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Production of four avocado (*Persea americana*) varieties' seedlings from the seeds under Katibougou's agroclimatic conditions in Mali

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Abstract: The socio-economic and nutritional importance, as well as the various possibilities of using avocado, give it a reason to promote its production among the main fruit species cultivated in Mali. Four varieties of avocado (Hass, Ettinger, Linda, and Kampong) evaluated for their growth performance. The seedlings were generated using two production techniques, direct sowing in pots and the toothpick technique, under greenhouse conditions. The seedlings were transplanted in the Rural Polytechnic Institute for Training and Applied Research (IPR / IFRA) of Katibougou (IPR/IFRA) orchard under Fisher's block device with three replications. The findings were as follows: the toothpick method recorded the shortest germination time compared to direct seeding in pots, with 13 days against 43 days after sowing, respectively. For the Kampong, Hass, Linda, and Ettinger varieties, the rates of seed germination were 67%, 60%, 50%, and 43%, respectively. Linda produced significantly more leaves with an average of 73 leaves, followed by Hass, Ettinger, and Kampong with averages of 51, 37, and 35 leaves on the 56th day after transplantation, respectively. Likewise, Linda had the most branch ramifications, followed by Hass, Ettinger, and Kampong, with averages of 3, 2, 1, and 1, respectively at the 56th day after germination. These findings suggest that, among the tested varieties, the Linda cultivar growths quickly compared to others. Moreover, this study proves that the avocado plants as well as its cultivation can successfully be introduced in Katibougou, Koulikoro-Mali.

Keywords: Avocado, varieties, seedlings, production techniques, adaptability, Mali.

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Résumé : L'importance socio-économique et nutritionnelle, ainsi que les diverses possibilités d'utilisation de l'avocat justifient l'introduction de la culture ou de la production d'avocat parmi les principales espèces fruitières cultivées au Mali. Quatre variétés d'avocat (Hass, Ettinger, Linda et Kampong) ont été testées. Les plants provenaient de deux techniques de production, à savoir le semis direct en pots et la technique du cure-dent, dans la serre. Les plants ont été transplantés dans le verger (conditions réelles) de l'IPR/IFRA de Katibougou. Les

résultats ont révélé que la méthode du cure-dent a enregistré le temps de germination le plus court par rapport au semis direct en pots dont 13 contre 43 jours après le semis. Les graines des variétés Kampong, Hass, Linda et Ettinger enregistré respectivement un taux de germination de 67 %, 60 %, 50 % et 43 %. Linda a produit significativement plus de feuilles avec une moyenne de 73 feuilles, suivie de Hass, Ettinger et Kampong avec des moyennes de 51, 37 et 35 feuilles au 56 -ème jour après la transplantation de façon respective. De même, Linda avait le plus de ramifications, suivie de Hass, Ettinger et Kampong, avec des moyennes de 3, 2, 1 et 1 de façon respective au 56-ème jour après la transplantation. Ces résultats suggèrent que, parmi les variétés testées, Linda pousse plus rapidement que les autres. Cela suggère que la culture de l'avocatier ainsi que la production d'avocat peuvent être introduits avec succès à Katibougou, Koulikoro-Mali.

Mots-clés : Avocatier, variétés, plants, technique de production, adaptabilité, Mali.
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1 Introduction

Mali is a Sahelian country in Central West Africa with a total land area of 1,241,238 km² (A.D.P, 2013), about 60% of which is sub-Saharan or desert. However, the Malian economy is mainly based on the rural sector occupying about 80% of the working population, with agricultural sector contributing to sub-sector to the GDP estimated at 46% of the gross domestic product (GDP) (N.D.S.I, 2013). The development of agriculture is a priority to ensure food self-sufficiency. Thus, the vegetable and fruit sector plays an important role in Mali's socio-economic development policy (Helvetas 2003). In general, horticultural crops production improves food security and the living conditions for peoples because of its nutritional quality and the very high additional value per surface unit (DEMBÉLÉ, 2001).

