raw materials for producing commercial bio-pots, such as coconut coir (Xiong *et al.* 2017; Iriany *et al.* 2020). So, oil palm trunk is a possible alternative raw material for the fabrication of plantable bio-pots, and its nutrients can also serve plant growth and be recycled back into the soil by allowing the material to decompose in soil (Ainon *et al.* 2011).

In addition, the oil palm trees are classified as monocots. The morphology of trunk in a cross section clearly displays vascular bundle cells surrounded by parenchyma cells. The vascular bundle cells are the main supporting cells mostly parallel to axis of the trunk. The portion between vascular bundle cells and parenchyma cells plays a key role in determining the physical and mechanical bulk properties, as well as the chemical composition (Darwis *et al*. 2013; Choowang *et al.* 2019). The largest proportion of vascular bundle cells is found in the outer zone of trunk, and their prevalence gradually decreases towards center of the trunk, while the wood bulk density simultaneously drops from 420 kg/m^3 to 270 kg/m^3 on coming from the outer zone to the inner zone of trunk (Srivaro *et al.* 2018). The cell arrangement in the oil palm trunk, discussed above, is useful for modifying its properties by thermal compression (Choowang and Hiziroglu 2015; Hamzah *et al.* 2017; Muzakir *et al.* 2020). The cells in oil palm lumber easily collapse under compression perpendicular to the grain, improving both density and mechanical properties. Heat and moisture enhance the dimensional stability of the thermally compressed oil palm lumber (Hartono *et al.* 2016). The abundant carbohydrate polymers cellulose, hemicellulose and starch in an oil palm trunk are also helpful to self-bonding during hot pressing (Boon *et al.* 2019; Choowang *et al.* 2019).

Hence, the aim of this study was to investigate the fabrication of a plantable bio-pot from a 5 mm thick transverse sheet of oil palm trunk without adding binder, instead of using the particulate or fibrous intermediate products for plantable bio-pot production. The fabrication of oil palm trunk plantable bio-pots was done as described in a previous study by Choowang and Suklueng (2019). According to the density distribution in the oil palm trunk, the three zones of the trunk were reshaped under different temperatures of a hot metal mold tray, under a fixed pressure and duration of compression, and were evaluated. The pot making conditions that gave the best characteristics were further analyzed for biodegradation and nutrient content of the product. The growth of bird chili (*Capsicum annuum* 'Super-hot2 F1') and Thai eggplant (*Solanum virginianum* 'Yhadthip F1') in the oil palm trunk bio-pots was compared with those in commercial plastic pots.

EXPERIMENTAL

Material

This study utilized 24-year-old oil palm trees from a local plantation in Surat Thai province, in southern peninsular Thailand. The two oil palm trees that have the same height of the trunk (around 11 meters) were chosen for raw material preparation. Each felled tree was cut down at 0.5 meters above the ground and cut into 1 meter long logs. The logs had diameters in the range from 37 to 43 cm, obtained from part of trunk 3 to 5 meters above the cut down zone, and were sawn into 1.5 inch thick lumber following a polygonal sawing pattern to separate the trunk into outer, middle, and inner zones, according to the density distribution in cross section of the stem (Choowang 2018). The green lumber was air-dried to a moisture content below 20%. The lumber was planed and sliced parallel to grain into 5 mm thick sheets. The oil palm trunk sheets had 5 mm thickness in radial direction, 6.5 mm width in the tangential direction, and 160 mm length in the longitudinal direction.

