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Successful grafting elite cocoa clones (*Theobroma cacao* L.) as a function of the age of rootstock

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A R T I C L E I N F O

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A B S T R A C T

Côte d'Ivoire, the world's largest cocoa producer, faces numerous challenges because the yield of orchards is low due to several factors including the non-use of improved plant materials. This work is part of ICRAF's Vision for Change (V4C) project, which aimed at contributing to the regeneration of cocoa farms by making effective plant materials available to small cocoa producers. It essentially consisted in evaluating the effect of the age of the rootstock on the success of grafting to obtain a satisfactory quantity of improved plants in the nursery. The study was carried out in Adiopodoumé at the National Agronomic Research Center (CNRA). Ten elite cocoa clones from the "Vision for Change" project were used as scions. Top grafting was performed on seedlings of 2, 3- and 4-months used as rootstocks. The experimental design was a randomized complete block design with 3 replications. Data collection was focused on the grafting success rate and morphological parameters. The results showed that the grafting success rate is proportional to the rootstock age. Two months after grafting, the success rate was low. This indicates that grafting should eventually start at 3 months. This period could therefore represent a good stage to successfully graft and replant cocoa seedlings.

1. Introduction

Theobroma cacao L. (Malvaceae) is one of the important perennial tree crops in tropical agroforestry systems [1] that is cultivated for its beans. Côte d'Ivoire produced 40% of the world cocoa beans with 2,180,000 tons in 2019 [2] contributing to 20% of gross domestic product (GDP) and 50% of export earnings [2,3]. This speculation supports more than 6 million people directly and indirectly through 600,000 family farms of less than 10 ha [4]. However, with 400 kg ha^{-1}, the yield of Ivorian cocoa orchards is much lower than the potential yields which exceed 3000 kg ha^{-1} [5,6]. This poor performance is due to many challenges from which the use of unimproved plant material is the most plausible one. Indeed, improved cocoa plant materials with a high and stable yield elaborated by the National Agronomic Research Center of the past decade [7] are available even though they are not yet been released to farmers. One of the cost-effective approaches to rehabilitate these orchards while reducing the juvenile phase, is to go for the vegetative propagation method by grafting which is most likely the most appropriate solution [8–10]. Grafting consists of stimulating the assembly cambiums of two plants to develop a single plant.

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In this combination, the portion of the attached selected plant is named the scion whilst the host plant is called the rootstock [11,12]. The host assumes the mineral nutrition of the new plant while the scion includes the genetic material that will be expressed [13]. According to Ref. [14], the utilization of species rootstock and practice of grafting at an early stage of development can result in better success percentage. Grafting is known to reduce the period between flowering and fruiting. One of its benefits is that new plants

are identical to the original one. For vegetative propagation of cocoa different methods of budding and grafting had been tried [15–19]. Clonal propagation with side grafting system can use superior local clones adapted to the local environment [20]. However, among the different grafting techniques, top grafting is the most used in cocoa plant propagation which is expected to gain a superior trait combination between two parents by clonal method [21].

However, producing healthy seedlings for grafting at the right time is critical for developing improved plant materials needed for rejuvenating the old orchards for the sake of sustainable cocoa bean production in Côte d'Ivoire. In the rehabilitation and rejuvenation program, the grafting of cocoa seedlings or young plants in nursery was initiated without knowing the adequate age of the plants which would ensure better success in the field for this propagation technique of cocoa clones. Indeed, for a sustainable development of Ivorian cocoa production, a better knowledge along with a mastery of the development parameters of the young trees for the grafting success in the nursery and their growth in the field is necessary.

Various studies were conducted to assess the grafting success rate, the growth, and the performance of the cocoa seedlings by Refs. [12,16,22] in order to choose the best clones to be promoted to sustain the production in the field. The performance of this technique on cocoa farming was assessed in Côte d'Ivoire through 10 new elite cocoa clones coded C1, C8, C9, C14, C15, C16, C17, C18, C20, and C21. High production and tolerance to black pod disease were the projected focus characters. Before endorsing these clones to farmers, as planned in the context of the Vision for Change project supported by Mars Incorporated and executed in this country, some factors still needed to be understood, such as their grafting success rate at different periods and their growth characteristics in nursery.