Fruit production forms a key component of agriculture in the tropical area. In Africa, fruits constitute an important export item and a source of high currency income. For instance, Malian mango production was 600,000 tons in 2015, which led to generating about 30 million USD in export incomes (Rahinatou, 2020, I.F.M., 2016). Furthermore, a large part of the harvest of fruits such as mango, banana, papaya, and avocado is consumed locally. They are therefore the first-rate food products for millions of people in tropical areas and a part of the subtropical region (RAKIPOV, 1987, van der Wal et al., 2006, Mukhametzyanov et al., 2023, Altendorf and Agriculture Organization of the United Nations 2017). Mali is experiencing a quite critical food security situation due to its high reliance on natural rainfall (approximately 75% of agricultural production is made up of rainfed crops), and limited intensification and diversity of crops (M.R.D.R.M, 2013).

The avocado tree (*Persea americana* Mill.) is a tropical tree native to Central America, cultivated for its fruits (GONZÁLEZ-CORTÉS, 2012 , Paull and Duarte, 2025). Avocados have high protein levels, antioxidants (Vitamin E), minerals (K, Mg, and S), and oil content (20–30%) contribute to improving the health of its consumers (Griesbach, 2005). Although avocado is one of the fruit crops that represents significant potential in the export market. Consumer tastes are increasingly turning to these fruits for their taste and nutritional qualities. However, Africa produces only 13% of the global avocado production (COMTRADE, 2017). Thus, it should be mentioned that cultivation/production and research on the avocado tree are not common in Mali. This is one of the reasons for the low national fruit production, including avocados. On the other hand, the short times of avocado seedlings production involve technical skills (Njuguna, 2017), which are interesting in the industry or activity of many fruit plant production as well as their fruit. Consequently, this study was conducted to produce avocado seedlings from

the seeds via specific techniques and observe their agromorphological performances as well as the identification of the variety presenting an easy adaptation under the agroclimatic conditions of Katibougou at the seedling stage.

2 Material and Methods

2.1 Material

2.1.1 Study area

The study was conducted in the laboratory of Agro-physio-genetics and plant biotechnology and in the experimental field of IPR/IFRA of Katibougou, Its geographical coordinates are 12° 56 North altitude; 7° 32 West longitude, 326 m altitude (DICKO, 2018).

2.1.2. Plant material

In this study four varieties of avocado trees (*Persea americana*) belonging to Lauraceae family from Ivory coast were used as shown in Table 1.

Table 1 Description of the avocado varieties used for the study

Varieties	Characteristics	References
Hass	Guatemalan breed, belonging to the group A flowers type. Highly productive and widely cultivated in Mexico, California, Israel, and Spain. Green, pear-shaped fruit, weight ranges from 250 to 350 g, excellent-quality flesh, non-fibrous, containing 18 to 23% oil.	(Lahav and Gazit, 1994, Gaillard and Godefroy, 1994, Moore-Gordon et al., 1997)
Linda	Guatemalan breed, belonging to the group B flowers type, originated from California. The fruit weighs from 500 to 1000 g and contains 15 to 20% oil.	(Lahav and Gazit, 1994, Gaillard and Godefroy, 1994)
Ettinger	Guatemalan x Mexican hybrid, belonging to group B flowers type. Vigorous, upright, mainly cultivated in Israel. Piriform fruit, bright green in colour, thin-skinned, with a weight average ranging from 250 to 350 containing 18 to 22% oil.	(Lahav and Gazit, 1994, Gaillard and Godefroy, 1994)
Kampong	Guatemalan x Caribbean hybrid, belonging to group B flowers type. Native to Florida, the fruit is ovoid and pear-shaped, with a weight average from 550 to 850 g.	(Lahav and Gazit, 1994, Gaillard and Godefroy, 1994, CARL W. CAMPBELL, 2002)

2.1.3. Manure application

On the test site/plot, we applied 32 kg, or 20 t/ha compost made from diverse organic wastes combined as basal manure, from Friendship Group of African Farmers (FGAF)

2.1.4. Technical material

The technical materials used in this study comprised the calliper, plastic bags, razor blade, toothpicks and scales.

2.2 Method

2.2.1 Experimental design

Seedlings were produced from seeds in the greenhouse of the laboratory of agrophysio-genetics and plant biotechnology, experiments of the seedlings test and their growing parameters after germination were observed and measured in the orchard of IPR/IFRA of Katibougou. The design used was the Fisher block in 3 replicates. Each block or replicate had 4 varieties, and each variety corresponded to a treatment. Hence, there were 4 treatments including Hass, Ettinger, Linda and Kampong. The blocks were arranged perpendicular to the direction of the orientation of slope, which is from North-East to South-West. Then, the blocks were 2.5 m x 2 m or 5 m² in size and spaced 0.25 m between them. The arrangement of the seedlings in each replicate or block was linear, forming a median, with a spacing of 0.40 m between the seedlings.

