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Exploring grafting to propagate and conserve *Garcinia kola* a vulnerable species in Côte d'Ivoire

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Abstract: *Garcinia kola*, a high-socioeconomic and multipurpose fruit tree, has been shown to have a low germination and long juvenile phase, which limit its cultivation initiative. Our study aimed to determine successful *G. kola* grafting conditions to promote its cultivation. So trials were carried out in June and August, testing four grafting methods: simple whip, top cleft, side cleft, and chip budding made on 12- and 36-month-old rootstock. The grafts were unwrapped at 15, 22, and 29 days after grafting. The results showed that the month of June is the favorable period for *G. kola* grafting. The best grafting success was observed with the chip budding and top cleft grafting methods applied on the 36- and 12-month-old rootstocks, respectively. The graft unwrapping time at 29 days after grafting promotes the best grafting success. The combined effect showed that the best graft success rate was recorded in June on 36-month-old rootstock (43.33%) with the chip budding and side cleft grafting method and 83.33% for the graft made on 12-month-old rootstock with the top cleft grafting method, respectively. This study is an important step for good plant material for domestication and cultivation of this resource.

1. Introduction

Garcinia kola is a native tree found in the tropical rainforests of West and Central Africa and belongs to the Clusiaceae family. *G. kola* is recognized as one of the non-timber forest products of great socio-economic importance (Assogbadjo *et al*., 2017; Codjia *et al*., 2018). The

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fruits, seeds, stems, roots, and bark are used for food and medicine for the treatment of several diseases such as diarrhea, laryngitis, gonorrhea, headache, and gastritis (Maňourová *et al*., 2019). The seed trade is an activity of great economic importance (Kouame *et al*., 2016; Maňourová *et al*., 2019).

Despite the importance of the species, no enhancement program is undertaken. However, *G. kola* is one of the species identified as a priority agroforestry species to benefit from a domestication program in West Africa (Franzel *et al*., 1996). In addition, *G. kola* is an agroforestry species, which contributes through the exploitation of its fruits and seeds to the diversification of farmers' income and the reduction of famine (Maňourová *et al*., 2019). However, the cultivation of the species by farmers remains very difficult due to the low germination capacity of the seeds and the time required for the plant to enter into flowering and fruiting, which is between 20 and 30 years (Yakubu *et al*., 2014; Agwu *et al*., 2018). It is therefore urgent to find effective strategies for the regeneration of elite trees that can induce early fruiting of the species. According to Sanou *et al*. (2004) and Leakey *et al*. (2017), domestication and genetic improvement strategies are necessary to conserve genetic material and improve fruit production. Leakey and Simons (2000) reported the growing interest in the genetic improvement of tropical forest trees aimed at developing tree cultivars with fruits with desirable characteristics.

Vegetative propagation of plants plays an important role in the production of high-quality plants for the domestication of forest trees (Leakey and Akinefessi, 2008). Cuttings, grafting, budding, and layering are vegetative macropropagation methods mainly used for the regeneration of several species (Love *et al*., 2017). Among these methods, grafting is the most used to improve the quality of plants. Grafting technique mainly involves joining parts of plants (scion and rootstock) in a manner to unite both parts so they can form a plant. A large number of research works have been carried out on agricultural fruit trees using grafting. Akinnifesi *et al*. (2009) reported that grafted trees of *Uapaca kirkiana* began to produce fruits only after 2-3 years, while those derived from seedlings took 12-15 years. Grafting techniques were also successfully used on *Allanblakia floribunda* Oliv. (Clusiaceae) to reduce the long juvenile phase of about 10-12 years to less than 5 years (Asaah *et al.,* 2012).

Concerning *Garcinia kola*, grafting is a recent area to explore. In Nigeria, Yakubu and Akinyele (2021) indicated the suitability of *G. kola* for grafting with 52% of grafting success. But these authors investigate only one source of the grafts using a single grafting technique. However, several research studies have shown that the success of grafting depends on several factors such as the grafting technique, the grafting period, and the age of the rootstock (Munjunga *et al*., 2013; Akter *et al*., 2016; Nguyen and Yen, 2018). In Côte d'Ivoire, works on vegetative propagation of *G. kola* have until now focused on cutting (Kouakou *et al*., 2016; Dao *et al*., 2020). More in-depth investigations to ensure efficient production of quality plants are necessary on *G. kola* grafting ability. The objective of this study is to determine the conditions favorable to the successful grafting of *G. kola*.