Oil Palm Trunk Plantable Bio-pot Preparation

The self-designed metal mold tray fixed to a laboratory hot press was used for reforming the 5 mm thick sheets of oil palm trunk to pot shape. The oil palm trunk plantable bio-pot mold compression process is shown in Fig. 1. The oil palm trunk sheets at moisture content in the range from 15 to 20% were inserted between the upper and lower parts of the hot metal mold tray warmed to a target temperature of 160, 180, or 200 °C. Two sheets of oil palm trunk were arranged to have crossed grain directions for making one bio-pot. Four bio-pots were compressed at the same time in one hot mold compression run. The hot mold compression step was adapted from a previous study (Choowang and Suklueng 2019). The mold at target temperature was fixed in a laboratory hot press and slowly pressed to reform two sheets of oil palm trunk to pot shape, until the maximum pressure of 50 kg/cm^2 that was held for 3 min. After that the pressure was reduced to open the mold gap for allowing the steam to vent out for around 30 seconds. The pressure was then again raised to 50 kg/cm^2. The oil palm trunk plantable bio-pot was taken out after completing a total pressing time of 8 min. The edges of the oil palm trunk plantable bio-pots were trimmed as the last preparation step. Each zone of the oil palm trunk was tested with the same process. Then all the finished oil palm trunk plantable bio-pots were kept in a sealed plastic box at room temperature until further testing.

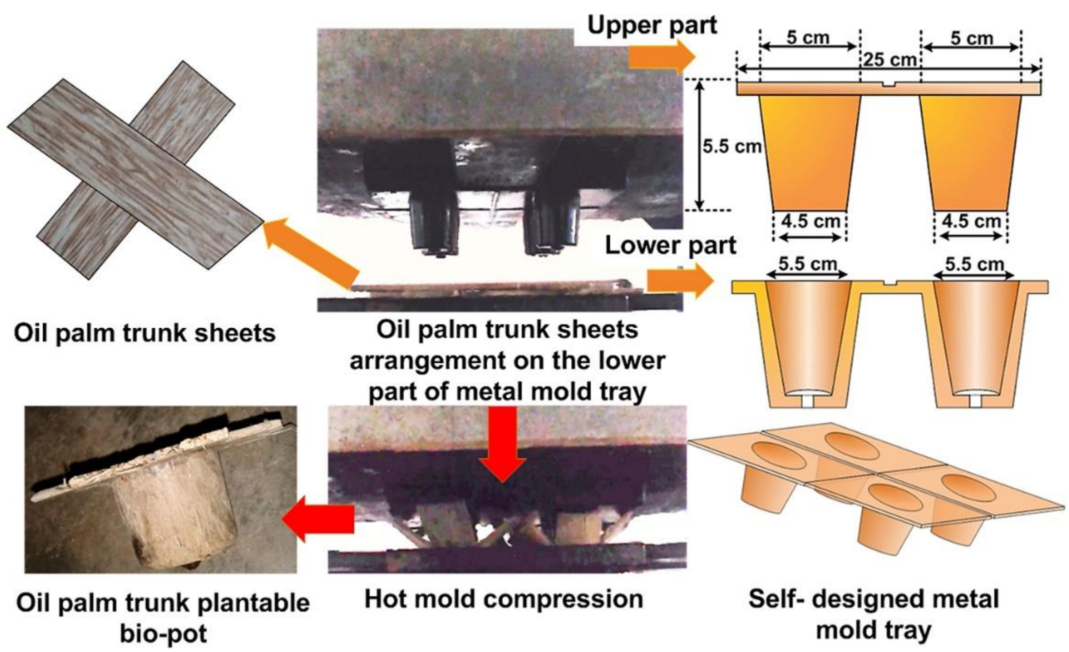

Fig. 1. Pictorial explanation of the oil palm trunk plantable bio-pot mold compression process

Characterization of Oil Palm Trunk Plantable Bio-Pots

Mechanical and other physical properties

A universal testing machine (Lloyd Instruments Ltd, Fareham, Hampshire, UK) was used to test the mechanical properties, by compression testing of oil palm trunk plantable bio-pots. For this, 10 pots of each part of the trunk and mold pressing temperature were conditioned at 20 °C and 65% relative humidity in the conditioning chamber until constant weight. The conditioned oil palm trunk plantable bio-pots were placed upside down on the base block of the testing machine. The crosshead was run at a constant 0.26 in/min speed to load the bottom of pot until the ultimate compression load dropped by 20%, due to the plantable bio-pot being damaged. The ultimate compression load (N) was reported as a mechanical property. As a physical property, water absorption after immersion was also investigated. All parts of the oil palm trunk that were prepared to plantable bio-pots with a variety of pressing temperatures were dried in a hot air-oven at 103 °C until constant weight. The oven dried bio-pots were immersed in cold water at 20 ± 3 °C for 2 h or for 24 h. The weight of oil palm trunk bio-pot was measured before and after soaking in the water for calculating the water absorption as follows,

