

Planting rosewood for the sustainable essential oil production: Influence of surrounding forest and seed provenance on tree growth and essential oil yield

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Photo 1.
Bois de rose (*Aniba rosaeodora*) : seedling (a), 8 years old tree (b),
2 years old plantation(c).
Photos Projet anib@rosa.

RÉSUMÉ

PLANTATION DE BOIS DE ROSE POUR LE DÉVELOPPEMENT DE LA PRODUCTION D'HUILE ESSENTIELLE : INFLUENCE DU MILIEU FORESTIER ENVIRONNANT ET DE LA PROVENANCE DES GRAINES SUR LA CROISSANCE DE L'ARBRE ET LA PRODUCTION DE L'HUILE ESSENTIELLE

L'huile essentielle de bois de rose (*Aniba rosaeodora* Ducke) recherchée pour ses propriétés olfactives est un ingrédient majeur de la parfumerie de luxe. En raison d'une surexploitation ces dernières décennies, le bois de rose est désormais considéré comme une espèce en voie de disparition. Envisager de produire de l'huile essentielle à partir de plantations s'avère une alternative pertinente. Nous avons planté 605 arbres de bois de rose issus de graines de deux provenances de Guyane française sur une parcelle de 5 445 m². La plantation présente la particularité d'être entourée de forêt primaire. Après une période de 9 ans, nous avons évalué l'effet de la position de l'arbre par rapport à la forêt environnante et de la provenance des graines sur les traits dendrométriques (hauteur, circonférence, biomasse ligneuse) et le rendement en huile essentielle. Les arbres présentent une croissance moyenne en hauteur de 0,7 m/an, en circonférence de 2,5 cm/an, avec une production de biomasse aérienne de 990,5 kg de masse sèche/ha/an. Les rendements en huile essentielle varient entre 0,6 % et 3,6 %, avec une production moyenne de 2,1 %. La position de l'arbre par rapport à la forêt environnante est le principal facteur affectant la croissance des arbres et la production d'huile essentielle : les arbres situés en bordure de la forêt environnante sont significativement plus petits et accumulent moins d'huile essentielle du fait de l'influence de la disponibilité de lumière. La provenance des graines a peu d'influence sur les caractéristiques dendrométriques et le rendement en huile essentielle. En conclusion, la mise en place de plantations pourrait être un système optimal et économiquement avantageux si l'on vise la production d'huile essentielle mais il importe d'éviter les effets de bord liés à la proximité de la forêt.

Mots-clés : *Aniba rosaeodora* Ducke, bois de rose, plantation, huile essentielle, traits dendrométriques, effet provenance, effet lumière, Guyane française.

ABSTRACT

PLANTING ROSEWOOD FOR SUSTAINABLE ESSENTIAL OIL PRODUCTION: INFLUENCE OF SURROUNDING FOREST AND SEED PROVENANCE ON TREE GROWTH AND ESSENTIAL OIL YIELDS

Essential oil from the Amazonian rosewood tree (*Aniba rosaeodora* Ducke) is valued as an important aromatic ingredient in luxury perfumes. Due to over-harvesting in recent decades, rosewood is now listed as an endangered species. Rosewood tree planting is now considered a viable alternative to logging as it can support both reforestation and sustainable agriculture thanks to sales of the essential oil extracted. We planted 605 rosewood trees in French Guiana from two seeds of local provenance, in a 5 445 m² plot surrounded by primary forest. Nine years after planting, we assessed the effect of the position of the tree relative to the surrounding forest and of the seed provenance on dendrometric traits (height, circumference, above ground woody biomass) and hence on the yield of essential oil. Measurements were made on 99 trees. Average growth rates for the young trees were 0.7 m/year in height, 2.5 cm/year in stem circumference and 990.5 kg dry mass/ha/year in above-ground biomass, while essential oil yields ranged from 0.6% to 3.6% with a mean of 2.1%. The position of the tree relative to the surrounding forest was the main factor affecting tree growth and essential oil production: trees located close to the surrounding forest were significantly smaller and accumulated less essential oil due to the reduced availability of light. Seed provenance had less effect on dendrometric traits and essential oil yields. In conclusion, although planting practices will need to be adapted to avoid the edge effects of proximity to the forest, short-rotation cultivation of rosewood trees could be the optimum and most economically attractive system for the production of essential oil.

Keywords: *Aniba rosaeodora* Ducke, rosewood, plantation, essential oil yield, dendrometric traits, seed provenance, light effect, French Guiana.