In addition, several other studies contributing to this research showed successful choices of appropriate clones or varieties on other fruit tree species growth like grapevines by Ref. [23], miombo fruit trees, and Cucurbita by Refs. [24,25], respectively. Effect of rootstock type, scion source and grafting methods on the healing of *Allanblackia stuhlmannii* grafts under two nursery conditions carried out by Ref. [8], and the rootstock growth, and development for increased graft success of mango (*Mangifera indica*) in nursery conducted by Ref. [26] contributed to this research too. However, according to Refs. [27,28], the choice of specific rootstock is becoming increasingly difficult as a result of the availability of numerous new rootstocks. This is influenced by factors such as incompatibility, plant species, type of graft, environmental conditions like temperature and moisture, and rootstock growth activity [29,30].

Also, a decade ago, investigations on cocoa grafting regeneration revealed that under conditions as leaf area reduced to 50% and time of cut back of first rootstocks fixed at 12 days after grafting, three-month-old rootstocks were more suited to budding with success rates ranged from 30 to 50% [7]. Nevertheless, a study conducted by Ref. [22] compared two grafting techniques (budding and top grafting) in nursery and their effects on some growth parameters of ten elite cocoa clones in Côte d'Ivoire conducting to the result that the success rates were 68% and 77% for budding and top grafting, respectively. Recently [9,12], reported on the compatibility of ten elite cocoa clones grafted on mature trees and on the growth and development patterns of the same ten elite clones grafted in nursery in Côte d'Ivoire, respectively.

Hence, according to Ref. [31], the knowledge of a suitable technique and appropriate time of grafting is important to boost the production, the productivity, and the area under farming. This study was built on the hypothesis that the age of the rootstock influences both the grafting success rate and the morphological performance of cocoa clones. In this context, the objective of this work was to evaluate the grafting success rate and the morphological performance of 10 elite cocoa clones according to the age of the rootstock through determining the grafting appropriate time and the suitable clones for grafting cocoa in nursery.

2. Materials and methods

2.1. Study area

The study was carried out from 2018 to 2019 at the Experimental Station of ICRAF Côte d'Ivoire located in Adiopodoumé, about 17

Fig. 1. Experimental site in Adiopodoumé, Côte d'Ivoire (Source: This study).

km on the road of Dabou. Adiopodoumé (5°32 North and 4°13 West, and 35 m of altitude) is in Yopougon known to be the largest suburb of Abidjan (Fig. 1). The temperatures vary from 23.5 to 32.4 °C. The relative humidity ranges from 59.1 to 99.7% with an average of 79.4%. The mean annual rainfall is 1750.5 mm and varies from 1320.3 to 2180.6 mm. The main soil type are Ferralsols with a sandy loam texture and available plant nutrients concentrated in the soil organic matter [32].

Table 1 showed the results of physico-chemical analyzes of the soil taken from the 0–20 cm layer and used for the experiment [33, 34]. It revealed that the soil is sandy-loamy-clay (48% sand; 31% silt, and 21% clay). The low apparent density (AD) (1.42 < 1.5 g/cm^3), indicated a good state of aeration and a good porosity of the soil, and therefore subject to a good water storage capacity. The organic carbon (C) content was low (3.6 g kg^{-1} < 40 g kg^{-1}) for an equally insufficient content (<1 g kg^{-1}) of total nitrogen (N) determined at 0.2 g kg^{-1} coupled with a high (18/1) C/N ratio (>10/1). The contents of exchangeable cations Ca, Mg and K were 5.5 cmol kg^{-1} (>2 cmol kg^{-1}), 3.9 cmol kg^{-1} (>0.20 cmol kg^{-1}) and 0.2 cmol kg^{-1} (>0.10 cmol kg^{-1}), respectively. The Ca/Mg ratio was low (1.41 < 10). However, the Mg/K ratio of 19.5 was large (>2). The highly acidic pH H_2O (4.6) was coupled with an insufficient level of assimilable phosphorus (AP - modified Olsen method) of 3 mg kg^{-1}, well below the threshold of 10 mg kg^{-1}. The soil was rich in free iron-Fe (25.5 cmol kg^{-1}) and exchangeable aluminum-Al (3.58 cmol kg^{-1}) characteristics of acidic Ferralsols, while the degree of phosphorus saturation (DPS) of 33.31% was greater than 20% (critical value).

