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Germination, seedling growth and dry matter accumulation of *Cola nitida* in the nursery as affected by seed biotype colour and storage duration in dodecahedron pyramidal device

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Summary: Long dormancy period and non-uniformity growth patterns of *Cola nitida* pose challenges for kola farmers, discouraging them from establishing kola plantations. Experiment was conducted at Federal University of Agriculture, Abeokuta, Ogun State, Nigeria to study the effects of seed colour and curing duration on germination, growth and dry matter yield of *C. nitida.* Experiment was 3 × 4 factorial, laid out in Completely Randomized Design. Treatments comprised seed colour (red, pink & white) and curing duration (12, 8, 4, and 0 weeks). The experiment had 12 treatments; each replicated three times. Data collected on germination, growth and dry matter were subjected to analysis of variance and means were separated using Duncan's Multiple Range Test ($P \leq 0.05$). Germination commenced at 4 WAS, on white, pink and red kola seeds stored for 8, 4 and 6 weeks with 10%, 6.66% and 3.33% respectively. At 8 WAS, white kola seeds stored for 12, 4 and 8 weeks had 93.3, 86.7 and 83.3% germination respectively. At 12 WAS, germination was completed for white kola 12-week stored in Dodecahedron Pyramidal Device (100%), while others range between 60.0 and 96.7%. White, pink and red kola seeds stored for 8, 4 and 12 weeks produced vigorous seedlings that were taller with more leaves than those of an un-stored seed at 18 and 20 WAS. In conclusion, white, pink and red kola (*C. nitida*) seed stored for 4, 8 and 12 weeks inside Dodecahedron Pyramidal Device resulted in rapid germination and improved morphological growth performance.

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Key words: C*ola nitida*, dormancy, dodecahedron pyramidal device, germination, storage, seed biotype colour

Introduction

Kola belongs to the family Sterculiaceae and the genus Cola, has about fourty (40) species in West Africa, twenty-five (25) of which are found in Nigeria. However, only two species; *Cola nitida* (Vent) Schott & Endl as well as *Cola acuminata* (P. Beauv) Schott & Endl are of economic importance. It is indigenous to Tropical Africa and has its centre of greatest diversity in West Africa. In the forest areas of West Africa, kola is perhaps second in importance only to oil palm in the list of indigenous cash crops. Kola nut has been an item of trade in West Africa and in the trans-Saharan trade routes for many centuries (Egbe & Sobamiwa, 1989). It has for hundreds of years served as an important article of internal trade in Nigeria and other parts of Africa (Nzekwu, 1961). Both species are important economic crops in the forest area of West and Central Africa, Carribean Islands, Mauritius, Sri Lanka and Malaysia (Eijnatten, 1969; Oladokun, 1982). Kolanut is an important economic cash crop to a significant proportion of Nigerian population who are involved in kolanut farming, trading, and industrial utilization. Nigeria has comparative advantage over other producers in terms of climatic condition and soil factors. The cultivation of kola in Nigeria is ecologically limited to the rain forest zones of South and riverine areas of the Savannah region. In large production, the crop pattern of kola nut is interspersed with cocoa and bitter kola. Kola will do well in soils suitable for cocoa and coffee and in soils which are marginal for these two crops. According to Asogwa et al. (2006) there is an abundance soil of high, medium, and low fertility that can be strategically exploited for kolanut cultivation in an effective land utilization policy in Nigeria. An estimated 700,000 hectares of good cocoa soil harbours kola as this crop is mostly grown in mixture with cocoa in Oyo, Osun, Ogun, Ekiti and Ondo States. Kola cultivation can be strategically pursued on suitable soils that have long been identified in the following parts of the country which share similar climatic and edaphic factors. Kola presently thrives in Ogun, Ondo, Oyo, Osun, Ekiti, Edo, Delta, Enugu, Anambra, Rivers, Cross Rivers, Abia, Akwa-Ibom and Niger States. These suitable soils scattered all over the country should be utilized for planting of new improved seedlings to ensure high production of kolanuts for export. Production of kola nuts is determined by the land covered and major occupation of the people of the areas. The land put under cultivation varied in each state, thus only the Southern parts of Edo and Adamawa State, non-riverine areas of Delta and Rivers States, most parts of Cross River and Akwa Ibom States, Ilorin area of Kwara State, Zaria area of Kaduna State, areas around rivers and streams if irrigation is provided, especially during establishment stages in

Kano State, Mokwa and large areas of the upper part of River Niger, provided irrigation is available in Niger State, Oturkpo and Kabba areas in Benue/Plateau/Kogi States and Lafia area in Nassarawa State (Asogwa et al., 2006; Opeke, 2005). The geo-political zones carved out based on geographic location for kola producing states in Nigeria are: South West (Ogun, Ondo, Oyo, Ekiti, Osun and Lagos (upperland area)), South (Edo, Delta, Rivers, Cross River and Akwa Ibom), South East (Anambra, Enugu and Abia), North central (Kwara, Nassarawa, Niger, Benue, Plateau and Kogi), North West (Kano and Kaduna) Ndagi et al. (2012).