RESUMEN

SIEMBRA DE PALO DE ROSA PARA EL DESARROLLO DE LA PRODUCCIÓN DE ACEITE ESENCIAL: INFLUENCIA DEL MEDIO FORESTAL CIRCUNDANTE Y DE LA PROCEDENCIA DE LAS SEMILLAS EN EL CRECIMIENTO DEL ÁRBOL Y LA PRODUCCIÓN DE ACEITE ESENCIAL

El aceite esencial de palo de rosa (*Aniba Rosaeodora* Ducke) es buscado por sus propiedades aromáticas que lo convierten en un importante ingrediente de la perfumería de lujo. Debido a la sobreexplotación de las últimas décadas, el palo de rosa está considerado actualmente como una especie en peligro de extinción. La producción de aceite esencial a partir de plantaciones supone una interesante alternativa. Se sembraron 605 árboles de palo de rosa a partir de semillas de dos procedencias de la Guayana Francesa en una parcela de 5 445 m². La plantación tiene la particularidad de estar rodeada de bosque primario. Nueve años después de la siembra, se evaluó el efecto de la posición del árbol respecto del bosque circundante y de la procedencia de las semillas en las características dendrométricas (altura, circunferencia y biomasa leñosa aérea) y el rendimiento de aceite esencial. Los árboles muestran un crecimiento promedio de altura de 0,7 m/año, 2,5 cm/año de circunferencia y una producción de biomasa aérea de 990,5 kg de masa seca/ha/año. Los rendimientos de aceite esencial varían entre 0,6% y 3,6%, siendo la producción promedio de 2,1%. La posición del árbol respecto del bosque circundante es el principal factor que afecta al crecimiento de los árboles y a la producción de aceite esencial: los árboles ubicados en el lindero del bosque vecino son significativamente más pequeños y acumulan menos aceite debido al efecto de disponibilidad de luz. La procedencia de las semillas tuvo poca influencia en las características dendrométricas y el rendimiento de aceite esencial. En conclusión, el establecimiento de plantaciones podría suponer un sistema óptimo y económicamente interesante para la producción de aceite esencial, pero es importante evitar los efectos de borde derivados de la cercanía del bosque.

Palabras clave: *Aniba rosaeodora* Ducke, palo de rosa, plantación, aceite esencial, características dendrométricas, efecto de procedencia, efecto de luz, Guayana Francesa.

Introduction

The tropical forest tree *Aniba rosaeodora* Ducke - Lauraceae, common name rosewood, originated in Amazonia and is highly sought after in French Guiana for its essential oil, a major ingredient of high quality perfumes and cosmetic products (Chantraine *et al.*, 2009). Beyond its cosmetic uses, rosewood essential oil is also known for its antibacterial, antifungal, cytotoxic, antioxidant and antimutagenic properties (Giordani and Kaloustian, 2006; Nóbrega de Almeida *et al.*, 2009; Sœur *et al.*, 2011). Rosewood essential oil was extracted from the wood at a large scale from 1875 to 1975 in French Guiana, and trees were felled in such proportions that natural populations were significantly depleted (Bruleaux, 1989). Export of rosewood oil has undergone a long decline and since 2001, French Guiana legislation bans the cutting of this species in the natural area (French Ministerial Order 2001/04/09). Today, Brazil is the only producer of rosewood essential oil worldwide. Therefore, at Brazil's request, rosewood is now included as an endangered species in the CITES database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, list II: CoP15; CITES, 2010). The risk of extinction of rosewood in its natural areas and its high economic interest underline the importance of planting rosewood trees in a way that favors optimal tree growth and the production of essential oil of constant quality. This is the context in which farmers in French Guiana plan to revive sustainable rosewood essential oil production by planting trees rather than by felling trees in natural areas. The plan is mainly based on results published by Chantraine *et al.*, (2009), who demonstrated the exceptional quality of rosewood essential oil from French Guiana. Since 1940, different plantation systems have been tested by re-planting natural seedlings. The influence of planting density, soil quality, and light availability on tree growth has also been evaluated. Tree growth was shown to be optimal in the following soil conditions: high clay content, high macro and micronutrient content, low soil density and high total soil porosity (Leite *et al.*, 2001). However good results were also obtained in soil conditions found in fallow and late secondary forest (Krainovic, 2011). Among the main environmental factors, light availability was shown to have the most influence in the survival, growth, and reproduction of rosewood (Barata, 2001; De Carvalho Gonçalves *et al.*, 2005; Takeda, 2008; Useche *et al.*, 2011). Rosewood is considered to be shade tolerant, but does require light for growth in height and diameter (Viera, 1970). On the other hand, Rosa *et al.* (1998) showed that juvenile trees do not tolerate full sunlight: as they reported that initial growth was poor, and many yellowing rachitic plants were observed, whereas planted under shade in a secondary forest produced a yield after four years. The same authors conducted an experiment in the region of Manicoré (Brazilian Amazonia) and found that a rate of 30% intercepted light increased the leaf area, chlorophyll concentration, and stomatal conductance, but reduced the height of the trees. In contrast, Alencar and Fernandes (1978) observed that trees planted in the open flourished and reached heights of 6-7 m with substantial foliage after six years, whereas shaded seedlings languished. In the same conditions, this species had an 80%

