

INNOVATIONS IN CASHEW PRODUCTION



*3rd CICC/ACA Research Proceeding
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SELECTION OF CASHEW MOTHER TREES BASED ON NUT CHARACTERISTICS OF CLONES

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ABSTRACT

The Cashew tree (*Anacardium occidentale*) is a multipurpose crop. The high energy and protein content of the kernel embedded in the nut shell, makes the nut of high economic importance. Nut characteristic are therefore, of great significance and concern to farmers and processors. Single tree cashew selections from farmers' field were assessed for their nut traits in a preliminary trial. Thirteen tree selections (KD102, YS103, OCJ5, EU202, BEL36, YS203, OCJ9, OCJ2, EN103, CR102, ORO9, BEL22, and ORO3) were cloned and established on Cocoa Research Institute of Nigeria experimental plots. These materials were evaluated for their nut and kernel characteristics. Samples of 80 nuts were randomly chosen from each clone and evaluated for the nut weight, length, width, thickness/girth, kernel and shell weight. Means of data collected were subjected to analysis of variance (ANOVA) to ascertain the variability in nut characteristics among the different clones. A dendrogram constructed broadly separated all 13 cashew clones into two main clusters at 3.53 dissimilarity coefficient using Dice's approach. Three clones (OCJ9, ORO9 and YS203) were distinguished and clustered into one group. Clone OCJ9 gave the highest nut weight (11.34 g), width (2.99 cm), and kernel weight (3.75 g). Clone ORO9 had the highest mean value of 2.24 cm and 7.97 g for nut girth and shell weight respectively. The highest nut length (3.99cm) was observed in clone YS203, with EU202 having the least nut weight (4.27g), nut length (2.55cm), nut girth (1.13cm), kernel weight (1.50g), and shell weight (2.73g). Clone KD102 had the least value of 1.91cm for nut width. Highly distinguished clones OCJ9, YS203 and ORO9 could be utilized as mother tree in breeding for improvement in cashew cultivars.

Key word: Cashew, clones, grafts, nut parameters, kernel weight

INTRODUCTION

In tropical and subtropical regions, cashew (*Anacardium occidentale* L.) is a multipurpose tree and cash crop providing source of income, foreign exchange and employment opportunities to producing countries. About 30 to 35 products could be obtained from the different part of the cashew tree; from the leaf, flower, stem, wood, apple and nuts (Kluczkowski, and Martins, 2016). Renowned for its rich nutritional content and numerous health benefits, cashew apple and nut are highly valued, playing key roles in human diet (Olaitan *et al.*, 2023). The product of commence of the cashew tree is the nut. The nut contains the white, creamy-colored edible kernel (Adeigbe *et al.*, 2016). As the demand for cashew nuts rises, there is a growing need to improve nut quality (Gopalakrishnan *et al.*, 2010).

The morphological evaluation of cashew nuts involves a comprehensive analysis of external characteristics, including size, shape, color, texture, and weight (Sanchez *et al.*, 2024). Quantitative traits such as size, weight, and shell thickness play a pivotal role in determining the quality and market value of cashew nuts. Processors prefer larger nuts size for easy processing. In an earlier study, assessment of kernel to shell ratio among different nut sizes showed excess of shell in the jumbo category compared to a smaller (extra-large) nut size group (Adeigbe *et al.*, 2016). Thus, in addition to other important traits, assessment of nut size in relation to it kernel size is an important attribute to consider in the selection of cashew mother tree for improvement.

Multiple factors, such as genetics, edaphic and environment, influence the variation of nut morphology (shell thickness, kernel percentage). Evaluation of nut morphology is the initial step in breeding programs (Kumar *et al.*, 2021). The present study focuses on the assessment of clonal cashew nut for mother trees selection in the development of improved cultivars.

MATERIALS AND METHODS

The study utilized mature cashew nuts sourced from 13 clonal accessions (KD102, YS103, OCJ5, EU202, BEL36, YS203, OCJ9, OCJ2, EN103, CR102, ORO9, BEL22, and ORO3) planted in zones 3 and 4 at the Cocoa Research Institute of Nigeria, Ibadan (7.2254oN, 3.8678oE). The accessions were planted on the field six weeks after grafting at a distance of 10m x 10m spacing. Periodic weeding was carried out using both manual and glyphosates herbicides. Selected nuts obtained from each of the accessions were air dried to a moisture content of 8%. Subsequently, 80 nuts in four replicates were randomly chosen from each category of clonal accession for the nut and kernel size assessment using completely randomized design according to the methods of Adewale *et al.*, 2010. Nut measurements were conducted at the Crop Improvement Laboratory of CRIN, Ibadan. Samples were evaluated for the nut weight, length, width, thickness/girth, kernel and shell weight. Nut weight was measured using a sensitive weighing balance (WT-H Zhongxin, China). The nut length, width, and thickness/girth were measured in millimeters using a Vernier caliper (TONE DC-150). The kernel and shell was separated using a hand operated steel cashew nut cutter. The kernel and shell weights were recorded separately. Means of data collected were subjected to analysis of variance (ANOVA) to ascertain the variability in nut characteristics among the different clones. Correlation among the studied traits was done using the Analyst option in SAS. A dendrogram was constructed based on the dissimilarity coefficient using Dice's approach.

RESULTS AND DISCUSSION

The thirteen accessions differed significantly ($P < 0.01$) from each other for the six morphological traits studied (Table 1). Clone OCJ9 produced the largest nut weight (11.34 g), followed by YS203 (11.22 g) and ORO9 (11.15 g). Same trend was observed in kernel weight; clone OCJ9 had the largest (3.75 g), followed by, YS203 (3.44 g) and ORO9 (2.83 g). Clone OCJ9 gave the highest nut weight (11.34 g), nut width (2.99cm), and kernel weight (3.75g). Clone ORO9 had the highest mean value of 2.24 cm and 7.97 g for nut girth and shell weight respectively. The highest nut length (3.99cm) was observed in YS203. Clone EU202 gave the least mean value for nut weight (4.27g), nut length (2.55cm), nut Girth (1.13cm), kernel weight (1.50g), and shell weight (2.73g). Clone KD102 had the least value of 1.91cm for nut width. Generally, the nuts fell in 3 categories of large (8-11 g), medium (6-7 g), and small (2-5 g) which constitute the largest proportion of nut size produced in Nigeria.

Table 1. Performance of thirteen cashew clonal accessions for nut traits

Accessions	Ntwt (g)	NtL (cm)	Ntwh (cm)	NtGth (cm)	Kwt (g)	Swt (g)
KD102	4.78bc	2.68bc	1.91e	1.45bcd	1.65c	3.11e
YS103	5.50bc	2.94bc	2.12cde	1.29cd	1.77c	3.65cde
OCJ5	7.19bc	3.15b	2.23cde	1.56bcd	2.34bc	4.80cde
EU202	4.27c	2.55c	1.97de	1.13d	1.50c	2.73e
BEL36	7.04bc	3.08b	2.28cde	1.50bcd	1.99c	4.95cde
YS203	11.22a	3.99a	2.52bc	1.72bc	3.44ab	7.70ab
OCJ9	11.34a	3.79a	2.99a	1.84ab	3.75a	7.15ab
OCJ2	8.43ab	3.19b	2.43bcd	1.57bcd	2.41bc	5.96abc
EN103	5.67bc	2.87bc	1.95	1.42bcd	2.18bc	3.42de
CR102	6.86bc	3.05b	2.17cde	1.49bcd	2.23bc	4.58cde
ORO9	11.15a	3.69a	2.79ab	2.24a	2.83abc	7.97a
BEL22	8.17ab	3.17b	2.36bcde	1.55bcd	2.52abc	5.56bcd
ORO3	7.17bc	3.12b	2.19cde	1.47bcd	2.18bc	4.81cde
F. sign	**	***	**	*	*	**

Means followed by the same letter(s) are not significantly different according to DMRT ($P < 0.05$)

*, **, *** - Significant at $P \leq 0.5, 0.1$, and 0.01

Key: Ntwt-Nut weight, NtL-Nut length, Ntwh-Nut width, NtGth-Nut Girth, Kwt-Kernel weight, Swt- Shell weight.

Nut weight had positive and significant ($P < 0.001$) correlation with nut length, nut width, nut girth, kernel weight, shell weight at r values of 0.96, 0.93, 0.67, 0.95, and 0.99 respectively (Table 2). Generally, positive and significant correlation exist among all the nut traits assessed. Thus, any of the nut trait is a good determinant of the other traits, in the cashew clones used in this experiment. Nut weight and girth is a reliable assessment of kernel weight as was also observed in Adeigbe *et. al.*, 2015.