The two Cola species (*C. nitida* and *C. acuminata*) of economic importance globally account for about 70 percent of the total world production of kolanuts (Jacob, 1973). About 90% of the kolanut produced in Nigeria is consumed locally within the country while 10% is exported (Quarco, 1973). The kola nut tree is referred to as "Igi owo" (i.e. money spinner (generating) tree) by the people of Remo in Ogun State, where it is well grown. Out of these lots, are of agricultural prominence, Ijare area of Ondo State is regarded as the centre of origin of *C. acuminata*. *Cola acuminata* is used mainly in the Southern and North Central zones of Nigeria largely in connection with social and religious ceremonies. In these areas, *C. acuminata* is still considered as first choice and the demand for them remains high. The cultivation of *C. nitida* in Nigeria began sometimes in the 19th Century. The nut (*C. nitida*) was observed to be grown plentifully in Agege and the Otta bush by 1854 while its cultivation was noted in Egba Division in 1902 and in Labochi and environs in 1901. From Agege, *C. nitida* cultivation presumably spread to the forest areas following first the course of the railway into Abeokuta, Ibadan and Offa replacing *C. acuminata* and penetrating later along stream and riverbanks into the Guinea Savannah and the present South-South and Southeastern States (Eijnatten, 1969). *C. nitida* frequently referred to as the "true kola of commerce" has featured in the internal trade of West Africa for several centuries. There are three types; the white kola, are cream colour, Pink which is more nearly a pale greenish-yellow, and the red kola, both being yielded by the same species and often occurring in the same pod. However, *C. nitida* possesses postharvest dormancy that physiologically inhibits germination with fiercely long dormancy period. This had discouraged many kola-nut farmers in Nigeria, especially some part of the Southwest, South-South and North Central region from the establishment of the new kola nut plantation. The existing old or moribund trees of kola had resulted in low supply of its nut to the market, thereby reducing the income of the kola farmer. The ever-increasing demand of kola nuts has led to sustained interest in cultivation of kola as efforts are made to increase both its hectarage as well as production per unit area. This simply means that abundant kola planting materials must be provided to open new farms. However, no sooner was such interest generated than it was realized that kola propagation is beset with several problems which need to be tackled to maximally obtain propagules of the right quantities and qualities at the right time. These problems are both inherent within the plant material itself as well as environmental (Oladokun, 1982).

Seed dormancy is a block to the completion of germination of a viable seed (nut) under favourable conditions (Hilhorst, 1995; Bewley, 1997; Li & Foley, 1997). This block to germination was reported to have evolved differently across species through adaptation to the prevailing environments, such that germination occurs when conditions for establishing a new plant generation are likely to be suitable (Hilhorst, 1995; Vleeshouwers & Bouwmeester, 1995; Bewley, 1997; Li & Foley, 1997; Baskin & Baskin, 2004; Fenner & Thompson, 2005). Therefore, this view gives rise to a diverse range of dormancy mechanisms to keep with the diversity of climates and habitats. However, Finch-Savage & Leubner-Metzger (2006) and Baskin & Baskin (2004) reported that dormancy can only be measured by the absence of germination and that a dormancy seed does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors that are otherwise favourable for its germination, i.e. after the seed becomes non-dormant. Additional reports by Vleeshouwers & Bouwmeester (1995); Fenner & Thompson (2005) indicated that dormancy should not just be associated with suspension of germination rather, it is a characteristic of the seed that determines the conditions required for germination. When dormancy is considered in this way, any environmental factor that alters the conditions required for germination is altering dormancy and by extension, when seed no longer requires specific environmental factors it is non-dormant. In *Garcinia C.*, the germination conditions from literature are contradictory. Some authors (Okafor, 1982; Kengue & Ndo, 2003; Mbolo, 2002) describe *Garcinia kola* seed as easy to germinate, while others (Oladokun, 1988; Gyimah, 2010; Adebisi, 2004; Anegbeh et. al., 2006; Idumah, 2014) describe it as exhibiting a high degree of dormancy covering 18-28 months. There have been some attempts to overcome the seed dormancy and enhance germination in some Nigerian and Ghanaian collections, but the high diversity of results makes it difficult to postulate a definite procedure for enhancing germination in the crop plant. However, dodecahedron is a compendium of twelve pyramids or a shape of regular pentagonal faces meeting at each of its twenty (20) vertices, with thirty (30) edges having 60 diagonals. Flanagan (1971) reported that pyramidal shapes made of pieces of cardboard were able to concentrate some pyramidal energy that could mummify foods and energize crop seeds without any external power source. Research in USA, Russia and Ukraine have shown that seeds placed inside pyramid prototypes showed better seedling vigour, growth and yield. Adetiloye (1985, 1996) studied the evolutionary sequence of five regular geometric shapes and opined that if the asymmetrical forms of the great pyramid can have the above beneficial effects, more regular symmetries such as tetrahedron, hexahedron, octahedron, icosahedrons and dodecahedron should exhibit similar if not better effects than the Egyptian type of pyramids. This technique has been successfully applied to arable crops, where it resulted in up to an 80% increase in yield. However, its application to tree crops, including kola, has not yet been investigated. This gap highlights the need to evaluate its potential effectiveness in kola production. Therefore, this study aims to investigate the effect of seed biotype colour and storage duration in dodecahedral pyramidal devices on germination, seedling growth and dry matter accumulation of kola (*C. nitida*) in the nursery.