survival index, with an average increase in height of 0.83 m/year, and diameter of 0.79 cm/year. Rosewood also grew well in partial shade in the primary forest (30% light) on a yellow clay oxisol. With 10 × 5 m spacing, in the seventh year after planting, the average increase in height was 0.75 m/year (Alencar and Fernandes, 1978).

The yield of essential oil ranged between 0.7% and 1.2% (g of oil per g of dried wood as a percentage; Santana *et al.*, 1997; Terezo *et al.*, 1972). Some authors have reported higher essential oil content (0.9% to 2.6%), in young trees (diameter < 10 cm) than in mature trees (Santana *et al.*, 1997). Reports of higher yields of essential oil from young trees suggest that short rotation or commercial thinning could provide sustainable sources of essential oil. In the context of French Guiana, forest land (0.5 - 2 ha) is traditionally cleared to produce a food crop for three years (Tsayem Demaze, 2008), produce rosewood in these conditions could be an alternative. Surrounding forest could provide shade during the first stage of tree growth according to the position of the tree in the plot. The aim of this study was to assess the influence of surrounding forest and the seed provenance on tree growth (dendrometric traits) and on the yield of essential oil to discuss the potential of production of young rosewood in these conditions.

Material and method

Study site and experimental design

French Guiana is situated in the Amazonian region between latitudes 2° and 6° N, and longitudes 51° and 53° W and ; primary tropical rainforest, rich in biodiversity covers 96 % of its area (Steege *et al.*, 2000). Our experimental rosewood tree plantation plot is located in Macouria region at an altitude of 20 m asl. The climate is equatorial with a 4-month dry season (August to November) and an 8-month wet season (December to July). Mean annual precipitation is 3,200 mm and mean annual temperature is 26.8°C (Montsinéry weather station). The geological substrate is Galibi granite.

The experimental plot was designed to resemble a farmers's plot, i.e. a small area (here 5,445 m²) surrounded by primary forest, which provided the necessary shade at the beginning of plant growth. In 2002, we planted 605 rosewood trees in 35 rows with 3 m × 3 m spacing, with 17 trees per row (density: 1,100 trees/ha). There were three meters between the external rows and the surrounding forest (trees height > 25-30 meters). The seeds originated from two different parts of East of French Guiana, half came from Cacao (4°34'60"N; 52°28'0"W) and half from Roura (4°43'59"N; 52°19'59"W). Nine years later, in 2011, 558 trees were still alive (8% mortality rate), and thinning was implemented by removing one out of three rows of the trees. Among the cut trees, we selected 108 trees (diameter classes representative of the population) grown from seeds to measure dendrometric traits and essential oil yield. Due to the non-repeatability of essential oil yield results we eliminated 9 trees of the sampling, total trees were 99: 25 trees originating from Cacao plus 30 from Roura were situated in the middle of the plot, and 24 trees originating from Cacao plus 20 from Roura were situated close to the surrounding forest (figure 1).

Tree dendrometric traits

We first measured the dendrometric traits of the all 99 trees: total height of the stem (H, m), stem circumference (C, cm) and stem diameter (D, cm) at breast height (i.e. 1.3 m above the ground). For each tree, we calculated the slenderness ratio (H/D) which indicates tree vigor and response to competition from overtopping and encroaching vegetation (Cole and Newton 1987). The above ground biomass (AGB, kg) of each tree was calculated using the formula $AGB = 0.0509 \rho D^2 H$ (Chave *et al.*, 2005), where ρ is the mean basic density calculated using the ratio of oven dried mass to green mass (g/cm). The mean basic density was measured using wood disks cut from all the trees (the sampling method is described in the following subsection). For our experiment, ρ was equal to 0.47 g/cm.