2. Materials and Methods

Site of study

The study was carried out from June 2018 to February 2020 in Abidjan at the University Nangui Abrogoua (UNA) research station (05°23´N, 04°00´W). This site is located in the forest zone where the rainfall pattern is bimodal with two dry seasons (from December to March and from July to August) and two rainy seasons (from April to June and from September to November). Mean annual rainfall varies between 1800 and 2000 mm. The mean monthly temperature varies between 27 and 30°C, whereas the mean relative humidity ranges from 70 to 84% (Kouakou *et al*., 2016).

Plant material

Plant materials were constituted of 12- and 36-month-old seedlings of *Garcinia kola* obtained in the nursery of the experimental research station of UNA. The average height and collar diameter of the rootstocks were 84.1 ± 10.04 cm and 1.31 ± 0.18 cm for 36-month-old seedlings and 43 ± 5.74 cm and 0.84 ± 0.10 cm for 12-month-old seedlings, respectively. These plants were used as rootstocks in this study. The mature fruiting tree located in Ahouabo (06°22´N, 03°82´W) was used for scion' collection.

Rootstock preparation and scion collection

Mature fruits were naturally collected under a

single tree in a cocoa field in Ananguié village (06°33´N, 03°67´W). The seeds from this fruit were used for the production of seedlings in the nursery. Seedlings of 24 and 36 months old were selected based on their vigor for use as rootstocks. The preparation of the rootstock concerned rootstocks aged 36 months old and consisted of reducing the lateral branches one week before the grafting operation in order to allow an accumulation of sap. In fact, the sap allows the scion, once placed, to maintain its vigor and accelerates its fusion with the rootstock. But no reducing branches were made on 12-month-old rootstock because there are no ramifications. The rootstock was watered every day one week before the grafting operation.

For scion collection, non-flowering lateral shoots of current season's growth were cut from a superior mature tree selected according to farmers' criteria, which included good physical and sanitary characteristics (such as vigorous growth and absence of parasites) as well as the quality of the fruits and nuts (tasty pulp and size of seeds). These shoots (15-20 cm long) were collected early in the morning (between 6 and 7 am) using disinfected scissors with 70% alcohol. To avoid dehydration of the shoots, they were stored in a damp, moistened gunny bag and packed in a cooler before transportation to the nursery. They were free from disease and unignified. They were used to provide the scions or buds for grafting onto the rootstocks depending on the grafting technique being tested. Grafting on rootstocks was carried out early in the morning, the day after the collection of the grafts, due to the long distance between the collection location and the nursery.

Grafting methods and experimental design

In order to determine the most favorable period for successful grafting of *Garcinia kola*, the grafting operation was carried out over two periods. The first trial was carried out in June (main rainy season) and the second in August (short dry season). At each trial period, four grafting techniques were tested in order to identify the optimized grafting success. These techniques were simple whip, top cleft, side cleft, and chip budding and were made according to Takoutsing *et al*. (2014). The grafting operations were made on 36-month-old and 12-month-old rootstock. All the grafting techniques were made on 36-month-old rootstocks. But only simple whip and top cleft techniques were applied on 12-month-old rootstock due to their small diameter (<1 mm), inapt for chip budding and side cleft technique application. The scions constituted of shoots were used for simple whip, top cleft, and side cleft. While buds were used for chip budding. To determine the time required for the graft to weld for each technique, the graft was unwrapped at 15, 22, and 29 days after grafting.

