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Effects of different spacing and polybag sizes on growth of oil palm (*Elaeis guineensis* Jacq.) seedlings in the main nursery

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Abstract. The significance of regulating spacing and polybag size in the primary oil palm nursery lies in ensuring an optimal growth environment for uniform and healthy seedlings. However, current recommendations provide limited quantitative evidence on how reduced spacing and smaller polybags influence seedling performance, leaving gap in a practical nursery management guideline. Therefore, an experiment was carried out in the oil palm main nursery to evaluate different spacing design and polybag sizes up to 14 months after planting (MAP). The spacing arrangement of seedlings significantly affected their growth performance compared to polybag sizes. Spacing below 0.75 m produced tall and etiolated seedlings, with height increasingly by 19.60% at 8 MAP and up to 32.00%at 12 to 14 MAP, accompanied by excessively elongated rachis length which made them unsuitable for field planting and problematic for nursery handling. In contrast, using smaller polybag size of 30 cm × 38 cm (12" × 15") resulted in only minor growth differences compared to the standard polybag, with no negative effect on seedling performance or nutrient content up to 12 MAP. There are specific needs for optimum seedling performance unrestricted by growth competition, minimal risk of etiolation, good survival rate, easy nursery maintenance, and reduced maintenance costs for higher profits. Based on current research findings, seedlings considered appropriate for field planting at 10 to 12 MAP must meet some specific criteria; including a bole diameter ranging between 49 to 64 mm, a total frond production between 11 to 15 per seedling, rachis length of frond 3 between 58 to 93 cm, seedling height within the range of 118 to 179 cm, and a petiole cross-section between 1.48 to 2.10 cm^2. These findings support the importance of maintaining acceptable spacing while supporting the use of smaller polybags to reduce costs without compromising seedling quality.

Key words: oil palm nursery, oil palm seedling, polybag sizes, polybag spacing.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) remains one of the world's most productive source of vegetable oil and vital commodity for the food, biofuel, and oleochemical industries. In Malaysia, a major producing country, the crop's economic contribution is substantial, with export earnings reaching RM 109.39 billion in 2024, highlighting its critical role in the national and global agricultural economy (Parveez et al., 2025). Oil palm's high oil yield per unit area makes it essential for meeting the growing global demand for fats and oils. Therefore, optimising its cultivation from the earliest nursery stages is crucial for maintaining productivity and supporting long-term industry competitiveness.

Oil palm nursery is the initiating link in the palm oil supply chain and the foundation for every successful oil palm plantation (Mutert et al., 1999; Mohd Rais, 2021). The production of superior and healthy oil palm seedlings has the potential for sustaining large oil yields for 25 years or more (Mutert et al., 1999; Mohd Rais, 2021). Good nursery management during seedling cultivation with proper planning and handling should be maintained at the highest standard to ensure healthy, vigorous, and uniform oil palm seedlings (Hassan et al., 2023). Furthermore, reducing the high rate of seedling mortality also keeps production costs low and increases profit (Mutert et al., 1999; Mohd Rais, 2021).

In 2007, MPOB introduced the MPOB Code of Practice (CoP) to emphasize the significance of high-quality planting materials and sound agricultural techniques in oil palm plantations (Bernama, 2017). This comprehensive Code outlines essential elements necessary for meeting the requirements of various activities and ensuring compliance with standards to meet user needs. The CoP comprises seven distinct guidelines tailored to different stages along the palm oil supply chain, including nurseries, estates, smallholders, mills, refineries, and bulking installations for handling palm and palm kernel oil. Notably, the Code of Good Nursery Practice for Oil Palm Nurseries (CoPN) was specifically introduced in July 2012 to address nursery-related practices (Ahmad et al., 2022). The CoPN provides guidelines that cover the aspects of growing oil palm planting materials in the nursery, from the point of germinated seeds or ramets received, until they are ready for field planting (MPOB, 2016; Mohd Rais, 2021).

The importance of polybag spacing and size at the main nursery of oil palm often depends on facilitating optimal growth conditions for seedlings. Proper spacing minimizes light competition between palms, allows for easy access for maintenance tasks such as weeding and manuring, and ensures uniform growth (Mutert et al., 1999; Laksono et al., 2019). The recommended polybag spacing changes according to the age of seedlings at field planting, with different triangular spacing values for various age ranges. The CoPN clearly stated that the polybag used shall be a perforated black polythene bag with 500 gauges (0.125 mm) of thickness and size shall not be less than 38 cm × 45 cm (15" × 18") (MPOB, 2016; Mohd Rais, 2021). A smaller polybag measuring less than 30 cm × 38 cm (12" × 15") may be used for seedlings or ramets that are kept in the polybag not more than 11 months after the sowing germinated seeds or ramets (MPOB, 2016).

Appropriate arrangement of polybags is highly determined by the size of polybag used. Polybag size of 38 cm × 45 cm (15" × 18") shall be arranged in not less than 0.9 m × 0.9 m × 0.9 m measured center to center to achieve an equilateral triangular spacing (MPOB, 2016; Mohd Rais, 2021). For the same objective, polybag size of 30 cm × 38 cm (12" × 15"), shall be arranged at not less than 0.75 m × 0.75 m × 0.75 m measured center to center and these two-design allowed approximately 14,000 and 20,000 seedlings per hectare, respectively (MPOB, 2016; Mohd Rais, 2021). Previous studies have shown that the growth of seedlings aged between 10 and 12 months in the main nursery showed satisfactory growth and in return, produces the highest fresh fruit bunch FFB in the field (Afandi, 2011; Afandi et al., 2019).

An experiment was conducted by Akpo et al. (2014b) to evaluate the effects of polybag sizes (small; 25 cm × 30 cm, medium; 31 cm × 31 cm and large; 40 cm × 40 cm), substrate type (forest soil, household waste substrate, arable soil and arable soil with manure) and fertilizer supply (no fertilization, split dose and full dose) on seedlings (Akpo et al., 2014b). Although substrate and fertiliser supply impacts were largely consistent over time (Fang et al., 2022), the effects of polybag size increased, eventually outpacing substrate, fertilizer, and the interaction effects approximately two months onwards. The number of leaves increased linearly with time, the height and collar diameter of seedlings increased exponentially. Data analysis with different growth models showed that polybag size had the most significant impact on seedling growth rates, followed by the substrate (Akpo et al., 2014b; Salisu et al., 2018). However, most previous studies evaluated polybag size independently or under experimental conditions that differ from current large-scale nursery operations, limiting their direct applicability to present nursery management.

Polybag size has a profound effect on oil palm seedling growth (Poorter et al., 2012; Salisu et al., 2018). In small polybags, applying 10 g of fertilizer once each month had fatal consequences on seedling's survival. Medium polybags filled with arable soil and animal manure, without any fertilizer, promoted good seedling development. This method seemed to be the best balance between quality and production cost, although large polybags produced the best seedlings. The interaction of the three factors (bag size, substrate and fertilizer) was not significant for seedling allometric variables (seedling height, leaf number, most developed leaf length and root-collar diameter) (Akpo et al. 2014a).