Extraction of essential oil

After felling, we removed a 5 cm thick disk from each stem at diameter breast height as a subsample. All the bark was stripped from the discs. The subsamples were conserved at -18°C until hydrodistillation. We sampled woodchips from the first five centimeters (without the bark) of each wooden disc, which corresponded to the newly formed wood. The woodchips were ground (Retsch en retz ZM200

grinder with a 1 mm sieve). The essential oil was extracted by hydrodistillation in a Clevenger-type apparatus for three hours in 500 mL of water according to the method of Guenther (1972). Water was removed from the essential oil using anhydrous sodium sulfate and the oil was then weighed. The essential oil was extracted from each wood sample in duplicate. The average yield of essential oil extracted from each tree was used for further statistical analysis. The volume of essential oil harvested from each tree was calculated using AGB, assuming that most of the biomass came from the stem (Takeda, 2008).

Statistics and data processing

Descriptive statistics and Analysis of variance (ANOVA) with XLSTAT software (2013, Paris, France) was used to investigate the effect of provenance and of the position of the tree in the plot according to the surrounding forest on dendrometric traits and essential oil yield. Normal distribution of the sampling was controlled by normality test (Shapiro test). Residual variance of each model was controlled by a visual diagnosis of the square root of absolute residual against predict values and the predictors. Correlation coefficients were calculated to determine the relationship between dendrometric traits and essential oil yield. Values were considered to be statistically significant at $p < 0.05$.