The experimental design adopted was a completely randomized block with two factors: the grafting technique and the unwrapped time for each trial period and the type of rootstock used. For the grafting carried out on 36-month-old rootstocks and at each trial period, 12 treatments were carried out (4 grafting techniques x 3 unwrapping times) and 6 treatments for 12-month-old rootstocks (2 grafting techniques x 3 unwrapping times). However, due to the limited availability of rootstock plants, the treatments were repeated twice. Each treatment consisted of 15 grafted plants. Over the two trial periods, a total of 720 plants were grafted from 36-month-old rootstocks (2 periods x 4 grafting techniques x 3 unwrapping times x 15 grafted plants x 2 replicates) and 360 plants grafted with 12-month-old rootstocks (2 periods x 2 grafting techniques x 3 unwrapping times x 15 grafted plants x 2 replicates).

Monitoring and data collection

The monitoring consisted of keeping the plot clean and regularly pulling out the weeds in the bags by hand in order to avoid any competition with the rootstocks. The unwrapping process, which consists of removing the ligature strips from the contact zone between the scion and the rootstock, was carried out at 15, 22, and 29 days after grafting in order to determine the time necessary for good welding between the scion and the rootstock. One week after each stripping operation, the rootstocks of the chip budding and the side graft were pruned at 2 cm above the grafting point without leaving any knots (Soloviev and Gaye, 2004). The data collection included the number of sprouted grafts and the days taken for each graft to sprout. Parameters evaluated during the experiment were the graft success, recovery time, and graft survival rate. The graft success rate (GsR) reflects the ratio of the number of successful grafts to the number of grafts performed and is expressed by the following formula:

$$GsR\ (\%) = \frac{(\text{number of successful grafts})}{(\text{number of grafts performed})} \times 100$$

The graft recovery time (GrT) corresponding to the sum of the recovery times of each graft, compared to the total number of successful grafts. It is expressed by the following formula:

$$GrT\ (day) = (\sum tr)/N$$

where *tr is* recovery time per graft and N the total number of successful grafts.

The survival rate of grafted plants was evaluated for 12 months after grafting taking into account the grafting technique and the age of the rootstock.

Statistical analysis

Data was subjected to analysis of variance (ANOVA) with respect to grafting season, technique, graft unwrapping time, and their interaction. When a significant difference was observed between the means (P <0.05), the ANOVA is supplemented by the least significant difference (LSD at P≤0.05) for separation of means. All the analyses were processed using the software Statistica 7.1.

3. Results

Effect of seasonality on the success of Garcinia kola grafting

The results indicated in Table 1 show that the graft success rate and the average recovery time of grafts carried out on rootstocks aged 36 and 12 months varied depending on the grafting period. The highest success rates for grafts carried out on rootstocks aged 36 months (34.02±2.47%) and rootstocks aged 12 months (48.33±5.00%) were recorded in the month of June. The lowest values of graft success rate were observed in the month of August. As for the average recovery time, the shortest (28.02±0.39 days and 20.72±0.69 days) were observed in grafts carried out in the month of June, respectively, with aged rootstocks of 36 and 12 months old. The month of June favors the success of *Garcinia kola* grafting with a higher success rate and an earlier recovery time. Furthermore, rootstocks aged 12 months showed good aptitude for grafting with an early graft recovery, unlike rootstocks aged 36 months old.

Effect of grafting technique on the success of Garcinia kola grafting

Grafting technique significantly influenced the graft success rate in 36-month-old rootstocks (P= 0.006) and 12-month-old rootstocks (P<0.011). On the other hand, no significant difference was observed in the average recovery time, whatever the technique, in the two types of rootstocks (Table 2).

Table 1 - Comparison of average values of grafting parameters according to period and age of rootstocks

Grafting period	Graft success (%)		Graft recovery time (day)	
	36 month old rootstock	12 month old rootstock	36 month old rootstock	12 month old rootstock
June	34.02 ± 2.47 a	48.33 ± 5.00 a	28.02 ± 0.39 b	20.72 ± 0.69 b
August	21.66 ± 1.46 b	27.77 ± 3.38 b	30.00 ± 0.52 a	23.27 ± 0.59 a
F	50.45	47.20	8.55	7.53
P	<0.001	<0.001	0.005	0.011

In a column, the values followed by different letters are significantly different at P<0.05.