2.2.2 Seeds pre-treatment and pre-germination

The pre-treatments consisted of using techniques to accelerate the germination of the seeds. Therefore, the first procedure was scraping the integument of the seeds and excising them using a blade that had been disinfected with alcohol.

2.2.3 Seeds pre-treatment via "toothpick" method

For seed pre-germination, the glass containers, toothpicks, and a blade were used (DESIMA, 2017). However, it has been performed. However, the seeds have been cleaned in water and removed from the pulp residues, and then 3 or 4 toothpicks have been used to pierce horizontally around the seed. Moreover, the wide base of the seeds was immersed in the water, latent the toothpicks were placed on the borders of the container to keep them in their “point up” position. Hence, from 7 to 10 days, the seeds started to split, leading to their germination. When the buds appeared, we transferred them to plastic bags.

2.2.4 Seeds sowing

The seeds, after being incised, were placed in the plastic bags keeping the upper (pointed) end upwards, and covered with a thin layer of soil of about 0.5 cm. Then, labelled the plastic bags with a marker.

2.2.5 Maintenance in the nursery

The maintenance was mainly based on watering every two days from the date of sowing, for seeds sown directly in plastic bags. In addition, for seeds subjected to the toothpick technique (during pre-germination), the main maintenance was to change the water in the bottles or glass containers every two days from the date of sowing, to avoid or limit the infestation by possible pathogens.

2.2.6 Establishment of the experimental test in the orchard

2.2.6.1 Transplantation

The seedlings were planted in holes, which had been dug to a depth of 18 cm and a diameter of 10 cm, with a spacing of 40 cm x 40 cm.

2.2.6.2 Setting up the shade

After transplantation in the orchard, we have set up a shade shelter with mosquito nets to minimize sunlight on the seedlings to reduce the risk of excessive evapotranspiration.

2.2.6.3 Maintenance in the orchard

The avocado plant nursery, like any other crop, requires maintenance for the seedling’s development. However, the maintenance in the orchard concerned the watering when necessary; weeding used to be performed when needed (after weeds were noticed). Moreover, hoeing used to be carried out every 15 days from the date of transplantation.

2.2.6.4 Seedling growth characters observation

To assess the seedlings’ growth characters and determine the quickest growing variety, we have recorded the height of the seedlings, the diameter of the seedlings at the collar, the number of leaves and the number per seedling. It should be noted that the growing seedling features were recorded at the 14^{th} day after the transplantation and on the 56^{th} day after the transplantation date.

2.2.6.5 Data processing and analysis

The collected data were recorded and verified using an Excel spreadsheet. The same Excel software was used to generate histograms. The data analyses were performed using the STATICEF MSDOS software. The separation of the mean was carried out via the method of analysis of Fisher (Anova) variance (Fisher, 1919, Fisher, 1992), and at a significance level of 0.05 or 5%.

3 Results

3.1 Seed germination rates under the toothpick technique and direct sowing

The seeds sown directly in plastic bags started to germinate on 37^{th} day after sowing. While we noticed the seeds germinated from the 10^{th} day of the seeds being subjected to toothpick technique. The seed germination rate for

the Kampong, Hass, Linda, and Ettinger were 67%, 60%, 50%, and 43%, respectively, indicating that Kampong recorded the best seed germination rate.

3.2 Seedling growing parameters

3.2.1 Seedling height

Seedlings' height on the 14th and 56th day post transplantation did not differ significantly among the for the assessed 4 verities (Figures 1 and 2).

