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Effect of translucent polybags on cocoa (*Theobroma cacao* L.) seedlings development and farm establishment success.

Konlan, S., Adu-Yeboah, P., Arthur, A., Quaye, A. K., Dogbatse, J. A., Amoah, F. M. and Atibila, N.

Cocoa Research Institute of Ghana, P. O. Box 8, New Tafo-Akim.
Tel. +233 (0) 243 314 068; Email: Sampson.konlan@gmail.com

Abstract

Nursery and field experiments at Cocoa Research Institute of Ghana, were laid out in completely randomised block and randomised complete block designs respectively, with 4 replicates each to determine the effects of sachet water polybags on cocoa seedlings performance. Treatments were (i) black polybags (17.5 x 25 cm), (ii) black polybags (13.2 x14.7 cm) obtained from input suppliers, and (iii) translucent sachet water polybags (13.2 x 14.7 cm) obtained from dumpsites. Data collected include moisture retention in polybags, seedling emergence, leaf chlorophyll content and fluorescence, seedling growth, dry matter accumulation and performance of transplanted seedlings. Results showed that the translucent sachet water polybags had no significant adverse effects on seedling performance in the nursery and farm establishment when transplanted at 3 months. Although maintaining seedlings up to 6 months in the nursery adversely affected the growth of seedlings raised in the small black and translucent sachet water polybags, their survival in the field were statistically similar to those raised in the recommended polybags. The proportion of plants jorquetting and average jorquette height 12 months after transplanting were not affected by the sachet water polybags. Long term growth in the field was improved in plants established with seedlings raised in the translucent polybags and transplanted at 3 months. Based on the results, it was concluded that the translucent sachet water polybags can be used to raise cocoa seedlings for farm establishment when the seedlings are 3 months old.

Key words: Cocoa, translucent, polybag, survival, establishment, growth

1. Introduction

In Ghana, an estimated 350,000 farmers are engaged in cocoa cultivation, employing over 800,000 smallholder farm families in six cocoa growing regions. These farm families earn about 70-100 % of their total annual incomes from cocoa cultivation (Anim-Kwapong and Frimpong 2005). Since its successful introduction from Equatorial Guinea in 1879 (Opoku-Ameyaw *et al*., 2010), the cultivation of cocoa in Ghana has remained a rain-fed smallholder industry with no significant environmental control methods such as irrigation to increase productivity. In spite of its smallholder nature, the cocoa industry is the most important forex earner and highest contributor to the agricultural component of Ghana's gross domestic product (GSS, 2013). Any significant drop in productivity therefore, will not only affect the livelihoods of the farmers and farm families engaged in cocoa cultivation but will also present a significant challenge to the Ghanaian economy and the global cocoa industry.

Typically, cocoa farms in Ghana are established using 3-6 months old seedlings raised from hybrid materials (Amoah *et al*., 1999; Oppong*et al*., 2005). The bulk of the seedlings are usually raised in nursery bags. In some instances, farmers raise seedlings on seed beds which are later transplanted by bare-root while a minority still establish cocoa by direct seeding (Oppong *et al*., 1999). Several reports suggest that the survival of cocoa seedlings in the field is significantly influenced by the method used in the nursery (Oppong *et al*., 1999; Amoah *et al*., 2001), as well as field and climatic conditions during establishment (Ofori *et al*., 2014).

Studies on other tree crops have shown that seedlings raised using bigger polybags with the potential to contain larger soil volumes, performed better with respect to height and stem diameter increase in the nursery, and survival rates among transplanted seedlings (ven der Hossen and Nantwi 1975; Adu-Berku *et al*., 2011). In the Ghanaian cocoa industry, research has concluded that a black polybag of size of 17.5 x 25 cm (containing 3 kg topsoil at field capacity) was suitable for maintaining seedlings in the nursery up to 6 months before transplanting (Opoku-Ameyaw *et al*., 2010). For shorter durations (3 months), smaller black polybags (12.5 x25 cm, 12.5 x 20 cm & 12.5 x 15 cm) were recommended after 5 months of nursery study (Oppong *et al*., 2007).

However, when using these recommended polybags for raising cocoa seedlings farmers encounter challenges including availability, affordability and transport of nursed seedlings with up to 5 kg of earth over long distances by head porterage (Oppong *et al*., 2007; Adu-Berku *et al*., 2011; Adu-Yeboah *et al*., 2015). To address these challenges, many farmers have resorted to raising their seedlings in the translucent sachet water polybags that are collected from community dumps sites, which otherwise litters the environment.

However, the effects of this small translucent polybags on seedling development in the nursery and subsequent establishment success, as well as growth and yield of cocoa have not been established.

To address these concerns, an experiment was set up in 2013 to understand how the use of the translucent sachet water polybags affect cocoa seedling performance in the nursery and field.

2. Materials and methods

2.1 Experimental site and design

The experiment was conducted at the main nursery of the Cocoa Research Institute of Ghana (latitude 6°13' N, longitude 0°22' W, altitude 222 m above sea level) in 2013. The experiment was laid out in completely randomised design (CRD) in the nursery and randomised complete block design (RCBD) in the field. Treatments were (i) standard black polybag (17.5 x 25 cm), (ii) translucent sachet water polybag (13.2 x 14.7 cm) and (iii) small black polybag (13.2 x 14.7 cm). Each polybag was perforated at the bottom to facilitate drainage of excess water. Sixty polybags were filled with topsoil for each treatment, arranged under shade with 50 % light penetration and thoroughly watered. One seed was sown per polybag which were watered every other day. The seed source for the experiment comprise a mixture of hybrids developed by the Cocoa Research Institute of Ghana.

