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Sanitary Quality Improvement of Cashew Nuts through Orchard Rehabilitation in Daloa, Côte d'Ivoire: A Case Study of Anacardium *occidentale L*

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Abstract

The cashew sector has become a vital driver of economic and social growth in northern, central, and eastern Côte d'Ivoire. One key factor affecting marketability is the sanitary quality of raw cashew nuts, usually measured by the Kernel Output Ratio (KOR). This study aims to improve nut quality in the Haut-Sassandra region by examining how orchard rehabilitation impacts sanitary standards. Conducted in six representative orchards in the Daloa Department, the research evaluated the technical process of rehabilitation practices. It also involved a systematic survey of cashew tree diseases and insect-related damages, along with a detailed analysis of nut sanitary quality. The results provide insights into how orchard renewal strategies can enhance post-harvest hygiene, pest management, and nut grading. The principal diseases observed in cashew trees (Anacardium occidentale L.) included anthracnose, bacterial blight, gummosis, and rust. Orchards with the lowest tree density (100 trees/ha) exhibited the lowest disease incidence and severity indices, suggesting a correlation between planting density and phytosanitary resilience. Major insect pest damage was attributed to infestations by *Apate terebrans, Diastocera trifasciata*, and *Helopeltis spp*., with significantly higher attack rates recorded in non-rehabilitated orchards compared to rehabilitated ones. Assessment of cashew nut quality parameters revealed that rehabilitated orchards produced superior results, with an average of 177 nuts/kg and a usable kernel yield of 286.76%. In contrast, non-rehabilitated orchards yielded 171 nuts/kg and a kernel rate of 253.34%. According to Kernel Output Ratio (KOR) standards, nut samples from rehabilitated orchards were classified as very high quality, underscoring the positive impact of orchard rehabilitation on both plant health and post-harvest product value.

Keywords: Rehabilitation; Cashew Orchard; Cashew Nuts; Quality

1. Introduction

African agriculture provides livelihoods for over 60% of the working population and satisfies approximately 80% of the continent's food requirements (Fok *et al*., 2013). It predominantly comprises cash crops such as peanuts, cotton, sugarcane, coffee, cocoa, and cashew nuts and staple food crops including rice, maize, millet, sorghum, cassava, cowpeas, fruits, and vegetables. Among these, the cashew tree (Anacardium occidentale L.) has emerged as one of the fastest-growing cash crops, offering significant export potential for African economies. Initially introduced in the 1960s as a strategy to combat soil erosion, cashew cultivation has since evolved into a perennial, income-generating crop for a growing number of producers (Djaha *et al*., 2012; Yao *et al*., 2013). Its expansion reflects ecological utility and economic relevance, particularly in regions seeking sustainable agricultural diversification and rural development.

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Since 2015, Côte d'Ivoire has become the world's leading producer and exporter of raw cashew nuts, with an output exceeding 944,673 tonnes (CCA, 2024). Cashew cultivation represents a dynamic source of economic growth, particularly through its capacity to stimulate rural development and generate employment in agricultural communities. Despite the substantial volume of national production, the average yield of Ivorian cashew orchards—ranging from 350 to 500 kg/ha remains significantly lower than that of major producing countries such as India and Brazil, where yields typically reach 1,000 to 1,500 kg/ha (Djaha *et al*., 2010; FIRCA, 2016). This yield gap is largely attributed to parasitic pressures affecting cashew trees, including fungal and insect-related constraints that compromise both the quantity and quality of harvested nuts (NARI, 2009; Viana *et al*., 2007).

In addition to insect pests, over a dozen diseases have been documented on cashew trees (*Anacardium occidentale* L.). Among the most significant are anthracnose caused by *Colletotrichum gloeosporioides*, powdery mildew caused by *Oïdium anacardii*, leaf rust (*Cephaleuros virescens*), and leaf wilt attributed to *Laetiporus* sp. These pathologies have been identified since the establishment of the national cashew health map in Côte d'Ivoire (Koné *et al*., 2015 ; Soro *et al*., 2020). Powdery mildew alone can lead to yield losses ranging from 70% to 100% (Sijaona, 2001), while anthracnose was responsible for a 40% reduction in Brazil's cashew production in 2000 (Topper, 2002).