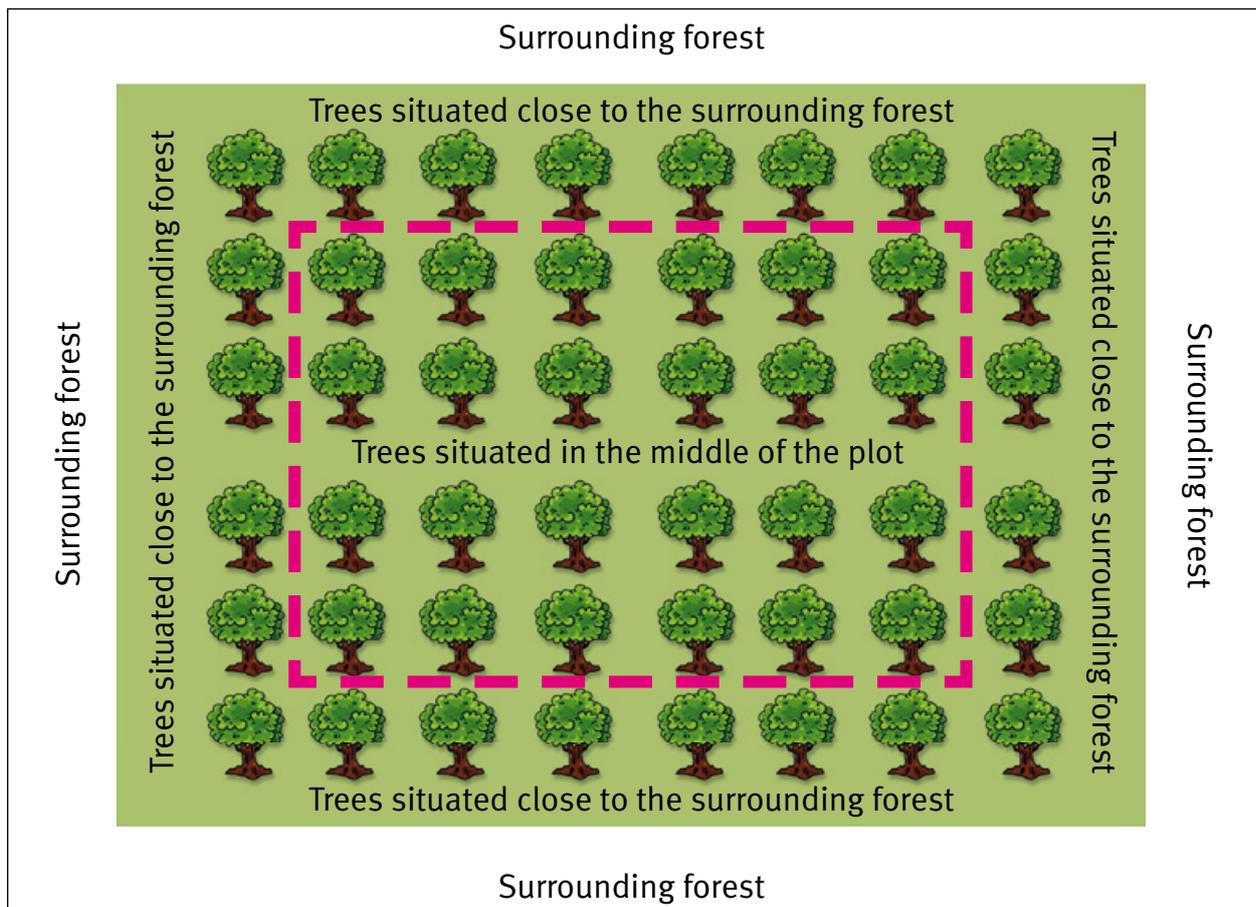


Figure 1.

Scheme of the position of the trees situated close to the surrounding forest, and trees situated in the middle of the plot

Results and discussion

Dendrometric traits

The dendrometric traits are presented in table I and figure 2. The mean growth of the 9-year old rosewood trees was 0.7 m/year in height and 2.5 cm/year in circumference, which correspond to an AGB of 990.5 kg/ha/year based on oven-dried wood (for all the trees of the plot). AGB was determined using the model of Chave (2005) with mean basic density. However, due to a possible radial and longitudinal variability of basic density in the stem, further studies will be carry out to test the influence of these parameters. The growth of our sampled trees is similar to that of trees in the same age class planted under partial shade (30% light) in Brazil: height 0.75 m/year (Alencar and Fernandes, 1978). Barata (2001) reported an increase in height of 0.63 m/year and 0.50 m/year for trees in the age class planted in an open field on the Belem campus and at the Benfica site in Brazil. We also observed variability of the dendrometric traits. Stem height ranged from 2.4 m to 9.0 m, stem circumference from 9 cm to 35 cm, and the slenderness ratio from 45 to 140 (figure 1). Except tree effect, the position of the tree in the plot was the main factor that explained the growth of the rosewood trees: 45% of variance in circumference, 23% of total height, and 34% of tree slenderness (table I). The rosewood trees growing close to the surrounding forest, were smaller and more slender ($p < 0.001$), than trees growing in the middle of the plot. This difference is commonly observed in dominated trees with less access to sunlight due to the surrounding forest. One tree may grow faster than another if it has access to a larger supply of resources (light, water, nutrients)

in the environment, or if has access to the same supply but manages to acquire a greater share than the other tree. Low intraspecific competition also increased the solar radiation intercepted by the crowns of the trees growing in the middle of the plot. Hansen *et al.* (1993) observed the same surrounding forest effect in a plantation of Douglas fir surrounded by an old forest in which trees growing less than 20 m from edge of the plot were significantly smaller and more slender than trees growing well inside the plot. Seed provenance, with a low explained variance (table II), had less impact on tree growth. Seed provenance could improve tree growth when growth conditions are not optimal. Seed from both provenances (Roura and Cacao) produced similar results in good growth conditions (trees situated in the middle of the plot) but seeds from Roura grew better ($p < 0.001$) in less favorable conditions (trees situated close to the surrounding forest). This is in line with results of other authors who emphasized the possibility of improving the growth rate by further study of genetic provenance (Barata, 2001; May and Barata, 2004).

Essential oil yield

Rosewood essential oil yield ranged from 0.6% to 3.6%, mean $2.1\% \pm 0.6$ (table I; figure 2). The great majority of the sampled trees (82.6%) had a high yield of essential oil, i.e. more than 1.2%, which several authors (Chantraine *et al.*, 2009; Santana *et al.*, 1997) consider to be high value for adult trees. To our knowledge, this is the first time the yield of rosewood essential oil has been evaluated in such a large sample of young planted trees. Our yields are higher than those of Ohashi *et al.* (1997) and Santana *et al.* (1997) who reported yield of essential oil ranging from 0.7% to 2.6% in young trees (diameter < 10 cm, circumference 31 cm) in Brazil.

Table I.

Mean (and standart deviation) of dendrometric traits: height = H (m), circumference (cm), slenderness ratio (H:D), Above ground volume (AGB, kg dry wood), yield of essential oil (% dry matter), according to the position of the tree (close to the surrounding forest vs middle of the plot); Total AGB (kg) and essential oil (kg) for all the plot (n total = 99 trees) - 9 years trees rosewood from French Guiana.

