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Research Article

Optimization of the Production of *Anacardium occidentale* L. Through the Multiplication of Elite Trees in a Semi-Controlled Environment in Senegal

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Abstract

In Senegal, *Anacardium occidentale* L. (Sapindales, Anacardiaceae) is among the most popular agroforestry species, due to its multiple uses in both environmental, socioeconomic and food terms. However, although the plantations are gaining momentum they are facing regeneration problems. To improve the current production trend, rigorous and efficient choices must be made in the selection of sowing techniques. The present study aims at making a contribution to improving knowledge on the species' sylviculture for a better use. For this purpose, separate but not independent experiments have been set up using a completely randomized block design (RBD) at the station. The methodological approach consisted of measuring the germination, initial growth and leaf growth parameters. The results show that the top aril position, large nuts, dune sand and the sowing in bags are the most effective treatments to improve the germination of *A. occidentale* L. nuts. The species presents a recalcitrant character. Thus, cashew plants are transplantable, after three months of breeding in the nursery. At this age, the double planting grafting technique is best suited. These results, concerning embryonic silviculture, show a good regeneration capacity of *A. occidentale* L., opening up good prospects for the production of seedlings in nurseries in order to improve old plantations by clear cutting, introducing elite trees and by grafting on adult subjects.

Keywords

Anacardium occidentale L., Spread, Elite Trees, Recalcitrant, Tolerance, Sowings, Grafting

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1. Introduction

Agricultural production has been negatively impacted by the climatic variability occurring in recent years. To cope with the situation, local populations have opted for certain emerging plantations such as cashew. Cashew tree cultivation is an economic activity for many tropical countries [15] because the nut, which is the main commercial product [34], is also used in several fields including food, cosmetics, medicine and the automotive industry [4]. Today, the harvesting and marketing of forest fruit trees is an essential component of production systems and poses as an alternative to field crops. They represent an essential food source among local populations.

In Senegal, cashew plantations continue to grow and represent 1.22% of the area [42], representing a real development opportunity. However, to better take advantage of this opportunity, more attention must be paid to the selection of effective sowing techniques, good quality nuts and good mastery of sylvicultural techniques. Sylviculture begins with a good mastery of the germination conditions, the growth conditioned by the intrinsic characteristics of the species and the ecology [48, 31, 26]. The research by [47] and [24] show that most forest species are propagated fairly well by seeds. *A. occidentale* L. can be reproduced in three different ways: direct seeding, transplanting of plants raised in nurseries and cuttings [28]. However, the most widespread mode of propagation in the production areas of Senegal is direct seeding at the rate of three nuts / poquet (73%) (Samb *et al*., 2018). Similar results were found in Benin by [49].

This form of multiplication causes a wide variation in the rate of regeneration [43] from nuts of natural crossing due to reproduction mode (allogamy). The plantations set up are very heterogeneous with variable productions. These conventional propagation techniques may constitute a limit to the development of the sector, hence the need to step up research efforts to improve knowledge of the different stages of quality plants production. Production begins with the selection of certified seeds, germination, growth and improvement of young plants. Germination is a very important step in the reforestation, restoration and rehabilitation programs of the forest and agroforestry ecosystems in Senegal. Vegetative multiplication (grafting) allows the conservation of interesting characters from selected elite trees and the increase of production [5].

Although several studies have been devoted to germination [13, 38, 6] and to the grafting of cashew trees [19, 20, 51], to our knowledge, few investigations have been given to the stimulating factors apart from abiotic factors and pretreatment with water or artificial scarification [23]. Although the germination of the cashew tree is well controlled, it is not the case for the role of the provenance, the sowing position, the size of the nuts, the sowing substrate, the sowing method, the saving of seeds, which generally takes place in the air ambient. In Fatick, Kolda, Sédhiou and Ziguinchor, the production areas in Senegal, a significant number of producers of *A. occidentale* L. sow seeds using conventional methods [21]. Therefore, the promotion of elite sowing techniques, the rigorous and selective choice of seeds will give a satisfactory technological progress for the different stakeholders in this sector. This lack of information on the embryonic silviculture of the species seriously limits the cashew sector.