The proliferation of these diseases and pests is exacerbated by the diversity of technical itineraries and inadequate orchard maintenance, which collectively undermine tree productivity. In response to the limited oversight of the cashew sector and the growing phytosanitary threats to national output, innovative production techniques have been introduced most notably through orchard rehabilitation. These

2. Materials and methods

2.1. Study area

The study was conducted in the central-western region of Haut-Sassandra, specifically in the localities of Nanoufla, Madoguhé, and Zokogué. The climate in this area is classified as tropical humid, characterized by a distinct dry season from October to March and a rainy season from April to September. These seasonal cycles alternate with average temperatures ranging between 24.65 °C and 27.75 °C (Ligban *et al*., 2009). Vegetation varies across the region, with dense forest cover dominating the southern zones and wooded savannah prevailing in the northern areas. The soils are predominantly ferralitic, exhibiting strong to moderate desaturation levels, which influence both crop performance and orchard management strategies (Ligban *et al*., 2009) (Figure 1).

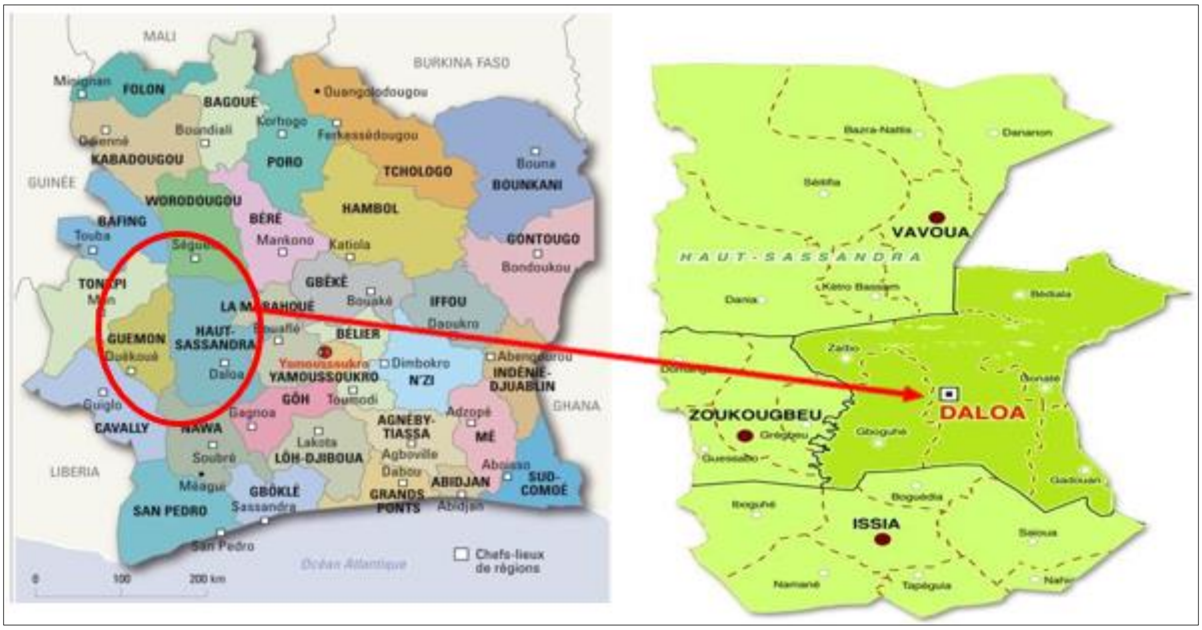


Figure 1 Presentation of the study area in the Department of Daloa, Source: RGPH, 2015

2.2. Material

The biological material used in this study consisted of cashew tree (*Anacardium occidentale* L.) specimens sourced from selected orchards. The technical material employed included standard laboratory glassware and specialized devices such as a drying oven, autoclave, and fume hood, which were used for sample preparation, sterilization, and controlled handling of plant material during phytosanitary assessments.