2.2. Plant

Planting material was composed of the 10 cocoa clones used in the revitalization program of the cocoa sector in Côte d'Ivoire coded as C1, C8, C9, C14, C15, C16, C17, C18, C20, and C21. These clones were characterized by their high productivity (1400–4000 kg ha^{-1}) and their tolerance to black pod disease (Table 2). Clones C1, C8 and C9's source is the International Quarantine Center Reading, UK while the others were selected locally.

2.3. Methods

The study focused on the ten elite cocoa clones. The rootstock is made up of cocoa clones' seedlings. To produce the rootstocks, the polyethylene bags were filled with a substrate composed of 1/3 compost, 1/3 Arabic soil, and 1/3 sand. Pre-germinated cocoa beans were sown in these filled bags. Fungicides (Ridomil Gold66WP) and insecticides (Banko plus) were applied fortnightly to the seedlings in order to ensure protection against the attacks of fungi and insects. Manual weeding was undertaken every two weeks to avoid competition between the rootstocks and weeds. At grafting stage, young seedlings of homogeneous size were selected to serve as rootstocks. Rootstocks were raised for two, three, and four months in the shade house.

The budwoods of the ten clones were collected from the research plots at Adiopodoumé. Healthy scions of each clone that had no visible signs of disease or pests according to visual observations were collected randomly from actively growing trees the day before each grafting operation. These scions were stored in fresh banana leaves and placed in a humid place to ensure their viability. The collected scions were removed with pruning clippers. The branches were cut into 2, 3 or even 4 depending on their size, so that each of the pieces had at least two buds or even four as recommended by Ref. [8].

Each budstick was enveloped in parafilm, a biodegradable material that keeps the graft from drying out to avoid breaking the emerging buds. This grafting consisted of transversely sectioning the rootstock with a shears and thereafter posing a slit with the help of a graft. The graft was beveled and inserted into the slit, then all ligated using a transparent plastic film [8].

Table 1
Physico-chemical characteristics of the soil at 0–20 cm depth before the experiment [33,34].

Soil characteristics	Values
Clay (g kg^{-1})	21
Silt (g kg^{-1})	31
Sand (g kg^{-1})	48
AD (g cm^{-3})	1,42
pH $_{H2O}$	4,6
pH KCl	4,1
Δ pH	0,5
Organic carbon - C (g kg^{-1})	3,6
Total nitrogen - N (g kg^{-1})	0,2
AP (mg kg^{-1}) – Olsen-Dabin	3
Ca (cmol kg^{-1})	5,5
Mg (cmol kg^{-1})	3,9
K (cmol kg^{-1})	0,2
Ca/Mg	1,41
Mg/K	19,5
Free Fe (cmol kg^{-1})	25,5
Exchangeable Al (cmol kg^{-1})	3,58
DPS (%)	33,31

AD: Apparent density; AP: Assimilable Phosphorus, DPS: Degree of phosphorus saturation.

Table 2
Characteristics of the ten cocoa clones [12].

Clones	Characteristics (% Black pod disease incidence)	Yield (kg/ha)	Origins
C1	8	2.3	Trinidad
C8	15	1.8	Trinidad
C9	10	2.3	Trinidad
C14	8	2.8	Côte d'Ivoire
C15	17	2.0	Côte d'Ivoire
C16	8	4.0	Côte d'Ivoire
C17	11	1.9	Côte d'Ivoire
C18	16	1.4	Côte d'Ivoire
C20	15	1.4	Côte d'Ivoire
C21	Unknown	1.6	Côte d'Ivoire

The experimental design was a randomized complete block design with three replications. The 10 cocoa clones were grafted at the 3 ages of the rootstock including 2, 3, and 4 months. The experimental unit consisted of five grafted seedlings for each age of rootstock and each clone replicated three times giving a total of 450 seedlings for the entire experiment.