Observation comparison of DxP planting material (PM) under normal nursery practices between a previous study by Afandi (2011) and the current study showed that there was an improvement in the quality of oil palm seedlings over time (Afandi, 2011). Therefore, it is possibility that smaller polybag sizes and closer arrangements of polybags may be considered for use in the main nursery. The production of high-quality seedlings during the main nursery stage is crucial for ensuring growth, successful field establishment, and long-term yield potential (Siti Atikah et al., 2019). These seedlings are more capable of withstanding transplanting stress and maintaining vigorous growth under filed conditions. The use of closer spacing might optimize the available space without compromising seedlings allowing higher plant density and better land use efficiency, compared to the conventional spacing (Applied Agricultural Resources Sdn Bhd., 2020). Understanding the influence of these factors on early seedling growth is crucial for improving nursery productivity.

This study was conducted to determine the effects of different seedling spacings and polybags sizes on the growth performance, dry matter production, and overall vigour of oil palm seedling at the main nursery stage. By quantifying these key growth responses, the study aims to identify the most efficient spacing arrangement and polybag size that support healthy seedling development and can contribute to improvements in current nursery practices. The results presented in this work may provide a new perspective on standard nursery practices, thereby strengthening the MPOB CoP 1001: 2015 – Code of Good Nursery Practice for Oil Palm Nurseries (Second edition) (MPOB, 2016).

Previous studies have investigated the effects of polybag size, substrate type, and fertilisation on oil palm seedling growth (Afandi, 2011; Poorter t al., 2012; Akpo et al., 2014a, 2014b; Salisu et al., 2018). While polybag size consistently influenced seedling height, collar diameter, and leaf development, most studies were conducted under small-scale or experimental conditions, limiting their applicability to contemporary large-scale nursery practices. Additionally, interactions between polybag size and spacing have not been reassessed under latest operational standards, leaving a gap in optimizing land use efficiency and seedling quality.

MATERIALS AND METHODS

Study site

The trial was carried out at Tapak Semaian Hong Seng Sdn. Bhd., Jalan Muar, Yong Peng, Johor. Inland mineral topsoil was used as the growing medium, following standard practice in main nurseries (Gillbanks, 2003). The soil was sieved through a 5 mm mesh to remove stones, large clods (> 1 cm), and other debris before being filled into large polybags and lined up in a triangular pattern. Uniform three-month-old seedlings were selected from pre-nursery before transferring into the polybags (Keni et al., 2023). Seedling maintenance followed standard practices recommended by the MPOB (MPOB, 2016). Throughout the study, seedlings were watered twice daily with approximately 500 mL of water per seedling using the overhead sprinkler irrigation. Sprinklers are commonly used in nurseries to maintain soil moisture, a critical factor in effective crop irrigation management (Jobbágy et al., 2016). The seedling treatments plots were arranged symmetrically at each sprinkler point to ensure same amount of daily watering (Figs 1–2). Fertilisation was carried out monthly using a balanced NPK compound fertilizer at rates recommended for main nursery. Pest and disease monitoring was performed weekly. Any infestations were managed using approved nursery level measures.

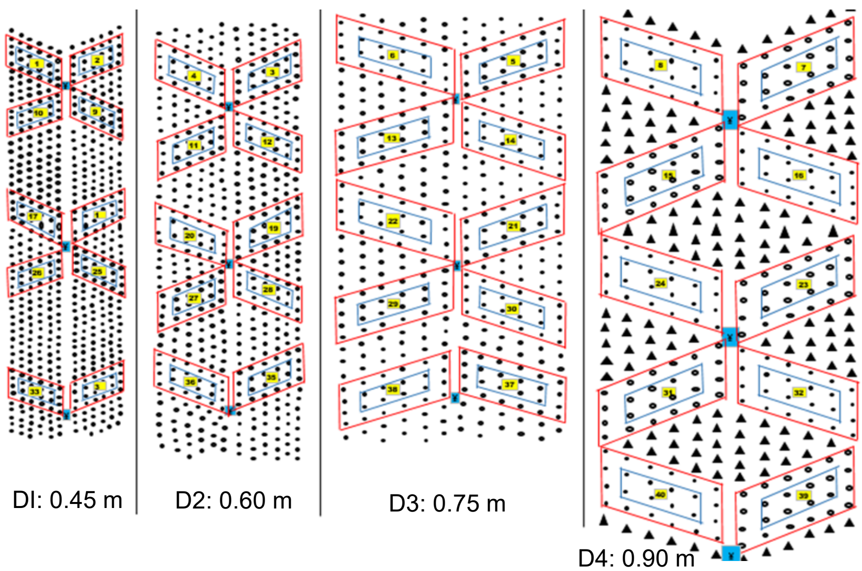

Figure 1. Plot arrangement at the main nursery with seedlings plots arranged symmetrically on each sprinkler point.

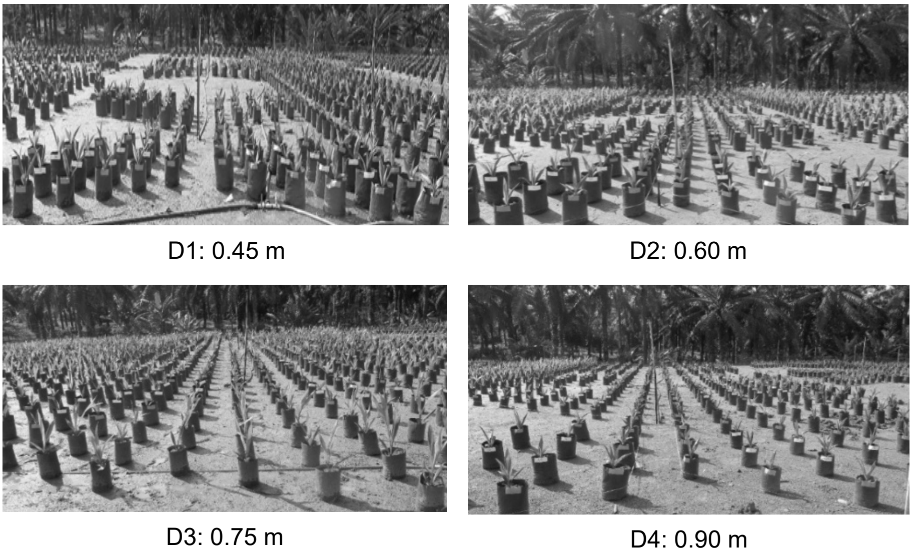

Figure 2. An overview of the arrangement of seedlings in triangular polybag spacing at trial site.

Experimental details

Commercial DxP materials of *Elaeis guineensis* Jacq were used for this trial. The experiment was conducted using a randomized complete block design (RCBD) with five replications to minimize environmental variation within the nursery. Blocking was based on uniformity of light exposure and slope direction across the nursery area to control for potential micro-environmental effects. Each treatment combination was randomly assigned within each block to ensure unbiased placement.

Table 1. Treatments on polybag spacing and size

Treatment	Polybag spacing and size
	Polybag spacing (Triangular polybag spacing) (D)
D1	0.45 m × 0.45 m × 0.45 m
D2	0.60 m × 0.60 m × 0.60 m
D3	0.75 m × 0.75 m × 0.75 m
D4	0.90 m × 0.90 m × 0.90 m
	Polybag size (S)
S1	38 cm × 45 cm (15" × 18")
S2	30 cm × 38 cm (12" × 15")

Note: D4 and S1 are the current standard practices for the main nursery for up to 12 months while D3 and S2 was up to 11 months (MPOB, 2016).