3. Methods

3.1. Experimental setup

The experimental design consisted of six cashew orchards (*Anacardium occidentale* L.), with two orchards selected per locality. In each location, the orchards were subdivided into two plots: one hectare of rehabilitated land and one hectare of non-rehabilitated land, resulting in a total area of 2 hectares per orchard.

Rehabilitation was carried out through density reduction, achieved by identifying and removing intermediate, non-productive, or diseased trees. The remaining trees were retained at a spacing of 8 to 10 meters to optimize canopy aeration and phytosanitary conditions. Tree removal was performed using a chainsaw, and stump recutting was executed at three standardized heights 50 cm, 75 cm, and 100 cm above ground level. To prevent fungal infections, the cut surfaces were treated with a fungicide. Additionally, stumps were whitewashed with lime to protect against termite infestation. This rehabilitation protocol was designed to improve orchard health, reduce pest and disease pressure, and enhance the sanitary quality of cashew nuts.

3.2. Horticultural parameters

The horticultural parameters assessed in this study included is the number of cut trees, planting density before and after rehabilitation, and the number of debarked stumps. Each parameter was evaluated through direct manual counting conducted on individual plots. The number of cut trees was recorded by counting all felled cashew trees per hectare following rehabilitation. Plant population was determined by counting the total number of trees per hectare both prior to and after the rehabilitation process. The number of debarked stumps, resulting from tree removal, was also recorded manually on each plot to assess the extent of intervention and stump treatment coverage.

3.3. Sanitary conditions in cashew orchards

3.3.1. Assessing the impact of major diseases

Disease incidence was assessed on ten cashew trees (*Anacardium occidentale* L.) randomly selected along the diagonals of each orchard plot. For each disease observed, the incidence rate was calculated as the proportion of infected trees relative to the total number of trees inspected, following the methodology described by Cooke (2006). The incidence of each disease was determined using the following formula 1:

$$Disease\ Incidence\ (\%)\ =\ (Number\ of\ Diseased\ Trees\ /\ Total\ Number\ of\ Trees\ Inspected)\ \times\ 100$$

3.4. Assessment of Disease Severity Index

The severity index (Is) for major cashew tree diseases namely anthracnose, bacterial blight, flower blight, leaf blight, and nut rot was assessed on ten trees per plantation using the inverted 'U' sampling method. Evaluations focused on the crown of each tree, where a 1 m^2 quadrat was placed on two opposite sides at foliage level. Within each quadrat, the number of infected leaf buds, flower buds, and young cashew nuts was recorded for each disease.

The severity index for each disease was calculated using the following formula, adapted from Kranz (1988):

$$\text{Is} = \frac{\sum (\text{Xi x ni})}{\text{N.Z}} \qquad (2)$$

Where: Is = Disease severity index at the site, Xi = Severity i of the disease on the tree, ni = Number of trees with severity i, N = Total number of trees observed, and Z = Highest severity scale.

The severity of the disease was calculated using a visual rating scale ranging from 0 to 9 (Groth et al., 1999; Cardoso et al., 2004), with:

- 0 = No symptoms;
- 1 = 1-5% of the surface infected;
- 3 = 6-10% of the surface infected;
- 5 = 11–25% of the surface area infected;
- 7 = 26–50% of the surface area infected;
- 9 > 50% of the surface area infected.

The severity index (Is) for gummosis was determined using a scale of 0 to 5, with:

- 0 = no symptoms
- 1 = early stages of infection
- 2 = marked symptoms
- 3 = more than half of the trunk affected
- 4 = trunk and branches showing symptoms
- 5 = dead tree.

3.5. Assessment of the impact of rehabilitation on the sanitary quality of cashew nuts

Cashew nut samples were randomly collected tree by tree across orchard plots and subsequently dried. At the end of the harvest, the total quantities obtained were designated as master samples. From each master sample, a one-kilogram subsample was extracted using the quartering method to ensure representativeness. Nut quality was evaluated according to the procedure described by RONGEAD (2015). The parameters considered included, Grain size (nuts/kg), Kernel rate (%), Kernel yield (%), Defect rate (%), Out-turn or KOR (lbs/80 kg) Grain size refers to the number of nuts per kilogram and is expressed in nuts/kg. It typically ranges from 150 to 240 nuts/kg. This parameter was calculated by dividing the number of nuts (N) counted in the sample by the sample's weight (P_1) in kilograms, as shown in Formula 3:

$$\text{Grainage (Noix/kg)} = \frac{N}{P1} \qquad (3)$$

The percentage of kernels (PK) reflects the quantity of kernels in the sample.