Table 2 - Comparison of average values of grafting parameters according to grafting technique and rootstock age

Grafting techniques	Graft success rate (%)		Graft recovery time (day)	
	36 month old rootstock	12 month old rootstock	36 month old rootstock	12 month old rootstock
Simple whip	26.94 ± 2.83 b	32.77 ± 3.11 b	29.33 ± 0.56 a	21.94 ± 0.69 a
Top cleft	28.88 ± 3.34 b	43.33 ± 5.99 a	29.33 ± 0.48 a	22.05 ± 0.69 a
Chip budding	32.22 ± 3.66 a	-	27.83 ± 0.77 a	-
Side cleft	23.33 ± 2.80 c	-	29.55 ± 0.86 a	-
F	4.55	12.44	1.38	0.01
P	0.006	<0.001	0.258	0.906

In a column, the values followed by different letters are significantly different at P<0.05. - Not evaluated.

The highest graft success rate (32.22±3.66%) was obtained with the chip budding technique on rootstocks aged 36 months. While on 12-month-old rootstocks, the highest graft success rate (43.33±5.99%) was recorded with the simple whip technique. Concerning the average graft recovery time, it was between 27 and 29 days with grafts carried out on rootstocks aged 36 months, respectively, for the chip budding technique and the other techniques. While for plants aged 12 months, the average recovery time is 21.94±0.69 days for the simple whip technique and 22.05±0.69 days for the top cleft grafting technique. However, no significant difference is observed between these two average recovery times. The chip budding and top cleft grafting techniques are more favorable in rootstocks aged 36 and 12 months, respectively. Figure 1 shows an overview of the recovery of grafted plants with the different grafting techniques applied.

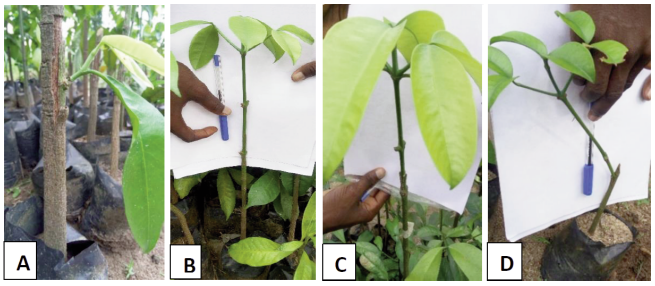

Fig. 1 - Successful grafts from different grafting techniques: (A) Chip budding ; (B) Simple Whip ; (C) Top cleft ; (D) Side cleft.

Effect of graft unwrapping time on the success of Garcinia kola grafting

The results presented in Table 3 show that only the graft success rate was significantly influenced ($P < 0.001$) by the graft unwrapping time. The highest percentages of graft success (38.75±2.71% and 55.83±5.42%) were obtained when the grafts were unwrapped at 29 DAG on 36- and 12-month-old rootstocks, respectively. While the lowest graft success rate (16.66±1.33% and 24.16±3.57%) was recorded when the grafts were unwrapped 15 days after grafting on 36- and 12-month-old rootstocks, respectively. The average recovery time for rootstocks aged 36 months is between 28 and 29 days, while that of rootstocks aged 12 months is between 21 and 22 days. The graft unwrapping time of 29 days is favorable to the success of grafting *Garcinia kola* in both types of rootstocks.

Combined effect of seasonality, grafting technique and graft unwrapping time on Garcinia kola grafting success

The interaction of season, grafting technique, and graft unwrapping time significantly influenced the graft success rate regardless of the age of the rootstock (Table 4). On the other hand, no significant difference was observed in terms of graft recovery time. For grafts carried out in the month of June on rootstocks aged 36 months, the highest graft success rates (43.33±8.81% and 43.33±3.33%) were obtained with the chip budding and side cleft techniques, respectively, and were unwrapped at 29 days after grafting. Concerning the grafts carried out in the month of June on rootstocks aged 12 months, the best graft success rate (83.33±3.33%) was recorded with the top cleft technique when unwrapped at 29 days after grafting. While the lowest graft success rate (23.33±3.33%) was obtained with the simple whip technique when the grafts were unwrapped 15 days after grafting. The graft recovery time varies from 24 to 30 days and 19 to 22 days after grafting with grafts performed in June on 36-month-old rootstocks and 12-month-old rootstocks,