Table 2. Correlation between nut traits measured

	Nut weight	Nut length	Nut width	Nut girth	Kernel weight	Shell weight
Nut weight	-	0.96***	0.93***	0.67***	0.95***	0.99***
Nut length	-	-	0.88***	0.66***	0.92***	0.96***
Nut width	-	-	-	0.69***	0.89***	0.92***
Nut girth	-	-	-	-	0.57***	0.69***
Kernel weight	-	-	-	-	-	0.91***
Shell weight	-	-	-	-	-	-

*** - significance at $p \leq 0.001$

From Table 3, the total genetic variation among the 13 accessions was accounted for by four Principal Component (PC) axes, with variance proportions ranging from 91.73% (PC1) to 1.11% (PC4). The eigenvalues for each axes followed the descending trend as the variance proportion. The total variations (98.62%) among the thirteen accessions as explained by the first three PC axes were 91.73%, 4.93% and 1.97% respectively. By decreasing magnitude, prominent traits with high eigenvector loadings in PC1 were: Nut weight (0.42), shell weight (0.42) nut length (0.41), nut width (0.40), and kernel weight (0.40). Nut girth (0.80) was the most discriminatory in PC2.

Table 3. Eigenvalues, variance proportions and eigenvectors showing the prominence of each trait to each PC axes

Characters	PC1	PC2	PC3	PC4
Nut weight	0.4249	-0.0595	0.0679	-0.1883
Nut length	0.4141	-0.2744	0.4117	-0.3040
Nut width	0.4064	0.0509	-0.8672	-0.0144
Nut girth	0.3796	0.8029	0.2523	0.3694
Kernel weight	0.4012	-0.5206	0.0852	0.6996
Shell weight	0.4217	0.0529	0.0550	-0.4960
Eigenvalues	5.5038	0.2951	0.1183	0.0667
Variance	91.73	4.93	1.97	1.11
Cumulative	91.73	96.65	98.62	99.73

A dendrogram (Figure 1) constructed on the basis of Dice's dissimilarity coefficient broadly separated all the 13 cashew clones into three main clusters at dissimilarity coefficient of 1.75, and two main clusters at 3.53 dissimilarity coefficient.

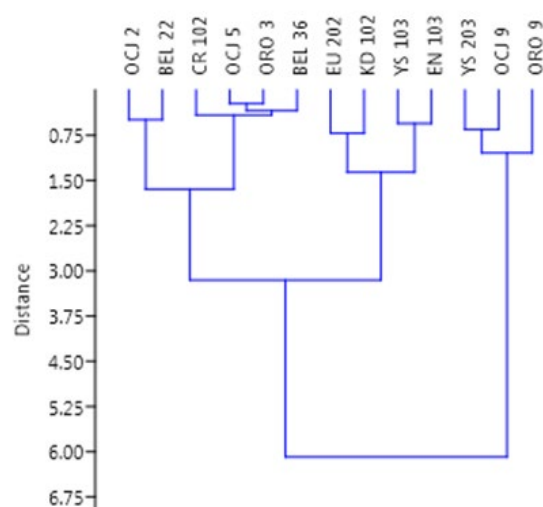


Figure 1. A dendrogram separating cashew clones into two main clusters

CONCLUSION

Development of improved cashew variety is of great importance in Nigeria and Africa. Evaluation and selection of mother tree comes first in the production of new clones or hybrids with desirable traits. Nut weight, nut size, nut shape, kernel weight, kernel grade, nut yield, disease and insect pest resistant, easy peeling of testa, easy detachment of the nut from the apple, canopy size, canopy shape, flower sex ratio, and nut production cycle are characteristics used as phenotypic markers in the selection process. In this preliminary study, three cashew clones; Clone OCJ9, YS203 and ORO9 were identified with desirable traits of large nut size, positively correlated with large kernel that could be advanced for further assessment and for possible inclusion or utilization as mother tree.

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ON-FARM EVALUATION OF CASHEW (*ANACARDIUM OCCIDENTALI* L.) PROGENIES FOR EARLINESS TO FLOWERING AND NUT YIELD IN THE AFFRAM PLAINS OF GHANA

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Abstract

The flowering and fruiting of cashew coincides with the annual drought stress. The identification of genotypes with high flowering intensities could constitute a viable strategy to evade drought. Eight (8) cashew genotypes were evaluated on farmers' field at Agotime I and Agotime II in the Affram Plains of Ghana. The trial was laid out in a randomized complete block design and the following traits were measured: canopy spread-EW, canopy spread-NS, flowering intensity, nut yield, cumulative yield, nut weight and shelling. There were significant genotype effects on all traits at all sites except nut weight and shelling at Agotime I. Flowering intensities were in the range of 2.3 - 30 %, whereas cumulative and mean nut yields in the second year of bearing were in the range of 30.1 – 190 kg ha⁻¹ and 60 - 332 kg ha⁻¹. Nut weight and shelling also ranged from 5.9 - 8.7 g and 18.5 - 36.4 % respectively. Mean values for all the traits measured were comparable across the two farm sites. Flowering intensity correlated significantly with cumulative yields ($r = 0.64$), shelling ($r = 0.79$), canopy spread - NS ($r = 0.63$) and canopy spread - EW ($r = 0.65$). Broad sense heritability for flowering intensity were high (0.43 - 0.97). Progenies SG 266 × TAN 992 and BE 059 × TAN 992 combined high flowering intensities with wider canopies and higher yields as well as better nut weights and shelling. Our study suggests that, genetics play a modest to high role in explaining differences in flowering intensities of cashew progenies and this could be used in the selection of drought-escape cashew varieties.

Key words: Flowering intensity, accumulated yield, mean yield, drought and climate change

Introduction

Cashew is an economic crop of high export value to producing countries (Oliveira 2008; Eze *et al.*, 2023). In spite of its high potential in alleviating poverty and boosting development, the cultivation of cashew is constrained by low nut yield. This have been attributed to the prolonged dry spells, high temperatures and declining soil fertility levels (Adu-Gyamfi *et al.*, 2019) as well as pests and diseases (Abdulai *et al.*, 2021). Cashew thrives well in an annual rainfall range of 1000 - 2000 mm (Sys *et al.*, 1993; Dedzoe *et al.*, 2001) over a temperature range of 25 - 28 °C (Dendena and Corsi 2014) with a pronounced dry period of 5 - 6 months (Dedzoe *et al.* 2001) for optimum productivity. It develops well on drained, deep, light to medium textured soils (Dedzoe *et al.*, 2001) with a pH range of 4.5 - 6.5 (Ngatunga *et al.*, 2001).

Flowering is one of the critical processes of production in nut tree crops (Jameel *et al.* 2018). However, drought, which is the most common abiotic stress severely affects flower development and yield of several plant species (Chen *et al.*, 2023). In many cashew producing countries in the tropical and subtropical regions, flowering and fruiting coincides with the annual drought and these periods are characterized by severe moisture stress, low humidity, ghastly winds and high temperatures (Asante and Amuakwa-Mensah, 2015). The harmful effect occurs at several levels of plant functions, leading to a drastic reduction in yield and high rate of dried cashew flowers (Bello *et al.*, 2017).

Drought-escape is a common adaptable strategy exploited by plants in response to drought stress. In this strategy, flowering and fruiting is accelerated to shorten the entire life cycle before severe drought stress hinders productivity (Riboni *et al.*, 2016). While flowering intensities of similar tree crop species like citrus has been influenced by genotype and drought (Agustí *et al.*, 2020; Mesejo *et al.*, 2022), the magnitude of the effect of genotype and environment on cashew flowering intensity in cashew has not been established.

Multi-location evaluation of cashew hybrids has enabled breeders to identify superior varieties for specific environments. The introduction of high yielding food crops with a short growing season is considered to be an effective strategy for narrowing food gap (Okatan *et al.*, 2016; Lateef *et al.*, 2018). Currently, very few hybrids in Ghana have been evaluated at single locations. (Adu-Gyamfi *et al.*, 2022).

The objectives of the present study are to: (1) Identify cashew hybrids that combine high flowering intensity with high yields (2) determine the heritability of canopy spread - EW, canopy spread - NS, cumulative yield, mean yield, nut weight, shelling and flower intensity (3) assess the phenotypic correlation among canopy spread - EW, canopy spread - NS, cumulative yield, mean yield, nut weight, outturn and flower intensity.

MATERIALS AND METHODS

Cashew progenies, experimental design and crop management

A total of nine F1 cashew progenies were evaluated in this experiment. This included four progenies (BE 059 × TAN 100, BE 059 × TAN 992, BE 059 × TAN 992, SG 287 × TAN 992) being evaluated at Agotime I while the remaining four (BE 059 × TAN 039, BE 107 × TAN 039, SG 266 × TAN 992, SG 287 × TAN 240) were assessed at Agotime II against the standard (SG 287 × TAN 100) on farmers field. Manual pollinations were carried out at the Wenchi Agricultural station to produce the nine F1 progenies. Selection for these materials were based on nut yield and nut weight (Cocoa Research Institute of Ghana Annual reports, 2008/2009, page 164). The Affram plains in the

Transitional zone is characterized by a mean annual rainfall of 1300 mm with mean annual temperature range of 26.1 - 28.9 °C (Lacombe *et al.*, 2012; Owusu and Waylen, 2013). Soil samples were randomly collected from 16 different spots in each of the experimental site at a depth of 0 - 15 cm before establishment of the trial.