The calculation method was based on formula 4

$$PK = \frac{\text{Poids des amandes sains + pellicules}}{\text{Nombre d'amandes saines}} \qquad (4)$$

The Kernel Output Ratio (KOR) represents the quantity of good kernels, expressed in pounds (lb), that can be obtained from an 80 kg bag of raw cashew nuts after shelling. It is denoted in lb/80 kg bag and serves as a key indicator of the average quality and market value of usable kernels derived from a sample.

To estimate KOR, all nuts in each 1 kg sample were manually cracked and sorted into three quality categories:

- Lot 1: Healthy nuts, 100% accepted
- Lot 2: Pitted nuts, 50% accepted
- Lot 3: Rotten or immature nuts, 100% rejected

For each batch, the shell, testa (skin), and kernel were separated. The KOR was then calculated using the following formula, adapted from Rongead (2015):

$$KOR = \frac{(P2+\frac{P4}{2})/P1\times100}{100\times80\times(\frac{1}{0.45359})} \qquad (5)$$

Where:

- P2 = Weight of healthy kernels (kernels + skins) accepted at 100%;
- P4 = Weight of kernels + skins of walnuts rejected at 50%;
- P1 = total weight of the nut sample.

The kernel yield and the quantity of usable kernels were calculated using the following formulas 6 and 7:

$$\text{Usable Kernel } (UK) = P2 + P4/2 \qquad (6)$$

Kernel Yield

$$Ra = (P2 + P4/2) / P1 \times 100 \qquad (7)$$

The defect rate was evaluated by measuring the quantity of nuts in the sample showing defects such as: immature and pitted nuts (blue category), and stunted, empty, moth-eaten, mouldy, or buttered nuts (red category). The nuts and shells were weighed and expressed as a percentage. All nuts in each 1 kg sample were cracked open.

- Healthy nuts (shells and kernels) were placed in a green plastic bowl.
- Nuts accepted at 50% (shells and kernels) were placed in a blue plastic bowl.
- Rotten or immature nuts (shells and kernels) were placed in a red plastic bowl.
- The defect rate was calculated using Formula 8 (RONGEAD, 2015).

$$\text{TD} = \frac{(\text{P3+P5})\text{x}100}{\text{P1}} \qquad (8)$$

Where:

- P1: Total weight of the sample
- P3: Weight of kernels + shells rejected at 50%;
- P5: Weight of kernels + shells rejected at 100%.

3.6. Statistical Analysis

The data collected were analyzed using Statistica version 7.1 and Microsoft Excel 2013. Excel was employed to generate tables and graphical representations of the various parameters. Statistical analyses were conducted using Statistica software, including:

- Analysis of Variance (ANOVA) to identify significant differences among individuals across parameters.
- When significant differences were detected, the Smallest Significant Difference Test (SSDT) at a 5% significance level was applied to separate the means.
- Principal Component Analysis (PCA) was also performed to explore and visualize interactions between horticultural traits and plant health indicators across orchard samples.

4. Results

4.1. Horticultural parameters

Tree density across orchard types varies according to location (Figure 2). Rehabilitated orchards were thinned to a minimum density of 110 to 122 trees per hectare, representing an approximate 50% reduction in tree count per plot. In contrast, non-rehabilitated orchards maintained higher densities, ranging from 187 to 200 trees per hectare (Figure 2).

By site

- In Nanoufla, rehabilitated orchards reached an average density of 122 trees/ha.
- In Madoguhé, the post-rehabilitation density was 110 trees/ha.
- In Grégbeu, the density was reduced to 115 trees/ha.