Treatments followed a 4×2 factorial structure, consisting of four polybags spacing (D1, D2, D3, and D4) arranged in a triangular planting pattern and two polybag sizes (S1 and S2), as shown in Table 1. Each experimental plot contained eight recording seedlings per treatment per replicate, resulting in a total of 320 seedlings (4 spacing × 2 sizes × 5 replicates × 8 seedlings). The study duration was 14 months. Growth performance of oil palm seedlings was evaluated based on fresh weight of plant and media, vegetative growth parameters, nutrient content, dry matter production, and field observation.

The selected spacing distances (0.45 m, 0.90 m) and polybag sizes (30 × 38 cm, 38 × 45 cm) were chosen to create a gradient from restrictive to optimal growth conditions, reflecting common commercial nursery practices. Spacing directly affects light interception and competition, influencing seedling architecture and the risk of etiolation (Corley & Tinker, 2016; Oomen, 2023). Similarly, polybag size constrains root development, nutrient uptake, and biomass accumulation, with smaller volumes known to limit later growth stages (Poorter et al., 2012; Afandi, 2011). This combination provides a scientifically supported range to evaluate their combined effects on oil palm seedling performance.

Fresh weight of seedling and soil media

The fresh weight of seedling and soil media was determined at the age of 14 MAP for standard density (D4) only to evaluate the differences in weight for ease in handling during seedling transfer from nursery to field planting.

Vegetative growth measurements

Total green fronds (frond seedling^{-1}), frond length (cm), palm height (cm), bole diameter (mm) and petiole cross-section of frond 2 (PCS, cm^2) were taken at 8 months, 10 months, 12 and 14 months from planting (MAP) as described by Zuraidah et al. (2017). The fresh weight of seedlings and media were determined at the ages of 10, 12 and 14 MAP to evaluate the differences in weight for ease of handling during seedling transfer from nursery to field planting. Plant growth analysis, involving destructive sampling of four plants per treatment was carried out at 10, 12, and 14 MAP. The oil palm seedlings were separated into rachis, leaflets, bole, and roots. To accelerate the drying process, samples were cut into smaller pieces, and dried at 60 °C for 48 hours, until constant weight was achieved, before being weighed for dry weight determination (Militello et al., 2018).

Foliar analysis

The interpretation of the changes in the chemical composition of leaves was carried out to analyze the content of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg). Dried samples of rachis, leaflets, roots, and stems were dried and ground. Approximately 1 g of oven-dried plant tissue sample was weighed, placed into a silica basin and subsequently heated at 500 °C in a muffle furnace for 4 hours. The sample was then mixed with 10 mL of 20% nitric acid, covered with a watch glass and digested in a steam bath for 1 hour. Once the digestion process was completed, the sample was filtered through an Albert 502 filter paper into a 100 mL volumetric flask. Then, Ca and Mg were determined using an atomic absorption spectrophotometer (Perkin Elmer 3100, USA). Phosphorus was determined colourimetrically with a spectrophotometer (Genesys 20, USA) using the vanadomolybdate yellow method. Plant K content was determined by a flame photometer (Sherwood 410, UK). In contrast, plant N content was determined by wet digestion using concentrated H_2SO_4 in the presence of a catalyst to convert the organic N to the ammonium form. The solution releases free ammonia following NaOH alkaline distillation. The distillate was collected in boric acid and diluted with HCl and with a mixed indicator (pH 4.5) and NH4 determined by titration until the red colour was obtained.

Analysis of data

All data were analysed using SAS statistical software (version 9.4; SAS Institute Inc., Cary, NC, USA) to evaluate the effects of polybag spacing (D1-D4), polybag size (S1-S2), and their interaction on the growth performance of seedlings. The experiment followed a RCBD with five replicates. Prior to analysis, the data were tested for normality using the Shapiro-Wik test and for homogeneity of variances using Levene's test. All data were subjected to analysis of variance (ANOVA). When significant differences were detected, treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% probability level ($P \leq 0.05$). The seedling growth performance was established with a coefficient of variation (CV) value that was adopted in research for data analysis: (1) CV value less than 7.0% would be rated as high precision; (2) value between 7.0 and 19.0% would be moderate precision; (3) value greater than 19.0% but below 25.0% would be regarded as low accuracy; and (4) value greater than 25.0% shows very low accuracy (Couto et al., 2013). Results are presented as mean ± standard error (SE).

RESULTS AND DISCUSSION

The relationship between the polybag sizes and fresh weight of oil palm seedling

The fresh weight of the seedling and the soil media is shown in Table 2. The average total fresh weight measurements, including roots and soil media, at 10 to 14 MAP were 22.99 kg (S1) and 12.23 kg per seedling (S2), respectively, with a percentage weight difference of up to 46.82%. This disparity is attributed to unrestricted growth, particularly in the root section, as observed by Poorter et al. (2012). Additionally, the S1 and S2 polybags had average soil weights of 19.95 kg and 9.51 kg, respectively, resulting in a 52.32% difference in fresh soil weight between the two.

The use of different sizes of polybags not only affected the fresh weight of seedlings but also impacts the weight of the soil media, consequently influencing the workload during seedling transfer. The lightweight soil in 30 cm × 38 cm polybags facilitates easier handling and transport of seedlings, minimizing the workload during their transfer from the nursery to the planting site in the field, as suggested by Hashim et al. (1987). The utilization of smaller polybag volumes significantly enhances nursery efficiency and economic viability by reducing labour and time requirements. Studies by Adu-Yeboah et al. (2015) and Gebisa (2024) demonstrate that smaller or medium-sized polybag allowmore seedlings to be transported per trip and lower input use, thereby substantially lowering logistic overhead for large-scale distribution. These findings indicate that reducing polybag size can enhance operational efficiency and nursery management without compromising seedling quality.

Table 2. Average fresh weight of seedling and soil media for standard density at 14 months after planting

Polybag size	Total fresh weight of seedling (kg)	Weight of soil media, (kg)	Total fresh weight of seedling and soil media (kg)
SI	3.04	19.95	22.99
S2	2.72	9.51	12.23

Note: S1 = 15" × 18" (38.10 cm × 45.72 cm); S2 = 12" × 15" (30.48 cm × 38.10 cm).

Vegetative Characteristics of Seedlings

The ANOVA tables of the vegetative growth components of DxP seedlings at ages 8, 10, 12 and 14 MAP are shown in Table 3. The height of seedlings is a significant parameter in evaluating their growth (Klymenko et al., 2010). The results showed that the size of the polybag used significantly influenced the seedling height as early as 8 MAP, with a significant difference ($P \leq 0.01$), and a similar effect was noted on polybag spacing. The impact of the treatment on the height of the seedlings was gradually increased up to 14 MAP. At 10 MAP, both treatments had significantly higher growth components of oil palm seedlings such as rachis length, bole diameter, relative leaf area, frond dry weight and petiole cross-section. This was due to the early establishment phase of the seedlings during which competition for resources such as light, nutrients, and space was intense, significantly impacting various growth parameters. The seedlings were still in a critical growth stage, explaining why multiple parameters are influenced by planting density (Bonneau et al., 2014; Lewis et al., 2020; Bonneau et al., 2022). However, as the seedlings reached 14 MAP, only rachis length was consistently affected by both treatments over time. This condition occurred because by this stage, the seedlings may have undergone some adjustment and acclimatization to the planting density, leading to a more specific impact on rachis length compared to other parameters (Bonneau et al., 2014; Lewis et al., 2020; Bonneau et al., 2022). During the 12 MAP, spacing treatment affected the number of total fronds, rachis length and seedling height. It only started to significantly increase frond production and relative leaf area during 14 MAP. Meanwhile, for polybag size treatment, frond dry weight and petiole cross-section showed that it was highly significant starting from 12 MAP and beyond, except for rachis length and seedling height. Also, the petiole-cross section was commonly used as a parameter to calculate frond dry weight (de Maijer, 2023).