2.2 Data collected

2.2.1 Data on nursery seedlings

Forty polybags per treatment were randomly selected for collection of data on final emergence. Twenty of these polybags were further selected, tagged and used to determine leaf chlorophyll content (CL-01, Hansatech Instruments) and fluorescence (FP 100Fluorometer , Photon System Instruments), leaf number plant^{-1}, total leaf area, seedling growth (height and stem diameter) and accumulated dry matter at 3 and 6 months after sowing (MAS). Available soil moisture (%) in the polybags was determined with a soil moisture meter (HH2, Delta Devices Ltd.) at 48 hours after watering. Percent emergence was determined following the procedure described by Ugese *et al*. (2010) as:

$$E\ (\%) = \frac{TEs}{TSs} x\ 100$$

Where:

E (%) - percent final emergence from 40 polybags
TEs - total number of seeds emerged
TSs - total number of seeds sown

Plant height was measured from the collar to the apical meristem using a standard metre rule while stem diameter was measured with digital calipers five centimeters from the collar of the seedlings. Leaf area at 3 and 6 MAS was determined using a photometer (Delta-T Devices, England) in the laboratory after destructive harvesting of plant samples.

Dry matter accumulation at 3 and 6 MAS in the nursery was also determined through destructive harvesting of 20 seedlings per treatment. The harvested plant materials were first separated into leaves, roots and stems and weighed to obtain fresh weights, which were then summed to obtain total fresh weight.

The total fresh weight was divided by the number of plants harvested to obtain fresh weight plant^{-1} (Fwt) for each respective treatment harvest. The plant parts were oven dried at 80 ^{o}C until a consistent weight was obtained. The samples were again weighed and their respective dry weights summed to obtain total dry weight. This was also divided by the number of plant samples to obtain dry weight plant^{-1}(Dwt). Dry matter accumulated plant^{-1} (DM_p) as a percentage of total fresh weight at harvest was then determined as:

$$DM_p\ (\%) = \frac{Dwt}{Fwt} \times 100$$

Where:

DM_p - average dry matter accumulated per plant (%)
Fwt - average fresh weight per plant
Dwt - average dry weight per plant

2.2.2 Data on Transplanted Seedlings

The first and second batches of the seedlings were transplanted to the field respectively in June (3 months old) and September (6 months old) 2013 with plantain planted at 3 x 3 m as temporary shade. The seedlings were initially planted at 1 m^2 and later thinned to 2 m^2 after a year. Plant census was conducted through quarterly field counts during the first year of establishment. The number of plants surviving at each quarter was recorded and survival rate expressed as:

$$S_{rate}\ (\%) = \frac{Ps}{Ts} \times 100$$

Where:

S_{rate} - survival rate
P_s - number of plants surviving
T_s - total number of seedlings transplanted

Data on number of plants jorquetting at one year after transplanting was also taken and expressed as a percentage of the total number of plants present. On each occasion, heights at which jorquette formation took place were recorded. Information on rainfall, atmospheric temperature and relative humidity (Table 4) were obtained from the meteorology unit of Cocoa Research Institute of Ghana.

2.3 Data analysis

The data collected was analysed by ANOVA and means separated using the least significant difference at 5 % probability.

Data on available soil moisture, final emergence, survival rate and percent jorquetting were first subjected to angular transformations while leaf number per plant was square root transformed before statistical analysis.

3. Results

3.1 Available moisture, seedling emergence and leaf chlorophyll

Available soil moisture (%) within the polybags (Fig. 1) was not significantly ($p>0.05$) influenced by bag type during the 6 months of seedling growth in the nursery. Differences in final emergence of seedlings 1 MAS and seedling survival in the nursery which depends largely on available soil moisture were therefore not significant.