The trial was laid out in a randomized complete block design with two replications of 12 plants per cross/plot at a spacing of 10 m × 10 m (100 plants per hectare) in June, 2019. The standard agronomic practices for cashew production in Ghana were duly followed.

Measurement of agronomic traits

The data on nut yield per plot per annum was estimated from the weight of raw nuts collected from each progeny throughout the fruiting season from 2021 - 2023. Nut yield (NY) records were obtained during October - April annually. Cumulative yield was estimated as the sum of nut yields obtained from each progeny in the 2021 and 2023 seasons respectively. Nut weight (NW) was estimated as the weight of 1 kg of raw cashew nuts divided by the number of nuts. Shelling % was estimated as (weight of healthy kernels divided by the weight of raw nuts) × 100 for each progeny. Canopy spread was measured by marking each tree on the side as north, south, east and west with the help of a GPS device. Measurements were taken from east - west (EW) and from the north - south (NS) direction using a tape measure during 2023 cropping season. Flowering intensity was recorded during the flowering period in December based on visual score where 0 equals no flower, 25 equals 1/4 canopy covered with flower, 50 equals half of canopy covered with flower, 75 equals 3/4 of canopy covered with flower and 100 equals full flower.

Statistical analysis

For the data obtained, plot-level values were used in analyses of variance (ANOVA) following tests for normality (based on the plot of residuals). Analysis was carried out separately for each location as progenies were not identical across the two locations. The F1 progenies were analyzed to test for significant differences using the average trait values across years, with progenies considered a fixed effect and replicates as random factor, using the GenStat statistical software, version 12 (VSN International Ltd., Hemel Hempstead, UK).

The following model was used for the location analysis:

$$Y_{ijk} = \mu + B_j + G_j + L_k + GL_{jk}$$

Where,

Y_{ijk} = observed trait value of genotype j in block i of Environment k , μ =grand mean, B_i =block effect, G_j =effect of genotype, L_k = Environmental effect, and GL_{ijk} = error (residual) effect of genotype j in block i of environment k . Duncan multiple range test (DMRT) was used test differences among means at the 5 % probability level. The phenotypic, genotypic and environmental variances were calculated according to the formula suggested by Singh and Chaudery (1999) as follows:

$$\text{Environmental variance } (\sigma^2 E) = \text{MSE}$$

$$\text{Genotypic variance } (\sigma^2 G) = (\text{MSG} - \text{MSE})/b$$

$$\text{Phenotypic variance } (\sigma^2 P) = \sigma^2 G + \sigma^2 E$$

Where MSE is error mean square (environmental variance), MSG is mean square attributable to progeny, and b is the number of blocks. Broad sense heritabilities were calculated as the ratio of genotypic variance to phenotypic variance as follows:

$$h^2b = \sigma^2 G / \sigma^2 P$$

Where h^2b , $\sigma^2 G$, and $\sigma^2 P$ are broad sense heritability, genetic variance and phenotypic variance respectively. Pearson correlation coefficient estimate among traits were classified as weak (- 0.30 to 0.30), moderate (-0.50 to - 0.30 and 0.30 to 0.50), strong (- 0.90 to -0.50 and 0.50 to 0.90) and very strong (-1.0 to -0.9 and 0.9 to 1.0). Phenotypic correlations among traits were estimated using META-R (Alvarado *et al.* 2018). The analysis on nut yield and nut weight utilized 2-year nut yield data (2021-2023), 2 - year shelling data and two-year nut weight data (2021 - 2023) respectively. The analysis on canopy spread in the east to west and north to south direction also utilized measurements June 2023.

Results

Soil analysis

The soils were predominantly lithosols with basic reaction pH of 7.3 and 7.0 at Agotime I and II respectively (Table 1). With the exception of total phosphorus content which was 100 % and 50 % higher than the recommended levels at Agotime I and Agotime II, the nitrogen, magnesium, carbon and potassium levels were lower compared to the reports of Dedzoe *et al.* (2001) respectively. Comparatively, all the nutrient levels at Agotime I were higher than Agotime II and based on these soils' chemical composition, the soils at Agotime I appeared to be more fertile than Agotime II.

Table 1. Soil characteristics of experimental sites at a depth of 0 – 15 cm

Soil Parameters	Location		Critical values
	Agotime I	Agotime II	
Soil pH	7.26	6.99	5.2-7.5
Organic C (%)	0.80	0.60	2%
Total N (%)	0.05	0.05	0.10%
Avail. P (ppm)	22.25	16.30	>10ppm
Exch. Mg (cmolc kg ⁻¹)	0.72	0.58	0.8 cmolc kg ⁻¹

Genotype and Environment

The analysis of variance revealed significant genotype effects ($P < 0.05$) on flower intensity, canopy spread - EW, canopy spread - NS, mean yield and cumulative yield at both Agotime I and Agotime II, except for nut weight which was significant only at Agotime II (Table 2 and 3). Flowering intensities at Agotime I and Agotime II ranged from 8.1 - 29.8b % and 2.3 - 22.4 % respectively (Table 4). The progenies, SG 287 × TAN 240, SG 266 × TAN 992 and BE 059 × TAN 039 gave significantly ($p < 0.05$) higher flowering intensities compared to the standard (SG 287 X TAN 100) at Agotime I, while BE 059 × TAN 100, BE 059 × TAN 992, SG 138 × TAN 100 and SG 287 × TAN 992 significantly ($p < 0.05$) outperformed the standard at Agotime II (Table 5). There were no significant differences in flowering intensities between the two locations.

Canopy spread at Agotime I and Agotime II ranged from 2.5 - 6.0 m in the EW and 2.4 - 5.6m in the NS and 1.5 - 4.9m for EW and 1.5 - 4.4 m for the NS respectively (Table 4 and 5). Similar to flowering intensities, the progenies, SG 287 × TAN 240, SG 266 × TAN 992 and BE 059 × TAN 039 at Agotime I and BE 059 X TAN 100, BE 059 X TAN 992, SG 138 X TAN 100 and SG 287 X TAN 992 at Agotime II gave significantly ($p < 0.05$) wider canopy compared to the standard (SG 287 X TAN 100). Differences in canopy spread in both locations were not significant.

Mean yield recorded a range of 30 - 166 kg ha⁻¹ and 53 - 190 kg ha⁻¹ at Agotime I and Agotime II respectively (Table 4 and 5). At Agotime I, SG 266 × TAN 992 gave the highest yield of 166 kg ha⁻¹ and this was closely followed by the standard SG 287 × TAN 100 and SG 287 × TAN 240 with yields of 164.4 kg ha⁻¹ and 134.5 kg ha⁻¹ respectively. In contrast, BE 107 × TAN 039 and BE 059 × TAN 039 significantly gave lower mean yields compared to the standard. At Agotime II, SG 287 × TAN 100 gave the highest mean yield of 190 kg ha⁻¹ and this was followed by BE 059 × TAN 992 with yields of 145 kg ha⁻¹. BE 059 X TAN 100 gave the lowest mean yield of 53 kg ha⁻¹.

On the other side, cumulative yields also recorded a range of 60.3 - 332.1 kg ha⁻¹ and 106 - 293 kg ha⁻¹ at Agotime I and Agotime II respectively (Table 4 and 5). At Agotime I, SG 266 × TAN 992 gave the highest cumulative yield (332.1 kg ha⁻¹) and was followed by SG 287 × TAN 240 and the standard (SG 287 × TAN 100). Progenies BE 107 × TAN 039 and BE 059 × TAN 039 significantly gave the lowest cumulative yields. Meanwhile at Agotime II, BE 059 × TAN 992 gave the highest cumulative yield of 293 kg ha⁻¹ and this was followed by SG 287 × TAN 992, SG 287 × TAN 100, and SG 138 × TAN 100 which recorded yields of 190, 156 and 148 kg ha⁻¹. The progeny BE 059 × TAN 100 gave the lowest cumulative yield of 106 kg ha⁻¹. Mean and cumulative yield were not significantly different across sites.

Nut weight also varied over a range of 5.9 - 8.7 g at Agotime II (Table 5). At this site, BE 059 X TAN 992 gave the highest nut weight (8.7 g) and this was closely followed by the standard (SG 287 X TAN 100), BE 059 X TAN 100 and SG 138 X TAN 100 with nut weights of 8.2g, 7.3g and 7.3g respectively. Overall, the progenies SG 266 × TAN 992, SG 287 × TAN 240 and BE 059 × TAN 992 combined high flowering intensities with wider canopies, higher cumulative yields and better nut weight and shelling values.