The morphological characteristics of the clones were evaluated ten days and then one month after grafting and consisted in the measurement of the number of emerged shoot and the height of seedlings. At one month after grafting, the number of branches, the length of the main branch, the diameter of the main branch, the number of leaves, the number of internodes of the main branch, and the height of the plant were determined. The grafting success rate was determined as the proportion of individuals having retained at least one emerged shoot leading to a branch. This rate was determined as follows:

$$Success\ rate = Number\ of\ successful\ grafts\ x\ 100/total\ number\ of\ rootstocks$$

2.4. Statistical analysis

Data were subjected to two-way analysis of variance, using the general linear model of Statistical Analysis System software version 9.2 [35] to compare the age of the rootstock and the performance of the clones. When Analysis of variance showed significant differences, Duncan's test at 5% was used to separate the means to identify differences between clones, age, and factors studied.

3. Results

3.1. Success rate of grafting cocoa clones according to the age of the rootstock

The comparative study of the age of the rootstock on the ability to graft elite clones revealed a significant difference ($P < 0.0001$) between the age of the rootstock for the grafting success rate. The grafting success of elite cocoa clones varied according to the age of the rootstock (Fig. 2). Indeed, two months after grafting, except for the clones C9 and C15 which showed success rates estimated at 3 and 6.7%, respectively, the success rate was zero for other clones. Concerning the three-month-old rootstocks, the high success rate was recorded with clone C17 displaying 46.7%. It was followed by clones C21, C20, and C15 with 33.3%, 26.7%, and 26.7%,

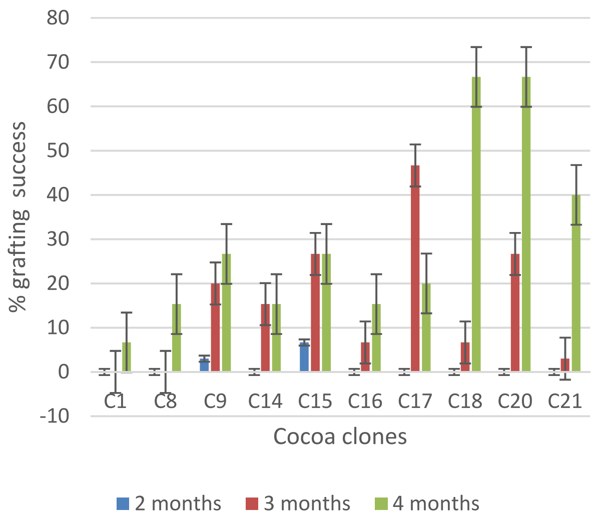

Fig. 2. Grafting success rate of the rootstock.

respectively. However, zero success rate was observed with clones C1 and C8. At 4-month-old, the ten clones exhibited successful grafting with clones C18 and C20 showing the highest success rate of 66.7% followed by clones C21 (40%), C9 (26.7%), and C15 (26.7%).

With regard to clone C1, when we consider the three ages of rootstock, the highest success rate was obtained with the 4-month-old rootstocks, while all grafting failed with the two other rootstock ages. The same trend was observed with clone C8. As for clone C9, it exhibited success rate for the three ages of rootstock with the highest rate being displayed by 4-month-old rootstocks, followed by the 3-month-old and the 2-month-old rootstocks. Concerning clone C14, only 3- and 4-month-old rootstocks showed success rates. Clone C15 registered success rate on the three ages of the rootstock with the highest rate for both 3 and 4-month-old rootstocks and the smallest for the 2-month-old rootstocks. The 4-month-old rootstocks showed better success rates than the 3-month-old rootstocks for clones C16, C18, C20, and C21. Moreover, results revealed that only clone C17 showed high grafting success rate for the 3-month-old rootstocks compared to the 4-month-old ones. The overall grafting success were less than 5% for the 2-month-old rootstocks, about 18.7% for the 3-month-old rootstocks and 32.7% for the 4-month-old rootstocks (Fig. 3).