Based on the ANOVA table, spacing was more influential and affected seedlings growth than polybag size at the age of 10 to 12 MAP. It was the seedling height and rachis length that were among the most affected. However, statistical analysis of two-way interaction demonstrated that neither spacing nor polybag size was significant for seedling allometric variables in either month. This finding contrasts with a previous study (Afandi, 2011), which reported significant interaction effects on bole diameter and petiole cross-section parameters comparing spacing and polybag size. This was due to the considerable impact of restricted space or closer planting arrangement as opposed to previous studies where the competition effect between seedlings was more substantial.

The results of treatments effect on seedling growth at 8 MAP are shown in Table 4, Figs 3 and 4, respectively. Seedlings grown under the denser planting system (D1) attained a significantly greater height (113.32 cm), a 19.6% increase over those at standard spacing (D4, 91.16 cm), likely due to competition for light and space stimulating vertical growth. However, a consistent variation was observed by other parameters. Meanwhile, the effect of using polybag size S2 showed significantly lower values on most seedling growth parameters as compared to S1. At this stage, the seedlings gave their undesirable growth due to the adverse conditions of the spacing and polybag sizes. This delay in growth could be attributed to inadequate spacing between seedlings, inappropriate polybag sizes, or other unfavourable environmental factors affecting the seedlings' development.

Table 3. ANOVA table for oil palm seedlings at 8, 10, 12 and 14 months after planting (MAP)

Variation	df	Frond production	Total frond (sdg^{-1})	Rachis length (cm)	Height (cm)	Bolediameter (mm)	Relative leaf area (cm^2)	Frond dry weight (kg)	Petiole cross section (cm^2)
8 MAP									
Spacing (D)	3	-	2.025	50.905*	1,097.447**	66.730**	-	0.001	0.063*
Size (S)	1	-	2.025	83.665*	407.809**	75.625*	-	0.0009*	0.083*
D × S	3	-	0.292	10.021	23.084	11.174	-	0.000	0.005
10 MAP									
Spacing (D)	3	1.700*	2.166*	2,131.435**	3,789.137**	172.589**	0.1182**	0.0006**	0.0642**
Size (S)	1	0.400	1.600	649.394**	1,540.081**	165.934**	0.0156*	0.0024**	0.214**
D × S	3	0.000	0.467	74.522	31.638	67.670	0.002	0.000	0.006
12 MAP									
Spacing (D)	3	0.692	4.558**	4,107.685**	12,829.553**	434.186*	0.041	0.003	0.297*
Size (S)	1	0.0250*	1.225	858.216**	1,990.074**	164.430	0.170*	0.0081**	0.731**
D × S	3	0.092	0.092	35.209	78.482	35.988	0.007	0.001	0.042
14 MAP									
Spacing (D)	3	2.091**	9.758**	6,656.168**	14,782.457**	558.394*	0.078**	0.001	0.087
Size (S)	1	0.025	2.025*	858.865**	1,932.100**	58.033	0.134**	0.0031**	0.342**
D × S	3	0.025	0.092	48.575	168.393	36.084	0.012	0.000	0.077

Note: MAP = Months after planting, figures at each column are the mean square (MSE) of the treatment. *, ** Significant at $P \leq 0.05$ and ≤ 0.01 respectively.

Table 4. The effects of polybag spacing and size on vegetative growth at 8 months after planting (MAP)

Distance	Total frond (sdg^{-1})	Rachis length (cm)	Height (cm)	Bole diameter (mm)	Frond dry weight (kg)	Petiole cross section (cm^2)
D1	9.20a	44.92a	113.32a	34.94a	0.30a	0.89a
D2	8.60ab	39.91b	94.45b	28.98b	0.28b	0.73b
D3	8.10b	40.42b	92.04b	30.19b	0.28b	0.73b
D4	8.60ab	42.02ab	91.16b	31.88ab	0.29ab	0.83ab
LSD (0.05)	0.7625	3.2450	4.9210	3.2420	0.0128	0.1227
MSE	1.4522	26.1372	347.8626	30.0370	0.0003	0.0345
CV (%)	9.6507	8.4710	5.4955	11.2371	4.8858	16.8587
Polybag Size						
S1	8.85a	43.26a	100.94a	32.87a	0.29a	0.84a
S2	8.40a	40.37b	94.55b	30.12b	0.28b	0.75b
LSD (0.05)	0.5392	2.2950	3.4790	2.2930	0.0090	0.0867

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$.

Inadequate spacing and incorrect polybag sizes can hinder the seedlings' growth leading to undesirable outcomes such as stunted growth or poor development (Cui et al., 2020). Furthermore, field development of seedlings aged 6 and 8 MAP resulted in high mortality due to transplanting shock and pest infestation (Afandi et al., 2019).

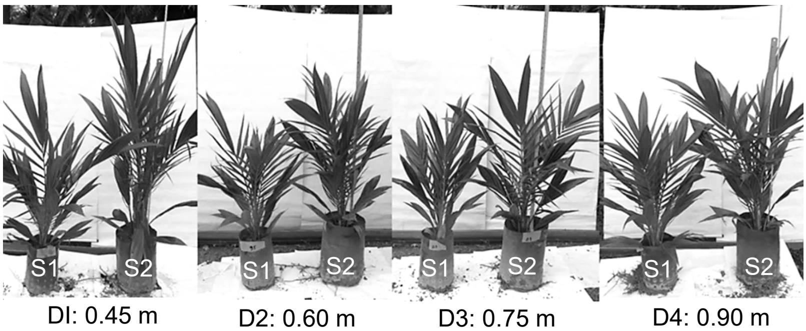

Figure 3. Comparison of seedling growth at age 8 month after planting (MAP) under different spacing and polybag size.

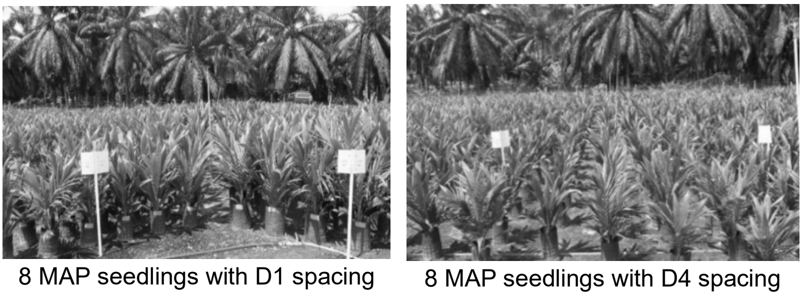

Figure 4. Growth of seedlings at age 8 month after planting (MAP) with D1 (0.45 m) spacing begins to show etiolation characteristics as compare to D4 (0.90 m).