These adjustments reflect the implementation of rehabilitation strategies aimed at optimizing tree spacing, improving canopy ventilation, and enhancing overall orchard productivity.

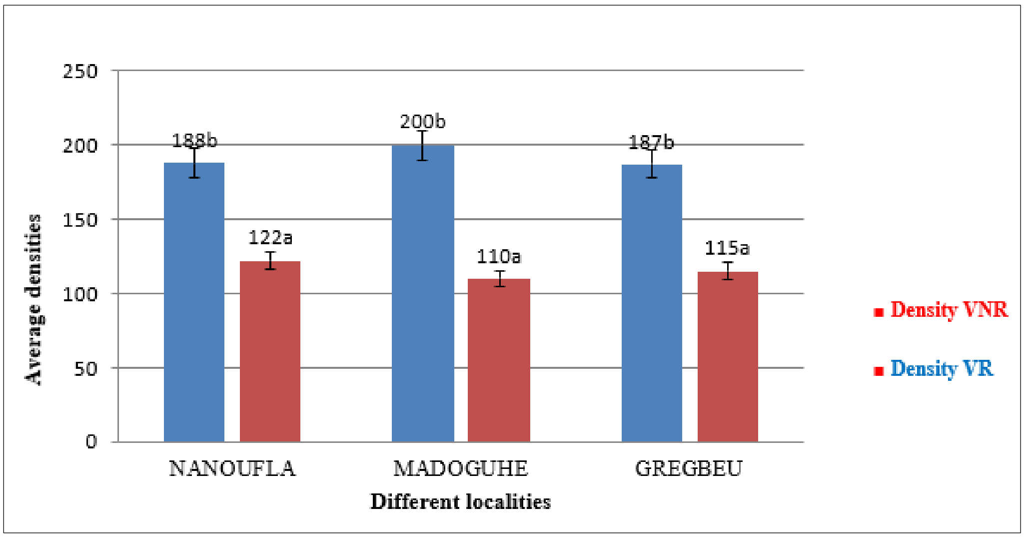


Figure 2 Average density of orchards by location according to orchard type Health parameters of cashew orchards

4.2. Assessment of the incidence and severity of diseases according to orchard type

Table 1 presents the incidence and severity of major diseases by orchard type. Disease prevalence varied by pathology and orchard condition. Non-rehabilitated orchards showed the highest attack rates: anthracnose (48.6%), nut rot (40.8%), bacteriosis (47.2%), gummosis (8.3%), and rust (26.9%). In rehabilitated orchards, rates were lower: anthracnose (28.8%), nut rot (34.4%), bacteriosis (37.2%), gummosis (1.1%), and rust (25.5%). Statistical analysis revealed a significant difference only for anthracnose incidence between orchard types; other diseases showed no significant variation.

Disease severity indices varied by pathology and orchard type. Rehabilitated orchards recorded the lowest severity levels: anthracnose (6.1%), nut rot (7.0%), bacteriosis (6.7%), gummosis (0.2%), and rust (5.2%). In contrast, non-rehabilitated orchards showed higher indices: anthracnose (7.6%), nut rot (7.2%), bacteriosis (7.0%), gummosis (0.4%), and rust (5.6%). Statistical analysis revealed a significant difference in anthracnose severity between orchard types, while differences for nut rot, bacteriosis, gummosis, and rust were not statistically significant.

Table 1 Disease incidence rates and disease severity indices in cashew orchards in Daloa