The present general objective of this study is a contribution to improve the knowledge on the cultivation of cashew trees and increase the productivity of cashew plantations in Senegal. This study's interest lies in the fact that it constitutes an initial stage of a vast program of rehabilitation of cashew plantations. It is in this context that the study is undertaken and focuses on the evaluation of elite trees of *A. occidentale* L. through the provenance, the sowing position, the size of the nuts, the sowing substrate, the sowing mode, the retention time and their responses to different grafting techniques. The findings of the study provide useful information that may assist producers in future rehabilitation programs.

2. Material and Methods

To optimize the production and fix the problems encountered during the restoration or reforestation activities of the cashew tree, this work aims at studying the factors stimulating its multiplication. It evaluates the germination capacity, the initial growth and the leaf development of *A. occidentale* L. through the origin, the sowing position, the size of the nut, as well as the sowing substrate, the sowing mode and the time of conservation. It also assesses the different responses of the species to grafting techniques and the regeneration capacities according to the age of the rootstock. The seeds used in the experiments come from the 15 elite trees (ET) of mass selection in the main cashew production areas of Senegal. These trees are characterized by their production and their nuts quality [44].

2.1. Germination

The first experiment consisted of analyzing the germinative behavior of the species through the provenance effect. The provenance corresponds in this work to the mixture of nuts from elite trees belonging to the same area. The provenance factor has four levels: Fatick, Kolda, Sédhiou and Ziguinchor.

In this logic of technology research, a second experiment was set up. It consisted of evaluating the germinative behavior of the cashew tree through four sowing positions (top aril, down aril, ventral and dorsal positions) based on seeds of the best origin in terms of germination capacity.

The second experiment focuses on determining the best size for optimal germination of *A. occidentale* L. based on the previous results (provenance, sowing position). To do this, the nuts were graded using a scale (Digital Scale, Professional-MINI 500 g x 0.1 g), numbered and then made up into three (03) lots. The first batch includes nuts of smaller size (<5 g) called "small", the second batch of nuts with size between 5 and 8 g called "medium" and the third batch of nuts of larger size (>) to 8 g called "large" (Figure 1).

Figure 1. *Numbering (a), bagging (b), weighing (c) of cashew nuts.*

Figure 2. *Experimental design of sowing substrate and sowing method.*

The third experiment consisted of identifying the most suitable or appropriate sowing substrate for the cultivation of the cashew tree at the germination stage on the basis of the previous results. Two types of substrate were used: dune sand and humus soil (Figure 2). The results of the physicochemical analyzes of the different soil substrates are given in Table 1.

The fourth experiment consisted of comparing farmers (direct sowing) and conventional (sowing in bags) practices, because surveys have shown that 73% of producers practice direct sowing without any pre-treatment. Based on the previous results, the nuts were put to germinate on a 4.8 m^2 board (bare roots) and in plastic bags 25 cm x 15 cm x 15 µm in size (Figure 2). The physicochemical characteristics of the board floor were analyzed (Table 1).

Table 1. *Physico-chemical Analysis of the different substrates.*

Soil samples	White carbon	Carbon value	pH water ½, 5	EC 1/10 µs/cm	% C	Organic mater	Phosphorus
Humus soil	19.7	17.2	7.28	45.4	0.495	0.853	0.135
Plank floor	19.7	8.3	6.69	149	2.257	3.891	0.626
Dune sand	19	18.6	6.69	34.3	0.082	0.142	0.119

A fifth experiment has been carried out to help improve knowledge about the germination of the species. The influence of the storage time in ambient air on the germination of the nuts of *A. occidentale* L. is studied base on the previous results, of the nuts harvested at different dates (July 2015, July 2016 and July 2017) have been used.