Materials and methods

Experimental location, seed material and source

The experiment was conducted in the screen house of the College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta, Ogun State Nigeria (Latitude 7° 15'N Longitude 3° 25'E). Fresh *C. nitida* seeds of

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same mother plant were sourced from a local market in Olugbo, Abeokuta, Area of Ogun State, Southwestern Nigeria. Seeds/nuts smaller than 15 g or infested/infected with insects/diseased were discarded. Seeds of 15 g in weight were used for this study. The seeds/nuts were separated into three biotypic colours – red, pink and white ***(Table 1)***.

Treatment definition

Factor 1: includes kola seed biotypes colour at 3 levels (white, pink & red)

Factor 2: includes storing duration at 4 levels (12, 8, 4, and 0 weeks)

Table 1. Treatment combinations

0wk White	Unstored fresh white nuts/seeds
4wk White	White Nuts/seeds stored for 4weeks inside Dodecahedron Pyramidal Shape
8wk White	White Nuts/seeds stored for 8weeks inside Dodecahedron Pyramidal Shape
12wk White	White Nuts/seeds stored for 12weeks inside Dodecahedron Pyramidal Shape
0wk Pink	Unstored pink fresh nuts/seeds
4wk Pink	Pink Nuts/seeds stored for 4weeks in Dodecahedron Pyramidal Device
8wk Pink	Pink Nuts/seeds stored for 8weeks in Dodecahedron Pyramidal Device
12wk Pink	Pink Nuts/seeds stored for 12weeks in Dodecahedron Pyramidal Device
0wk Red	Unstored fresh red nuts/seeds
4wk Red	Red Nuts/seeds stored for 4weeks in Dodecahedron Pyramidal Device
8wk Red	Red Nuts/seeds stored for 8weeks in Dodecahedron Pyramidal Device
12wk Red	Red Nuts/seeds stored for 12weeks in Dodecahedron Pyramidal Device

Description of the storing medium

Dodecahedron Pyramidal Shapes were fabricated with the use of plywood as described by Adetiloye (1996) (***Figure 1***), which serve as a medium inside which kola nut seed were stored. The temperature and the relative humidity of each of the storage media were measured with the aid of thermometer and hygrometer respectively (***Table 2***). The volume and surface area of Dodecahedron Pyramidal Device (DPD) used for the study were determined using the geometry formula derived by Mark (2022). The Dodecahedron Pyramidal Shape edge length was 11.43 cm and the angle with 108^0.

$$V = ((15 + 7\sqrt{5}))/4 \; e^3$$
$$A = 3\sqrt{25 + 10\sqrt{5}} \; e^2$$

e = Length of an edge

Fresh sawdust was collected and filled into 50 cl containers which had earlier been punched at 3 points underneath for percolation to allow for excess water drainage. After preparing the seeds in accordance with the treatments, they were sown inside the cups at seeding rate of one seed per cup, horizontally on their sides at a sowing depth of about 4-5 cm. The saw dust was watered to get wet for two weeks before planting to allow for partial weathering and moisture percolation into the medium.

Figure 1. The picture of sealed Dodecahedron Pyramidal Shapes with thermometer and hygrometer devices placed inside for measurement of temperature and relative humidity.

Table 2. Temperature (°C) and relative humidity (%) value of the storing medium (Dodecahedron Pyramidal Shape) and labouratory room before sowing of *Cola nitida* nut recorded fortnightly for 12 weeks.

	Temperature (℃)		**Relative humidity (%)**	
Weeks	Dodeca-hedron pyramidal Shape	Labouratory room	Dodeca-hedron pyramidal Shape	Labouratory room
0*	27.7	29.2	78	79
2	28.5	28.9	79	80
4	28.4	29.2	78	79
6	28.4	29.3	78	81
8	29.5	29.5	79	82
10	28.9	28.9	80	83
12	28.7	29.0	79	81

Experimental design

The experiment was a 3 x 4 factorial laid out in a completely randomized design with three replicates. Ten seeds were sown per treatment giving 120 seeds per replicate which amounted to 360 treated nuts plus 90 untreated nuts (control) giving a total of 450 nuts for the whole experiment. Watering was carried out daily, early in the morning and evening to prevent the plant from water stress.

Data collection

Data were collected on Germination percentage using the next formula (Adebisi, 2013):

$$\frac{\text{number of seeds germinated} \times 100}{\text{number of seeds sown}}$$

Morphological growth performance of the seedlings was measured with two plants randomly selected and tagged.

Plant height (cm): The tagged plantlets were measured from base (on top of the growth medium) to the shoot apex with a meter ruler fortnightly.

Number of leaves/plants: Leaves on the tagged plants were recorded at an interval of 2 weeks.