Table 3 - Comparison of average values of grafting parameters according to graft unwrapping time and rootstock age

Graft unwrapping time (day)	Graft success rate (%)		Graft recovery time (day)	
	36 month old rootstock	12 month old rootstock	36 month old rootstock	12 month old rootstock
15	16.66 ± 1.33 c	24.16 ± 3.57 c	29.66 ± 0.58 a	22.41 ± 1.05 a
22	28.12 ± 2.01 b	34.16 ± 4.83 b	28.58 ± 0.47 a	21.58 ± 0.91 a
29	38.75 ± 2.71 a	55.83 ± 5.42 a	28.79 ± 0.71 a	22.00 ± 0.62 a
F	53.70	39.03	0.96	0.26
P	<0.001	<0.001	0.386	0.767

In a column, the values followed by different letters are significantly different at P<0.05.

Table 4 - Comparison of mean values of grafting parameters depending on the interaction of season, grafting technique, graft unwrapping time, and rootstock age

Grafting period	Grafting Technique	Graft unwrapping time (Day)	Graft success rate (%)		Graft recovery time (day)	
			36 month old rootstock	12 month old rootstock	36 month old rootstock	12 month old rootstock
June	Simple whip	15	15.00 ± 2.88 d	23.33 ± 3.33 e	28.00 ± 1.15 a	20.66 ± 2.40 a
		22	16.66 ± 4.40 d	33.33 ± 3.33 d	28.00 ± 1.15 a	20.66 ± 2.40 a
		29	28.33 ± 4.40 c	50.00 ± 5.77 b	28.66 ± 0.66 a	21.00 ± 1.52 a
	Top cleft	15	25.00 ± 2.88 c	40.00 ± 5.77 c	30.00 ± 1.15 a	19.33 ± 1.33 a
		22	31.66 ± 6.00 c	56.66 ± 8.81 b	29.33 ± 1.76 a	20.00 ± 2.30 a
		29	4.00 ± 5.77 b	83.33 ± 3.33 a	28.00 ± 1.15 a	22.66 ± 0.66 a
	Chip budding	15	23.33±3.33 c	-	26.00 ± 1.15 a	-
		22	40.00 ± 5.77 b	-	28.00 ± 1.15 a	-
		29	43.33 ± 8.81 a	-	24.33 ± 2.02 a	-
	Side cleft	15	13.33 ± 3.33 d	-	28.66 ± 0.66 a	-
		22	30.00 ± 5.77 c	-	28.00 ± 1.15 a	-
		29	43.33 ± 3.33 a	-	29.33 ± 1.76 a	-
	F		*12.87*	*1.18*	*0.852*	*0.34*
	P		*0.003*	*0.013*	*0.543*	*0.713*
August	Simple whip	15	10.33 ± 3.33 e	20.00 ± 5.77 d	32.66 ± 1.76 a	23.66 ± 1.45 a
		22	23.33 ± 3.33 c	26.66 ± 3.33 c	28.66 ± 0.66 a	22.00 ± 1.15 a
		29	30.00 ± 5.77 b	36.00 ± 5.77 b	30.00 ± 1.15 a	23.66 ± 1.45 a
	Top cleft	15	13.33 ± 3.33 d	13.33 ± 3.33 e	30.00 ± 1.15 a	24.00 ± 1.15 a
		22	20.00 ± 5.77 c	20.00 ± 5.77 c	28.00 ± 1.15 a	23.66 ± 1.45 a
		29	23.33 ± 3.33 c	46.66 ± 6.66 a	30.66 ± 0.66 a	20.66 ± 0.88 a
	Chip budding	15	20.00 ± 5.77 c	-	32.00 ± 2.30 a	-
		22	26.66 ± 3.33 c	-	28.66 ± 0.66 a	-
		29	36.66 ± 3.33 a	-	28.00 ± 1.15 a	-
	Side cleft	15	13.33 ± 3.33 f	-	30.00 ± 1.15 a	-
		22	16.66 ± 3.33 e	-	30.00 ± 3.05 a	-
		29	26.66 ± 3.33	-	31.33 ± 4.37 a	-
	F		*1.10*	0.13	*0.51*	2.95
	P		*0.038*	<0.001	*0.788*	0.116

In a column, the values followed by different letters are significantly different at P<0.05. - Not evaluated.

respectively. While for grafts performed in August, the graft recovery time varies from 28 to 32 days and 20 to 24 days after grafting for grafts performed on 36-month and 12-month rootstocks, respectively, 36-month-old, regardless of the grafting technique and graft unwrapping time.