3.2. *Comparative study of the morphological parameters of the clones according to the age of the rootstock*

The comparative analysis of cocoa clones according to different ages of the rootstock is shown in Table 3. Significant differences in the morphology of the clones between the 3 different ages of the rootstock ($P < 0.0001$) were observed. For clone C1, all the rootstock ages did not showed differences for the studied parameters. Only plant height showed difference among the 3 rootstock ages with the highest obtained for the 4-month-old rootstocks and the smallest for the 2-month-old rootstocks. On the other hand, differences were observed among the age of rootstock for clones C8, C18, and C20 concerning all the parameters measured. The highest values were recorded by the 4-month-old rootstocks for all the parameters followed by the 3-month-old and the 2-month-old rootstocks. Concerning the other clones like C9, C14, C15, and C16, significant differences were observed among the rootstocks ages only for the height of plant and not for the other parameters, with the highest height of plant displayed by the 4-month-old rootstocks and the lowest by the 2-month-old rootstocks. Moreover, in clone C17, differences were observed among the three rootstock ages for all the morphological parameters except the number of leaves and the number of internodes. Indeed, considering the number of emerged shoots, the number of branches, the main branch length, and the main branch diameter, the highest values were observed with the 3-month-old rootstocks followed by the 4-month-old and 2-month-old rootstocks. In addition, the highest height of plant was registered by the 4-month-old rootstocks followed by the 3-month-old and the 2-month -old rootstocks. With clone C21, except for the number of emerged shoots and the main branch diameter, the 4-month- old rootstocks showed the highest values for the other parameters, followed by the 3-month-old and the 2-month-old rootstocks. For comparison, overall, the 4-month-old rootstocks showed the highest or best data compared to the other two rootstock ages under study.

4. Discussion

This current study has revealed that grafting according to the rootstock age strongly influences the performance of elite cocoa clones ($P < 0.001$), and the grafting success rate is proportional to the age of the rootstock. These results are consistent with the findings of [14]. In fact, the older the rootstock, the higher the probability of success of the grafting as shown by Fig. 2: 1% at two (2) months, 18.7% at three (3) months, and 32.7% at four (4) months. The 3 and 4-month-old rootstocks grafting success rates, although low, were higher than the 2-month-old ones. Therefore, according to the current work, to ensure a good resumption of the graft, it is necessary to do the grafting at an advanced age of the rootstock from three (3) months to 4-months in the nursery. The current results,

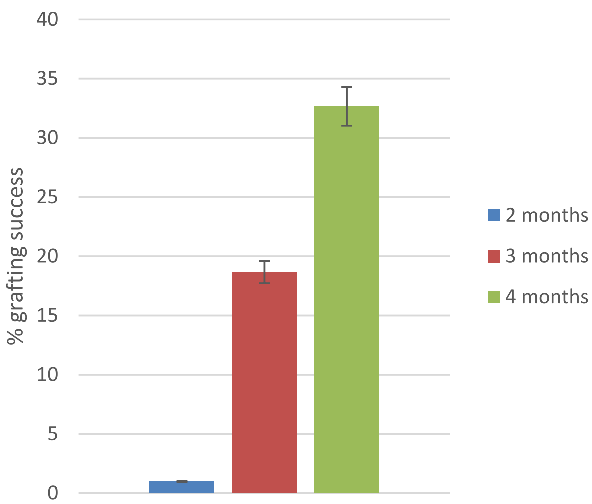

Fig. 3. Grafting success rate of clones according to the age of the rootstock.

Table 3
Morphology of cocoa clones according to the age of the rootstock.