Heritability estimates and correlations among traits

Heritability estimates were high to moderate across the two sites (Table 2 and 3). At Agotime I, the highest heritability estimate was recorded for mean nut yield (0.95) followed by flower intensity (0.93), canopy spread EW (0.89), canopy spread NS (0.87), cumulative yield (0.64), nut weight (0.14) and shelling (0.08) (Table 2). Heritability estimates at Agotime II recorded the highest for shelling (0.71) followed by nut weight (0.70), mean yield (0.57) canopy spread - EW (0.47), canopy spread - NS (0.48), flower intensity (0.43) and cumulative yield (0.13) (Table 3).

A positive significant correlation was recorded between flowering intensity versus cumulative yield (0.64), canopy spread - EW (0.65) and canopy spread - NS (0.62) and shelling (%) (0.79). Shelling (%) also positively correlated with canopy spread - EW (0.70), canopy spread - NS (0.70). Mean yield also positively correlated with cumulative yield (0.74) (Table 6). In contrast, a negative significant correlation was recorded between nut weight and shelling (- 0.67) (Table 6).

Table 2. Mean square from analysis of variance for canopy spread - EW, canopy spread- NS, cumulative yield, mean yield, nut weight, shelling and flower intensity (%) of five cashew progenies evaluated at Agotime I in the Afram Plains of Ghana.

Source	Df	Canopy spread – EW(m)	Canopy spread -NS (m)	Cumulative	Mean Yield (kg ha ⁻¹)	Nut weight (g)	Shelling (%)	Flower intensity (%)
Block	1	0.05	0.15	1364	2063.6	5.9	161.3	24.4
Progeny	4	3.1**	2.67**	22903***	7157.3***	2.4	82.3	210.6***
Residual	3	0.18	0.18	5093	193.4	0.4	14.2	7.6
$\sigma^2 G$		1.46	1.25	8905	3481.9	0.9	34.0	101.5
$\sigma^2 P$		1.64	1.43	13998	3675.4	1.4	48.2	109.1
Heritability		0.89	0.87	0.64	0.95	0.71	0.71	0.93

*, **, ***Significantly different at $p \leq 0.05$ $p \leq 0.01$ and $p \leq 0.001$, respectively. Genotypic variance ($\sigma^2 G$), Environmental variance ($\sigma^2 E$).

Table 3. Mean square from analysis of variance for canopy spread - EW, canopy spread, cumulative yield, mean yield, nut weight, shelling and flower intensity of five cashew progenies evaluated at Agotime II in the Afram Plains of Ghana.

Source	Df	Canopy spread – EW(m)	Canopy spread -NS (m)	Cumulative	Mean Yield (kg ha ⁻¹)	Nut weight (g)	Shelling (%)	Flower intensity (%)
Block	1	0.1	0.5	43650	10041	0.83	8.6	12.8
Progeny	4	3.8*	3.4*	9980*	6057*	1.2	26.1	123.2***
Residual	3	1.4	1.2	7753	1681	1.6	22.3	48.8

$\sigma^2 G$		1.2	1.105	1113.5	2188	0.2	1.9	37.2
$\sigma^2 E$		2.6	2.305	8866.5	3869	1.4	24.2	86.0
Heritability		0.47	0.48	0.13	0.57	0.14	0.10	0.43

*, **, ***Significantly different at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Genotypic variance ($\sigma^2 G$), Environmental variance ($\sigma^2 E$).

Table 4. Mean cashew canopy spread - EW, canopy spread - NS, cumulative yield, mean yield, nut weight, shelling and flower intensity of five cashew progenies evaluated at Agotime I in the Afram Plains of Ghana from 2022 - 2023.

Genotype	Canopy spread-NS (m)	Canopy spread-EW (m)	Flowering Intensity (%)	Mean yield (kg ha ⁻¹)	Cumulative yield (kg ha ⁻¹)	Shelling (%)	Nut weight (g)
BE 107 X TAN 039	4.1a	4.1a	8.1a	30.1a	60.3a	27.4a	8.4a
BE 059 X TAN 039	4.5a	4.7a	19.5b	73.9b	148b	31.6a	7.3a
SG 287 X TAN 100	2.4c	2.57c	9.0a	164.4c	244cb	23.4a	7.6a
SG 287 X TAN 240	5.6b	6.0b	29.8b	134.5c	269cb	30.9a	6.2a
SG 266 X TAN 992	4.1a	4.3a	28.3b	166c	332.1c	32.0a	7.7a
Mean	4.1	4.3	18.9	113.8	210.7	29.1	7.5

Different letters, separately on mean values of canopy spread, yield, cumulative yield, nut weight, flowering intensity and shelling (%) indicate significant difference at $p \leq 0.05$ level based on Duncan's multiple range test.

Table 5. Mean cashew canopy spread - EW, canopy spread- NS, cumulative yield, mean yield, nut weight, shelling and flower intensity of five cashew progenies evaluated at Agotime II in the Afram Plains of Ghana from 2022 - 2023.

Genotype	canopy spread EW (m)	canopy spread NS (m)	Flowering Intensity(%)	Mean yield (kg ha ⁻¹)	Cumulative Yield(kg ha ⁻¹)	Nut weight (g)	Shelling (%)
BE 059 X TAN 100	4.4ac	4.3ac	11.1a	53a	106a	7.3ab	25.3ac
BE 059 X TAN 992	4.0ac	4.0ac	17.0c	145b	293bc	8.7b	26.3ac
SG 138 X TAN 100	5.1c	4.9c	7.7a	78a	148ab	7.3ab	27.6ac
SG 287 X TAN 100	1.5b	1.5b	2.3b	190b	156ab	8.2ab	18.5a
SG 287 X TAN 992	4.2ac	4.1ac	22.4c	95a	190b	5.9a	36.4bc
Mean	3.8	3.8	12.1	112	178.6	7.6	26.8

Different letters, separately on mean values of canopy spread, yield, cumulative yield, nut weight, flowering intensity and shelling (%) indicate significant difference at $p \leq 0.05$ level based on Duncan's multiple range test.

Table 6. Phenotypic correlation coefficients for cashew canopy spread - EW, canopy spread - NS, cumulative yield, mean yield, nut weight, shelling and flower intensity of five cashew progenies evaluated at Agotime I & II in the Afram Plains of Ghana from 2022 - 2023.

Trait	Cumulative Yield (kg ha ⁻¹)	Flowering intensity (%)	Mean Yield kg ha ⁻¹ ()	Nut Weight (g)	Shelling (%)	Canopy Spread EW (m)
Flowering	0.64*	-				
Mean yield	0.74**	0.12	-			
Nut weight	-0.07	-0.55	0.15	-		
Shelling	0.22	0.79**	-0.33	-0.67*	-	
Canopy spread (EW)	0.10	0.65*	-0.49	-0.52	0.70**	0.99***
Canopy spread (NS)	0.05	0.62*	-0.55	-0.48	0.70**	0.98***

*, $P < 0.05$, **, $P < 0.01$, *** $P < 0.001$.

Discussion

In the study, there were wide variations in flowering intensity in the two trial sites. We observed high heritability estimates (0.43 - 0.93) for flowering intensity for cashew which is comparable to the estimates reported in other species like mango (0.79) (Sankaran *et al.*, 2020) and alfafa (Adhikari *et al.*, 2019). High heritability of flowering intensity shows the inherent genetic control of flowering as seen in other crops. Since flowering is an important trait for selection, the presence of variation in flowering intensity for cashew shows a large potential to manipulate its expression. Similarly, genetic control for canopy spread - EW, canopy spread - NS, cumulative yield, mean yield, nut weight, and outturn were high at Agotime I. Contrastingly, the low heritability estimates obtained for shelling (0.10), nut weight (0.14), cumulative yield (0.13) at Agotime II where soil nutrient levels were comparatively low (Table 1) and this could imply that selection for these traits under poor soil environmental conditions will be difficult. Similar findings has been reported by Adu-Gyamfi *et al.* (2019). The significant positive correlations observed between flowering intensity and other yield related component (cumulative yield, shelling, canopy spread

EW, canopy spread -NS) indicate that selection for flowering intensity could improve nut yield. This suggests that cashew progenies may employ accelerated flowering intensity rate to evade drought stress and ensure high yields. Our findings are consistent with Kumar and Abbo (2001) who emphasized that plants with high flowering intensity in the early months of the season could mature early to avoid terminal drought stress. Further, the superior performance observed with progenies SG 266 × TAN 992 and BE 059 × TAN 992 which combined high flowering intensities with wider canopies, higher cumulative and mean yields with better nut quality suggest that these progenies could possibly possess drought escape alleles that ensures high productivity and better tolerance to drought stress. They could, therefore, be utilized as donors to develop drought escape cashew hybrids. Nevertheless, while our scope of study is limited to the evaluation of only nine progenies in transitional zone, further studies are required to identify progenies adapted to specific agro - ecological zone in the cashew belt.