The most appropriate seedling growth assessment was at the age of 10 to 12 MAP (Fig. 5). At this age, the seedlings were very ideal for field planting or to be sold by nursery operators. It was important to determine seedling growth parameters at of 10 MAP, as it is the minimum age of seedlings allowed for field transplanting under MPOB Code of Good Nursery Practice for Oil Palm Nurseries (MPOB, 2016).

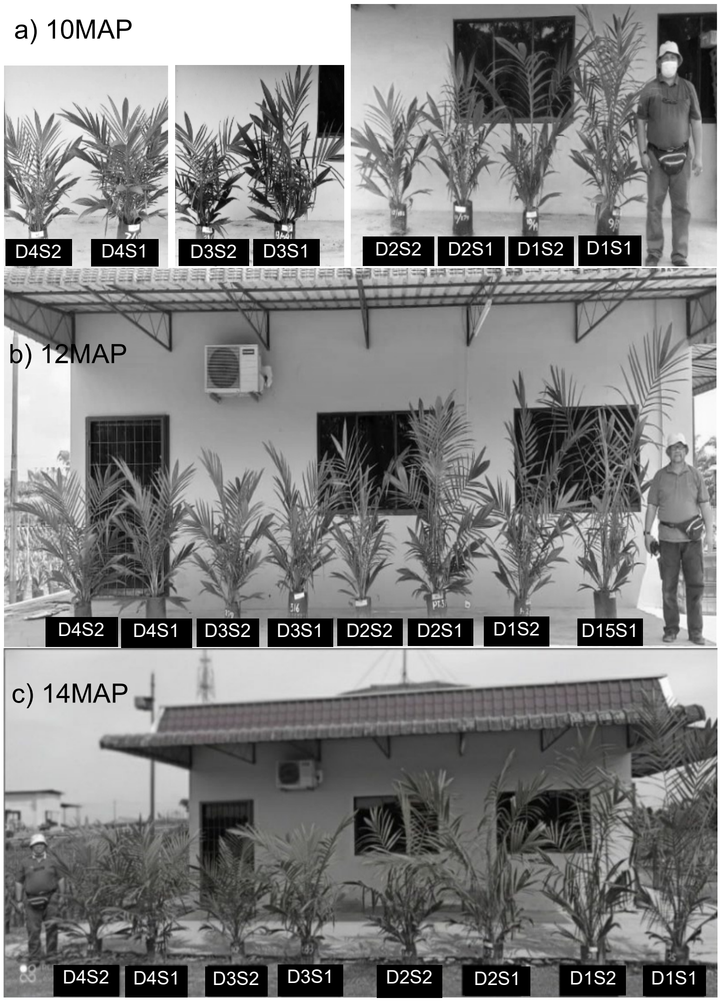

Figure 5. Comparison of seedling growth at 10, 12, and 14 months after planting (MAP) under different spacing and polybag sizes (D1S1–D4S2). Images are arranged chronologically and grouped consistently by treatment to facilitate visual comparison of height, canopy development, and overall seedling performance.

The results of the study in Tables 5, 6 and 7 showed that all parameters have a CV value below 19%, and were highly accurate in the total frond, height, frond dry weight and petiole cross-section. This suggests that there was an influence of spacing and polybag size on growth of the seedlings. Furthermore, Afandi et al. (2019) clarified that there was no significant difference in the cumulative mean of FFB yield as well as its components at 10 MAP and 12 MAP treatments over eight years, which in return found 10 MAP gave a comparable FFB yield similar to the 12 MAP seedlings (Afandi et al., 2019).

Table 5. The effects of polybag spacing and size on vegetative growth at 10 months after planting (MAP)

Distance	Frond production	Total frond (sdg^{-1})	Rachis length (cm)	Height (cm)	Bole diameter (mm)	Relative leaf area (cm^2)	Frond dry weight (kg)	Petiole cross section (cm^2)
D1	3.90b	12.00a	91.77a	165.74a	55.74a	0.55a	0.38a	1.72a
D2	4.70a	12.30a	66.42b	147.38b	46.22c	0.53a	0.37b	1.57b
D3	4.50ab	11.90ab	61.91b	126.78c	48.88bc	0.36b	0.36b	1.54b
D4	3.90b	11.20b	60.65b	124.22c	52.44ab	0.36b	0.37b	1.58b
LSD $_{(0.05)}$	0.6121	0.7138	9.1380	7.9870	4.9560	0.0587	0.0090	0.0906
MSE	0.6363	1.8272	704.7183	1,251.6541	101.2846	0.0353	0.0005	0.0518
CV (%)	15.7212	6.5754	14.2119	6.1821	10.6458	14.2289	2.6803	6.1766
Polybag Size								
S1	4.35a	12.05a	74.22a	147.23a	52.86a	0.47a	0.38a	1.67a
S2	4.15a	11.65a	66.16b	134.82b	48.78b	0.43a	0.36b	1.53b
LSD $_{(0.05)}$	0.4328	0.5047	6.4610	5.6480	3.5050	0.0415	0.0064	0.0640

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$.

It can be concluded that the rachis length and height values were significantly higher in D1 and D2 as compared to D3 and D4 at 10 and 12 MAP (Tables 5 and 6). Spacing had a significant influence on the behaviour of plants such as affecting the plants' architecture, development, weight and quality (Makhadmeh et al., 2017).

Table 6. The effects of polybag spacing and size on vegetative growth at 12 months after planting (MAP)

Distance	Frond production	Total frond (sdg^{-1})	Rachis length (cm)	Height (cm)	Bole diameter (mm)	Relative leafarea (cm^2)	Frond dry weight (kg)	Petiole cross section (cm^2)
D1	3.00ab	13.70b	130.98a	242.46a	65.66b	0.87a	0.46a	2.46a
D2	2.90b	13.00c	101.93b	196.85b	60.30b	0.72a	0.45ab	2.35ab
D3	3.10ab	14.30ab	88.07c	169.70c	65.49b	0.76a	0.43b	2.14b
D4	3.50a	14.50a	87.91c	163.92c	76.02a	0.81a	0.47a	2.54a
LSD $_{(0.05)}$	0.4819	0.6749	6.8070	9.6400	6.4410	0.1389	0.0286	0.2837
MSE	0.2386	2.1068	1,259.7168	3,904.3797	168.3696	0.0426	0.0019	0.1864
CV (%)	16.8353	5.3101	7.2686	5.4447	10.5146	19.2167	6.9588	13.0584
Polybag Size								
S1	3.10a	14.05a	106.85a	200.29a	68.89a	0.85a	0.46a	2.51a
S2	3.15a	13.70a	97.59b	186.18b	64.84a	0.72b	0.43b	2.24b
LSD $_{(0.05)}$	0.3408	0.4773	0.8130	0.8130	4.5540	0.0982	0.0202	0.2006

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$.

High planting density may increase the intensity of the competition. The rachis length and height correlated with increasing plant density per unit area and is mainly caused by competition due to limited light in crowded spacing. The elongation of the rachis, relative to overall growth, suggested that the oil palm seedlings were experiencing stress, which was likely induced by light competition (Corley & Tinker, 2016; Oomen, 2023).