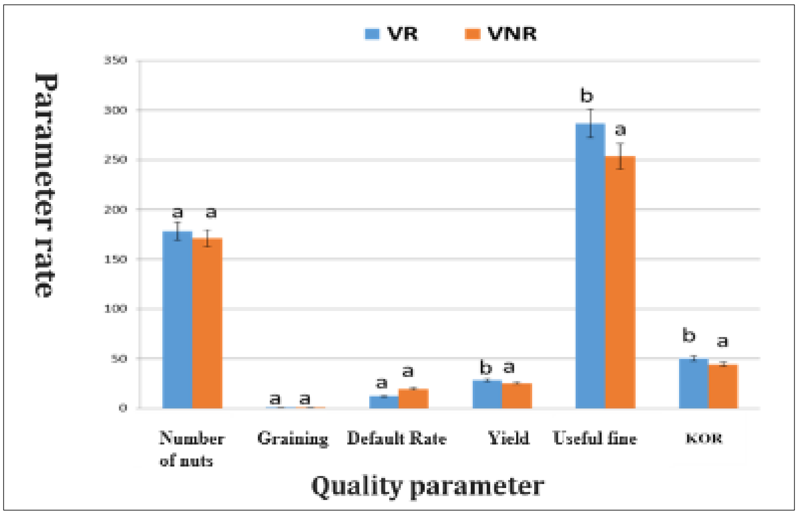
Diseases	Sanitary level	Non-Rehabilitated Orchards	Rehabilitated Orchards	F	P
Anthracnose	Incidence	48,6 ± 20,1a	28,8 ± 8b	7,46262	0,014777
	Sévérité	7,6 ± 1a	6,1 ± 1b	10,31579	0,005441
Nut rot	Incidence	40,8 ± 9,8a	34,4 ± 9,3a	1,99623	0,176849
	Sévérité	7,2 ± 1,5a	7 ± 1,4a	0,10000	0,755918
Bacteriosis	Incidence	47,2 ± 12,8a	37,2 ± 14,8a	2,34252	0,145416
	Sévérité	7 ± 1a	6,7 ± 1,2a	0,18182	0,675497
Gummosis	Incidence	8,3 ± 25	1,1 ± 2,2	0,74531	0,400720
	Sévérité	0,4 ± 1,3a	0,2 ± 0,4a	0,22535	0,641406
Rust	Incidence	26,9 ± 5,8a	25,5 ± 9,3a	0,14327	0,710030
	Sévérité	5,6 ± 1a	5,2 ± 0,6a	1,23077	0,283654

P: Probability at the 5% threshold; values followed by the same letter on the same line are not significantly different at the 5% threshold according to the Newman-Keul test.

4.3. Assessment of the impact of rehabilitation on the sanitary quality of cashew nuts

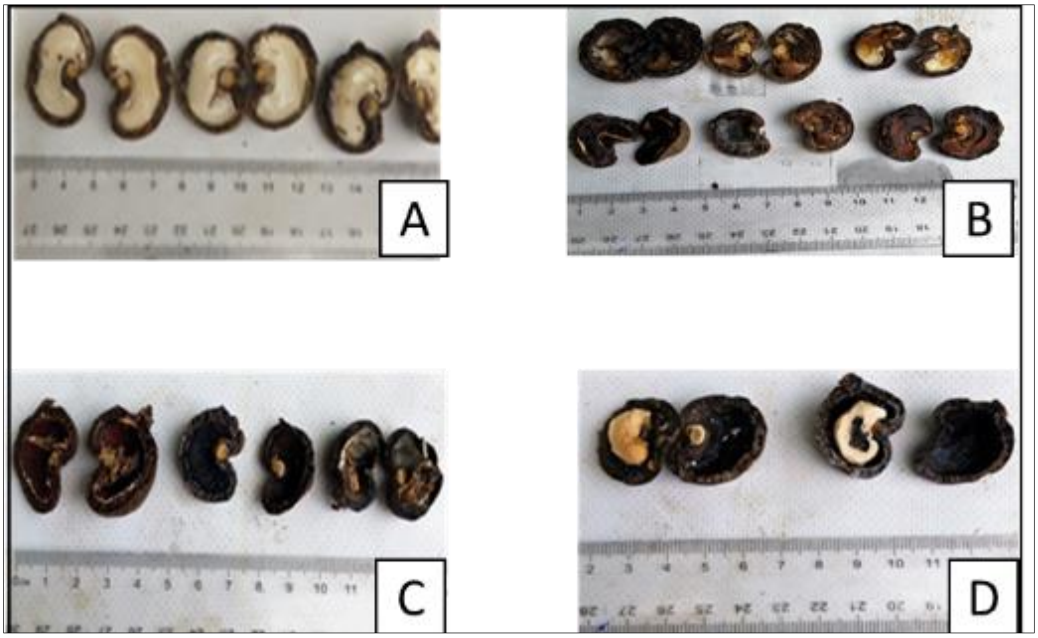
Cashew nut quality parameters varied according to orchard type. Rehabilitated orchards recorded a higher nut count (177 nuts/kg) and a superior useful kernel rate (286%) compared to non-rehabilitated orchards. Conversely, non-rehabilitated orchards showed the highest defect rate (19.36%). The KOR (Kernel Output Ratio) of nuts from rehabilitated orchards was 50.52%, indicating very good quality based on standard KOR evaluation criteria (Figure 3).