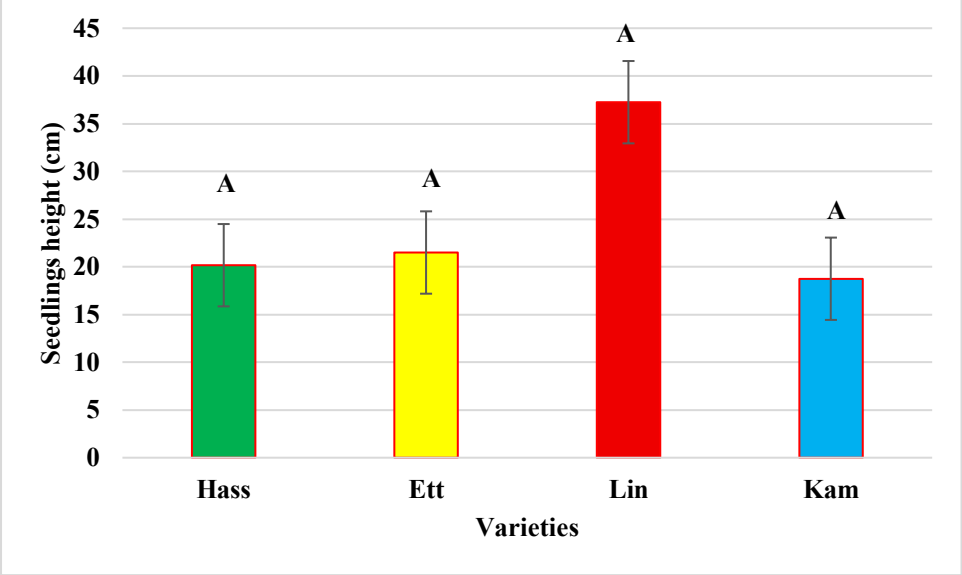

Figure 1. Seedlings' height at first observation (14th day after transplanting)
Notes: Hass= Hass, Ett= Ettinger, Lin= Linda, Kam= Kampong. Histograms with a common alphabet letter at the top indicate no significant difference with the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

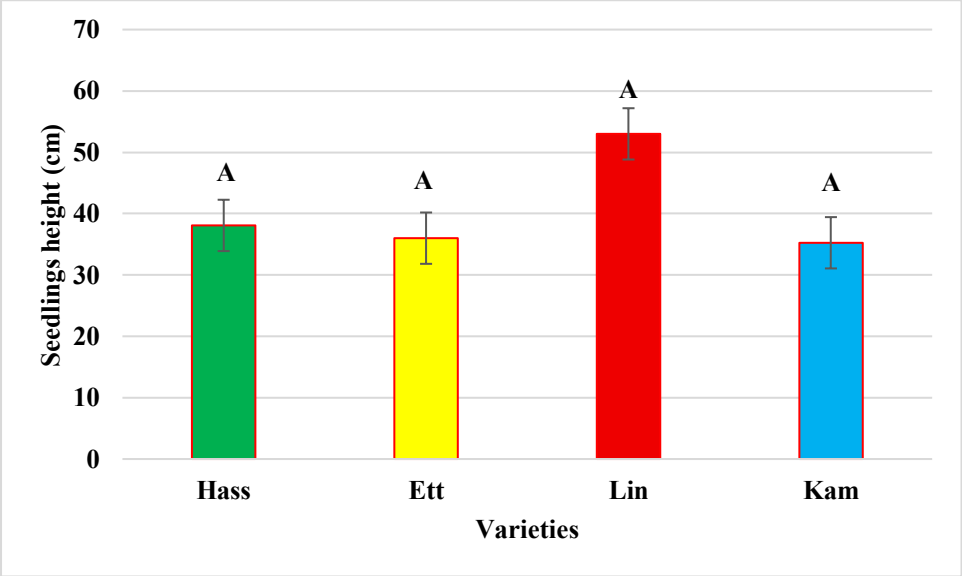

Figure 2. Seedlings' height at the second observation (56th day after transplanting).
Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference with the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

3.2.2 Seedling collar diameter

The analysis of collar diameter on the 14th and 56th day after transplantation of the seedlings did not show any significant difference among the 4 avocado varieties (Figures 3 and 4).