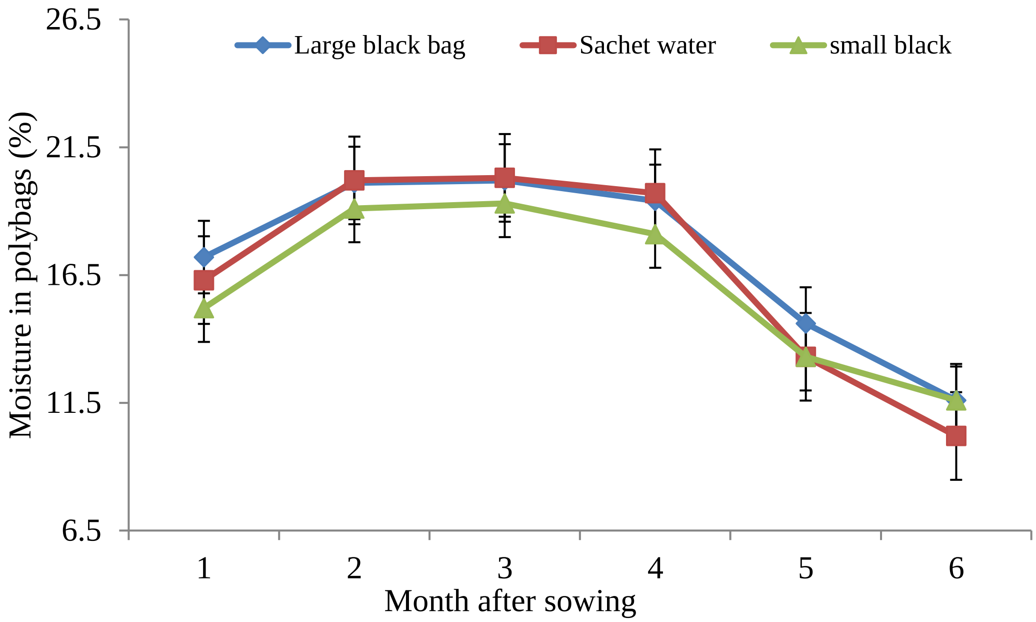


Figure 1. Soil moisture content as affected by polybag type 1 to 6 months after sowing in the nursery.

Leaf chlorophyll content (Fig. 2A) and fluorescence (Fig. 2B) were both not significantly ($p>0.05$) influenced by polybag type during the 6 months of seedling growth in the nursery. Leaf chlorophyll content peaked at 3 MAS after which there was a steady decline till seedlings were transplanted at 6 MAS.

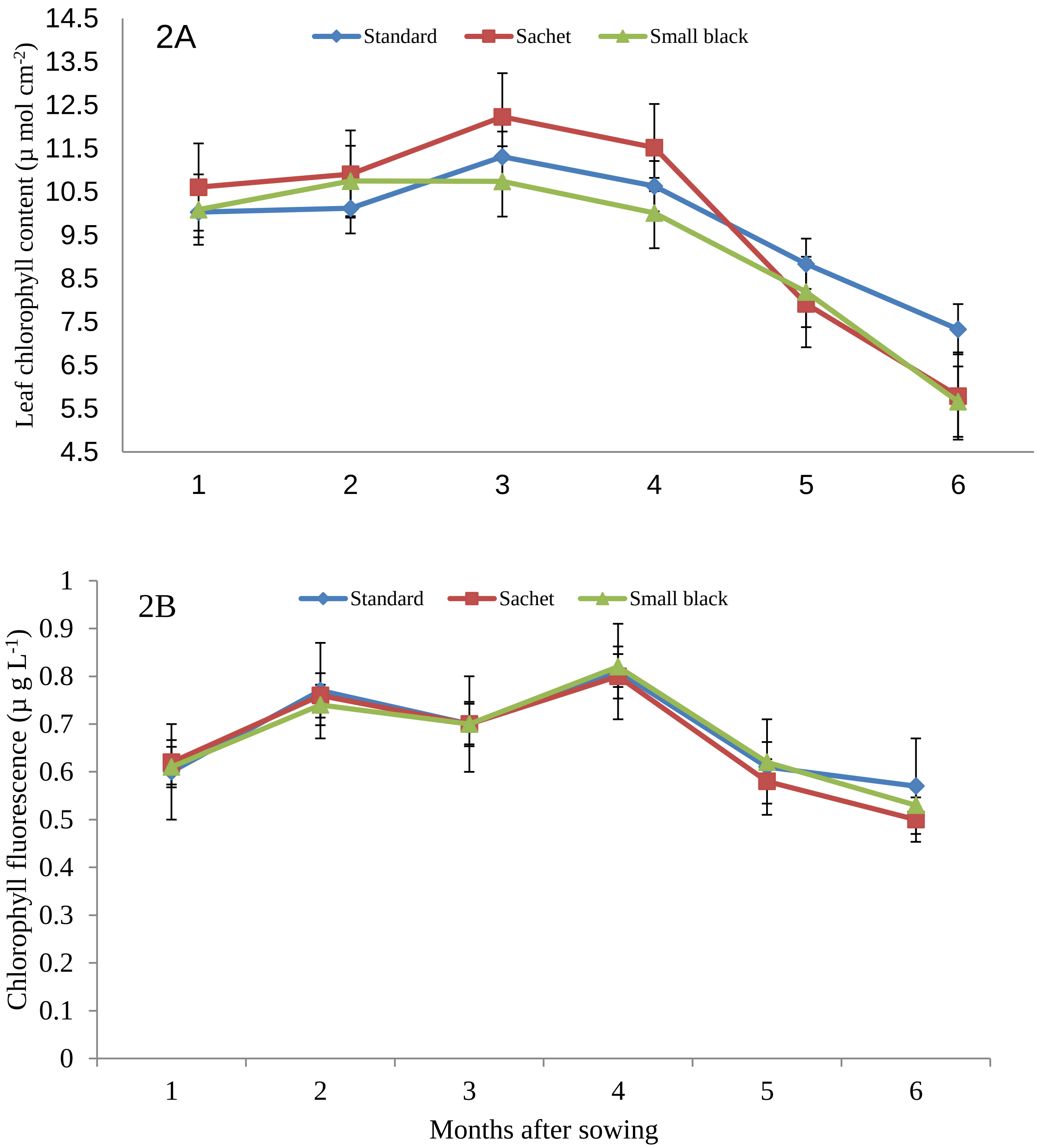
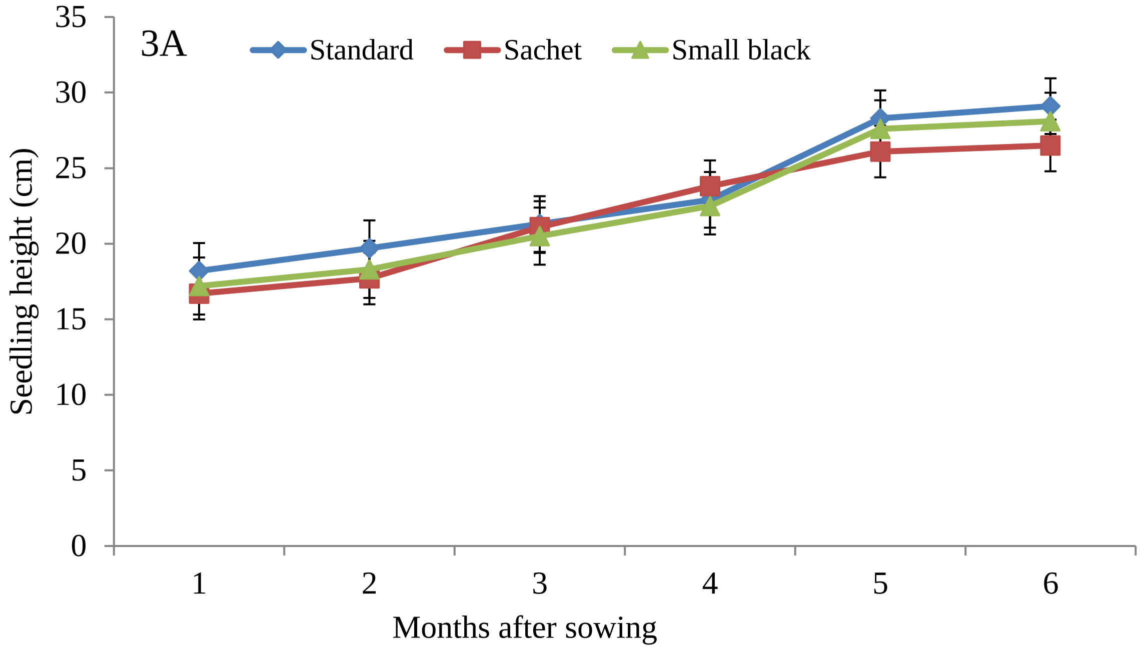