Origin of the seed	Trees situated in the middle of the plot			Trees situated close to the surrounding forest			All the plot
	Cacao	Roura	Σ^3	Cacao	Roura	Σ^3	
Height (m)	6.3 (1.1)	6.2 (1.3)	6.3 (1.2)	5.5 (0.8)	5.9 (1.1)	5.7 (0.9)	6.0 (1.1)
Slenderness ratio	82.3 (16.6)	80.6 (17.8)	81.3 (17.0)	104.6 (16.5)	84.9 (14.0)	95.7 (18.2)	87.7 (18.8)
Circumference (cm)	25.3 (6.7)	25.3 (6.8)	25.3 (6.7)	17.0 (4.1)	22.1 (4.7)	19.3 (5.0)	22.7 (6.6)
AGB (kg)	10.8	11.1	10.9	4.3	7.6	5.8	8.7
Yield EO ² (%)	2.2 (0.6)	2.3 (0.7)	2.2 (0.6)	1.7 (0.5)	2.2 (0.4)	1.9 (0.5)	2.1 (0.6)
AGB ¹ (kg) of all the trees of the plot			604.9			256.2	861.2
EO ¹ (kg) of all the trees of the plot			13.9			5.3	19.3

¹ Accumulated AGB¹ and Accumulated EO¹ (total AGB and essential oil yield obtained for all the trees of the plot n = 558 trees);

² EO: essential oil; ³ Σ = Sum of Cacao and Roura.

These results suggest that short-rotation cultivation of trunk wood could be the optimal and economically attractive system for the production of essential oil from the stem. Because the value of the essential oil is dependent of the chemical composition, further studies are necessary to evaluate the quality of essential oil of French Guiana rosewood.

Because of the wide range of tree circumferences in our sample (9 cm to 35 cm), we analyzed the relation between tree diameter and essential oil yield. We observed that, when the effect of the tree position was not taken into account, tree circumference was positively correlated with essential oil yield ($p < 0.001$; $R^2 = 0.31$), i.e. the bigger the tree circumference,