2.2. Germination Experiments

The experiments were carried out at the National Center for Forest Research (CNRF) nursery in Dakar located between 14°43‘N and 17°26’W using a completely randomized block design (RBD) with three (03) repetitions. Each treatment consists of 30 seeds with 3 repetitions, for a total of 90 nuts for each treatment. To assess the germination capacity of the species, the nuts were soaked in tap water for 48 hours to remove the integumentary inhibition. They were then germinated at the rate of one nut per bag. The seeds germination corresponds to the emergence of young plants from those above the ground (Figure 3).

Figure 3. Cashew nut germination.

The test duration was set at the germination period which spanned 30 days. Daily monitoring was done to estimate the date of germination. Watering was done daily at the rate of 03 watering cans per block and weeding was done as needed.

The number of sprouted nuts is counted daily until the seeds have fully germinated or germination has stopped. From these observations, the average germination time (AGT) and the final germination rate (FGR) were calculated.

The AGT or delay of Germination (DG) is the time interval between sowing and the first germinated seeds [10].

$$AGT = \sum(\mathrm{Gi\ X\ Ji})/\mathrm{Gt} \quad (1)$$

Avec: AGT =Average germination speed

Gi = germination rate for day i

Ji = day i: number of days since the first sowing

Gt = total number of sprouts

$$FGR = \frac{\text{Number of sprouted seeds}}{\text{Total number of seeds}} \times 100 \quad (2)$$

$$\mathrm{GEK} = \frac{\text{number of seeds germinated daily}}{\text{total number of seeds tested}} \mathrm{X}\ 100 \quad (3)$$

The germination evolution kinetics (GEK) obtained under the experimental conditions, depend on the germination conditions and the treatments undergone by the seeds [35].

The shape and color of the nuts have been described using the description of the cashew tree [27].

2.3. Grafting Experiments

The different grafting techniques and the optimal age of the rootstock were also tested using the same type of experimental device. The factors studied were the three-level grafting technique (terminal slit, single plating, double plating) to determine the techniques that best apply to the species and the age of the two-level rootstock (12 months, 18 months) to study the optimal age of the rootstock. Well cut grafts, relatively homogeneous grafts with 15 cm long were used. The grafts were taken from a potentially elite tree for its high annual production (33 kg year-1) and the quality of its nuts (nut weight: 13 g) (A 386 X: 392625; Y: 1394162). The collection was done using a pruner and then the grafts were kept in a thermostat for 24 hours. The incisions were made by an Electric Knife with Wooden Handle. The ligation was made by plastic bags (Figure 4). The grafted plants were numbered and then labeled. The grafting techniques used have been described by [14, 50, 51].

Figure 4. Grafting material (a), grafting design (b), labelling (c).

The duration of the test was set at the grafting period which spanned three (03) months. Variables (recovery time, recovery rate, survival rate, diameter and height) of the seedlings were analyzed.

2.4. Data Analysis

Each treatment included 30 nuts with 3 repetitions. The germination data for each trial was angularly transformed (Y = 2ArcSin√X) and then all of the variables studied were subjected to a factor analysis of variance using XLSTAT 6.9. A ranking of the means was performed using the LSD test. Depending on the case, the effect of the treatments is analyzed for the following variables: provenance (Fatick, Kolda, Sédhiou and Ziguinchor), sowing position (top aril, low aril, ventral and dorsal position), size of the nut (small, medium, large), sowing substrate (dune sand and humus soil), sowing method (direct sowing or in plastic bags), storage time (seeds freshly harvested in 2015, seeds from 2016 and seeds from 2017), technique grafting (terminal slit, single plating and double plating) and age of the rootstock (rootstocks aged 12 and 18 months).

3. Results and Discussion

3.1. Germination

A highly significant effect of the factors studied (provenance, sowing position, size of the nut, method of sowing, storage time) on the germination parameters was observed (Table 2).