$$\% A = [(A_1 - A_0)/ A_0] \times 100 \tag{1}$$

where A is water absorption (%), A_0 is the oven dry weight from hot air oven at 103 °C until constant weight, of oil palm trunk plantable bio-pot before soaking in water (g), and A_1 is the weight of wet oil palm trunk bio-pot after soaking in water for 2 h or 24 h (g). The physical property tests of the oil palm trunk plantable bio-pots were done with 10 replications.

Biodegradation and nutrition content evaluation

The oil palm trunk plantable bio-pots that showed the maximum mechanical properties and fixed pot shape after physical property testing were chosen for biodegradation testing, assessed from weight losses in two stages, namely plant seedling pot growth and planting in the soil. The 60 plantable bio-pots were each given equal amount of nursery material, mixed from sand, coconut flakes and chaff charcoal in the same portion (by volume). The plantable bio-pot with nursery material was daily irrigated in the morning and in the evening. After 50 days, the 30 bio-pots were randomly selected for assessing the durability in seedling stage use. The remaining plantable bio-pots were embedded in soil for 30 days before measuring their weight losses in the planting stage. The weight losses in both these stages were calculated as follows

$$\% ML = [(W_0 - W_1)/ W_0] \times 100 \tag{2}$$

where ML is the weight loss (%), W_0 is the oven dry weight from hot air-oven at 103 °C at constant weight, of original plantable bio-pot (g), W_1 is the oven dry constant weight from hot air-oven at 103 °C of plantable bio-pot after the biodegradation testing (g), as recorded for seedling and planting stages.

Furthermore, the oil palm trunk raw material and the oil palm trunk plantable bio-pot after biodegradation testing were also analyzed for contents of potassium, nitrogen, and phosphorus, the main nutrients necessary for plant growth. The concentrations of potassium and phosphorus were measured using a spectrometer (Spectroquant Pharo 300, Merck Millipore, Darmstadt, Germany) at 690 nm. An N/protein (CE Instruments Flash EA 1112 Series, Thermo Quest, Milan, Italy) analyzer was employed in the nitrogen content analysis.

Plant Growth Evaluation

The growths of bird chili (*Capsicum annuum* ‘Super-hot2 F1’) and Thai eggplant (*Solanum virginianum* ‘Yhadthip F1’) of East-West seed brand (East West Seed International Co Ltd, Nonthaburi, Thailand) were evaluated. Firstly, the 50 pots of oil palm trunk plantable bio-pots and the plastic pots with a similarly capacity were given equal amounts of nursery material (same as in biodegradation analysis) as shown in Fig. 2. Each pot was implanted with one seed of either bird chili or Thai eggplant. Watering was applied two times per day for 40 days. After 40 days, 25 samples of young plants in both containers that showed 4 to 5 foliage leaves were transplanted in the soil with 15 cm spacing between the young plants. They were still daily irrigated. The plastic pots were removed before planting the young plants into the soil, while the young plants together with their oil palm trunk plantable bio-pots were transplanted into the soil.

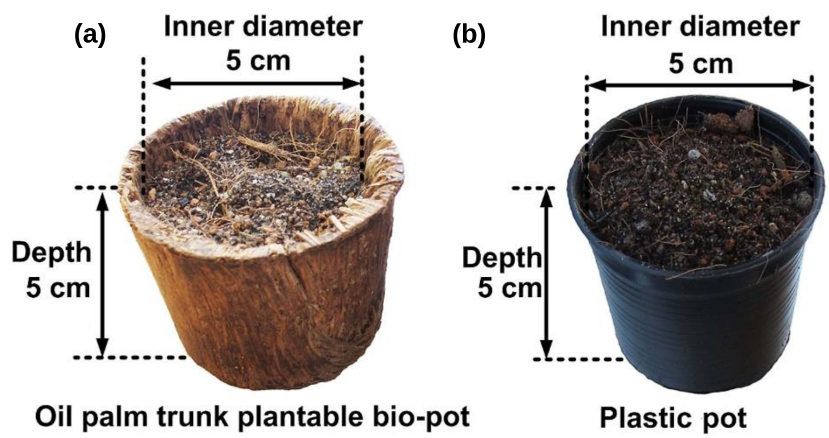

Fig. 2. The dimensions and preparation of the oil palm trunk plantable bio-pots (a), and of plastic pots (b) for plant growth evaluation

The growths of bird chili and Thai eggplant were considered from seed germination, leaf number, leaf greenness, plant height and total dry biomass.