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Leaf area/plant (cm^2): The lengths by breadths of 2 tagged leaves multiplied by 0.72 (Oladokun, 1988) were summed and averaged at an interval of 2 weeks.
Stem diameter (mm): The diameter of each of the tagged seedlings was measured using a Digital Calliper (Model Hotso 342) at an interval of 2 weeks.
Dry matter yield of leaves, stem and root (g/plant): The fresh samples of known weight were oven-dried at the Laboratory of the Department of Horticulture COLPLANT, FUNAAB using cabinet dryer (LEEC BS EN 12150) at temperature 60^{0}C until constant weight is attained.

Statistical analysis

The data obtained during the experiment were subjected to Analysis of Variance (ANOVA) to determine the level of treatment effects on germination and early growth of kola seedlings using CoStat (CoStat, 1996). Mean performance of the treatments were carried out using Duncan's Multiple Range Test (DMRT).

Results

Germination percentage (%) of Cola nitida seed as affected by biotype colour and storage duration in Dodecahedron Pyramidal Device (DPD) across 20 weeks after sowing (WAS) in the nursery

Germination was observed to be delayed within the first 4 weeks after sowing across all treatments (mostly between 0 and 10%). At 6 WAS, more than 50% germination had occurred for white seeds cured for 8 weeks in DPD, while other treated nuts ranges between 0 and 40%). The differences were significant $p \leq 0.05$. At 8 and 10 WAS, rapid increase in percentage germination for stored coloured seeds were observed, while white, pink and red seeds stored for 12 weeks had (93.3 and 96.7%), (76.7 and 93.3%) and (63.3 and 76.7%) in that order. However, at 12 WAS, germination had completed (100%) for white kola seed stored for 12 weeks, and all other treatments within the same period had between 60.0 and 96.7% germination. From 14 to 20 WAS, germination was at its peak for white, pink and red seed stored for 12 weeks in DPD between the tune of 96.7 and 100% germination (***Table 3***).

Morphological growth performance of kola nut (Cola nitida) seedlings as influenced by seed colour and storage duration in Dodecahedron Pyramidal Device (DPD)

Plant height (cm)

For most treatments, plant height generally increases over time, and significantly no differences, except red un-stored seed with a significantly reduced plant height from 12 to 20 WAS. However, white, pink and red biotypes treated with DPD, regardless of storage duration, perform similarly well in terms of plant height. At 12 WAS, Pink nut 12- week stored had the highest (31.53 cm), closely followed by red seed 4-week stored (30.0 cm), other treatments ranged between 23.23 and 29.92 cm and the seedlings raised from red un-stored seed had the least. Same trend was observed at 14 and 16 WAS. Meanwhile, at 20 WAS, Pink and White seed stored for 8 weeks were the tallest with height value of 41.83 and 40.17 cm respectively (***Table 4***).

Number of leave/plants

At 12 WAS, the number of leaves produced from seedling raised from pink seed stored for 12 weeks was higher (6.33) compared to un-stored red seed (3.50) ($P < 0.05$). All other treatments, which ranged between 4.00 and 6.17 cm were not significantly different. At 14 WAS, seedling raised from 12-week stored red seed had the highest (8.17), followed by 8-week stored pink seed (7.67) and 4-week stored red seed (7.17) while other treatment ranged between 5.50 and 6.67. The differences were not significant ($P < 0.05$). Same trend was observed at 16 WAS. At 18 and 20 WAS, white seed stored for 8 weeks recorded the highest (9.17 and 9.83) respectively (***Table 5***). This was followed by red seed stored for 12 weeks with 8.83 each relative to each period and red seed stored for 4 weeks with 8.50 and 8.83 in that order. In contrast, red un-stored seeds had the least (6.50 and 6.67).

Stem girth (mm)

At 12 WAS, seedling produced from white seed 12-week stored gave highest stem girth (1.70 mm), followed by Red, 8-week stored (1.37 mm) and Red, 12-week stored (1.22 mm). The lowest values were from Red and Pink un-stored seeds and Red 4-week stored (0.88–0.95 mm). At 16 WAS, white seed stored for 12 and 8 weeks gave the highest girth value (2.38 and 2.18 mm), which was significantly different from other treatments' values range between 1.45 and 1.91 mm ($P < 0.05$). All treatments showed improved girth, ranging from 1.85 to 2.85 mm at 18 WAS. Within the same period, white 12-week stored had the highest girth value (2.85 mm), followed by pink 8-week stored (2.55 mm) and red 12-week stored (2.62 mm). The differences were not significant $P < 0.05$. At 20 WAS, seedlings raised from white seed 12, 8-week stored and pink seed 8-week stored had 2.81, 2.76 and 2.43 mm respectively. Others recorded between the tunes of 1.91 to 2.37 mm and were not significantly different ($P < 0.05$) (***Table 6***).