However, instead of etiolation, seedlings in D1 and D2 spacing also showed relatively wide internodes of the leaflets. These features are not appropriate to characterise the seedlings as normal growth. In the normal spacing of D4, the average rachis length was only between 60.65 to 87.91 cm at and 12 MAP, while D1 showed the longest rachis length of 91.77 to 130.98 cm at the same time point. The tallest seedling was also recorded in D1 at 242.46 cm, which was 32% higher than in normal seedlings at 12 and 14 MAP (Tables 6 and 7). This indicates that the narrow spacing causes the seedlings to grow tall and etiolate as well as to have a rachis that elongates rapidly because of light competition (Fig. 5). During the 12 MAP and 14 MAP, when the spacing was adequate as seen in D3 and D4, the bole diameter increased due to the lower competition provided by larger spacing. The seedlings growth parameter with significantly higher value was found to be in seedlings grown in S1 polybag as compared to S2 but the difference was less than 8%. The results showed that the growth was not highly significant at 12 MAP when planted at D4 and D3 and S1 and S2. The differences were 6.67 and 6.88% respectively, and these differences were relatively small and acceptable. Based on these findings, therefore, oil palm seedlings can be maintained at the main nursery for up to 12 MAP by using S2 polybag size.

Table 7. The effects of polybag spacing and size on vegetative growth at 14 month after planting (MAP)

Distance	Frond production	Total frond (sdg^{-1})	Rachis length (cm)	Height (cm)	Diameter (mm)	Relative leaf area (cm^2)	Frond dry weight (kg)	Petiole cross section (cm^2)
D1	2.00b	14.00b	174.25a	283.35a	62.51b	1.06b	0.45b	2.42b
D2	2.30b	15.90a	142.67b	246.50b	76.94a	1.19a	0.45b	2.44ab
D3	3.00a	16.10a	119.38c	210.19c	77.25a	1.06b	0.47a	2.61a
D4	2.80a	15.90a	120.13c	198.26d	66.39b	0.98c	0.47a	2.57ab
LSD $_{(0.05)}$	0.3121	0.6254	5.8820	10.5000	6.6440	0.0689	0.0168	0.1735
MSE	0.6113	3.3568	1,992.7045	4,338.3905	177.0263	0.0404	0.0008	0.0840
CV (%)	13.4928	4.4116	4.6162	4.8882	10.2487	7.0256	3.9841	7.5447
Polybag size								
S1	2.50a	15.70a	143.74a	241.53a	71.98a	1.13a	0.47a	2.60a
S2	2.55a	15.25b	134.47b	227.63b	69.57a	1.01b	0.45b	2.42b
LSD $_{(0.05)}$	0.2207	0.4422	4.1600	7.4280	4.6980	0.0488	0.0119	0.1227

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$.

Recent studies showed that D1 and D2 cause seedlings to quickly compete for space and light even when planted using standard polybag sizes (S1). This condition will cause distorted growth as well as complicating seedlings maintenance work at main nurseries such as fertilizing, pest and disease control, census and culling (Fig. 6). Meanwhile, spacing at D3 and D4 using both polybags S1 and S2 still showed normal growth at each stage of seedling age. Data on the height from the combination treatment of D1S1, D1S2, D2S1 and D2S2 showed between 188.10 to 249.98 cm at 12 MAP as compared to the standard plot which was between 160.72 and 178.69 cm, and there was a difference of 20%. Taller seedlings would complicate the transportation, and field planting and are vulnerable to wind damage during planting. Therefore, planting spacing of less than 0.75 cm is not recommended. Larger polybags produce bigger and heavier seedlings, which increase the logistic burden during transport and field planting. Therefore, a more manageable seedling size is preferable from a practical and operational standpoint (Akpo et al., 2014a; Anaba et al., 2020).

Figure 6. Narrow spacing arrangement of 0.45 m and 0.60 m.

Dry weight of oil palm seedlings

Dry weight measurements at different harvested ages are presented in Table 8 and Fig. 7. The dry weight of the seedlings in all treatments increased markedly with age. The aboveground dry weight slightly decreased when the spacing increased as in D3 and D4. However, the difference was not significant. The data obtained showed that the dry weight of the roots was not significantly affected by polybag spacing. The dry weight of the aboveground, roots, as well as total dry matter, was significantly higher in S1 than in S2. The difference was between 11.71% to 13.20% and 11.62% to 22.65% for aboveground and roots, respectively. Meanwhile, the disparity ranges from 12.81% to 14.04% on the total dry weight of the seedlings.

Table 8. The effects of polybag spacing and size on seedlings dry weight

Treatment	Above ground (g seedling^{-1})			Root (g seedling^{-1})			Total Dry matter (g seedling^{-1})		
	10 MAP	12 MAP	14 MAP	10 MAP	12 MAP	14 MAP	10 MAP	12 MAP	14 MAP
Polybag Spacing									
D1	329.08a	577.14a	900.34a	113.28a	133.08a	131.78b	442.34a	710.20a	1,035.09a
D2	336.15a	512.30a	819.65ab	116.30a	132.45a	142.11ab	452.46a	644.76a	961.74a
D3	356.94a	509.84a	771.43ab	115.71a	130.41a	152.95ab	472.65a	640.24a	924.36a
D4	370.14a	529.64a	755.86b	119.48a	137.24a	168.14a	489.60a	666.86a	923.98a
LSD $_{(0.05)}$	52.10	107.50	133.60	12.26	25.78	24.96	50.39	114.60	148.50
Polybag Size									
S1	372.68a	565.90a	863.12a	123.36a	149.86a	167.74a	496.04a	715.76a	1,030.83a
S2	323.47b	498.54a	762.02b	109.02b	116.73b	129.75b	432.49b	615.28b	891.75b
LSD $_{(0.05)}$	36.84	76.04	94.49	8.67	18.23	17.65	35.63	81.02	105.0

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$; MAP = Months after planting.

Total dry weight of seedlings increased gradually from 10 to 14 MAP cross all treatments, suggesting continuous biomass accumulation during the nursery stage (Fig. 7). Treatments D2S1, D2S2, and D3S1 produced the highest total dry weight, around 950 to1,000 g plant^{-1} at 14 MAP, while D3S2 and D4S2 recorded slightly lower values. The overall trend showed a slight decreased across treatments, indicating limited variation in growth performance. These results imply that moderate spacing combined with adequate polybag size enhances canopy expansion and root development, contributing to better seedling vitality. Furthermore, the reduced spacing of 0.75 m yielded comparable biomass to the conventional 0.9 m, confirming that nursery space can be efficiently optimized without compromising seedling growth and quality.