The seed germination was assessed each 10 days from 10 days on until transplanting into the soil. The seed germination success was calculated by equation (3)

$$\% SG = (S_1 / S_0) \times 100 \quad (3)$$

where SG is the seed germination (%), S_0 is number of total seeds, and S_1 is number of germinated seeds.

After 20 days, the leaves of the chili or the eggplant were counted. The sample was a randomly selected 25 pots at each 10 days of counting the leaves, and the plant height (cm) was also measured. Five pots of young plants were taken for measuring the leaf greenness that represented the chlorophyll content, to the SPAD (Soil Plant Analysis Development) unit. The leaf greenness was determined using a chlorophyll meter (SPAD-502, Minolta Camera Co., Osaka, Japan), while the total dry biomass (g) was assessed after the experiments run for 20, 40, 50, and 80 days. All parts of the young plants were cleaned and dried in a hot air oven at 103 ± 3 °C until constant weight. Finally, the dry biomass of these plants was recorded. Each total dry biomass measurement was also done with 5 replications.

RESULTS AND DISCUSSION

Oil Palm Trunk Plantable Bio-Pot Characterization

All zones of the oil palm trunk were tested with gradual reshaping under hot compression by a metal mold tray, to form them into pot shapes, and they maintained their shape after pressure was removed, with two pieces of oil palm trunk joined together in each pot. The softening of chemical components in oil palm trunks was activated by the steam vapor from moisture in the trunk during hot compression. This promoted an arrangement with vascular bundle cells that were almost perpendicular to the compression load to reform following the mold shape. The increasing contact area between oil palm sheets especially at the bottom area of the pot mold caused cell interlocking. In addition, the carbohydrate polymers and lignin in hot and moist conditions reacted as natural adhesives and supported the cross-linking of the two oil palm sheets and fixing them in pot shape (Boon *et al.* 2019; Choowang and Luengchavanon 2021).

Figure 3 reveals that the ultimate compression load of oil palm trunk plantable bio-pot depended on the zone of trunk and mold temperature. The failure of the oil palm trunk plantable bio-pots under compression testing mostly occurred from vascular bundle cells that collapsed and split. The bonding area of oil palm trunk sheets at the sidewall was separated, as shown in Fig 3(a). The outer zone of the oil palm trunk is composed with a rich portion of the vascular bundle cells that contribute to the density and strength of the trunk (Srivaro *et al.* 2018). So, the plantable bio-pots fabricated from the outer zone of the oil palm trunk gave the highest average ultimate compression loads over others zones of trunk. The outer zone of trunk in pot shape showed the average ultimate compression loads of 1019.29 N, 1408.68 N, and 1327.73 N when molded at temperatures of 160, 180, and 200 °C, respectively. Increasing the mold temperature enhanced the average ultimate compression load of the oil palm trunk plantable bio-pot, especially on using the outer and middle zones of trunk. Unfortunately, the mold temperatures tested did not significantly affect the ultimate compression load for the inner part of the trunk, giving an ultimate compression load of only 353.67 N on using 160 °C mold temperature. This is because the inner part of an oil palm trunk has the lowest density and only a small portion of vascular bundle cells. Besides, the cellulose and lignin that contribute to strength and rigidity of wood, respectively, are also low in the inner part compared to other zones of the trunk (Choowang *et al.* 2019).