Figure 2: Leaf chlorophyll content (A) and chlorophyll fluorescence (B) of cocoa seedlings as affected by polybag type 1-6 months after sowing in the nursery.

3.2 Seedling growth and dry matter accumulation in the nursery.

The type of polybag used did not significantly ($p>0.05$) influence seedling height 1-6 MAS (Fig. 3A) and stem diameter 1-4 MAS (Fig. 3B). At 5 and 6 MAS, average stem diameter of seedlings raised in the standard polybag was significantly ($p<0.05$) different from those of seedlings raised in the small black and translucent sachet water polybags (Fig.3B).



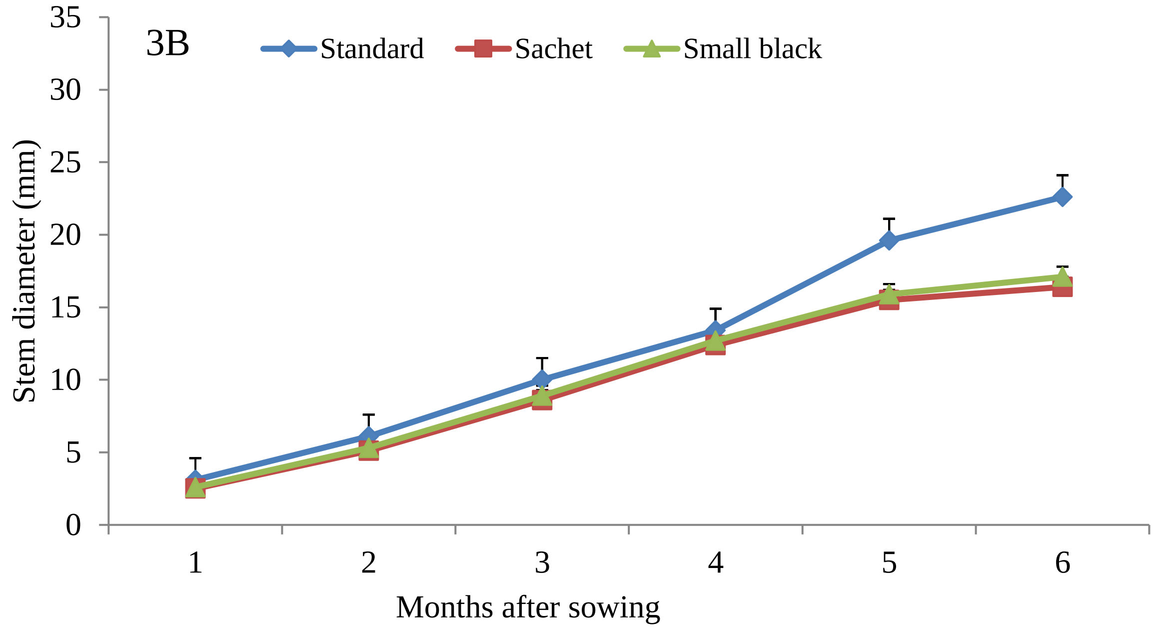


Figure 3. The effect of polybag type on height (A) and stem diameter (B) increase by cocoa seedlings 1-6 months after sowing in the nursery.