Clones	Number of emerged shoots			Number of branches			Number of leaves			Number of internodes		
	Age of rootstock (month)											
	2	3	4	2	3	4	2	3	4	2	3	4
C1	0.0 a[a]	0.0 a	0.3 a	0.0 a	0.0 a	0.3 a	0.0 a	0.0 a	1.0 a	0.0 a	0.0 a	0.5 a
C8	0.0 b	0.0 b	0.5 a	0.0 b	0.0 b	0.5 a	0.0 b	0.0 b	1.2 a	0.0 b	0.0 b	0.5 a
C9	0.2 a	0.3 a	0.5 a	0.2 a	0.3 a	0.5 a	0.5 a	0.5 a	1.2 a	0.1 a	0.3 a	0.5 a
C14	0.4 a	0.5 a	0.4 a	0.4 a	0.5 a	0.4 a	0.0 a	1.9 a	1.5 a	0.0 a	0.6 a	0.5 a
C15	0.2 a	0.5 a	0.4 a	0.2 a	0.5 a	0.4 a	0.7 a	1.9 a	1.4 a	0.3 a	0.9 a	1.0 a
C16	0.0 a	0.1 a	0.3 a	0.0 a	0.1 a	0.3 a	0.0 a	0.4 a	1.2 a	0.0 a	0.2 a	0.7 a
C17	0.0 b	0.6 a	0.4 ab	0.0 b	0.6 a	0.4 ab	0.0 a	1.6 a	1.5 a	0.0 a	0.7 a	1.1 a
C18	0.0 b	0.2 b	1.2 a	0.0 b	0.2 b	1.2 a	0.0 b	0.4 b	4.5 a	0.0 b	0.2 b	2.0 a
C20	0.0 b	0.5 b	1.4 a	0.0 b	0.5 b	1.4 a	0.0 b	1.3 b	4.0 a	0.0 b	0.7 b	1.9 a
C21	0.0 a	0.6 a	0.7 a	0.0 b	0.5 b	1.4 a	0.0 b	1.9 b	2.3 a	0.0 b	1.1 a	1.3 a
Means	0.04	0.3	0.6	0.04	0.3	0.6	0.1	1.0	2.0	0.1	0.5	1.0

Clones	Main branch diameter					
	2	3	2	4	2	4
C1	0.00 a	0.00 a	0.00 a	1.17 a	12.26 c	18.46 a
C8	0.00 b	0.00 b	0.00 b	0.24 a	12.33 c	20.20 a
C9	0.13 a	0.86 a	0.07 a	0.32 a	11.73 c	19.53 a
C14	0.00 a	1.20 a	0.00 a	0.23 a	11.40 b	16.00 a
C15	0.53 a	1.40 a	0.16 a	0.33 a	11.40 b	16.00 a
C16	0.00 a	0.20 a	0.00 a	0.2 5 a	12.26 c	19.73 a
C17	0.00 c	2.13 a	0.00 b	0.34 ab	11.53 c	18.40 a
C18	0.00 b	0.20 b	0.00 b	0.83 a	11.33 c	19.26 a
C20	0.00 b	1.20 b	0.00 b	0.84 a	11.40 c	19.80 a
C21	0.00 b	2.07 ab	0.00 a	0.50 a	11.80 c	19.80 a
Means	0.07	0.93	0.02	0.41	11.66	19.05

[a] Means with the same letters in the same line are not significantly different with Duncan's test at 5%.

in accordance to those of [11,22] could be explained by the fact that rootstocks of advanced age (3 months and 4 months) have a large reserve of hormones and can easily renew and regenerate their cells while that of 2-month-old with lower success could be attributed to the low carbohydrate reserves. Our results concur also to those of [14,36] who stated that rootstock age is affected by regenerating ability of plant slices due to the differential activity of meristematic cells. These findings are also in agreement to Ref. [7] works in 2013 on the cocoa trees, which showed that the highest success rates were observed for grafts at 3 and 4 months. However, these current results are contrary to those obtained in another perennial fruit trees species such as the cashew tree (*Anacardium occidentale*), whose success rate is inversely proportional to the age of the rootstock; so, the younger the plant, the higher the grafting success rate [37].

Graft success depends on the rootstock-scion physiological compatibility and the proper alignment of tissues in the graft union [22, 38]. The low grafting success recorded for some clones implies a relative mortality rate of the cocoa clones' seedlings. This is in line with previous works done by other authors. Indeed, mortality in the juvenile stage could be elucidated by the lack of vigor of the stem of the young cocoa tree at this age probably due to the composition of the substrate [18,39], and the small diameter of the stem of the less developed rootstocks. The overall grafting success recorded in the current study was low compared to those obtained with the same clones by Ref. [22] in Soubré, Côte d'Ivoire. This result is surely due to the dexterity of the grafter and/or the environmental conditions. The stretched attachment of the graft combination using the transparent plastic film in grafting may have limited aeration and/or water/nutrient transport, as adequate aeration and care of the graft union play significant roles in callus or shoot formation and the grafting success [28,40].