In contrast, SG 138 × TAN 100 together with the standard (SG 287 × TAN 100) gave low flower intensities, yet maintained appreciable mean and cumulative yields. This suggest that, some cashew progenies may employ other strategies to maintain high yield under drought stress. Interestingly, while larger nut weights (> 7 g) may attract premium price, SG 287 × TAN 240 in the current study gave low nut weights (6.2 g) but combined high flowering intensities with high mean and cumulative yields. Under such circumstances, introgression efforts involving the use of Brazilian accessions with jumbo nuts is emphasized (Aliyu and Awopetu, 2011; Adu-Gyamfi et al., 2022).

There is the potential for considerable gains to increase yield of cashew in high drought prone environments by accelerated flowering intensities. This would be important in the West African sub-region, where cashew is cultivated in the semi-arid areas. High flowering intensity traits can be transferred to recommended cashew varieties through hybridization with high early flowering materials. Selection of early flowering intensity cashew varieties that performs well in the tropical and subtropical regions of the world will undoubtedly increase the global production of cashew as well as help to develop climate resilient varieties.

Conclusion

Overall, our study suggests high genetic control of flowering intensity, cumulative yield, mean yield, canopy spread - NS, canopy spread - EW, nut weight under near optimal soil nutrient levels. This implies that flowering intensity trait can be directly selected to improve yield under drought conditions. However, under environmental conditions of low soil nutrient levels, selection for cumulative yield, nut weight and shelling will be ineffective. Progenies SG 266 × TAN 992 and BE 059 × TAN 992 combined high flowering intensities with wider canopies, higher cumulative and mean yields with better nut quality. While our study is confined to one ecology, the potential of these progenies could further be validated in multi-location tests.

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DETERMINANTS OF CASHEW NUTS EXPORT EARNINGS IN NIGERIA

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Abstract

Latest trend in cashew nut shows a global growth rate of 7-10 % annually. Prices of cashew nuts in Nigeria both at local and international markets impact significantly on its production.

Secondary data set were extracted from FAO and FAOSTAT on Nigerian cashew nut production and export supply quantity, value of cashew nut export quantity, producer prices of cashew nut, gross domestic product (GDP), interest rates, inflation rates and exchange rate for the period under study. Extracted data were analyzed using means, standard deviation, coefficients of variation, percentages and average growth rate. These were used to analyze trends in cashew nuts production, export quantities, and cashew nuts export earnings. The Augmented Dickey-Fuller test (ADF) was used to examine the stationary time series data. The Johansen's method was used in verifying co-integration among the variables of the model. The error correction mechanism (ECM) was used to investigate the factors influencing cashew nut export earnings.

The results showed that there are fluctuating trends in the cashew nuts production between 1980 and 2021 with an average annual production over the period being 241,315 MT. There is a high fluctuation in annual percentage change in cashew nuts production, ranging between -0.52 and 37.72%, with an average of 0.56% over the study period. The coefficient of variation reflects a high degree of instability in cashew nuts production ranging between 0.00 and 99.68% during the period of the study. The results of unit root tests with ADF shows that the values of the variables of the model are not stationary at their original values, but become stationary after the first difference. Johansen co-integration analysis reported a long-run relationship among variables.

Hence, the study found that macroeconomic variables such as gross domestic product, inflation rate, and exchange rate, as well as cashew nut production and export supplies are significant determinants of cashew nuts export earnings over the period in review.

Keywords: Cashew nuts, Export, Nigeria

Introduction

One of the most well-known cash crops in the world today is Cashew (*Anacardium occidentale* L.), a tree crop that originated in Brazil and was originally planted to assist in the prevention of soil erosion (Ogunwolu *et al.*, 2020). Today, cashew provides people and countries with raw materials, food, and income (Ogunwolu *et al.*, 2020). Cashew is a significant cash crop with a tremendous potential to produce foreign exchange, employment, and to stop Nigeria's desertification. The crop is a significant industrial raw material, and demand in the food, beverage, and confectionery industries is rising. The commodity is also seeing an increase in industrial demand on global markets. The level of foreign competition and the results of policy action will determine how much cashew production will increase over time (Alawode and Adeniranye, 2020). In Nigeria, cashew is universally cultivated and has strong potential for export with production taking place in 27 of the country's 36 States and in every geopolitical region. In Nigeria, 7–8% of non-oil export revenue comes from cashew nut exports. Cashew trade supplements the income of roughly 50,000 farmers and an additional 55,000 individuals engaged along the cashew value chain, the projected export value ranges from US\$25 to US\$35 million yearly (ITC, 2011).

Cashew nut is a significant contributor to the economic growth in Nigeria and much discrepancies exist in yield records, in 2015 national raw cashew nut production was estimated at 836,500MT on 366,000ha with an average yield of 2,286kg/ha (Adeigbe *et al.*, 2015). In 2017, the crop brought in roughly 24 billion naira through exports (Lawal and Uwagboe, 2017). The crop has high investment and export potentials. Exports recorded an annual average amount of US\$33.10 million for the product over the same period. In 2020, cashew nut exports from Nigeria yielded around 192 million U.S. dollars (Statista, 2022). The highest value was achieved from trading in unshelled nuts. In the previous year, a higher amount of approximately 229 million U.S. dollars was exported and that year, a peak of around 342 million U.S. dollars was achieved (Statista, 2022). The continuous increase in export earnings from cashew nuts will depend on the production, export supply, international competitiveness and the effects of policy intervention. Thus, this study sought to investigate the averages figures and trends in cashew nuts production and export supply in Nigeria and also determine macroeconomic variables affecting cashew nut earnings in Nigeria.

Materials and methods

The sample size is forty (40) year's annual time series data covering the period between 1980 and 2020. The data set were extracted from secondary sources. These sources included publications of FAO and FAOSTAT. Data were specifically collected on Nigeria's cashew nut production and export supply quantity, value of cashew nut export quantity, producer prices of cashew nut, gross domestic product (GDP), interest rates, inflation rates and exchange rate for the period under study (1980-2020). Nigeria's cashew nut production and export supply quantity was measured in metric tonnes (MT), value of cashew nut export quantity and producer prices of cashew nut were measured in millions United States Dollar (USD), inflation rates was measured in percentage, exchange rate was measured as number of Naira exchanged

for USD, the interest rate in the economy measured in percentage and GDP measured in millions USD.

The means, standard deviation, coefficients of variation, percentages and average growth rate were used to analyze trends in cashew nuts production, export quantities, and cashew nuts export earnings. The Augmented Dickey-Fuller statistics was used to examine the stationarity of time series data. The Johansen's method was used in verifying co- integration among the variables of the model. The error correction mechanism (ECM) was used to investigate the factors influencing cashew nut export earnings over the study period using the implicit model specified as:

$$\Delta \ln Y_t = \alpha_1 + \alpha_2 \Delta \ln Y_{t-1} + \alpha_3 \Delta \ln X_{2t-1} + \alpha_4 \Delta \ln X_{3t-1} + \alpha_5 \Delta \ln X_{4t-1} + \alpha_6 \Delta \ln X_{5t-1} + \alpha_7 \Delta \ln X_{6t-1} + \lambda_1 ECM_{t-1} + u_t \quad (1)$$

where:

Y is the export supply of cashew nuts in metric tonnes; X1 is the agricultural land area in square kilometres; X2 is cashew nuts production quantity measured in metric tonnes

X3 is the exchange rates was measured as amount of Naira exchanged for USD

X4 is the interest rate in the economy measured in percentage

X5 is the inflation rate in the economy measured in percentage

ECM_t is the error correction factor.

Δ is the difference operator; t-1 is the lagged values of variables;

Ln is the logarithm operator; U_t are stochastic random errors

α₁, α₂, α₃, α₄, α₅, α₆, and λ₁ are parameters to be estimated.

The ADF technique was adopted for examining the unit root in the variables of the model. The absolute value of the ADF statistics is compared with the critical values of 1, 5, and 10% levels. If the absolute values of the ADF statistics are lower than the critical value at 1, 5, and 10% level. The null hypothesis of the presence of unit root cannot be rejected. Hence, the series is not stationary. However, if the ADF statistics are higher than the critical value at 1, 5, and 10% respectively, the null hypothesis of the series containing the unit root is rejected and hence the series is stationary and can be used for regression analysis.