Grafted plants survival rate

The survival rate was not significantly influenced by the grafting technique (Fig. 2). The grafting techniques tested on both types of rootstocks showed a survival rate of 100% at 12 months after grafting. The figure 3 presented a grafted plant of *Garcinia kola*.

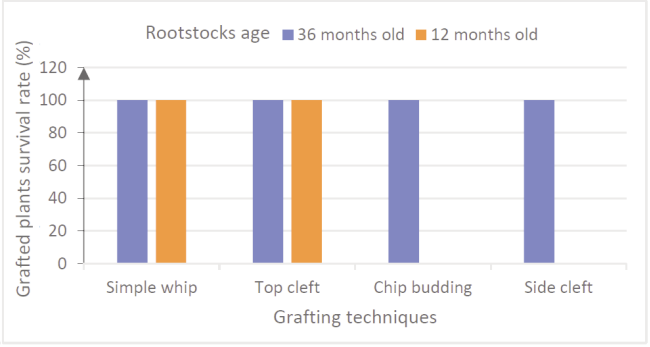

Fig. 2 - Survival rate of *Garcinia kola* grafted plants with differents grafting techniques on 36 and 12 month old rootstoks.

Fig. 3 - *Garcinia kola* grafted plant with the chip budding technique 12 months after grafting.

4. Discussion and Conclusions

In this study, The higher graft success observed in June with 12- and 36-month-old rootsocks and their earliness in graft recovery time, unlike grafts performed in August, would be due to the optimum humidity in the month of June (Karadeniz, 2005). Indeed, June was characterized by an abundance of rain (361 mm) with an average temperature of 26°C. These conditions promote the well growth of plants and grafts success. This finding is in agreement with the results of Chipojola *et al*. (2013), who obtained similar results for *Anarcadium occidentale* in Malawi. While August is characterized by the short, dry season. The low rainfall and high temperatures during the August season slow down the physiological activity of the rootstock and favor the scions drying. These results are in agreement with those of Djaha *et al*. (2012), who observed a low success of cashew grafting in November in Korhogo, in the north of Côte d'Ivoire. According to these authors, the dry season would not favor the vegetative phase of the plant because of the harmattan and the scarcity of rains. Similar observations were made by Soloviev *et al*. (2004), who obtained low success rates on the grafting of African plum (*Sclerocarya birrea*) in the cold dry season and in the middle of the hot dry season. Ondo *et al*. (2018) reported a low success rate in the grafting of two clones (GT1 and PB 217) of *Hevea brasiliensis* (H.B.K.) (Muell. Arg) during the dry season in Gabon. Negative effects of dry season on graft success are also reported in mango by Sivudu *et al*. (2014) and in *Vitex payos* (Lour.) Merr. by Bala *et al*. (2017).

The best graft success rate recorded with the chip budding method on 36-month-old rootstocks, unlike the other grafting methods, could be explained, on the one hand, by the presence of latex at the level of the scion and of the rootstock. Indeed, notches made on the rootstock during the operation do not affect the wood. It could promote the welding between the bud scion and the rootstock in the chip budding method. Concerning the other grafting methods, the contact zone between the rootstock and the scion is largely between the lignified parts. This makes it difficult to weld between the rootstock and the scion. According to Takoutsing *et al*. (2014), the success of the grafting process depends on the level of lignification of the rootstock and the grafting method. These authors reported a 100% graft success rate of *Garcinia lucida* Vesque using the top cleft method on six-month-old rootstocks.