Provenances from Ziguinchor and Fatick do not differ in terms of germination rate. However, the research by [52] suggest that geographic, bioclimatic origin and germination conditions significantly affect germination capacity and plant development [3]. These results suggest that the differences observed are linked to the morphoponderal characteristics. The shape of the nuts and the germination rate are very well correlated (R^2 = 0.796). The color of the nuts has highly significant but negative correlation coefficients with the germination rate (R^2 = - 0.592), the time (R^2 = - 0.963) and the shape (R^2 = - 0.959). These results are in line with those of [17] who claim that the morphology of the seeds has proven to be a discriminating characteristic for the provenances of *Tamarindus indica* L. These connections are of interest to the silviculturalist since the shape of the nut is an essential criterion of seed quality and it determines the germination rate in cashew. The use of provenances with a higher genetic potential would certainly help improve the production and productivity of the species.

The study shows a significant effect of the sowing position on germination. The best performances were recorded with the top aril (94%), dorsal (91%), lower aril (86%) and ventral (85%) positions. The results confirm those of [29, 1, 33] which showed that the cashews sown flat (dorsal) and with end cap (aril upwards) had respective average germinations of 91.67% and 92.5%. However, the variations could be linked to internal or external reactions of the nuts when facing a sowing position. The good performance of the aril upward position would be explained by the natural position of the nuts on the tree duplicated in the substrate.

The study also shows a positive correlation between the size and the germination rate. Large nuts (> 8 g) gave the best performance. The size of the seeds has a very important effect on the life of the young seedling. Large nuts are characterized by their rich content in albumen and also have vigorous seedlings. The vigor of the seedlings is related to the complete digestion of the albumen. The abundance of seeds in albumen would constitute an important source of supply for the seedling which, in this case, would have more chance to develop [39]. Similar results were obtained by [45] on *Carapa procera*, [37] on *Gossypium hirsutum* and by [41] on *Tamarindus indica*. Similar results have been obtained with seeds from the origins of *Jatropha curcas* [22, 32]. [2] obtained seeds of *Alangium lamarckii* with germination rates of 76%, 74% and 59% respectively with large, medium and small seeds. However, the results of this work are in contradiction with those of [13] on *A. occidentale* L. who underline the existence of a low correlation between the size of the nuts and the germination rate. These differences could be explained by the different approaches used or by the origin of the nuts.

The quality of the sowing substrate is of great importance for the regeneration of *A. occidentale* L. Sowing on dune sand induces germination much earlier than humus soil. The good regeneration of the species on the dune sand would be the result of a coarse texture favoring a blooming and, therefore, more enhanced facilities that allow the nut to germinate more quickly. While the humus soil decreases germinative energy, this could be linked to the species' non-tolerance to heavy soils, rich in nutrients at the germination stage. The results are consistent with those of [3] who showed that the sheaths of *Prosopis africana* have better germination capacity on erosion sand. Therefore, at the germination stage, the cashew tree has no ecological requirements. However, the germination conditions must be maintained to ensure its survival. The species is very plastic and supports a wide range of soils [49, 8]. It can be cultivated on a variety of soils ranging from sand to clay [7, 40]. It develops on sandy, sandy-clay soils [7, 40], lateritic and rocky with a preference for fertile and well-drained soils. It should be noted that the species grows less on flooded or salty sites [25, 36] and tolerates slightly acid to neutral soil conditions, between pH 6.3 and 7.3 [8]. In Senegal, the species grows mainly on ferralitic, ferruginous and hydromorphic soils [44]. The adaptability of the species to soil and climatic conditions is a factor favoring its extension in all the agroecological zones of Senegal.

A highly significant effect of the sowing method on germination was observed (P = 0.001). The highest germination values were taken from the bags 90% while they are 56.6% in direct sowing. Nuts directly sown have sporadic germination. Direct seeding decreases the germination rate and lengthens the average germination time. This situation reflects the susceptibility of the species to direct seeding. The use of containers for the production of cork oak plants has contributed significantly to improving the growth of roots and aerial parts [53]. This sensitivity could be explained by the differences in temperature between the two sowing media but also by their textural characteristics.

The storage time has a depressive effect on the germination of *A. occidentale* L., which reduces the germination rate and lengthens the germination time.