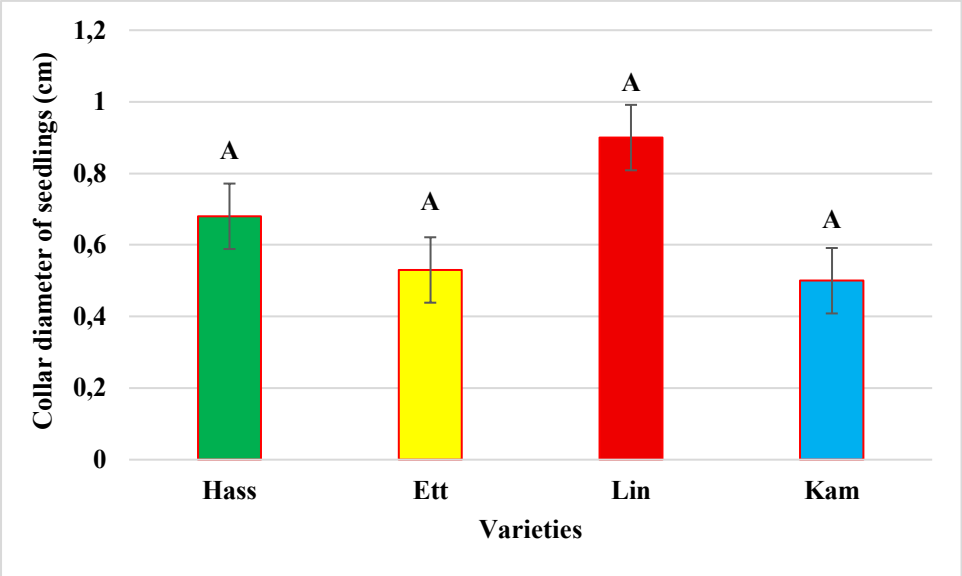

Figure 3. Collar diameter at first observation (14th day after transplantation).
Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference in the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

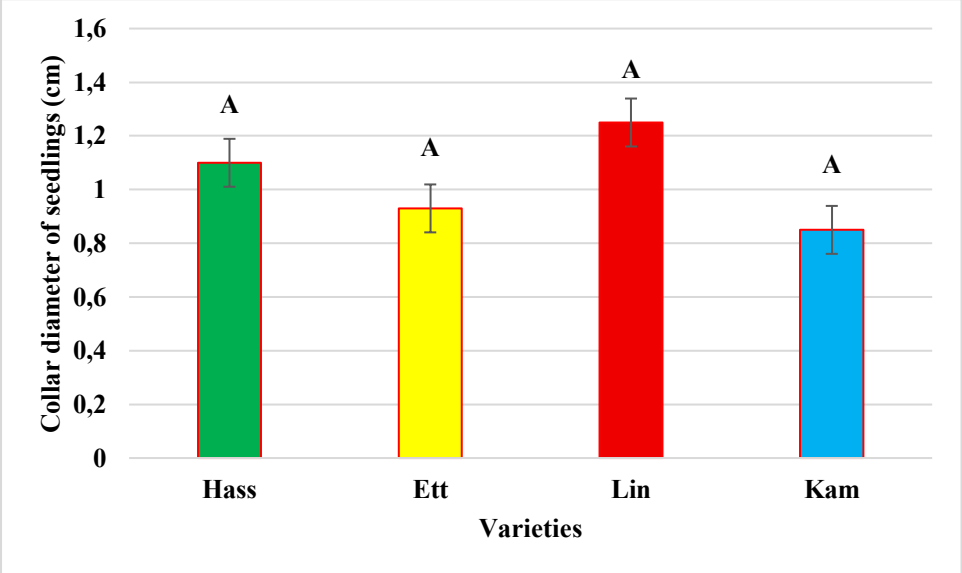

Figure 4. Collar diameter at first observation (56th day after transplantation).
Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference in the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

3.2.3 Leaves number

The number of leaves on the 14th day after transplantation showed a significant difference among the varieties, thus Linda had the greatest number of leaves, followed by Hass, Ettinger, and Kampong (Figure 5).