At the early growth stages in the nursery, bag type did not significantly ($p>0.05$) influence leaf number, leaf area and dry matter accumulated by seedlings at 3 MAS (Table 1).

Table 1. Leaf number, leaf area and dry matter accumulated per cocoa seedling at 3 months as affected by polybag type.

Bag type	Leaf number Plant^{-1}	Leaf area (cm^2 plant^{-1})	Dry matter (g) accumulated plant^{-1} at 3 months			
			Leaf	Stem	Root	Total
Standard black	7.3 (2.7)	30.9	1.06	0.77	0.43	2.26
Translucent	7.4 (2.7)	30.3	0.81	0.65	0.34	1.80
Small black	8.5 (2.9)	31.1	0.82	0.64	0.39	1.85
F-test	ns	ns	ns	ns	ns	ns
% cv	14.3	21.2	20.0	12.3	15.7	14.9

Note: Values in parenthesis are square root transformations. ns (no significant difference).

With time, seedlings in the small black and translucent sachet water polybags experienced significant ($p<0.05$) reductions in total leaf area per plant and dry matter accumulation which were seen at 6 MAS (Table 2). Leave area however remained similar (Table 2), suggesting that leaf size was the major factor accounting for the differences in leaf area between treatments at this stage.

Table 2: Leaf number, leaf area and dry matter accumulated per cocoa seedling at 6 months as affected by polybag type.

Bag type	Leaf number Plant^{-1}	Leaf area (cm^2 plant^{-1})	Dry matter (g) accumulated plant^{-1} at 3 months			
			Leaf	Stem	Root	Total
Standard black	12.3 (3.5)	763.9	2.66	1.96	2.13	6.75
Translucent	9.5 (3.1)	436.1	1.13	0.86	1.25	3.24
Small black	9.5 (3.1)	476.4	1.19	0.86	1.19	3.24
F-test	Ns	323.6	0.6	0.4	0.7	1.5
% cv	10.9	35.9	19.9	17.1	26.3	19.9

Note: Values in parenthesis are square root transformations. ns (no significant difference).

3.3 Plant survival and early growth in the field

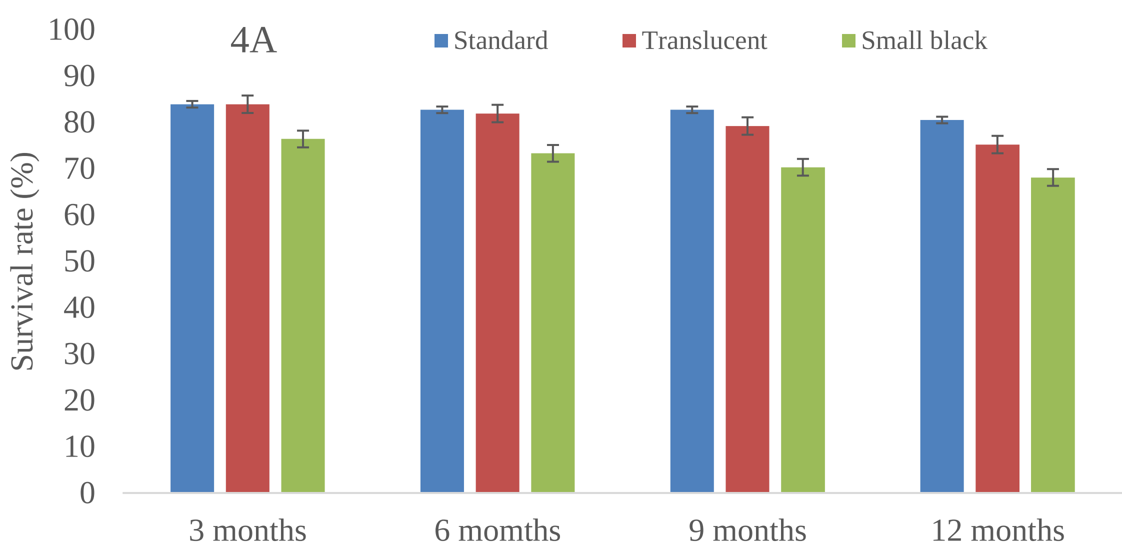
Summary of rainfall, temperature and relative humidity data during the 3 years of growth in the field are shown in Table 3. Total annual rainfall received were within the suitable range in 2013 and 2014, and below the minimum requirement in 2015. In spite of the low total annual rainfall in 2015, relative humidity, minimum and maximum average temperatures over the 3 years were all within suitable range for cocoa growth.

Table 3. Total annual rainfall, relative humidity, minimum and maximum average annual temperatures at Cocoa Research Institute of Ghana from 2013 to 2015.