The study highlighted the depressive nature of the storage time on the germination of *A. occidentale* L. The storage time reduces the germination rate and lengthens the germination time. The freshly harvested seeds (2017) recorded the best germination rate (95.56%) followed by those of 2016 (51.11%) and the germination of the seeds of 2015 is almost zero (4.44%). The study of the comparative morphology and germination of seeds of four *A. occidentale* L. morphotypes stored at 4 ° C for four ‘years reveals an average germination rate of 50.62% [18]. The average germination time increases depending on the shelf life. This situation reflects the loss of viability of the nuts due to the time of storage. The longer the storage time, the more the nuts lose their germination capacity. These results are similar to those of [11] who demonstrated that the behavior of the cashew tree is significantly affected by the shelf life of the nuts. These results are in line with those of [29] who showed that the germination rate of *A.*

occidentale varied between 93 and 98% in the first months after harvest, 55% in the 8th month and 45% in the 12th month. [12] specify a germination rate of 80% after 33 months of storage in ambient conditions without special precautions, reflecting the good conservation of the seeds of *Afzelia africana*. These differences could be due to the biology of the species. This phenomenon reflects the recalcitrant nature of the species seeds. The drop in the water content of the nuts simultaneously causes a loss of its viability. It appears from this study that the nuts of *A. occidentale* L. behave differently from those of *Carapa procera* [45]. Seed shelf life has an important role in the germination of the cashew tree. To increase the productivity of cashew, it would be interesting to suggest the use of seeds of the year for nurseries and plantations in the real world.

Table 2. *Analysis of Variance and germination parameters significance test according to the studied factors.*

Facors	Areas	Germination rate (%)	Delay of germination (days)
Provenances	Sédhiou	66.00 ± 0.03^{a}	08.41 ± 0.44^{a}
	Kolda	85.33 ± 0.03^{b}	08.30 ± 0.46^{a}
	Fatick	94.00 ± 0.03^{c}	11.82 ± 0.44^{b}
	Ziguinchor	93.33 ± 0.03^{c}	11.56 ± 0.44^{b}
	F	21.6	18.6
	P value	< 0.0001	< 0.0001
Sowings position	low aril	82 ± 0.91^{bc}	11.45 ± 0.12^{a}
	top aril	93 ± 1.03^{a}	11.93 ± 0.13^{a}
	dorsal position	89 ± 0.98^{ab}	9.93 ± 0.11^{b}
	ventral position	79 ± 0.87^{c}	10.87 ± 0.12^{ab}
	F	3.93	3.55
	P value	0.0086	0.0146
Size of nuts	large ≥8	98.25 ± 0.03^{a}	14.16 ± 0.36^{a}
	medium [5-8 g]	92.22 ± 0.03^{a}	12.10 ± 0.35^{b}
	small (<5 g)	89.18 ± 0.03^{a}	12.27 ± 0.38^{b}
	F	2.56	9.25
	P value	0.07	0.0002
Sowings mode	direct sowing	89.49 ± 0.03^{b}	14.47 ± 0.41^{a}
	dune sand	100.02 ± 0.02^{a}	11.26 ± 0.33^{c}
	humus soil	90.15 ± 0.03^{b}	12.79 ± 0.39^{b}
	F	4.88	19.04
	P value	0.0087	0.0001
Seeds conservation	2017	95.58 ± 0.11^{a}	19.38 ± 0.38^{a}
	2016	51.09 ± 0.14^{b}	18.90 ± 0.52^{a}
	2015	04.44 ± 0.14^{c}	22.10 ± 0.38^{a}
	F	173.96	1.19
	P value	0.0001	0.3

3.2. Grafting

Regarding the grafting technique, we notice its highly significant effect on the recovery time (P = 0.023). Terminal slit grafting had the lowest rates and the shortest recovery times (Figure 5).