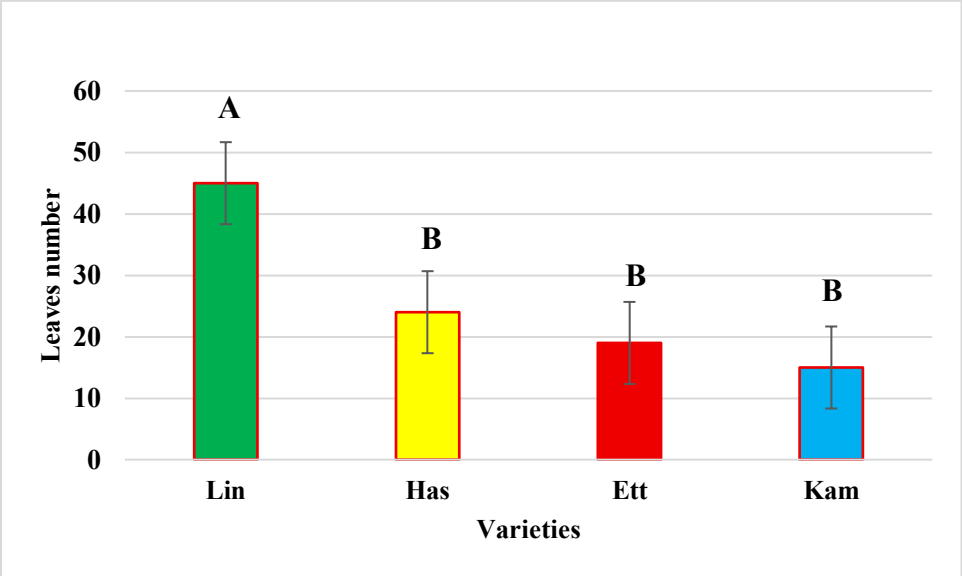

Figure 5. Analysis of variance of leaves number at the first observation (14th day after transplantation).

Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicates no significant difference with the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

The analysis of leaves number on the 56th day after transplantation showed a significant difference among the assessed varieties, Linda had the greatest number of leaves, followed by Hass, Ettinger and Kampong (Figure 6).

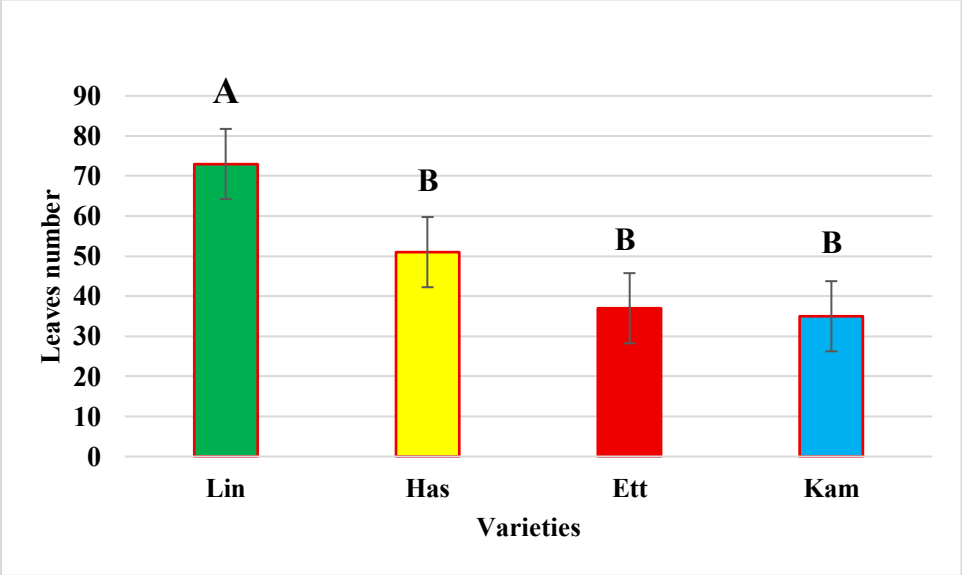

Figure 6. Leaves number at the first observation (56th day after transplantation).

Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference in the comparison of means with the Test at P<0.05, while those with different alphabet letters indicate a significant difference at P<0.05.

3.2.4 Branch Number

The branch number on the 14th day after transplantation showed a significant difference. Linda had the greatest branches number followed by Hass, Ettinger, and Kampong respectively (Figure 7).