Figure 4 illustrates the appearance of healthy and defective nuts (healthy, moldy, empty, shriveled). Statistical analysis revealed no significant differences in nut count, grading, or defect rate across orchard types. However, significant differences were observed in yield, useful kernel rate, and KOR.



Values followed by the same letter above the histograms are not significantly different at the 5% threshold according to the Newman-Keul test.

Figure 3 Quality parameters of cashew nuts according to different types of orchard



A) Healthy nuts; B) Mouldy nuts; C) Empty nuts; D) Shrivelled nuts

Figure 4 Healthy and defective nut characteristics

4.4. Correlation between horticultural parameters and pest levels in cashew orchards

Principal component analysis revealed that the number of cut feet (NPC) and debarked stumps (SE) are not associated with orchard health status. In contrast, a strong positive correlation was observed between orchard density and both the incidence and severity of key diseases, including anthracnose, bacteriosis, and nut rot (Figure 5).

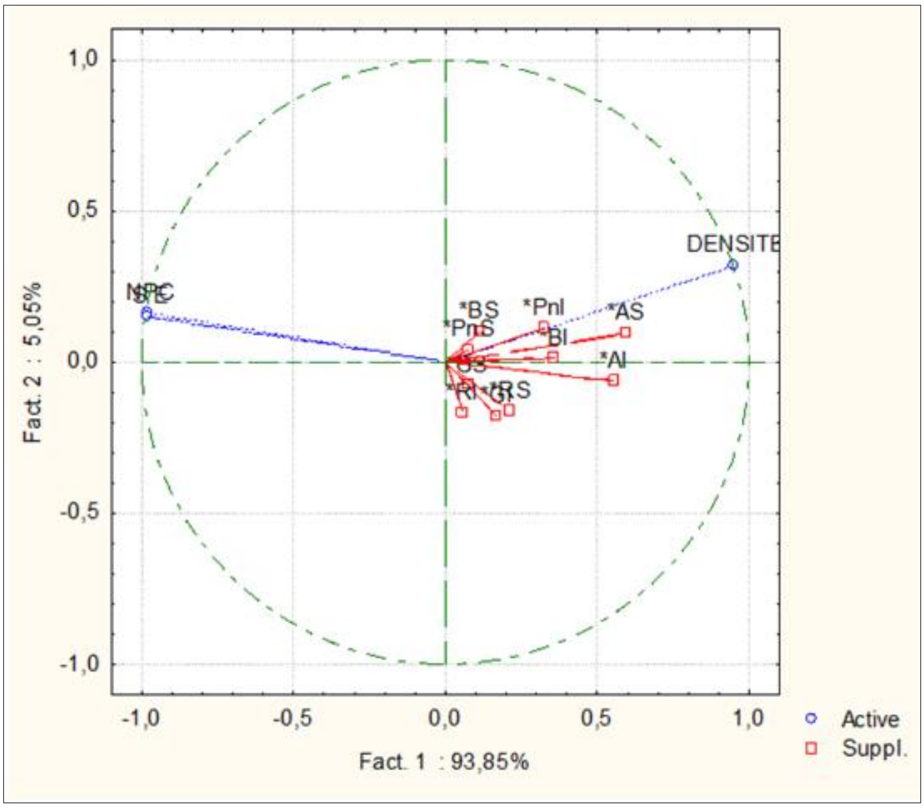


Figure 5 Principal component analysis of major diseases affecting cashew orchards