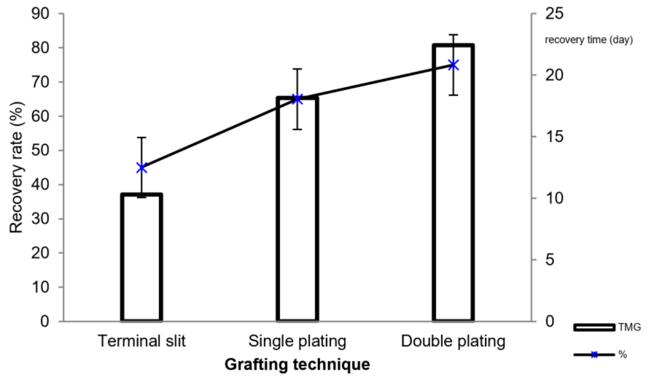

Figure 5. *Grafting technique on recovery rate and germination time.*

The evolution curves of the plants leaves grafted by single plating and by double plating are located above those of the plants grafted by terminal slit (Figure 6). In the first month after grafting, no difference was detected between the different treatments. In month 2, a gradual change in the number of leaves was noted on the plants grafted by double and single plating with an average of 5 leaves. From the second month, an exponential change in the number of leaves (7) of plants grafted by double plating was noted (Figure 6).

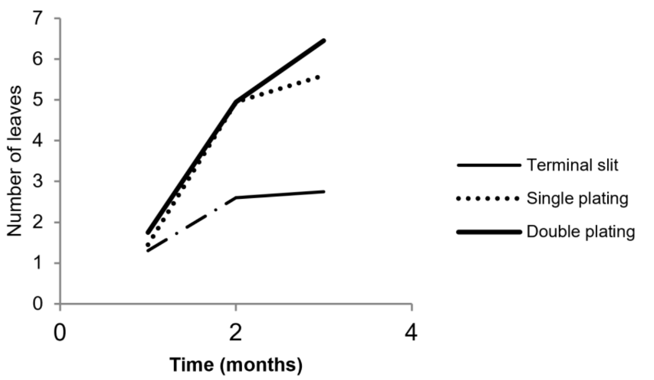

Figure 6. *Evolution of leaves number based on grafting technique.*

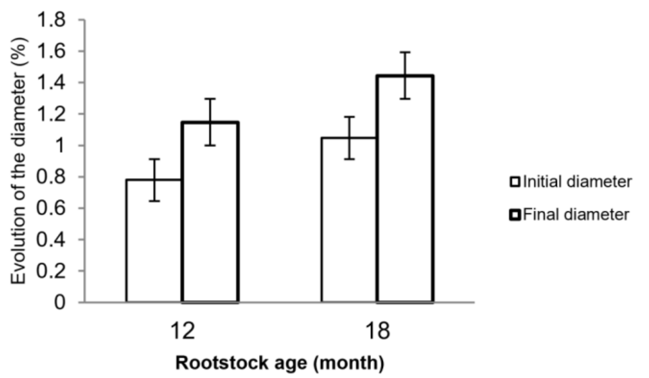

Figure 7. *Average increase of rootstock diameter based on the age.*

Plants aged 18 months give the highest values with an average increase of 0.1 cm compared to 0.08 cm for plants aged 12 months (Figure 7).

Figure 8 presents the evolution of the height of the grafted plants as a function of the age of the rootstocks and of time. It can be seen that the height evolution curve of 12-month-old rootstocks greatly exceeds that of 18-month-old rootstocks. This situation shows the faster growth of younger rootstocks with an evolution percentage of 88% compared to 18-month-old rootstocks (60%). The 12-month rootstocks yield 7 leaves and the 18-month rootstocks record 3 leaves, after three months of follow-up (Figure 9).