Likewise, according to Ref. [27], rootstock affects significantly the growth parameters and varies from cultivar to cultivar in grapevine. Additionally [28], conducted a field experiment to study the effect of different rootstocks on the growth and physiological parameters in grapevine varieties revealing that among all rootstocks used, two performed well for vegetative growth and physiological parameters.

In this present study, the grafting analysis according to the rootstock age showed difference between clones for the 4-month-old rootstocks which is the best among the three periods. It appears that the performance of plants resulting from the grafting at 4 months were higher than those of the other two grafting periods. This age of the rootstock made it possible to distinguish the best performing clones. Therefore, best grafting success in cocoa is achievable with three to four-month-old rootstocks irrespective of the genotypes or clones involved. Rootstock seedlings that have strong growing will have higher yields than small, weak or dwarf rootstock. Consequently, it is possible that rootstock seedlings of 4-month-old have a potential in nursery due to their robust development while those of 2-month-old have the worst growth as can be seen in grafting success and the morphological growth parameters results [41–43]. Our results supported the findings of [12,22] with the same clones. Besides, according to Refs. [44,45], it is consistent that rootstock age and scion type play a critical part in reaching grafting success. Grafting onto 4-month-old rootstocks could save cost compared to 2 and 3-month-old ones. Results exhibited at 4-month-old rootstocks with clones C20 and C18, high-performing than the other clones could be enlightened by the fact that these two clones were probably the most compatible scions among the ten used.

These current results are in line with the recommendations made by Refs. [46,47], and [22] who indicated that the minimum age for successful top grafting for cocoa in nursery is four-month-old rootstocks. Moreover, the morphological growth parameters studied contribute to the vegetative development of cocoa clones, and thus, contribute to higher yield as mentioned by Refs. [22,25], and [12].

However, to achieve a success rate of around 80–90%, the rootstock must be at least 6-month-old when the grafting is performed by an experienced grafter according to Ref. [41], while [18] mentioned seedlings of 6–8 months. But at this period, producing grafted seedlings seems more costly to the nurserymen compared to 4-month-old rootstocks due to among many reasons, the size of the shade house and the quantity of plants it can contain, and the difficulty of seedlings management and transportation in the field. There is also a time saving in the production of seedlings in the nursery with the 4-month-old rootstocks compared to those of 6–8 months. Otherwise, several conditions are necessary for successful grafting including environmental and physiological conditions of rootstocks [48]. This success requires a highly skilled workforce who comply with enabling conditions such as affinity, vigor of the scion and the rootstock, use of good tools, sanitation of hands and tools while executing the grafting, time of entry into production of the graft, contact of the vessels carrying the sap, health of the graft, preservation of air and water, and also time of grafting which vary according to the species and pruning process. Thus, grafting is usually best when done during the rainy season [8,24,45,49]. Indeed, according to Ref. [28], periodic variations in temperature confuse the managing of planting agendas in affordable nurseries.

5. Conclusion

Our findings suggest that the grafting success rate is influenced by the age of the rootstock. The grafting success rate recorded at 4-month-old rootstocks was the highest. It is obvious that this time could be used to obtain optimal grafting success and maximum seedlings of cocoa clones. This period made it possible to distinguish C20 and C18 as the more efficient clones. These results are promising as they may provide an effective technique for those interested in propagating cocoa seedlings in nursery. Further works are needed to optimize the grafting technique in view of gaining more success and subsequently good growth of scions. These findings reveal that cocoa seedlings grafted at 4-month-old rootstocks could be a cost-effectively and time-saving sustainable propagation technique for improving productivity and quality cocoa.

Author contribution statement

Jean-Claude N'ZI, PhD: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Issouf KONE, Master: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kacou Alban Antoine MBO, PhD: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Siaka KONE, Master: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Christophe KOUAME, PhD: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Additional information

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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