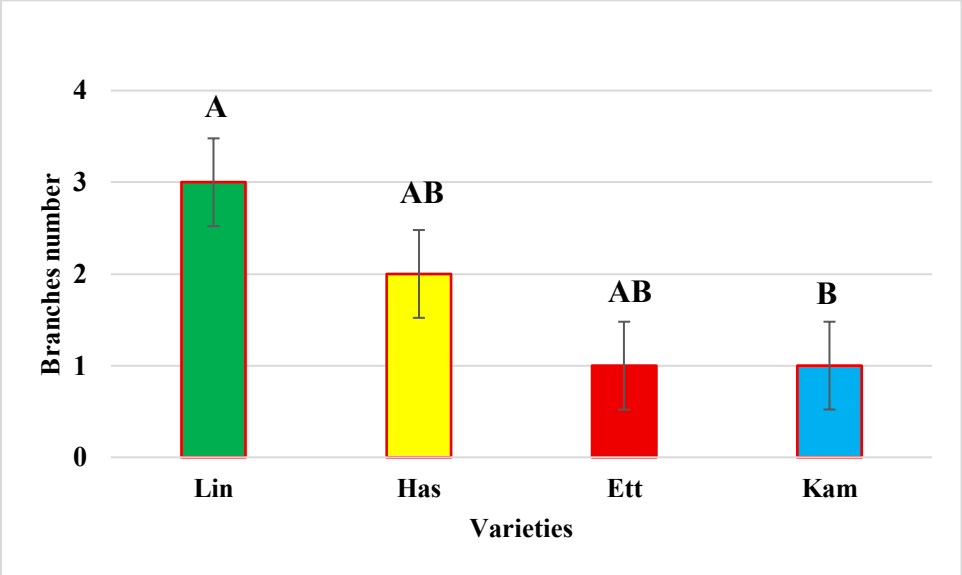

Figure 7. Branch number at the first observation (14th day after transplantation).
Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference with the comparison of means with the Test at $P<0.05$, while those with different alphabet letters indicate a significant difference at $P<0.05$.

The branch number on the 56th day after transplantation showed a significant difference. Linda had the greatest number of ramifications, followed by Hass, Ettinger, and Kampong, respectively (Figure 8).

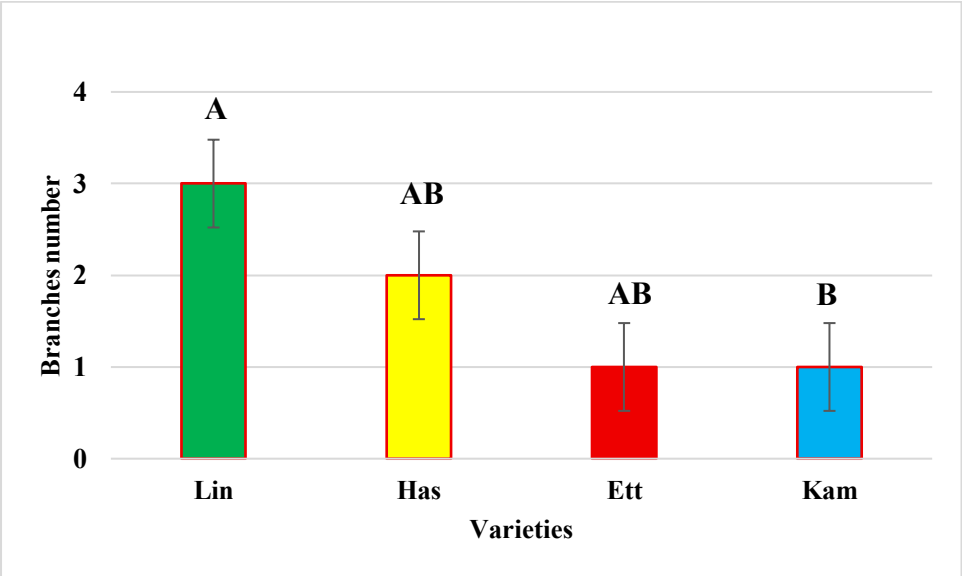

Figure 8. Branch number at the first observation (56th day after transplantation).
Notes: Hass = Hass variety, Ett = Ettinger variety, Lin = Linda variety, Kam = Kampong variety. Histograms with a common alphabet letter at the top indicate no significant difference in the comparison of means with the Test at $P<0.05$, while those with different alphabet letters indicate a significant difference at $P<0.05$.

4 Discussion

In Mali, we noticed a recurrence of avocado in the market, but it turns out that most of this production comes from the external market of certain neighbouring countries, such as the Ivory Coast and Guinea. The relatively high cost of avocados in the local market is certainly linked to the lack of mastery of avocado production techniques. Therefore, at the end of this study, we produced seedlings of four varieties of avocado trees (Hass, Ettinger, Linda and Kampong) and studied their growing parameters such as agromorphological features under agro-climatic conditions of Katibougou, Koulikoro-Mali.