Leaf area (cm^2)/plant

At 12 WAS, seedlings raised from 8-week stored white seeds recorded the highest leaf area (189.2 cm^2), which was significantly higher ($P < 0.05$) than that of seedlings from un-stored red seeds (107.7 cm^2). Other treatments had intermediate values ranging from 110.9 to 188.1 cm^2, and the differences were not significant. At 14 WAS, the leaf area remained highest in seedlings from 8 and 4-week stored white seeds (194.5 cm^2 and 191.8 cm^2 respectively). The lowest values were observed in seedlings from un-stored pink (112.6 cm^2) and red (112.2 cm^2) seeds. The differences were significant ($P < 0.05$). At 16 WAS, 4-week stored white seeds recorded the highest leaf area (186.5 cm^2), followed closely by 12-week stored white seeds (182.8 cm^2). In contrast, seedlings from un-stored pink (112.5 cm^2) and red (118.3 cm^2) seeds maintained the lowest values, with a significant difference ($P < 0.05$) (***Table 6***). At 18 WAS, the 8-week stored white seeds produced the largest leaf area (214.8 cm^2), significantly higher compared to un-stored red seeds (119.8 cm^2). By 20 WAS, the trend persisted with 8-week stored white seeds maintaining the highest leaf area (219.0 cm^2), followed by 4-week stored white seeds (182.3 cm^2). The lowest leaf area remained with un-stored red seeds (121.3 cm^2), significantly reduced compared to stored seeds ($P < 0.05$) (***Table 7***).

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Table 3. Germination percentage of kola (*Cola nitida*) seeds in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing								
Bio-Colour	Duration in PD	4	6	8	10	12	14	16	18	20
	12-week stored	3.33ab	26.6bc	93.3a	96.7a	100a	100a	100a	100a	100a
White	8-week stored	10.0a	53.3a	83.3abc	93.3ab	93.3abc	93.3ab	93.3ab	100a	100a
	4-week stored	0.0b	26.6bc	86.7ab	86.7abc	90.0ab-d	96.7ab	96.7ab	100a	100a
	un stored nut	0.0b	13.3cd	63.3bc-e	73.3ab-e	86.7a-d	93.3ab	93.3ab	86.7ab	96.7a
	12-week stored	3.33ab	40.0ab	76.7abcd	93.3ab	96.7ab	100a	100a	100a	100a
Pink	8-week stored	3.33ab	10.0cd	70.0ab-e	76.7ab-d	80.0bcd	83.3ab	83.3ab	93.3ab	100a
	4-week stored	0.33ab	10.0cd	56.7def	70.0bc-e	76.7cd	96.7ab	96.6ab	96.7ab	96.7a
	un stored nut	0.0b	10.0cd	53.3cde	66.7cde	73.3de	86.7ab	86.7ab	93.3ab	96.7a
	12-week stored	3.33ab	13.3cd	63.3bcde	76.7ab-d	86.7ab-d	96.7ab	96.7ab	100a	100a
Red	8-week stored	0.0b	3.33d	50.0def	60.0cd	80.0bcd	83.3ab	83.3ab	90.0ab	96.7a
	4-week stored	6.66ab	16.6cd	46.7ef	60.0de	80.0bcd	86.7ab	86.7ab	90.0ab	100a
	un stored nut	0.0b	0.0d	26.7e	50.0e	60.0e	80.0b	80.0b	83.3b	83.3b

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 4. Plant height (cm) of kola (*Cola nitida)* seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing				
Bio-Colour	Duration in DPD	12	14	16	18	20
	12-week stored	28.95a	33.67a	34.67a	34.83a	34.83a
White	8-week stored	29.35sa	32.33a	33.33a	40.17a	41.17a
	4-week stored	29.12a	28.67a	31.67a	32.33a	33.67a
	un stored nut	28.08a	30.17a		33.17a	33.33a
	12-week stored	31.53a	34.50a	35.50a	38.00a	39.50a
Pink	8-week stored	27.75a	30.33a	33.50a	40.00a	41.83a
	4-week stored	27.87a	31.33a	33.50a	36.17a	36.83a
	un stored nut	27.53a	29.67a	32.00a	34.83a	35.17a
	12-week stored	29.92a	33.03a	36.33a	39.17a	39.33a
Red	8-week stored	23.23a	27.00a	29.83ab	31.83a	32.00a
	4-week stored	30.00a	33.33a	35.33a	37.33a	38.03a
	un stored nut	12.92b	16.17b	18.17b	21.83a	22.50a

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 5. Number of leaves of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing				
Bio-Colour	Duration in DPD	12	14	16	18	20
	12-week stored	5.33ab	6.67a	6.67a	6.67a	6.67a
White	8-week stored	5.17ab	6.67a	7.00a	9.17a	9.83a
	4-week stored	4.67ab	6.17a	6.17a	6.17a	6.17a
	un stored nut	4.67ab	5.50a	5.50a	5.83a	5.83a
	12-week stored	6.33a	6.50a	6.50a	8.00a	8.00a
Pink	8-week stored	5.17ab	7.67a	7.67a	8.00a	8.00a
	4-week stored	6.17ab	6.33a	6.33a	7.00a	7.00a
	un stored nut	4.17ab	5.50a	5.67a	6.67a	6.67a
	12-week stored	5.50ab	8.17a	8.33a	8.83a	8.83a
Red	8-week stored	4.00ab	6.50a	6.50a	7.50a	7.50a
	4-week stored	4.83ab	7.17a	7.67a	8.50a	8.83a
	un stored nut	3.50b	5.50a	5.50a	6.50a	6.67a