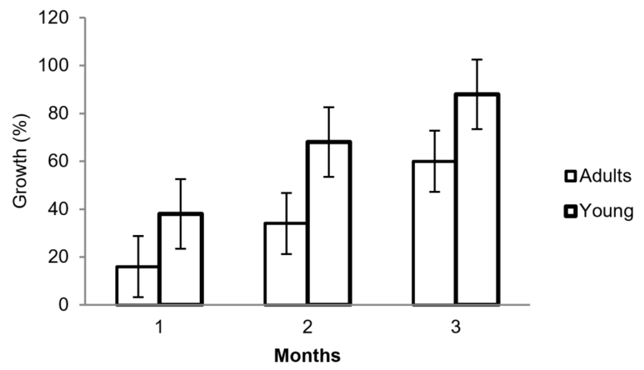

Figure 8. *Evolution of the grafted plants height growth based on rootstock age and the time.*

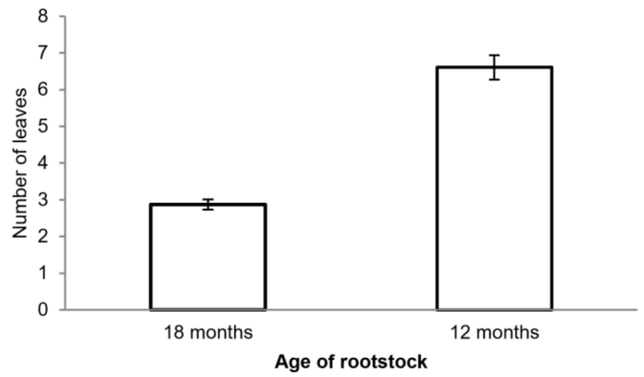

Figure 9. *Evolution of leaves number based on the rootstock age.*

This is normal because current observations have shown that in general, length growth decreases when the generative base ages [16]. However in this case, the rootstocks considered are at a relatively young age in the life of the tree (12 and 18 months) and it is difficult to believe that only the difference in age leads to such a difference (88 % and 60%). However, research results on cashew grafting techniques seem mixed and contradictory. This does not benefit producers. So it would be interesting to harmonize the research and to document the approaches well.

4. Conclusion

The results show that cashew grafting is possible and double plating is the most appropriate technique (75%) followed by single plating 65% and the terminal slit records 45%. However, recovery rates of 80-85% have been recorded in Tanzania [9]. The poor performance of the terminal slit could be related to its stripping. The lasting success of a transplant is determined by the presence of leaves on the rootstock [46]. If you remove them all, the combination dies in no time, death starting with the rootstock, the screened tubes being the first to show symptoms of necrosis. The more leaves we leave on the subject, the better the two partners are doing. However, the best results have been obtained with juvenile subjects.

This research highlights the fact that the embryonic silviculture of the species is now well known. These different treatments / factors are good selection criteria for setting up rehabilitation programs.

Abbreviations

AGT	Average Germination Time
CNRF	National Center for Forestry Research
CRA	Regional Agricultural Center
DG	Delay of Germination
DPF	Forest Productions Department
DPV	Plant Productions Department
ENSA	Higher National School of Agriculture
ERAIFT	Regional Post-University School of Integrated Planning and Management of Forests and Tropical Territories, Kinshasa, RD Congo
ET	Elite Trees
FGR	Final Germination Rate
GEK	Germination Evolution Kinetics
ISFAR	Higher Institute of Agricultural and Rural Training
ISRA	Senegalese Institute for Agricultural Research / (CNRF/ISRA)
RBD	Randomized Block Design
UAD	Alioune Diop University
UT	University of Thies

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Author Contributions

Cheikh Oumar Samb: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing

Ousmane Cisse: Data curation, Formal Analysis, Software, Visualization, Writing – original draft

Alioune Badara Diop: Data curation, Methodology, Software

Mame Arame Sene: Investigation, Resources

Alioune Ba: Investigation, Resources

Moussa Dieng: Software, Visualization

Samba Arona Ndiaye Samba: Formal Analysis, Methodology

Elhadji Faye: Supervision, Validation

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

Cheikh Oumar Samb: Forestry, sylviculture, forest management, ecology, plant breeding

Ousmane Cisse: forestry, Forest management, cartogry - teledetection

Alioune Badara Diop: Mangrove ecosystem, forest management

Mame Arame Sene: Forestry

Alioune Ba: Forestry

Moussa Dieng: Cartography, biogeography

Samba Arona Ndiaye Samba: Soil science, forestery

Elhadji Faye: Agronomy, forestery, botanic, systematic, ecology