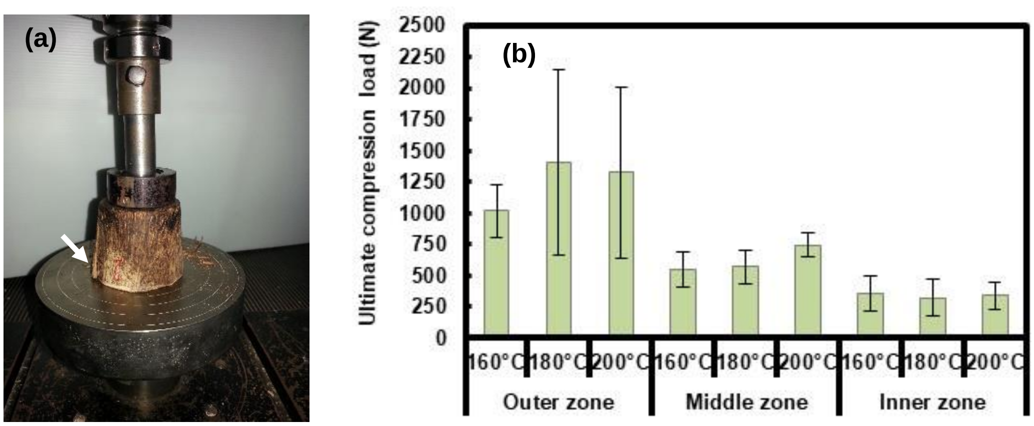

Fig. 3. The compression testing of oil palm trunk plantable bio-pot (a) and the ultimate compression load by part of oil palm trunk plantable bio-pot and secondarily by mold temperature

According to the results shown in Fig. 3(b), the increase in ultimate compression load with mold temperature was supported by the changes in oil palm trunk's chemistry at elevated temperatures. The hemicellulose is degraded to smaller sugar monomers that further link with lignin, increasing the apparent lignin content, while the amorphous regions of cellulose are restructured to a crystalline state (Komariah *et al.* 2021). These chemical effects during hot compression also promoted dimensional stability of oil palm trunk plantable bio-pots. Figure 4 (a) reveals that the outer zone of oil palm had good shape stability after soaking in the water for 24 h, especially after being compressed at 200 °C. All cases using the middle and inner parts of oil palm trunk in plantable bio-pots were damaged by the cells swelling when immersed in water.

Figure 4 (b) summarizes the water absorption by oil palm trunk plantable bio-pots. The inner part of the oil palm trunk gave the highest water absorption, similar to a prior study (Choowang and Suklueng 2019). The inner part of the trunk has starch granules in parenchyma cells that contributed to its hydrophilic behavior as plantable bio-pot (Choowang *et al.* 2019).

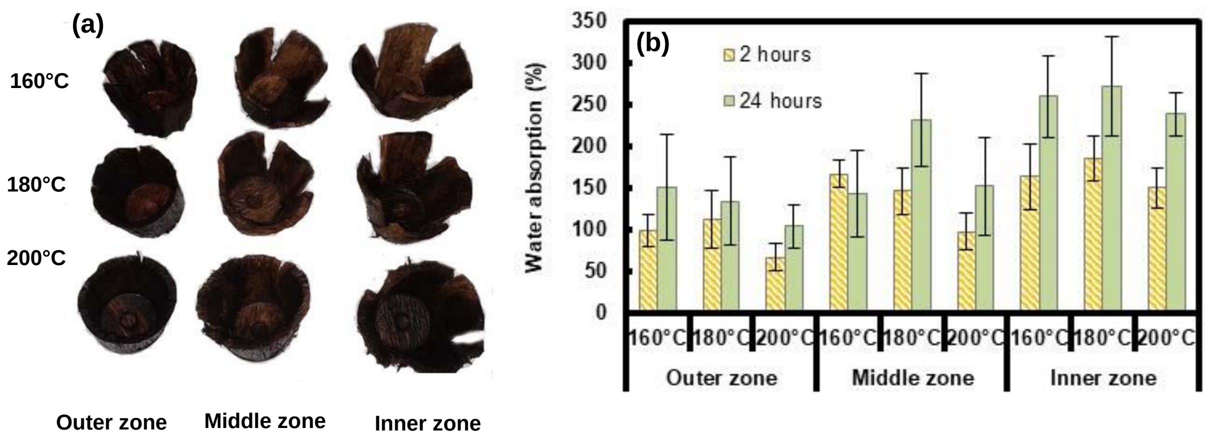

Fig. 4. The physical properties by zone of oil palm trunk used to make plantable bio-pots, also arranged by mold temperature. Oil palm trunk plantable bio-pot shapes after soaking in water for 24 h (a), and water absorption (b) after soaking in water for 2 or 24 h