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 6. Stem girth (mm) per plant of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing				
Bio-Colour	Duration in DPD	12	14	16	18	20
	12-week stored	1.70a	2.28a	2.38a	2.85a	2.81a
White	8-week stored	1.48ab	2.07ab	2.18a	2.77a	2.76a
	4-week stored	1.07ab	1.60ab	1.67ab	2.05a	2.03a
	un stored nut	1.03ab	1.50ab	1.58ab	2.01a	1.96a
	12-week stored	1.15ab	1.43b	1.53b	2.47a	2.20a
Pink	8-week stored	1.11ab	1.63ab	1.78ab	2.55a	2.43a
	4-week stored	1.10ab	1.41b	1.55b	2.10a	2.02a
	un stored nut	0.95b	1.27b	1.48b	2.00a	1.91a
	12-week stored	1.22a	1.71ab	1.91ab	2.62a	2.37a
Red	8-week stored	1.37ab	1.77ab	1.90ab	2.41a	2.26a
	4-week stored	0.88b	1.32b	1.48b	2.05a	2.01a
	un stored nut	0.88b	1.27b	1.45b	1.85a	1.91a

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 7. Leaf area (cm²) per plant of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing				
Bio-Colour	Duration in DPD	12	14	16	18	20
	12-week stored	173.6ab	177.3ab	182.8bc	175.5abc	181.2bc
White	8-week stored	189.2a	194.5a	174.3abc	214.8a	219.0a
	4-week stored	188.1a	191.8ab	186.5a	180ab	182.3ab
	un stored nut	149.4abc	153.3abc	174.3abc	165.3abc	155.6ab
	12-week stored	134.0abc	137.1bc	124.3bcd	142.0bc	150.0bc
Pink	8-week stored	132.9abc	136.1bc	140.2abcd	144.4bc	145.6bc
	4-week stored	132.7abc	137.2bc	146.8abcd	150.0bc	153.8bc
	un stored nut	110.9c	112.6c	112.5d	122.9bc	122.5c
	12-week stored	127.5bc	135.3bc	136.8abcd	143.0bc	143.4bc
Red	8-week stored	109.8c	113.3c	129.6abcd	138.0bc	144.0bc
	4-week stored	130.0bc	135.8bc	149.0abc	153.8bc	158.8bc
	un stored nut	107.7c	112.2c	118.3cd	119.8c	121.3c

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 8. Dry matter of leaves (g/plant) of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing			
Bio-Colour	Duration in DPD	20	22	24	26
	12-week stored	15.6a	11.3a	11.9a	12.23a
White	8-week stored	11.4ab	8.70a	9.20ab	10.46ab
	4-week stored	12.2a	7.36a	8.83ab	7.86bc
	un stored nut	8.06bcd	7.60a	6.30b	7.26bc
	12-week stored	7.60cd	8.20a	11.7a	7.96bc
Pink	8-week stored	10.3abc	6.10a	9.53ab	7.83bc
	4-week stored	8.70bcd	8.40a	7.20b	8.73abc
	un stored nut	5.73d	8.43a	11.6a	6.23c
	12-week stored	7.60cd	9.06a	7.63ab	7.00bc
Red	8-week stored	8.43bcd	8.86a	7.63ab	7.36bc
	4-week stored	8.37bcd	7.76a	8.06ab	7.46c
	un stored nut	6.97cd	6.56a	7.16b	6.46bc

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

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Table 9. Dry matter of shoot (g/plant) of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing			
Bio-Colour	Duration in DPD	20	22	24	26
White	12-week stored	4.80a	2.93a	3.76b	4.06ab
	8-week stored	3.96a	2.36c	3.33b	4.13c
	4-week stored	4.46bc	2.30a	3.63a	3.26c
	un stored nut	3.46b	1.96bc	2.16bc	3.21a
Pink	12-week stored	3.00de	2.33bc	3.20a	4.30b
	8-week stored	3.63cd	2.90cd	4.06c	3.30b
	4-week stored	3.03de	2.43bc	4.13bc	3.83a
	un stored nut	2.80cd	1.86bc	3.13bc	2.60de
Red	12-week stored	3.06de	2.36bc	2.53cd	3.10c
	8-week stored	3.26 c	2.13de	2.96de	3.65c
	4-week stored	3.26e	2.26e	3.26bc	2.56de
	un stored nut	2.40f	2.16cd	2.46cd	2.00e

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Table 10. Dry matter of root (g per plant) of kola (*Cola nitida*) seedlings in the nursery as influenced by seed biotype colour and storage duration in a Dodecahedron Pyramidal Device (DPD).

Treatment		Weeks after sowing			
Bio-Colour	Duration in DPD	20	22	24	26
White	12-week stored	4.90a	3.46a	3.36abc	3.50ab
	8-week stored	3.63ab	2.46ab	3.66bc	3.93bc
	4-week stored	4.26abc	2.90bc	3.06ab	2.90a
	un stored nut	2.50bc	1.96c	2.10a	1.96abc
Pink	12-week stored	2.36bc	2.63c	3.16ab	2.46bc
	8-week stored	3.40abc	2.23bc	3.46abc	2.66c
	4-week stored	2.43bc	2.43c	3.73abc	3.06bc
	un stored nut	2.10c	1.96ab	3.13c	2.60ab
Red	12-week stored	2.66bc	2.73ab	2.90bc	3.43bc
	8-week stored	2.36bc	2.73bc	2.96bc	2.53c
	4-week stored	2.40bc	2.56bc	3.03c	2.03c
	un stored nut	2.23bc	2.53c	2.50d	1.96c

Note: Means with same letter(s), same column, are not significantly different (P< 0.05).