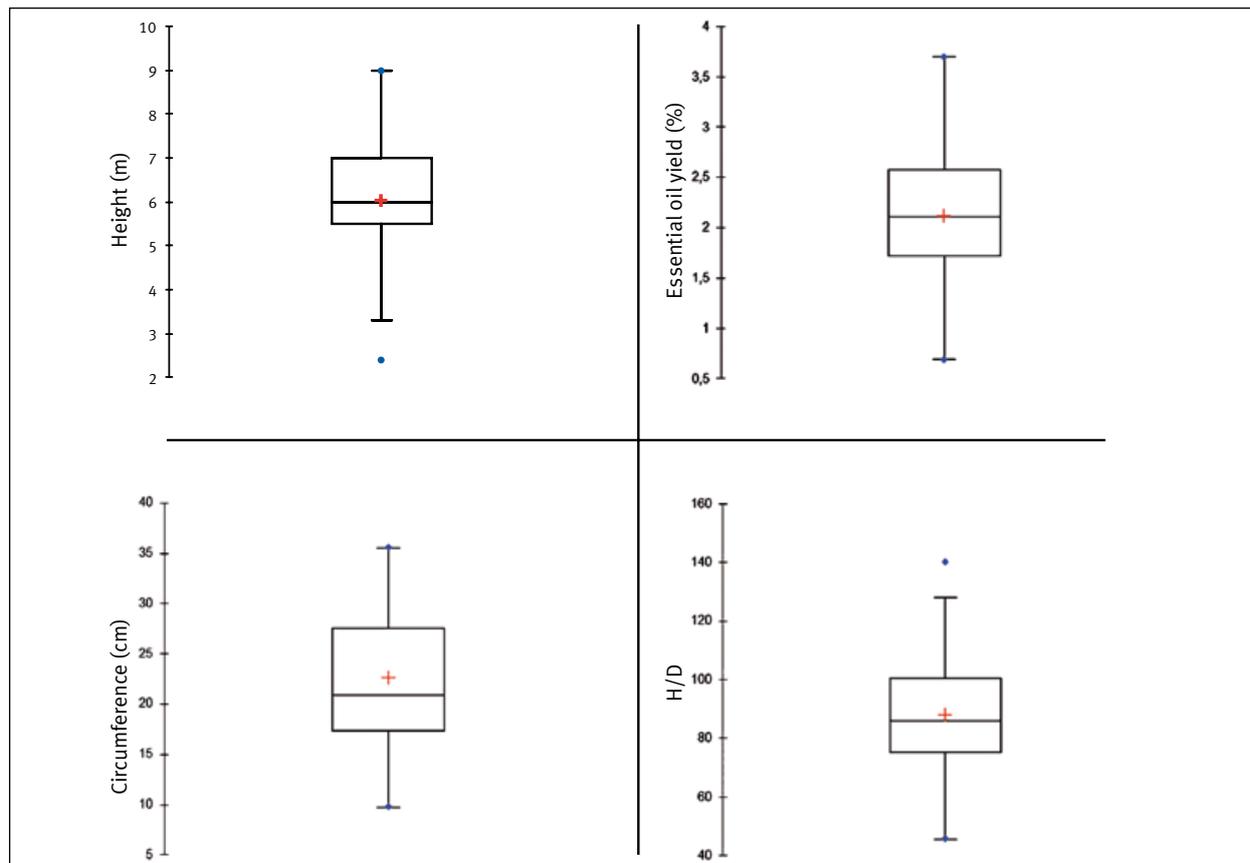


Figure 2. Box-whisker of dendrometric traits = H (m), circumference (cm), slenderness ratio (H/D), yield of essential oil (% dry matter) - 9 year trees rosewood from French Guiana (n = 99).

Table II.

Summary of ANOVA table, seed effect and tree position according to the surrounding forest on dendrometric traits: height, circumference, slenderness ratio (H/D); and yield of essential oil - 9 years trees rosewood from French Guiana (n = 99 trees).

Main effects	df	Height			Circumference			H/D			Essential oil yield (%)		
		F	Pr>F	EV	F	Pr>F	EV	F	Pr>F	EV	F	Pr>F	EV
Provenance effect	1	0,303	0,583	0	3,728	0,057	1	8,744	0,004	10	3,321	0,072	6
Position of the tree according to the surrounding forest	1	6,495	0,012	23	22,686	<0,0001	45	16,259	0,000	34	5,131	0,026	16
Provenance x position of the tree according to surrounding effect	1	0,885	0,349	23	4,504	0,036	46	7,345	0,008	44	3,224	0,076	22

EV: explained variance (%).

the higher the essential oil yield (table III). But when the effect of tree position, which influenced tree growth, was taken into account, there was no longer any correlation between stem circumference and the essential oil yield of trees growing in the middle of the plot, but a weak correlation was still found in trees growing close to the surrounding forest ($p < 0.1$). This result confirms that it was the environment (i.e. the position of the tree according to the surrounding forest) that influenced the yield of essential oil rather than tree growth dynamics. Variance analysis showed that tree position explained 16% of variance ($p < 0.001$) in essential oil yield. Trees growing in the middle of the plot had higher essential oil contents than trees growing close to the surrounding forest. These phenotypic variations were due to environmental effects, particularly light availability. The higher yield of essential oil produced by trees growing in the middle of the plot is a response to stress induced by a high level of sunlight. Sangwan *et al.* (2001) rightly emphasized that essential oil helps plants to adapt to environmental stresses (drought, intense radiation, and high temperature) and is also involved in defense mechanisms against pests. This hypothesis was corroborated by Manhaes *et al.* (2012), in *Aniba canelilla* (Lauraceae) a tree growing in the Amazon rainforest. These authors showed that essential oil yield of resprouts was inversely correlated with canopy openness, i.e., light increased the yield of essential oil. The same goes for herbaceous plants that are rich in essential oils: under warm sunny conditions, plants like geraniums (*Pelargonium capitatum* x *P. radens*; Weis, 1997) and Japanese mint (*Mentha arvensis* L.) produced higher essential oil yield or more biomass (Duriyaprapan *et al.*, 1986).

In the present study, we showed that tree effect significantly affected the yield of essential oil (table III). Maia *et al.* (2004, 2007) suggested, there are at least four types of rosewood trees in Brazil with different morphological characteristics, whose yield of essential oil ranged from 1.8%

to 3.4%. Further research is thus needed to correlate oil characteristics with source material, to ensure plantation are planted with the best genetic material.