The biodegradable pots need good mechanical properties for transportation during the marketing phase. However, biodegradable pots often show an inverse relationship between the degradation rate and the mechanical properties (Castronuovo *et al.* 2015), as do the oil palm trunk plantable bio-pots. Among the mechanical and other physical properties, the outer zone of oil palm trunk plantable bio-pot molded at 200 °C was chosen for assessment of biodegradation and nutrition content. The weight losses at the two stages of bio-pot use were slightly different. In the seedling stage the average weight loss was 7.15% and it increased to 7.43% after transplanting into the soil for 30 days, which can be compared to the previous report of Khalid and co-authors (2000). They found that oil palm trunk residues are degraded by less than 20% after being left in the field for 60 days. The loss of carbohydrates and the generation of toxic chemicals such as furfural in elevated temperature inhibit degradation by fungi and insects (Saliman *et al.* 2017; Hao *et al.* 2021). However, some fungal growth was visually observed on surfaces of the oil palm trunk bio-pots. The comparatively short biodegradation testing in this study did not affect the degradation of inorganic compounds in the oil palm trunk, mainly phosphorus, nitrogen, and potassium as shown in Table 1. The nutrients in the outer zone of oil palm trunk raw material included 1.31% phosphorus, 0.22% nitrogen, and 0.081% potassium based on the total dry weight. Possibly the increased phosphorus and nitrogen contents in the outer zone of oil palm trunk plantable bio-pot compressed at 200 °C after biodegradation testing were caused by the degradation and loss of other components. A previous study reported that some amount of hemicellulose, starch and extractives in oil palm particles are lost after the particles are steamed in an autoclave at 160 °C under 35 psi several times (Boon *et al.* 2019).

Table 1. Nutrient Concentration in Oil Palm Trunk and Its Plantable Bio-Pot

Material	Nutrient Concentration (% based on total dry weight)		
	Phosphorus	Nitrogen	Potassium
Outer part oil palm trunk raw material	1.31 (0.49)	0.22 (0.03)	0.081(0.038)
Outer part of oil palm trunk plantable bio-pot compressed at 200°C after durability testing	1.50 (0.06)	0.34 (0.01)	0.071(0.002)

Values in parentheses are standard deviations

Plant Growth Assignment

The moisture content is an important factor affecting seed germination *via* softening of the seed coat and allowing mobility of nutrients (Pipinis *et al.* 2020). According to the physical properties, oil palm trunk plantable bio-pot has a good ability to absorb and retain water, and it clearly performed well in seed germination of bird chili and Thai eggplant seeds, as shown in Fig. 5. After 10 days, the bird chili and Thai eggplant seeds were germinated by 38% and 54% respectively, on using the oil palm trunk plantable bio-pot as seedling container. Seedlings of bird chili and Thai eggplant in the plastic pots only germinated by 11% and 8%, respectively.