Dry matter leaves (g)/plant

At 20 WAS, seedlings raised from 12-week stored white seeds recorded the highest leaf dry matter (15.6 g/plant), which was significantly higher (P < 0.05) than that of un-stored pink seeds (5.73 g/plant). Other treatments ranged from 6.97 to 12.2 g/plant, and the differences were non-significant. At 22 WAS, dry matter content across treatments ranged from 6.10 to 11.3 g/plant, with white 12-week stored seeds producing the highest value (11.3 g/plant), followed by red 12-week stored (9.06 g/plant) and red 8-week stored (8.86 g/plant). However, no significant differences (P < 0.05) were observed. At 24 WAS, white 12-week stored (11.9 g/plant), pink un-stored (11.6 g/plant), and pink 12-week stored (11.7 g/plant) seedlings recorded the highest dry matter values. The lowest values were recorded in white un-stored (6.30 g/plant) and pink 4-week stored (7.20 g/plant), which were significantly lower than the highest values (P < 0.05). At 26 WAS, white 12-week stored seeds again recorded the highest dry matter (12.23 g/plant), while pink un-stored seeds had the lowest (6.23 g/plant). Other treatments ranged between 7.00 and 10.46 g/plant, and the differences were not significant (***Table 8***).

Dry matter shoot (g)/plant

At 20 WAS, the highest shoot dry matter was recorded in seedlings from 12-week stored white seeds (4.80 g/plant), which was significantly higher (P < 0.05) than that of un-stored red seeds (2.40 g/plant). Other treatments ranged between 2.80 and 4.46 g/plant, with values like white 4-week stored (4.46 g/plant) and white 8-week stored (3.96 g/plant) also showing relatively high performance. At 22 WAS, shoot dry matter ranged from

1.86 to 2.93 g/plant, with white 12-week stored seeds again producing the highest value (2.93 g/plant). The lowest values were observed in un-stored pink (1.86 g/plant) and white un-stored (1.96 g/plant) seeds. At 26 WAS, the highest shoot dry matter was observed in pink 12-week stored (4.30 g/plant) and white 8-week stored (4.13 g/plant). In contrast, un-stored red seeds recorded the lowest dry matter value (2.00 g/plant), and the difference was significantly $P < 0.05$ (***Table 9***).

Dry matter root (g)/plant

At 20 WAS, seedlings raised from 12-week stored white seeds recorded the highest root dry matter (4.90 g/plant), which was significantly higher ($P < 0.05$) than un-stored pink seeds (2.10 g/plant). Other treatments, including white 4-week stored (4.26 g/plant) and white 8-week stored (3.63 g/plant), produced intermediate values. Red and pink un-stored seeds produced the lowest root biomass overall. At 22 WAS, the white 12-week stored treatment again led with the highest root dry matter (3.46 g/plant), while the lowest value (1.96 g/plant) was observed in both pink and white un-stored seeds. All other treatments ranged between 2.23 and 2.90 g/plant and were not significantly different. At 26 WAS, white 8-week stored seeds again showed the highest root dry matter (3.93 g/plant), followed by white 12-week stored (3.50 g/plant). The lowest value was recorded in red un-stored seeds (1.96 g/plant), significantly lower than the best-performing treatments (***Table 10***).

Discussion

The study revealed delayed germination within the first 4 weeks after sowing across all treatments, consistent with the known physiological dormancy in *C. nitida* seeds, as previously reported by M.A.O. Oladokun (1990), who emphasized the influence of seed maturity, viability, and inherent dormancy on germination. Earlier researchers on kola agreed that kola nuts display fiercely long dormancy duration after harvest, which was not only seed coat induced but, physiological (Ashiru, 1969; Brown, 1970; Brown & Afrifa, 1971; Oladokun, 1985; Hammed et al., 2013). Boladale et al. (2024) and Oladokun (1988) while confirming the study of Brown & Afrifa (1971), reported that maturity and genetic origin of kolanuts are critical determinants of nut germination. Dormancy was largely overcome from the 6th week after sowing, especially for white biotype seeds stored in the DPD for 8 to 12 weeks. At 6 WAS, germination exceeded 50% in white seeds stored for 8 weeks, while other seeds showed less than 40% germination. By 12 WAS, white 12-week stored seeds reached 100% germination, outperforming red and pink seeds across all durations. This result strongly supports the hypothesis that seed pre-treatment using a geometric energy device (DPD) improves metabolic activation. Similarly, in the findings of Ogutuga & Daramola (1976); Oladokun (1986); Boladale et al. (2024), organic chemical contents and complex endogeneous compound changed from complex to simpler forms when nuts of *C. nitida* and *C. acuminata* stored for about six months. However, the cause of this dormancy as well as its nature was not properly understood but research reports had implicated alkaloids as a germination inhibitor (Wink, 1983). According to Flanagan (1991) & Eijnatten (1993), pyramidal structures can create resonance fields that alter water molecule organization and potentially stimulate biological processes such as enzyme activity and cell division, thereby releasing the amino acid strongly binded to its molecule for easy mobilization of nutrient for embryo activation. The rapid and consistent germination recorded for white seeds under DPD exposure suggests enhanced water imbibition and activation of embryonic cells, thereby accelerating germination processes. Furthermore, the white biotype consistently outperformed red and pink seeds, possibly due to genetic differences affecting seed coat permeability, dormancy level, or hormonal profiles. Boladale et al. (2024) & Hammed et al. (2018) also observed that seed coat colour in tree crops can significantly influence germination speed and uniformity, especially under pre-sowing treatment.