Weather parameter	Year			Suitable range (ICCO*)
	2013	2014	2015	
Total annual rainfall (mm)	1,516	1,749	1,088	1,500-2,000
Maximum average temperature (^{0} C)	31.8	31.6	32.3	30-32
Minimum average temperature (^{0} C)	19.4	18.5	18.8	18-21
Relative humidity (%)	81.9	83.1	79.2	70-80

*International Cocoa Organization.

The survival rates of cocoa seedlings transplanted at 3 months (Fig. 4A) was significantly ($p<0.05$) improved by raising seedlings in the standard black and translucent sachet water polybags at 3, 6, 9 and 12 months in the field compared to raising seedlings in the small black polybag. Transplanting seedlings at 6 months led to a significant ($p<0.05$) reduction in survival rate of seedlings in the translucent sachet water polybag compared to the other treatments at 3, 6, 9 and 12 months in the field (Fig. 4B).



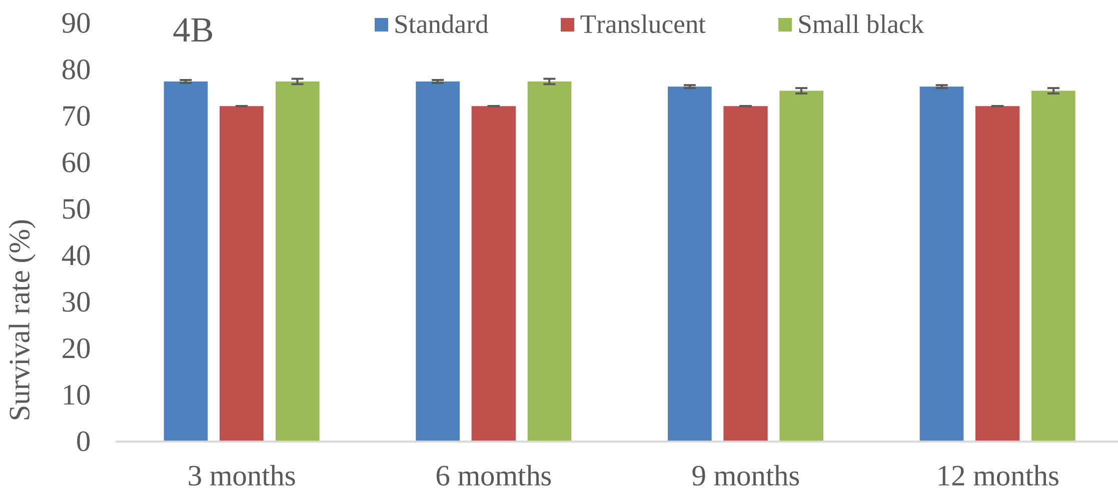


Figure 4. Effects of polybag type on the survival rates of young cocoa 3-12 months in the field after transplanting 3 (A) and 6 (B) months old cocoa seedlings.

The type of polybag used had no significant (p>0.05) adverse effects on the proportion of plants jorquetting and average jorquette height at one year after transplanting (Table 4). Regardless of the polybag type used, transplanting seedlings at 3 months greatly improved the proportions of plants jorquetting and formation of jorquettes at heights between 111.3 cm and 124.7 cm, with an average jorquette height of 122.7 cm (Table 4).

Table 4. Effect of nursery polybag type and age of transplants on jorquette formation and jorquette height of young cocoa plants 1 year after transplanting.

Bag type	Transplanted at 3 months		Transplanted at 6 months	
	% Jorquetting after 1 year	Average Jorquette height (cm)	% Jorquetting after 1 year	Average Jorquette height (cm)
Standard black	70 (62)	124.7	31.8 (33.8)	78.5
Sachet	40 (38)	132.1	24.3 (28.6)	68.2
Small black	50 (45)	111.3	14.2 (21.7)	62.0
F-test	ns	ns	ns	ns
% cv	35.0	14.4	30.4	32.0

Note: Values in parentheses are arc sine transformations

There were no significant residual influence (p<0.05) of polybags on stem diameter (5) and height (6) increase in the field from 12-36 months after transplanting, regardless of the age at which seedlings were transplanted (Fig % & 6). Generally, plant survival, stem diameter and height increase were improved by transplanting seedlings at 3 months after nursing.