The graft unwrapping time at 29 days after grafting enhances graft success more than those unwrapped at 15 and 22 days, whatever the rootstock's age. This means that this duration is sufficient for the establishment of the weld between the rootstock and the scion. Indeed, the realization of the anatomical welding is an essential condition for the success of the grafting (Scheidecker, 1961). In rubberwood (Hevea brasiliensis), grafts were generally unwrapped 21 days after grafting (Udayakumara and Seneviratne, 2005; Ondo *et al*., 2018).

The formation of new tissues by the rootstock and the scion at the level of the contact zone is done gradually over time. In this study, the average sprouting time differs according to the age of the rootstock, with 22 and 28 days for 12- and 36-month-old rootstocks, respectively, regardless of the graft unwrapping time. Similar graft recovery time was reported by Yao *et al*. (2019) in shea butter (*Vittelaria*

paradoxa), with a graft recovery time between 21 and 30 days. The reestablishing of the connection between the rootstock and the scion is manifested by the budding of dormant buds on the scion. The lower graft success rate observed with grafted plants unwrapped at 15 days after grafting can be explained by an incomplete welding of the two parts. Indeed, graft unwrapping leads to the separation of the rootstock and the scion. This opening of the contact zone causes it to dry out on the one hand and the proliferation of several pathogens, such as fungi, on the other hand, which accelerates the death of the graft. The combined effect of season, method, and unwrapping time significantly influenced the graft success rate. The best graft success rate was recorded on grafts made in June on 36-month-old rootstock (43.33%) with chip budding and side cleft grafting methods with grafts unwrapped at 29 days after grafting and 83.33% for grafts made on 12-month-old rootstock with the top cleft grafting method with grafts unwrapped at 29 days after grafting. This result would mean that this combination of season, grafting method, and unwrapping time depending on the age of the rootstock optimizes the success of the grafting. These results could be explained by favorable climatic conditions in June. Indeed, the month of June is in the great rainy season. In addition, chip budding and side cleft grafting methods were adapted to older rootstock because this method does not affect the wood (Yakubu *et al*., 2014). While the top cleft method promotes well-grafting to unlignified stems, such as the 12-month-old rootstock apical part. In this study, young *G. kola* plants, whatever their age, have a good ability for grafting when the grafts are unwrapped at 29 days after grafting. The short graft recovery time observed with 12-month-old rootstocks is in agreement with several authors who reported that younger rootstocks presented good ability for grafting in papaya (Nguyen and Yen, 2018) and in mango (Mahunu *et al*., 2009; Upadhya *et al*., 2014). Other trees, such as *Garcinia xanthochymus* (Hook. f.) [Syn. *G. tinctoria* (Wight)] (Krishnamoorthy *et al*., 2006), *Garcinia lucida* Vesque (Takoutsing *et al*., 2014), and Vittelaria paradoxa (Sanou *et al*., 2004), were successfully grafted. The best result obtained by using the top cleft method in this study suggests that this grafting method promotes well-grafting success. Several species were successfully grafted by the top cleft method, such as *Allanblakia parviflora* in Ghana (Ofori *et al*., 2008) and *Allanblakia stuhlmannii*, with grafting success over 70% (Munjunga *et al*., 2013).

The survival rate (100%) of all the grafted plants after 12 months indicates that grafting is an alternative for the production of quality plants for Garcinia kola. However, monitoring must be extended until flowering to confirm the long-term success of this technique.

This study has shown that it is possible to propagate elite trees of *Garcinia kola* by using the four grafting methods tested. Chip budding and side cleft were better on 36-month-old rootstocks, while the top cleft method is appropriate on 12-month-old rootstocks. The determination of adequate season (in rainy season) and graft unwrapping time (29 days after grafting) for the grafting success is very important to promote the utilization of this strategy by farmers for the species domestication and cultivation. The present study is the first in Côte d'Ivoire to systematically explore grafting techniques for the propagation and conservation of this vulnerable species with significant socio-economic value. Results of this study can be exploited by forest management structures to produce high-quality plants for agroforestry programs with several objectives, such as the mitigation of the effects of climate change and the improvement of farmers' incomes.

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