In this study, seeds of the red biotype nut required a longer period to achieve relatively uniform germination compared with the white and pink biotypes nut. This observation may be associated with the higher concentration of polyphenols present in the red biotype nut. According to Ogutuga (1975), the red-nut biotype of *C. nitida* contains approximately three times more polyphenols than the pink and white biotypes nuts. The elevated level of these compounds is believed to contribute to slower and less uniform germination. Similarly, Prohp et al. (2009) reported that delayed germination in the red-coloured biotype of *C. nitida* is linked to its relatively higher polyphenol content.

Growth attributes such as height of kola (*C. nitida*) increased progressively across treatments from 12 to 20 WAS, but with clear distinctions in performance. These findings agree with Oladokun's (1990) position that pre-conditioning enhances early vigour and canopy establishment in kola. The results suggest that DPD treatment not only enhances germination but also promotes more efficient resource utilization, leading to better shoot elongation and inter-nodal expansion. The number of leaves per plant showed similar trends; with pink 12-week stored and white 8-week stored seeds recording the highest leaf counts at most intervals. The production of more leaves contributes to a greater surface area for photosynthesis, leading to enhanced dry matter production. Hammed et al. (2017) observed a similar improvement in leaf development in treated kola seedlings, attributing it to improved hormonal balance and nutrient mobilization in pre-conditioned seeds, this suggest robust vascular development and lignifications, which are vital for long-term field establishment and resistance to transplanting stress. The observed improvement in girth may also be linked to enhanced cambial activity induced by more efficient early photosynthesis, corroborating the findings of Boladale et al. (2024) on morphological growth of seedlings following pre-germination treatments with curing media showed enhanced root development, increase stem elongation, and improved leaf expansion, resulting in healthier and more vigorous seedling growth during field establishment. Leaf area is a key determinant of photosynthetic efficiency, and larger leaf areas correlate with better biomass production. This reflects the improved physiological status of seedlings treated with DPD, as also suggested by Flanagan's (1991) bio-energetic model where organized energy fields enhance biological function at the cellular level. Biomass accumulation, the dry matter of leaves peaked in white 12-week stored seeds (15.6 g/plant at 20 WAS), with significantly lower values observed in red and pink un-stored seeds. The trend supports earlier assertions by Oladokun that pre-treated seeds have superior carbohydrate assimilation and partitioning. DPD exposure may enhance mitochondrial function or enzyme activation, facilitating efficient photosynthate accumulation in leaf tissues. Shoot and root dry matter followed the same trend, indicating better translocation of assimilates and root-soil interaction. These effects suggest that the DPD not only promotes above-ground growth but also stimulates below-ground architecture, which is essential for anchorage and nutrient uptake. This supports Boladale's (2024), assertion that pre-treatment affects total plant architecture, with significant implications for field establishment success. Interestingly, the lowest values in dry matter content were consistently recorded in un-stored red and pink seeds, confirming that lack of pre-conditioning limits physiological performance. Flanagan's (1991) pyramid resonance hypothesis suggests that structured energy fields may realign molecules to enhance enzymatic reactions and cell integrity, which could explain these observed disparities.

Conclusions

This study concluded that seed biotype colour and DPD storage duration significantly influence germination dynamics and seedling growth of *C. nitida*. White seeds stored for 12 weeks in the DPD consistently showed superior performance across all parameters measured. DPD conditioning offers a viable, non-invasive technique to improve seedling emergence, uniformity, and vigour, contributing to better stand establishment in the field. Adopting DPD technology for pre-treatment of kola seeds to improve germination and early seedling growth, especially for commercial-scale propagation are thereby recommended. Using white biotype kola seeds for commercial production where possible remain imperative as they consistently yield better results in all physiological parameters. This study promotes further interdisciplinary research that combines plant physiology, geometry, and biophysics to explore the mechanism of action behind DPD conditioning, to encourage the integration of DPD systems into nursery protocols and agronomic practice for other recalcitrant tropical seeds such as *Theobroma cacao*, *Irvingia gabonensis*, and *Dacryodes edulis*. Facilitating training programmes for nursery operators and extension agents on the setup and application of DPDs as eco-friendly seed enhancement technology required special intervention.

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