Production of biomass and essential oil

After nine years, the mean AGB was 8.6 kg/stem, and the total AGB of the 99 sampled trees was 861.2 kg (table I), which corresponds to a mean essential oil mass of 194.7 g/stem, and to a mass of 19.3 kg for all the harvested trees. The mean biomass and essential oil yield per tree are thus promising. Mean biomass production for the entire plot was 990.4 kg (dry wood)/ha/year and mean essential oil production was 22.2 kg/ha/year. Our results support the opinion of commercial distillers in Brazil that young rosewood stems provide higher oil yields than larger mature trees (Santana *et al.*, 1997), and we consider exploitation is feasible at 10 years of age, whereas Barata (2001), estimated that trees in an open-field plantation would require around 20 years of growth before being ready for felling and the distillation of rosewood oil. The position of the tree in the plot had a significant effect ($p < 0.001$) on biomass production and hence on the yield of essential oil and on the profitability of a plantation based on this management system. Overall stem biomass was: 1,249.5 kg (dry wood)/ha/year from trees situated in the middle of the plot compared to 680.5 kg (dry wood)/ha/year from trees situated close to the surrounding forest. Overall yield of essential oil was: 28.8 kg/ha/year for trees situated in the middle of the plot compared to 14.3 kg/ha/year from trees situated close to the surrounding forest. In other words, twice as much biomass and essential oil (604.9 kg dry wood and 13.9 kg of essential oil) was collected from 99 trees collected in the middle of the plot compared to trees collected at the edge of the plot (256.2 kg dry wood and 5.3 kg of essential oil).

Table III.

Pearson correlations between dendrometric traits and yield of essential oil of - 9 years trees rosewood from French Guiana according the position of the trees related to the surrounding forest (middle of the plot, close to the surrounding forest) and in all the plot.

Variables	Tree position	Yield of essential oil (%)
Total height (m)	All 99 trees	0.32***
Circumference (cm)		0.31***
Slenderness ratio		-0.08 ns
Total height (m)	55 trees in the middle of the plot	0.28*
Circumference (cm)		0.17 ns
Slenderness ratio		-0.001 ns
Total height (m)	44 trees close to the surrounding forest	0.28 ns
Circumference (cm)		0.39**
Slenderness ratio		-0.24 ns

ns: not significant; *: significant at $p < 0.1$; **: significant at $p < 0.05$; ***: highly significant at $p < 0.001$.

Potential for changing fallow to agroforestry by planting rosewood trees

In the specific context of French Guiana, where there is a need to develop sustainable farming systems, our results showed that traditional forest fallow plots can be profitably converted into rosewood (*Aniba rosaeodora*) planting areas. But, as plots are usually small (0.5 to 2 ha), management practices need to be adapted to minimize the negative effect of the surrounding forested area on the production of biomass and of essential oil by trees planted close to the surrounding forest. In our case study, 0.5 ha plot meant the same number of trees grew in the middle of the plot as close to the surrounding forest resulting in high variability of essential oil and biomass production. To optimize the production of biomass and essential oil it would be useful to i) use bigger areas to plant rosewood trees, and ii) to create a sufficiently wide buffer zone between the rosewood plantation and the surrounding forest to avoid the surrounding effect forest. These results provide the first data to help decision makers and farmers in French Guiana who plan to revive sustainable rosewood oil production based on plantations rather than on felling trees in natural areas. Since the rosewood tree is an endangered species, our results show that plantations could be a sustainable way to protect the species while at the same time producing its sought-after essential oil. However more research is needed to link the characteristics of the essential oil with the source of the material to ensure that plantations are planted with the best genetic material possible.

Conclusion

The overall aim of this study was to explore the commercial potential of young rosewood trees in a plantation located in a primary forest by assessing the effect of the surrounding forest and of the provenance of the seed on dendrometric traits of trees and hence on the yield of essential oil. After nine years of growth, the mean growth of trees was 6.0 m in total height and 22.7 cm in circumference with a high yield of essential oil (2.1%). Trees growing close to the surrounding forest were smaller with lower essential oil yield than trees growing in the middle of the plot due to the availability of light. Seed provenance had less effect on dendrometric traits and on essential oil yield. The results of our study show that, thanks to their high potential for biomass production and high yield of essential oil, young rosewood trees felled during thinning operations could be exploited commercially or dedicated plots could be used for short rotations. A better understanding of the surrounding forest effect on tree growth and essential oil yield is likely to help forest managers to design plantations that best achieve goals for productivity. This management system would not only protect an endangered species but also provide a sustainable source of rosewood trees for the production of essential oil.

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