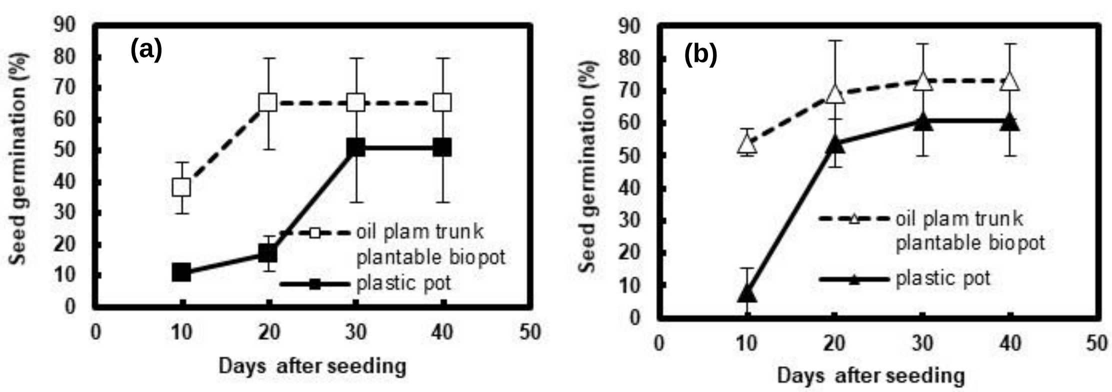

Fig. 5. The seed germination of bird chili (*Capsicum annuum* ‘Super-hot2 F1’) (a), and Thai eggplant (*Solanum virginianum* ‘Yhadthip F1’) (b), by using oil palm trunk plantable bio-pots or plastic pots (see legend in plot)

Figure 6 presents the leaf number, leaf greenness, plant height, and total dry biomass of bird chili and Thai eggplant on using oil palm trunk plantable bio-pot or plastic pot as seedling container from the seedling period (10 to 40 days) to transplanting into the soil (50 to 80 days). The leaf number, leaf greenness, plant height and total dry biomass of the plants did not differ between using an oil palm trunk plantable bio-pot or a plastic pot especially for the seedling period.