Results and Discussion

Averages and coefficients of variation in cashew nuts production in Nigeria between 1980 and 2020

Nigeria's cashew nuts production between 1980 and 2021 are presented in Table 1. There was an increasing trend between 1980 and 2009, and which declined from 2010 and 2021. On the average, the annual cashew nuts production over the study period was 241,315.60MT. There was a high fluctuation in the change in annual cashew nuts production, ranging from -0.52 to 37.72% over the period of study. The coefficient of variation reflects a high degree of instability in cashew nuts production ranging between 0.00 and 99.68%.

Table 1: Averages and Coefficients of variation in production of cashew nuts (MT) in Nigeria (1980-2020)

Sub-period	Average production (metric tonnes) per annum	Annual Percent change in production	Co-efficient of variation
1980-1989	25000.00	0.00	0.00
1990-1999	118900.00	33.73	93.47
2000-2009	590926.60	37.72	17.49
2010-2021	232248.90	-0.52	99.68

Source: Computed from FAOSTAT, 2023.

Averages and Coefficients of variation in export supply of cashew nuts (thousand USD) in Nigeria (1980-2020)

There was consistent increase in average export supply of cashew nuts in the economy across the sub-periods with an average of 36,707.71MT over the study period (Table 2). The average annual change in export supply of cashew nuts in the Nigerian economy between 1980 to 2021 ranged from 0.23% in the 1990-1999 sub-periods to 11.72% in the 2010-2021 sub-period, and averaging 0.32% per annum over the entire period of the study. The export supply of cashew nuts across the sub-periods reflected high degree of instability with the coefficient of variation ranging from 41.09% in the 2000-2009 sub-periods to 116.14% in the 1980-1989 sub-periods.

Table 2: Averages and Coefficients of variation in export supply of cashew nuts (metric tonnes) in Nigeria (1980-2020)

Sub-period	Average export supply (metric tonnes) per annum	Annual Percent change in export supply	Co-efficient of variation
1980-1989	311.04	1.14	116.14
1990-1999	17052.80	0.23	58.16
2000-2009	15916.00	1.57	41.09
2010-2021	98410.99	11.72	63.60

Source: Computed from FAOSTAT, 2023.

Averages and Coefficients of variation in export earnings of cashew nuts (thousand USD) in Nigeria (1980-2020)

Average export earnings of cashew nut per annum declined progressively over the study period ranging from 0.51 in the 2010-2020 sub-periods to 7.44% in the 1980-1989 sub-periods, with all period average of 0.46% (Table 3). There was a high degree of instability in the export earnings of cashew nuts with the coefficients of variation ranging from 40.96 to 122.48% in the study period.

Table 3: Averages and Coefficients of variation in export earnings of cashew nuts (thousand USD) in Nigeria (1980-2020)

Sub-period	Average export earnings (thousands USD) per annum	Annual Percent change in export earnings	Co-efficient of variation
1980-1989	1917.10	7.44	122.48
1990-1999	10344.40	2.46	87.38
2000-2009	8703.70	1.13	40.96
2010-2021	149380.10	0.51	91.63

Source: Computed from FAOSTAT, 2023.

The result of the root test for the original and the first difference value of the variable of the model is presented in Tables 4 and 5. In Table 4 all the absolute values of the ADF statistics are lesser than the critical values at 1%, 5%, and 10% levels respectively. Hence, the series contains a unit root at its original value and hence cannot be used for regression analysis to avoid having spurious outcomes. In Table 5, all the absolute values of ADF statistics are higher than the critical values at 1, 5, and 10% respectively indicating the series is stationary or contains no unit root at its first differences and is thus suitable for regression analysis.

Table 4: Result of ADF Unit Root for Variables (Original values)

Variables	Test statistics (ADF)	1% critical value	5% critical value	10% critical value	Decision
Y	0.073	-3.750	-3.000	-2.630	Non-stationary
X1	-2.035	-3.668	-2.966	-2.616	Non-stationary
X2	0.273	-3.662	-2.964	-2.614	Non-stationary
X3	-1.136	-3.662	-2.964	-2.614	Non-stationary
X4	-2.342	-3.662	-2.964	-2.614	Non-stationary
X5	-1.314	-3.668	-2.966	-2.616	Non-stationary
X6	-1.136	-3.662	-2.964	-2.614	Non-stationary

Source: Author Computation 2023

Table 5: Result of ADF Unit root test for variables of the model (first difference values)

Variables	Test statistics (ADF)	1% critical value	5% critical value	10% critical value	Decision
Y	-3.517	-3.750	-3.000	-2.630	I(1)
X1	-4.814	-3.675	-2.969	-2.617	I(1)
X2	-7.217	-3.668	-2.966	-2.616	I(1)
X3	-3.492	-3.668	-2.966	-2.616	I(1)
X4	-3.930	-3.668	-2.966	-2.616	I(1)
X5	-3.860	-3.675	-2.969	-2.617	I(1)
X6	-3.492	-3.668	-2.966	-2.616	I(1)

Source: Author Computation 2023

The Johansen Co-Integration technique presented in Table 6, the result indicates that there is at least one co-integration equation among the variable. Hence, a long-run relationship exists among the variable of the model, and thus Vector Error Correction Model (VECM) can be specified to obtain the short and long-run estimate of the relationship among the variables of the model.

Table 6: Result of Johansen tests for co-integration among variables of the model

Rank	Panus	LL	Eigen value	Trace statistics	5% critical value
0	42	-1722.545	0.825	131.284	94.150
1	53	-1690.234	0.502	66.669*	68.520
2	62	-1677.348	0.410	40.887	47.210
3	69	-1667.571	0.328	21.334	29.680
4	74	-1660.216	0.160	6.624	15.410
5	77	-1656.984	0.004	0.161	3.760
6	78	-1656.904			

Source: Author Computation 2023

Results of short run Vector Error Correction Model (VECM) regression analysis

The results of short and long run VECM regression analysis (Table 7) showed the value of R² is 0.580 and is statistically significant at 1%, confirming that the model has a good fit. In the short run, gross domestic product and exchange rate negatively influenced cashew nuts export earnings, while inflation rate positively influenced cashew nuts export earnings. This implies that GDP and Exchange Rate are inversely related to cashew nuts export earnings, while inflation rate is directly related to cashew nuts export earnings in the short run.

Table 7: Short run vector correction model (VECM) regression analysis results

Variables	Coefficients	Std error	z-value	p-value
Ce_1	-0.012	0.005	-3.260	0.001
Cashew nuts export earnings (Y)	0.125	0.099	1.260	0.208
Cashew nuts production quantity (X1)	0.1322	0.201	0.660	0.511
Cashew nuts export quantity (X2)	-0.157	0.117	-1.34	0.180
Gross domestic product (X3)	-0.556	0.276	-2.020	0.044*
Exchange rate (X4)	-0.427	0.260	-1.64	0.101***
Interest rate (X5)	0.036	0.341	0.110	0.915
Inflation rate (X6)	0.178	0.078	2.29 0	0.022 **
Constant	0.167	0.055	3.030	0.002**
R ²	0.580			
Chi-square	19.234*			
p-value	0.000			
AIC	4.081			

* Significant at 1% level **significant at 5% level Source: Author Computation 2023

In the long run, Cashew Nuts Export Quantity and Inflation Rate are negatively related to cashew nuts export earnings, while cashew nuts production quantity is positively related to cashew nuts export earnings (Table 8).

Table 8: Long run vector error correction model regression analysis results

Variables	Coefficients	Standard error	z-value	p-value
Ce_1	1	-	-	-
Cashew nuts export earnings (Y)	-1.551	1.562	0.990	0.321
Cashew nuts production quantity (X1)	4.659	1.478	3.150	0.002*
Cashew nuts export quantity (X2)	-7.363	1.940	3.790	0.000*
Exchange rate (X4)	-1.441	1.779	0.810	0.418
Interest rate (X5)	2.980	6.400	-0.470	0.641
Inflation rate (X6)	-15.442	1.511	-10.220	0.000*
Constant	112.399	-	-	-

* significant at 1% level

Source: Author Computation 2023

Conclusion

The study concludes that macroeconomic variables: GDP, Inflation Rate Exchange Rate, and cashew nut production and export supply quantities are significant determinants of cashew nuts export earnings over the study period.

Recommendations

This study recommends

1. Improved production and export supply of cashew nuts for significant boost in cashew nuts export earnings.
2. Reduced inflationary trend in the economy for sustainable export earnings from cashew nuts.
3. Evolvement of monetary policies that will enhance agricultural exports friendly exchange rate.

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Kosher, ACA

Sufficient Supply

1.6 million MT of
raw cashew nut per
annum

Social Impact

Major contribution
to job creation
for women and to
national GDP



GROWTH AND YIELD RESPONSE OF CASHEW GRAFTS TO SPACING IN THE GUINEA SAVANNA ZONE OF GHANA.