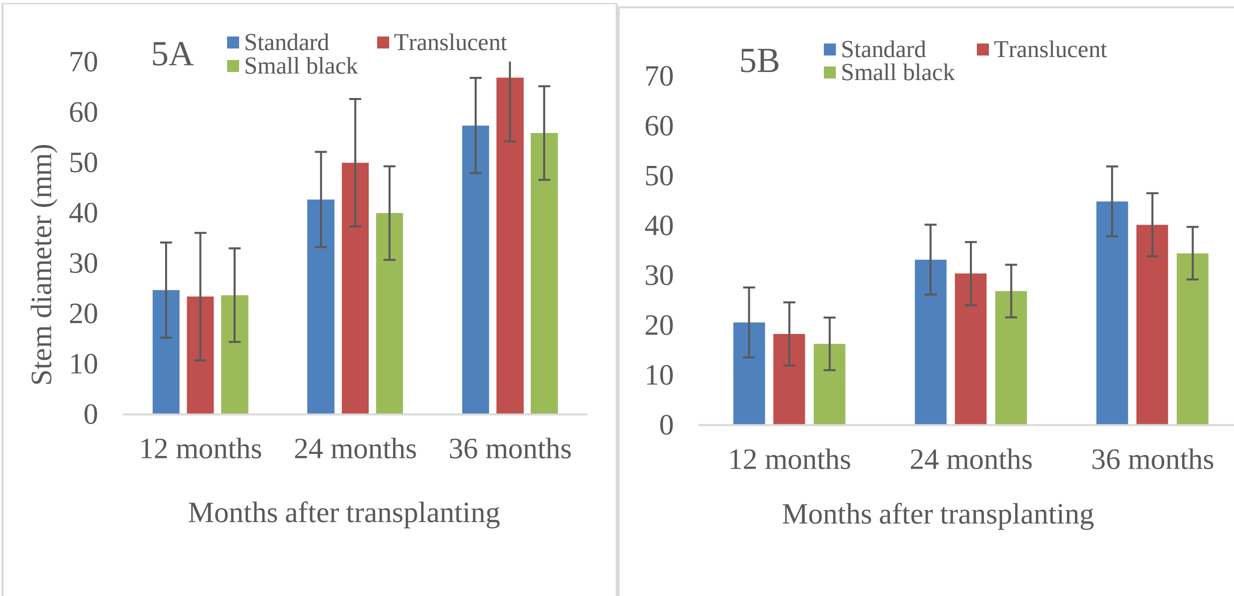


Figure 5. Residual effects of polybag type on the stem diameter increase of young cocoa 1, 2 and 3 years in the field after transplanting 3 (A) and 6 (B) months old seedlings.

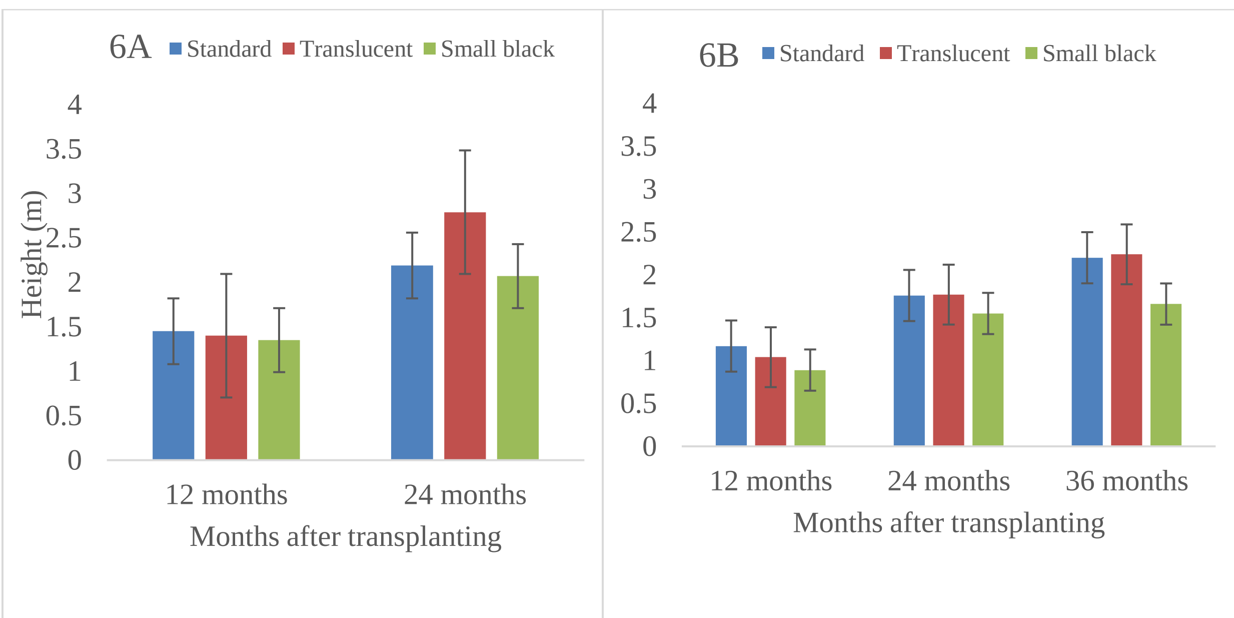


Figure 6. Residual effects of polybag type on the height increase of young cocoa 1, 2 and 3 years in the field after transplanting 3 (A) and 6 (B) months old seedlings.

4. Discussion

The similarity in available soil moisture in the different polybags was probably an attribute of the soil since it was sourced from the same location. Its water holding capacity was therefore, not expected to differ based on the type of polybag used. As a result, final emergence of cocoa seedlings 1 MAS after sowing was not affected. The peak moisture readings at 2, 3 and 4 MAS coincided with the peak rainy season (June-July) with high atmospheric humidity which might have inhibited water loss from the soil in the polybags through evapotranspiration. The subsequent decline in available soil moisture after the 4^{th} month can partly be explained by increased moisture uptake by the much larger seedlings and reduced atmospheric humidity with attendant increase in evapotranspiration.