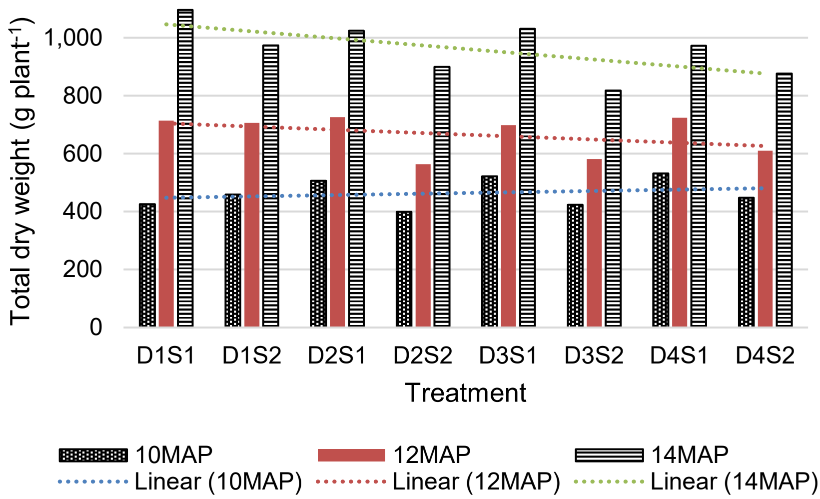

Figure 7. Comparison of total dry weight at various planting and treatments ages.

The superior performance of the larger S1 polybag is quantitatively demonstrated by a statistically significant 12.8% to 14.04% greater dry weight compared to S2. On the other hand, the non-significant effect of planting density on dry matter supports the inference that spacing can be optimized. These results collectively establish that seedling growth is principally controlled by polybag size, while nursery spacing can be efficiently reduced without compromizing biomass production.

Meanwhile, in treatments D1 and D2, the combination of closely arranged seedlings had a higher total dry weight. The primary cause for this observation was due to longer rachis and taller seedlings as discussed. The data suggest that the response to light competition, in terms of plant height and rachis length, became more pronounced with increasing competition density. According to Gruntman et al. (2017), plants showed greater height in crowded conditions compared to sparse treatments. The increase in plant height was accompanied by a corresponding increase in the total dry weight (Kalaitzoglou et al, 2019). However, a high value of total dry matter did not represent good quality seedlings. In nursery practice, oil palm seedling quality is assesed based on height, basal diameter, leaf characteristics, and shoot-root balance, rather than dry weight alone (Bhadouria et al., 2018; Wagino et al., 2018). Afandi (2011) found that seedling performance was optimal when the above-ground dry weight reached 666.20 g per plant. In contrast, the current study found that, the high total dry weight did not necessarily imply good quality of the seedling, as space and light competition led to etiolated and elongated seedling growth, resulting in an overall increase in dry weight. A previous study found that 10% of the variation in total dry matter production between polybag sizes 15" × 18" and 12" × 15" was attributed to the same spacing (Afandi, 2011). The discrepancy was only 10.4% if the same polybag size was used but required to be arranged in 0.9 m and 0.75 m spacing. These differences can be mitigated through effective agronomic practices within the expected period of one year after planting in the field.

High dry matter production can be achieved when compost is used as a growth medium compared to conventional soil media. Additionally, optimizing polybag size and implementing appropriate planting spacing arrangements also contribute to improved dry matter yield (Lord & Betitis, 2007; Afandi, 2011). The current study showed that without any restricting factors on seedling growth, the average total dry weight was 609.68 g and increased to 713.95 g when there was competition due to denser spacing.

Nutrient Status

The level of nutrient content in all seedling tissue (leaf, rachis, palm base, and root) was compared with the control plot, i.e. seedlings using polybag S1 and arranged with D4 spacing. A summary of nutrient analysis results are presented in Tables 9 and 10. Data showed that N values in leaf and rachis samples were found to be higher in closely arranged seedlings (D1 and D2). This is probably due to the high N requirement to accommodate the vegetative growth i.e. height and rachis of the seedlings. Nitrogen is required especially to young oil palm to increase the net assimilation rate which leads to promoting growth (Corley & Mok, 1972; Breure, 1982; Uwumarongie-Ilori et al., 2012). Nitrogen plays a crucial role in supporting rapid plant growth through enhanced chlorophyll and protein synthesis and nitrogen availability can influence plant physiological traits and performance (Andersen et al., 2010). Therefore, maintaining a sufficient N supply is crucial during the initial five years following planting (Goh et al., 2003). Meanwhile, there was no significant difference in major nutrient content in other parts of the seedling related to the spacing arrangement, except for phosphate only at 10 MAP.

There was also no significant difference in nutrient content for all seedling components when grown using S1 and S2 (Table 11 and 12). This indicated that the lower soil media in S2 (52.32%) was still capable of supplying nutrients for the entire seedling component up to 12 MAP. These results support and recommend the retention of seedlings in 12" × 15" polybags until the age of 12 MAP in the main nursery as compared to a maximum period of 11 months contrary to the recommendation stated in MPOB Code of Practice: Code of good nursery practice for oil palm nurseries (MPOB, 2016).

Table 9. The effects of polybag spacing and size on leaf nutrient content

Treatment	Leaf (% Dry matter)											
	N		P		K		Ca		Mg		B	
Distance	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP
D1	2.79a	2.83a	0.19a	0.19a	1.46a	1.51a	0.42a	0.38a	0.14ab	0.12b	16.70a	13.56a
D2	2.64ab	2.79ab	0.18a	0.18a	1.45a	1.57a	0.39ab	0.35a	0.13b	0.12b	17.10a	13.42a
D3	2.47b	2.70ab	0.15b	0.19a	1.39a	1.52a	0.36b	0.35a	0.13b	0.12b	16.12a	11.69a
D4	2.44b	2.59b	0.16b	0.18a	1.37a	1.51a	0.41a	0.37a	0.16a	0.15a	15.83a	11.68b
LSD (0.05)	0.2243	0.2184	0.0226	0.0133	0.1622	0.1203	0.0417	0.0620	0.0256	0.0249	1.9820	1.320
Polybag Size												
S1	2.59a	2.72a	0.18a	0.18a	1.41a	1.50a	0.40a	0.36a	0.13a	0.13a	16.47a	12.66a
S2	2.58a	2.74a	0.16a	0.19a	1.43a	1.55a	0.39a	0.35a	0.14a	0.12a	16.41a	12.52a
LSD (0.05)	0.1586	0.1544	0.0159	0.0094	0.1147	0.0850	0.0295	0.0438	0.0181	0.0176	1.4020	0.9336

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$; MAP = Months after planting.

Table 10. The effects of polybag spacing and size on rachis nutrient content

Treatment	Rachis (% Dry matter)											
	N		P		K		Ca		Mg		B	
Distance	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP
D1	0.66a	0.49a	0.09a	0.09a	1.10a	1.11a	0.27a	0.17a	0.07a	0.06a	11.88a	7.10a
D2	0.48b	0.45ab	0.09a	0.10a	1.20a	1.11a	0.21b	0.19a	0.06ab	0.05a	9.27b	9.39a
D3	0.38c	0.44ab	0.11a	0.10a	1.14a	1.16a	0.14c	0.20a	0.05b	0.06a	7.68b	11.34a
D4	0.39c	0.36b	0.11a	0.10a	1.30a	1.12a	0.15c	0.20a	0.06ab	0.06a	8.58b	6.26a
LSD (0.05)	0.0691	0.0820	0.0240	0.0199	0.2093	0.1935	0.0317	0.0337	0.0136	0.0104	1.645	4.778
Polybag Size												
S1	0.49a	0.45a	0.09b	0.09a	1.17a	1.11a	0.21a	0.20a	0.07a	0.06a	9.57a	7.92a
S2	0.46a	0.42a	0.11a	0.09a	1.21a	1.14a	0.17b	0.19a	0.06b	0.05a	9.13a	9.13a
LSD (0.05)	0.0489	0.0580	0.0170	0.0141	0.1480	0.1368	0.0224	0.0238	0.0096	0.0073	1.1630	3.378

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$; MAP = Months after planting.