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ABSTRACT

An experiment was established at Bole, a substation of the Cocoa Research Institute of Ghana, in the Guinea Savanna zone to study the impact of spacing on the growth and early yield of cashew grafts. The trial was laid out in a randomised complete block design with four replications. The treatments evaluated were (i) 4 m x 4 m, (ii) 8 m x 8 m, (iii) 5 m x 10 m, (iv) 10 m x 10 m, (v) 6 m x 12 m and (vi) 12 m x 12 m. Data collected on the cashew plants were stem diameter, height, canopy spread, yield and yield components. The data were subjected to analysis of variance and the means were separated, using the least significant difference at 5 % probability. Results show that plant spacing did not adversely affect stem diameter, height and canopy spread during the first five years after transplanting. The number of nuts produced per tree and mean nut weight were also not significantly affected by spacing. However, nut harvest per unit land area was consistently higher in the closely spaced (4 m x 8 m) cashew plants. These differences in yield were statistically significant throughout the eight years of yield monitoring. Based on the results, it is concluded that cashew grafts can be grown at a spacing of 4 m x 8 m for higher nut production in the Guinea Savanna agroecology of Ghana for up to eight years without the need to thin out.

Keywords: Cashew, spacing, Guinea Savanna, nut yield, grafts, canopy

INTRODUCTION

Cashew (*Anacardium occidentale* L.) is an important tree crop that is cultivated extensively in several tropical and subtropical countries (Aliyu et al., 2014; Nayak et al., 2020). There has been a steady increase in global cashew production over the years, reaching 4.2 million tons in 2020 (Babatunde et al., 2023). However, the productivity of cashew orchards in many regions remains low, often ranging between 500 to 800 kg of nuts per hectare at peak tree production. The low productivity is frequently attributed to several factors, including suboptimal plant population density, pests and diseases, and poor soil fertility management (Nayak et al., 2020). Therefore, one strategy to improve cashew productivity is the adoption of optimum plant spacing, which can significantly influence the growth and sustained yield of cashew trees (Mangalassery et al., 2019; Nayak et al., 2020). Earlier recommendations for cashew spacing ranged from 8 m² to 16 m². This recommendation was based on earlier research and farmer experience indicating that closer spacing gave higher early yield which unfortunately diminished within three years of bearing (Northwood and Tsakiris, 1967). However, these observations were made in cashew crops established with seedlings known to grow faster and bigger. The recent development of dwarf cashew materials and clones/grafts that grow slowly with smaller canopies offers opportunities to intensify crop densities. This can be achieved without the early onset of the adverse effects resulting from mutual shading in the much vigorous and larger seedlings. It is safe then, to assume that establishing cashew farms with grafts at higher plant densities will lead to sustained higher nut production for several years before mutual shading effects are encountered. The spacing of cashew trees has been shown to significantly impact their height, canopy spread, trunk diameter, and branching patterns. Interestingly, these growth parameters were found to be significantly improved in 5 m² compared to wider (7.5 m², and 10 m²) spacing treatments (Yadukumar et al., 2013). This behaviour was attributed to increased competition for light and nutrients in the close plant spacing, which led to greater resource allocation towards the above-ground vegetative growth. Similar results have been reported by Sousa et al. (2018) and Janani et al. (2022). According to Yadukumar et al. (2013), higher cashew nut yield per hectare was obtained in close spacing (5 m²) compared to a much wider one (7.5 m² and 10 m²). Saroj et al. (2014), working with the same plant spacings (5 m², 7.5 m², and 10 m²) reported similar yield patterns. In addition, they found that soil moisture retention was higher in the close-spacing treatments. Several other reports have also confirmed the importance of optimum spacing in cashew cultivation (Oliveira et al., 2006; Nayak et al., 2020). However, the higher nut production in closely spaced cashew trees negatively impacts desirable nut quality traits (Aliyu et al. (2014). The nut size, nut weight, and kernel weight were significantly higher in a wide spacing (10 m²) compared to close spacing crop. Similarly, Nayak et al. (2020) working with the same plant spacings (5 m², 7.5 m², and 10 m²) found that the nut size, nut weight, and kernel weight were significantly higher in the 10 m² plant spacing. The relatively lower plant densities in the wide spacing treatment and the resultant reduction in competition between plants, allowed for the production of bigger nuts. (Rejani et al., 2013; Tripathy et al., 2015; Yadukumar et al., 2001). During the early cultivation of the cashew in Ghana, Ekrement (1965) recommended an initial spacing of 6 m², which was to be thinned to 12 m². This recommendation was made for cashew seedlings based on the effects of mutual shading at the later stages of growth. The 12 m² plant spacing led to suboptimum populations and large gaps between plants in the Guinea Savanna agroecology which was the initial target of the crop. In other cases, farmers simply refused to thin out, resulting in extensive mutual shading and poor nut production. To address these problems, a second recommendation of 10 m² spacing was made to cashew farmers in the Guinea Savanna zone. This however was for the establishment of Cashew farms with seedlings, before the development of clones with relatively smaller and more compact canopies. The recent development of dwarf hybrid cashew materials and clones/grafts with smaller canopies portends well for the cashew industry since higher plant densities can be achieved, resulting in higher nut production per unit area. This trial, therefore, was established to determine the effect of spacing on the growth and yield of cashew grafts.

MATERIALS AND METHODS

Experimental site

The study was carried out at Bole substation (Lat 090 01' N; Long 020 29' W; Alt 305 m ASL) of the Cocoa Research Institute of Ghana from 2010 to 2018. Bole is located within the Guinea Savanna ecological zone of Ghana, with a single rainy season between May and October, followed by a prolonged dry season. Total rainfall in this ecological zone ranges between 800 mm and 1,200 mm per annum, with maximum temperatures up to 42 °C during the dry season (Kranjac-Berisavjevic *et al.*, 2014). The soils at Bole are classified as Savanna Ochrosol, locally known as Fuga and Na series (Dedzoe, 2001) and Lixisol by FAO (1990). The soils occur on summits, upper and middle slopes. They are reddish-brown, moderately well drained and moderately deep to deep (100-150 cm), concretionary with textures that range from sandy loams to sandy clays. They have low nutrient retention and a high base saturation (total amount of Ca, Mg, K and Na with respect to the CEC). These soils are fairly susceptible to erosion and compaction because of the poorly developed structure.

Experimental design and treatments

The trial was laid out in a randomised complete block design with four replications. Different cashew spacing that served as treatments were (i) 4 m x 8 m, (ii) 8 m x 8 m, (iii) 5 m x 10 m, (iv) 10 m x 10 m, (v) 6 m x 12 m and (vi) 12 m x 12 m. Cashew seeds were sown in the nursery at Bole to raise seedlings that will serve as rootstock. At four months after sowing, scions from elite cashew materials were grafted onto these seedlings. The grafts were nurtured in the nursery for four more months after which they were transplanted to the field during the major rains. Maintenance activities such as weed, pests and disease management, as recommended for cashew production in Ghana were carried out throughout the experiment.

Data collection and analysis

Data on seedling growth (diameter, height and canopy spread span) and nut yield from treatment plots were collected. In all, 15 core plants were selected and identified with tags for growth and yield data collection. The diameter of selected plants was measured with digital calipers 15 cm from the soil surface at the base of each plant. The height of these was also measured from the base of each plant to the tip of the leading apex. The canopy span was measured in East-West and North-South and the average was calculated as the estimated canopy span of the plant. The data was analysed (GenStat, version 12) following the procedures for analysis of variance and treatment means separated using the Lsd at 5 % probability.

RESULTS AND DISCUSSION

Trunk diameter and canopy span

Increases in stem diameter of the cashew transplants, which are a better indicator of tree growth, were unaffected by plant spacing one to five years after establishment (Table 1). There was no significant spacing effect on tree height (3-5 years) and canopy span (4-5 years) after transplanting (Table 2). In the case of the canopy span, spacing at 12 m² led to consistently larger canopies. Other studies, however, have reported significant effects of spacing on cashew seedlings' trunk diameter, height, and canopy span. Close spacing of cashew trees supported faster trunk diameter, height and canopy growth. These were attributed to higher competition for light and nutrients that led to greater resource allocation to above-ground vegetative growth (Yadakumar *et al.*, 2013; Sousa *et al.*, 2018 and Janani *et al.*, 2022). The absence of significant differences in trunk diameter, height, and canopy growth of the trees in this study can therefore be attributed to low inter-specific competition among trees, even in the closely spaced crop probably because they were clones with overall small sizes. Although the canopy span was unaffected by plant spacing in this study, the relative differences observed among the treatments have immense implications for nut yield since canopy span is positively correlated to cashew nut production per tree (Aliyu *et al.*, 2014).