Raising cocoa seedlings in polybags without nutrient amendment probably resulted in earlier depletion of nutrients in the smaller polybags. The general reduction in leaf chlorophyll content at the later growth stages in the nursery was therefore attributable to depleted nutrient supplies (Konlan *et al*., 2014), suggesting that chlorophyll concentration in the leaves of seedlings raised in the smaller polybags could be improved through nutrient amendment. Since, chlorophyll fluorescence relates inversely to photosynthesis (Gitelson, 1999), the reduction in chlorophyll fluorescence with seedling age probably suggest better utilization of photosynthetically active radiation (PAR). This was in spite of a reduction in the amount of chlorophyll per unit leaf area.
The improved efficiency in light use was therefore attributable to the expanding leave size which more than compensated for the reduction in chlorophyll content per unit leaf area (Peterson and Zelitch, 1982; Campbell *et al*., 1986).

The similar height attained by cocoa seedlings in the nursery, irrespective of the polybag type was probably as a result of competition for space and light. This was seen in the reduction of stem diameter of seedlings raised in translucent sachet water and small black polybags at 5 and 6 MAS, indicating that seedlings in those polybags channeled limited photosynthates towards stem elongation at the expense of diameter increase. This behaviour led to seedlings with thin weak stems towards the end of the nursery period, predisposing such seedlings to lodging in the field.

At the early growth stages (1-3 MAS), the nutrient contents in the polybags, irrespective of the size was probably sufficient to support seedling growth needs. The similarity in leaf numbers per plant, total leave area, chlorophyll concentration per unit leaf area and interception of similar amounts of PAR at this stage explains why seedlings accumulated similar amounts of dry matter. The continuous growth of the seedlings in the containers without nutrient amendment led to relatively lower nutrient amounts in the smaller polybags resulting in significant reductions in leave formation and expansion which ultimately affected photosynthesis and growth. In the nursery, the direct relationship between soil volume and nutrient availability was the major factor limiting the growth of seedlings raised in the small black and sachet water polybags in the long term.

Generally, the improved survival rates (70-85 %-transformed data) of seedlings transplanted at 3 MAS was due partly to less damage to their root systems (Amoah *et al*., 1999; Oliet *et al*., 2001), which meant that those seedlings suffered little transplanting shock, and partly to very favourable weather at the time of transplanting (Ofori *et al*., 2014). The difference in survival rates observed between seedlings raised in the translucent sachet water and the small black polybags, both of which contained the same volume of soil in the nursery was probably due to possible formation of beneficial relationships with mycorrhizae (Max *et al*., 1989; Teste *et al*., 2004; Neslihan *et al*., 2016) in the case of the translucent sachet water polybags, since a form of yellowish-grey growth was found in this polybag prior to transplanting.

Although transplanted late in the season (September), the relatively lower survival rates of seedlings transplanted at 6 months after nursing could not be explained by the micro-climate of the location since rainfall received following transplanting of these seedlings were above the recommended optimum. The lower than expected seedling survival was probably due to root damage during transplanting and physiological changes such as stunting, resulting from seedlings being pot-bound for 6 months in the nursery. These factors might have affected the ability of the seedlings to recover quickly and establish prior to the onset of the dry season, thus leading to higher mortalities.
The pattern of jorquetting by young cocoa established using 3 months old seedlings indicates that early transplanting improves the overall architecture of the tree. Also, the height at which this jorquettes formed is considered more suitable since the number of jorquettes and jorquette height respectively relates to yield and ease of farm management operations in cocoa cultivation. Generally, Seedlings transplanted at 3 months showed better growth compared with those transplanted at 6 months. The absence of stem diameter and height differences in the field 1-3 years after transplanting irrespective of polybag type was probably because seedlings transplanted had similar morphological and physiological attributes as shown by the nursery data (Table 1). The similarity in leaf area and chlorophyll content at the time of transplanting probably led to interception and assimilation of similar amounts of PAR in the field, leading to similar growth performance.

The relatively better growth seen in seedlings raised in the translucent sachet water polybags and transplanted at 3 MAS could be attributed to possible formation of beneficial relationship between the roots of the seedlings and mycorrhizae, which is reported to enhance moisture and nutrient uptake by tree seedlings (Max *et al*., 1989; Teste *et al*., 2004; Neslihan *et al*., 2016).

The growth differences in the nursery at 5 and 6 months which favoured seedlings in the standard polybags were largely influenced by soil volume in the polybags. These differences could not be sustained in the field probably due to the exposure of the root systems of all seedlings to larger soil volumes, where moisture and nutrients could be accessed. As a result, the differences were cancelled out leading to similar stem diameter and height at 1 year after transplanting.

Conclusions

The similarity in physiological and morphological attributes between seedlings raised in the small black and sachet water polybags, each containing the same soil volume, suggest that the translucent nature of the sachet water polybag had no adverse effects on the performance of the seedlings in the nursery. It did not also adversely affect transplanting success at 3 months and early growth of the transplanted seedlings. Generally, seedlings achieved better growth and percentage jorquetting with higher points of jorquette formation when transplanted at 3 months. It is therefore, more affordable to use the freely available translucent sachet water polybags for raising cocoa seedlings which should be transplanted to the field at 3 months old. The added benefits of direct removal of plastic waste from the environment through their utilisation in the nursery and indirect removal through reduced demand for production of nursery polybags by the plastic industry promotes environment sustainability.

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