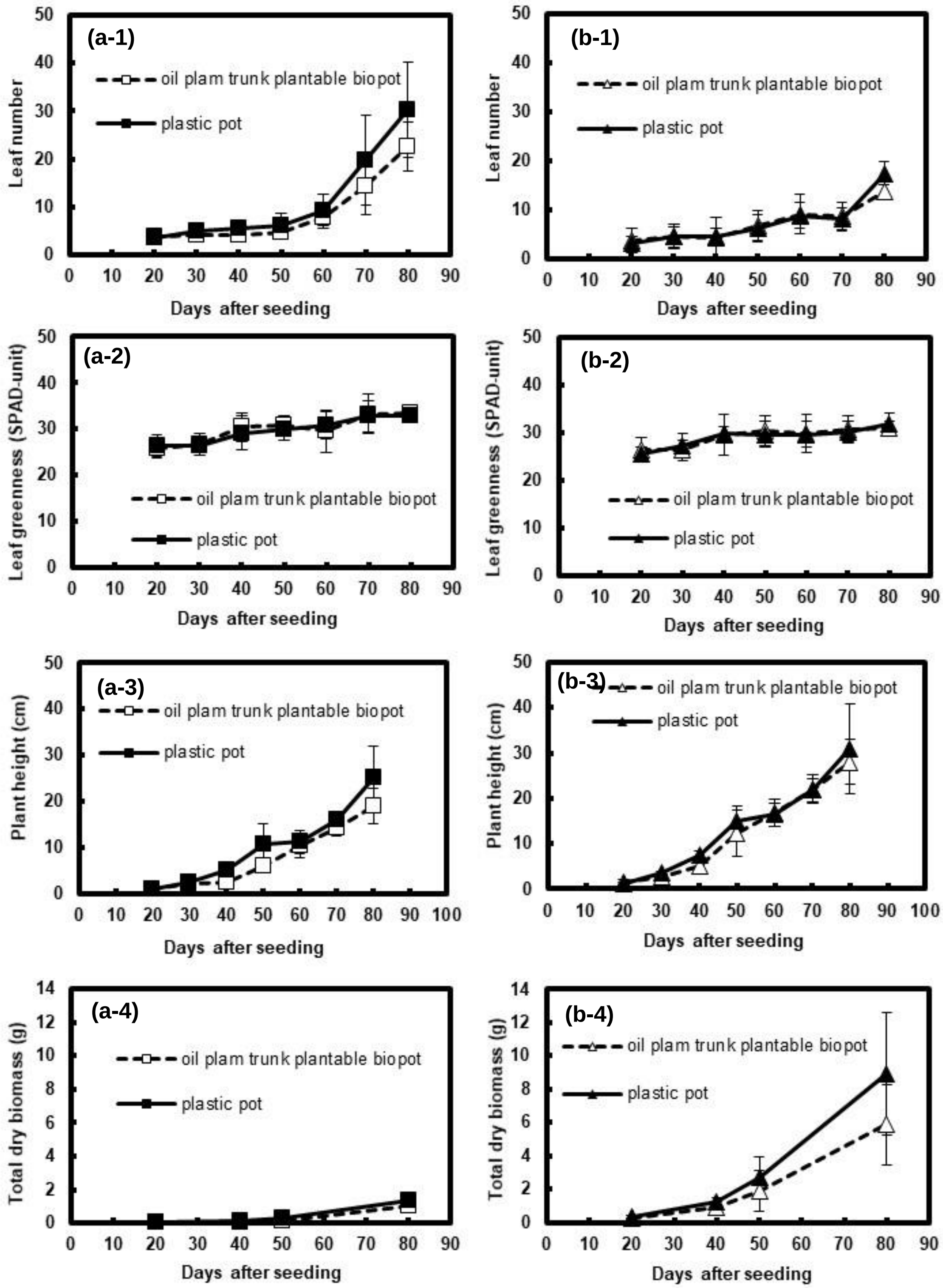

Fig. 6. Leaf number, leaf greenness, and plant height, and the total dry biomass of bird chili (*Capsicum annuum* 'Super-hot2 F1') (a), and Thai eggplant (*Solanum virginianum* 'Yhadthip F1') (b) on using oil palm trunk plantable bio-pots compared with plastic pots.

The results are related to the previous study of Iriany and coauthors (2020). They found that the growth of chili (*Capsicum annum*) seedling in the bio-pot prepared from water hyacinth petiole mixed with coconut coir was similar with seedlings in the polybag. In this current study, the oil palm trunk plantable bio-pot and plastic pot had similar volumes, inside diameters, and depths, which are the main factors affecting the seedling growth.

Observably, the plant height and total dry biomass of bird chili and Thai eggplant were slightly lesser with oil palm trunk plantable bio-pots than with plastic pots, especially during the transplanting period (50 days after seedling) as shown in Fig. 6 (a-3, b-3, a-4, b-4). Possibly the side wall of oil palm trunk bio-pot functioned as a strong barrier inhibiting expansion of plant roots, and the plants access to nitrogen might depend on fungi that rarely grow on the walls of oil palm trunk bio-pot (Uke *et al.* 2021). The roots of bird chili and Thai eggplant at 40 days after seeding were circling inside the plastic pots, while they could directly extend into the soil to collect nutrients after transplanting without the plastic pots (Fig. 7a). Young plants grown in oil palm plantable bio-pot had roots mostly grown through the degradation zone of oil palm plantable bio-pot walls, as seen in Fig. 7 (b) and (c). It is observed that the parenchyma cells with a high amount of starch could be degraded more easily than the vascular bundle cells.

Fig. 7. The growth in circles of bird chili roots in the plastic pot (a), and the Thai eggplant's roots grown through the walls of an oil palm trunk plantable bio-pot (b and c).

CONCLUSIONS

1. 5-mm thick slices from oil palm trunk were formed to pot shape. The zone of oil palm trunk used and the mold temperature strongly affected properties of the plantable bio-pots.
2. The vascular bundle cells and chemical effects of hot pressing improved the ultimate compression strength and water absorption of oil palm trunk plantable bio-pots. The outer zone of trunk with 200 °C mold temperature was the best case among those tested.
3. The use of outer trunk zone compressed at the high mold temperature of 200 °C strongly retarded biodegradation of the oil palm trunk plantable bio-pots, giving only 7.43% weight loss in the test method used. This weight loss might be caused by the degradation of carbohydrate polymers. The main nutrients were not reduced.

4. The growth of bird chili and Thai eggplants in oil plan trunk plantable bio-pots did not differ from that in plastic pots. The water absorption and retention by plantable bio-pots facilitated seed germination, while the strong walls of plantable bio-pots inhibited root growth after transplanting the young plant into soil with pot left on.
5. To quicken the degradation of oil palm trunk bio-pots and improve the growth of plant roots through the pot walls, thickness of the oil palm trunk sheet could be reduced, and the side walls of pots could be perforated in a future study.

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