5. Discussion

Orchard rehabilitation is a process aimed at reducing tree density per hectare, based on the initial planting density. This approach helps prevent post-rehabilitation tree collapse and enhances plot aeration and sunlight exposure, thereby limiting conditions favorable to fungal development. Unrehabilitated orchards, characterized by humid microclimates, were more conducive to fungal proliferation. These findings align with those of Soro *et al*. (2020), who demonstrated that high orchard density promotes pest development. A study on the impact of cashew orchard rehabilitation on sanitary quality in the Haut Sassandra Region revealed that non-rehabilitated orchards exhibited higher average pest infestation rates and greater disease severity indices. In contrast, rehabilitated orchards showed lower infestation levels. The observed symptoms were associated with anthracnose, flower blight, leaf blight, nut rot, bacterial infections, gummosis, and rust.

These results align with those of Soro *et al*. (2020), who demonstrated that parasite pressure increases with planting density. Orchards maintained at a density of 100 trees per hectare consistently showed lower infestation levels. Regular and proper maintenance at this density improves orchard health, likely due to reduced weed pressure since weeds can act as vectors for certain cashew tree diseases.

Furthermore, the study confirmed that cashew nut samples from rehabilitated orchards exhibited superior quality compared to those from non-rehabilitated orchards. The assessed quality parameters included grain size, defect rate, kernel yield, and outturn.

The number of nuts per kilogram in samples collected from different orchards was below the CODINORM standard (200–215 nuts/kg). This discrepancy is likely due to the predominance of 'Tout-venant' cashew varieties cultivated in the region, as well as environmental factors such as rainfall and producers' farming practices. These findings are consistent with those of N'Djolosse *et al*. (2016) and Amanoudo *et al.* (2017), who demonstrated that nut count per kilogram can be improved through adherence to good agricultural practices. Their studies also revealed a significant difference between maintained plots (150 nuts/kg) and unmaintained plots (163 nuts/kg).

These results are consistent with those of Mesmes-Just *et al.* (2017), who demonstrated that old, rehabilitated, and well-maintained plantations produce higher-quality yields than non-rehabilitated ones. Rehabilitation and maintenance reduce intra- and interspecific competition, improve light distribution, and enhance nutrient availability and photosynthetic efficiency. As Strong (1983) noted, competition can negatively affect plant growth, survival, and reproduction.

Defect rate variability appears to be influenced by post-harvest humidity, mould development, and storage or packaging methods. The Kernel Output Ratio (KOR) of rehabilitated and well-maintained orchards was significantly higher than that of non-rehabilitated and poorly maintained plots (Rongead, 2015). Poor KOR values and elevated defect rates in non-rehabilitated orchards are likely due to inadequate maintenance and excess humidity caused by canopy shading.

According to Amanoudo *et al.* (2017), grain size, kernel yield, and out-turn can be improved through the adoption of good agricultural practices. Their study revealed a significant difference in average grain size and out-turn between maintained and unmaintained plots.

6. Conclusion

The results of this study demonstrate that orchard rehabilitation significantly enhances plant health and nut quality. Rehabilitated orchards exhibited the lowest incidence and severity of major diseases, reflected in reduced attack rates and severity indices. Quality assessments revealed that cashew nuts from rehabilitated plots had a higher useful kernel rate and Kernel Output Ratio (KOR), while those from non-rehabilitated orchards showed a notably higher defect rate.

These results suggest that rehabilitation practices can serve as a strategic lever to improve the sanitary quality of cashew nuts in Côte d'Ivoire. By promoting healthier orchards and superior nut quality, such interventions could strengthen the country's competitiveness in the global cashew market.

Compliance with ethical standards

Acknowledgments

This study evaluated the impact of orchard rehabilitation on plantation health and cashew nut quality, positioning itself as an innovative initiative within Côte d'Ivoire's agricultural sector. The project was made possible through the financial and material support of key institutional partners: the Interprofessional Fund for Agricultural Research and Advice (FIRCA), the Project to Promote Competitiveness in the Cashew Value Chain (PPCA), the Cotton and Cashew Council (CCA), and the National Cashew Research Programme (PNRA).

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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