From the view of varietal purity, plants grown from seeds are not pure varieties like their mother plants (Sendekie, 2020). Cross-pollination occurs in avocado trees (Kämper et al., 2021, Reese et al., 2025) (pollen grain coming from another tree during fertilization, so there is genetic rearrangement in the seeds). The related seeds are therefore genetically different from each other and from the mother plant, but the genetic distance is often not very good except for those related to mutation. Hence, trees grown from seeds are very close to the mother tree and the phenotype (external appearance of the trees identical to each other and to the mother plant) is the same. This is why grafting is recommended in fruit production. Thus, these plants can also be used as rootstocks.

However, the toothpick method accelerated or led to seed germination around 30 days earlier than direct seeding or sowing in plastic bags. It should also be mentioned that the seeds subjected to that pre-germination technique in the present study enabled seeds to germinate earlier (7-10 days) than what is previously known (2-4 weeks) (DESIMA, 2017). Furthermore, the toothpick method leads to early germination of seeds compared to seeds treated with chemicals in a previous study, including GA3 500 ppm (T4), which took at least 18 days for early germination (Anusha MD and HM, 2019), suggesting that the toothpicks technique can be used under local conditions to produce avocado seedlings successfully. Hass had the highest rate of seed germination compared to the others, such as Ettinger, Linda, and Kampong. This could be related to other parameters, such as the seed size. For instance, in a previous study, it has been reported that the medium seeds had the highest germination rate (77.78%), followed by large seeds in size (55.56%) (Ndoro, 2018); and then, the level of maturity, the health status of the fruit, storage conditions (seed quality) could also be associated with seed germination.

Although there were significant arithmetic differences among the four varieties, with Linda in the lead, based on the recorded growing parameters. The traits such as height and collar diameter periods (14^{th} and 56^{th} day after transplantation) did not differ statistically among the assessed 4 avocado varieties. On the other hand, the analysis of biomass traits variances, such as the number and branches number revealed statistically significant differences among the 4 varieties (at 14^{th} and 56^{th} day after transplantation). The variety Linda appeared to be the most susceptible to these parameters at different observation periods. While an increase in height and the number of branches of seedlings consequently leads to an increase in the other traits measured and vice versa, which can lead to an increase in productivity (Nkansah et al., 2013). This proves that Linda could probably be productive compared to the others. (Ashworth and Clegg, 2003) also reported great variability between avocado varieties in terms of major morphological traits. According to (Nkansah et al., 2013), the study of the diversities of introduced and local avocado germplasm in Ghana based on morphological characteristics revealed that Ettinger had the highest height compared to Hass. In terms of branching, Hass had many more branches than Ettigger (Nkansah et

al., 2013), while Linda had the most leaves and branch producer compared to the others in our study. Mostly, the positive association between the seedling height, branches number and stem circumference indicates the possibility of improving important traits simultaneously (Nkansah et al., 2013). In fact, apart from productivity, these factors also significantly contribute to the long-term production of seedlings, especially in orchards, by reducing the rate of seedlings lodging (winds, etc.), creating a microclimate (an environment within the orchard that is in harmony with nature) and ensures a moderate rate of humidity, temperature, solar radiation (against certain pests, water stress, etc.). However, these can reassure the likelihood of sustainable avocado production in future. Since these varieties were among those introduced to Ghana, we therefore suggest that their adaptation might be possible under the agroecological conditions of Katibougou-Mali. Linda, which performed the best overall in this study, could be recommended or advised for use in avocado production in Mali.

5 Conclusion and perspectives

In the study, it has been pointed out and brought out some notions on the production techniques of avocado seedlings (*Persea americana*) in nurseries. The study also identified the avocado variety presenting at a young age, an easy adaptation to the agro-climatic conditions in Katibougou, among the tested varieties. However, Linda appeared to have the quickest growth, followed by Hass, Ettinger and Kampong, respectively. The challenges we have faced, as well as the notes or remarks and the findings, suggest that the first step for the promotion of avocado production is the popularization of knowledge, and the facilitation of access to information. Therefore, we suggest supporting research related to the avocado tree and its production by the appropriate institutions. This same study on these varieties should follow up on research on the fruiting period (early or late) because there may be a difference of some years from a genetic perspective.

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Authors contribution: D.C., A.S., I.A.M. and L.D. designed the study, D.C., E.L.N., D.A.D. and I.A.M performed the experiment, D.C. and B.S. analysed the data, D.C. drafted the first version of the manuscript, K.O.O., A.A-B., M.T., L.D., A.S. and D.C. revised the manuscript.
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Conflicts of interest statement
The authors declare no conflict of interest.

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