Table 11. The effects of polybag spacing and size on palm base nutrient content

Treatment	Palm base/bole (% Dry matter)											
	N		P		K		Ca		Mg		B	
Distance	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP
D1	0.98a	0.76a	0.21a	0.15a	1.35a	1.05a	0.18a	0.19a	0.10ab	0.08a	11.94a	6.46a
D2	0.65a	0.80a	0.15b	0.16a	1.01b	1.09a	0.13b	0.18a	0.07b	0.08a	10.25a	5.86a
D3	0.73a	0.67a	0.16ab	0.15a	1.01b	1.04a	0.14b	0.17a	0.08ab	0.07a	10.50a	5.26ab
D4	0.71a	0.64a	0.18ab	0.14a	0.11ab	1.00a	0.19a	0.15a	0.11a	0.08a	7.21b	4.39b
LSD $_{(0.05)}$	0.3717	0.1628	0.0561	0.0297	0.2917	0.1879	0.0274	0.0388	0.0289	0.0151	1.9200	1.1890
Polybag Size												
S1	0.72a	0.71a	0.17a	0.14a	1.10a	1.03a	0.16a	0.17a	0.09a	0.07a	10.13a	5.56a
S2	0.82a	0.73a	0.19a	0.16a	1.14a	1.06a	0.16a	0.18a	0.09a	0.08a	9.83a	5.42a
LSD $_{(0.05)}$	0.2628	0.1151	0.0398	0.0210	0.2062	0.1329	0.0193	0.0274	0.0205	0.0106	1.3580	0.8411

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$; MAP = Months after planting.

Table 12. The effects of polybag spacing and size on root nutrient content

Treatment	Root (% Dry matter)											
	N		P		K		Ca		Mg		B	
Distance	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP	10 MAP	12 MAP
D1	0.71a	0.72a	0.09b	0.09a	0.84a	0.71a	0.08a	0.09a	0.06a	0.06a	4.93a	5.86a
D2	0.80a	0.70a	0.12a	0.09a	0.95a	0.65a	0.08a	0.09a	0.06a	0.06a	4.28a	6.56a
D3	0.73ab	0.73a	0.10ab	0.10a	0.82a	0.78a	0.09a	0.08a	0.05a	0.06a	5.04a	6.01a
D4	0.62b	0.75a	0.09b	0.10a	0.81a	0.82a	0.08a	0.09a	0.05a	0.06a	4.58a	6.40a
LSD $_{(0.05)}$	0.1648	0.1211	0.0187	0.0167	0.2422	0.1863	0.0341	0.0136	0.0109	0.0085	1.010	2.387
Polybag Size												
S1	0.71a	0.72a	0.09b	0.08b	0.82a	0.73a	0.08a	0.09a	0.06a	0.06a	4.51a	5.79a
S2	0.72a	0.73a	0.11a	0.10a	0.89a	0.74a	0.08a	0.08a	0.05a	0.06a	4.91a	6.63a
LSD $_{(0.05)}$	0.1165	0.0856	0.0132	0.0118	0.1712	0.1317	0.0241	0.0096	0.0076	0.0060	0.7145	1.6880

Note: Means with the same letter within the same column were significantly different at $P \leq 0.05$; MAP = Months after planting.

Seedling Performance

Relative comparisons were made to compare the performance of previous seedlings (Afandi, 2011) with those used in this trial based on five growing parameters, namely total frond production, rachis length, height, bole diameter and petiole cross-section. A comparison was made with seedlings planted on the control plot using a polybag size of 15" × 18" with an arrangement distance of 0.9 m. This relative comparison indicates that the quality of the DxP oil palm seedlings used in the current study is superior to that of the previous batch of seedlings. The results of the present study shows that total frond production (14.05 sdg^{-1}), rachis length (130 cm), plant height (242 cm), bole diameter (68.89 mm), and petiole cross-sectional area (2.51 cm^2) were significantly greater than the values reported by Afandi (2011), who documented 13.44 sdg^{-1}, 72 cm, 152 cm, 67.21 mm, and 1.10 cm^2, respectively. These differences indicate a markedly improved vegetative performance relative to previously published findings. The mean difference was 35% and 24.90%, respectively, at 10 MAP and 12 MAP. The parameters of the rachis length, height and petiole cross-section contribute to this percentage. While total dry weight production at 12 MAP showed the same pattern, i.e. the seedlings used in the current study produced better total dry weight with differences of 19.68%, 27.28% and 21.44% for above-ground, root and total dry weight, respectively. This is indicative of a significant improvement in the quality of the current generation of planting materials over time.

This study addresses a key research gap by providing quantitative evidence on the effect of spacing and polybag size influence oil palm seedling growth up to 14 MAP. The results highlight the novelty of identifying the biological limits of seedling density, where spacing below 0.75 m leads to abnormal elongation and showing that the smaller polybag size remains adequate up to 12 MAP. These findings offer clear scientific implications by strengthening the physiological basis for nursery recommendations and supporting more cost-efficient management practices.

CONCLUSION

The results of the current study suggest that the arrangement of polybags of oil palm seedlings less than 0.75 m × 0.75 m × 0.75 m (30" × 30" × 30") produces tall, etiolated seedlings and is therefore not recommended for nursery practice. Spacing below 0.75 m increased seedling height by 19.60% at 8 MAP and up to 32.00% at 12 to 14 MAP. Accompanied by excessive rachis elongation, making the seedlings unsuitable for field planting and difficult to manage during routine nursery operations. The seedlings should be arranged in a triangular polybag spacing of 0.75 m (2.5') to 0.9 m (3.0'), resulting no adverse effect on growth. This assessment was made based on the seedling growth, dry weight production, nutrient content as well as routine nursery management. The use of the smaller S2 polybag; 30 cm × 38 cm (12" × 15"), resulted in only minor differences relative to the standard size, with no negative impact on seedling quality or nutrient status when maintained at the main nursery until 12 MAP.

RECOMMENDATIONS

The results of the current study also showed that the key factor affecting the overall performance of seedlings was the spacing arrangement in the main nursery instead of the polybag size used. Based on the present study, the recommended standard recorded by the DxP seedlings used suitable for field planting at age 10 to 12 MAP are as follows:

i. Bole diameter: 49 to 64 mm,
ii. Total number of frond production: 11 to 15 seedling^{-1},
iii. Rachis length of frond 3: 58 to 93 cm,
iv. The seedlings heights: 118 to 179 cm,
v. Petiole cross-section: 1.48 to 2.10 cm^2.

However, it should be noted that these measurements may vary depending on the specific oil palm planting materials and clones used.

These findings provide practical guidance for nursery operators, indicating that optimal spacing and appropriate polybag size can maintain adequate nutrient supply without compromising seedling quality. Future research should further examine how nutrient use efficiency changes under different management conditions to refine nursery recommendations.

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