Table 1: Stem diameter of cashew grafts as affected by spacing at 15 months, and from 2-5 years after transplanting

Spacing (m)	Stem diameter (mm)				
	15 months	2 years	3 years	4 years	5 years
4 x 8	21.0	26.0	31.2	38.0	83.2
8 x 8	17.1	24.6	30.0	37.6	87.5
5 x 10	15.4	22.1	29.6	35.6	82.6
10 x 10	19.7	26.9	37.0	43.7	85.4
6 x 12	20.6	27.3	33.9	40.3	89.7
12 x 12	20.1	27.0	34.6	39.9	87.7
F-test ($\alpha=0.05$)	ns	ns	ns	ns	ns
CV (%)	21.0	15.3	17.2	21.4	18.8

Table 2: Height and canopy span of cashew grafts as affected by spacing from 3-5 and 4-5 years respectively

Spacing (m)	Height (m)	Canopy span (m)			
	15 months	2 years	3 years	4 years	5 years
4 x 8	1.3	2.3	2.7	3.5	3.8
8 x 8	1.2	2.0	2.5	3.3	3.6
5 x 10	1.1	1.8	2.5	3.2	3.8
10 x 10	1.2	2.1	2.6	3.6	4.1

6 x 12	1.3	2.1	2.6	3.8	4.6
12 x 12	1.3	2.2	2.8	4.0	4.8
F-test ($\alpha=0.05$)	ns	ns	ns	ns	ns
CV (%)	10.3	30.9	12.9	16.3	17.9

Yield and yield components

Nut weight (g nut-1)

Spacing of cashew trees did not have significant adverse effects on the individual weights of cashew nuts monitored over five years (Table 3). There was a general reduction in nut weight across treatments in the seventh year, probably due to environmental causes (Alae-Carew *et al.*, 2020). Differences in cashew nut weight are usually due to genetic differences between trees (Ohler, 2007). However, environmental effects such as competition for moisture, nutrients, and light have been shown to alter this genetic characteristic (Olubode *et al.*, 2018). The use of grafts in this study evened out differences that might have arisen due to genetic variability. The similarity in nut weight therefore indicates that there were no adverse effects on inter-specific competition among cashew trees on the resources allocated to nut filling. Nut weight in Ghana is generally low, because of environmental and plant genetic factors (Adu-Gyamfi *et al.*, 2019; Dadzie *et al.*, 2014). In this study, the range of nut weight of 4.8 - 5.7 g for year 5 were comparably lower than the 5.2 to 6.3 g reported by Adu-Gyamfi *et al.* (2019). The fact that this study was conducted in the relatively drier and poorer soils of the Guinea Savanna zone of Ghana accounted for the differences in nut weight since their study was carried out in a more suitable Forest-Savanna transition zone. Earlier reports have shown that wide spacing (10 m²) of cashew trees improved resource allocation to nut filling, thereby resulting in superior qualities such as larger, heavier nuts with better outturn (Aliyu *et al.*, 2014; Tripathy *et al.*, 2015; Nayak *et al.*, 2020). The similar nut weights observed across the years in this study, therefore, indicates that sufficient resources were available for nut filling even in the closely spaced trees. This suggests that establishing these clones at wide spacing may result in the underutilization of farmer's resources.

Table 4: Effect of treatments on the weight per nut (g) harvested from cashew grafts 4-8 years in the Guinea Savanna zone of Ghana.

Spacing (m)	Year after transplanting				
	4	5	6	7	8
4 x 8	4.8	5.7	5.1	4.7	4.6
8 x 8	4.5	5.1	5.4	4.4	5.3
5 x 10	4.6	5.2	4.7	4.4	4.4
10 x 10	5.7	5.3	4.5	4.7	4.0
6 x 12	4.5	4.8	4.6	4.4	5.0
12 x 12	4.4	5.1	5.0	4.0	4.3
F-test ($\alpha=0.05$)	ns	ns	ns	ns	ns
CV (%)	18.7	13.8	13.6	10.5	11.2

Relation between canopy span and nut production

The canopy span of cashew trees had a significant positive influence on both nut production per tree (Fig. 1) and the overall nut yield per hectare (Fig. 2). These show that canopy span can be a good predictor of the number of nuts a tree produces (61.2 %) and nut yield in kg tree-1 (63.2 %). These relationships were consistent over several years. Larger canopies are reported to be associated with better nutrient uptake (Reddy *et al.*, 2003), efficient photosynthesis (Aneja *et al.*, 2000) and reduced stresses (Aliyu, 2006), ultimately supporting higher nut yields in cashew trees. The consistent relationships between canopy span on the one hand, and nuts tree-1 and nut yield in kg tree-1, underscore the importance of canopy span to nut production in cashew trees (Aliyu and Awopetu, 2011). However, the absence of real differences in canopy span among the treatments in this study meant that higher nut yield ha-1 was returned by treatments with a higher number of individual canopies. Thus, the closely spaced cashew crop with higher tree densities produced higher nuts per hectare in all the years.

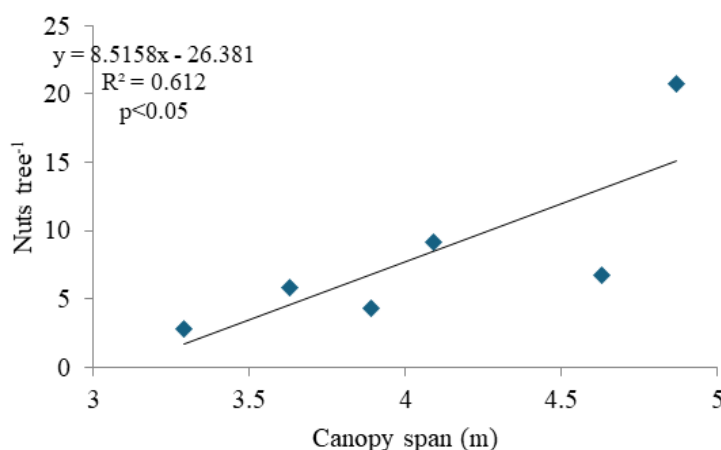


Figure 1: The relationship between crown size and number of nuts per tree (kg tree-1)

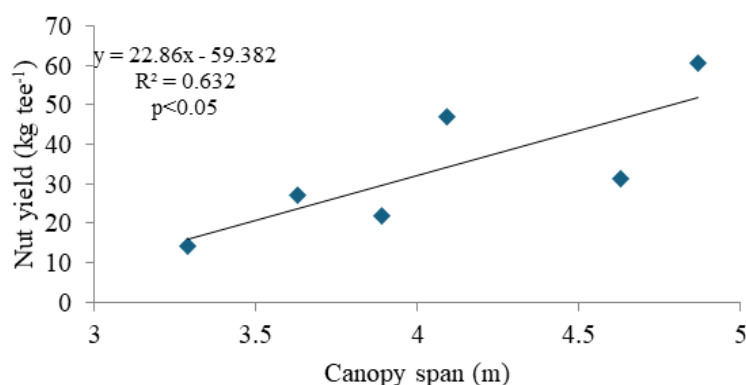


Figure 2: The relationship between crown size and dry nut yield (kg ha⁻¹)

Dry nuts yield

Spacing of cashew trees significantly affected nut production per unit land area from its onset. Closely spaced cashew trees that resulted in higher plant densities supported higher nut production per hectare from 3 to 8 years after transplanting (Table 5). Consequently, the cumulative nut yield was higher in the closely spaced treatments, with a positive relationship between plant spacing/density and nut yield per area (Figure 3). The 12 m² plant spacing, which had the least number of trees per hectare produced the least kg nuts ha⁻¹ (Table 5). This was due to sub-optimum plant populations and the failure of the relatively fewer trees to compensate for the reduced number of trees ha⁻¹. Similar results have been reported where wide spacing has led to lower yield per unit area, attributable to fewer trees being planted per hectare (Mangalassery *et al.*, 2019). High-density planting is known to significantly increase the number of trees per hectare, thereby increasing the total nut yield per unit area. This method is reported to offer advantages such as early and higher economic returns due to the increased yield per unit area (Mangalassery *et al.*, 2019). These earlier observations have been confirmed by this study in which nut yield has been found to be heavily dependent on the cashew tree density. In Ghana, recommended cashew clones for farmers have given low early nut yields in the range of 210.4–625.0 kg ha⁻¹ five years after transplanting in the Forest-Savanna Transition zone (Adu-Gyamfi *et al.*, 2019). Although this study was conducted in the relatively less suitable Guinea Savanna zone, nut yield obtained from the high-density (4 m x 8 m or 312 plants ha⁻¹) cashew crop at 5 years was comparable to the yield reported by Adu-Gyamfi *et al.* (2019). Yield fluctuations seen in this study between years may largely be due to differences in flowering intensity, fruit set and retention, and fruit development. These differences have been suggested to result from the strong influence of the environment (Aliyu and Awopetu, 2011).

Table 5: Effect of spacing on dry nut yield 3 - 8 years after transplanting in the Guinea Savanna zone of Ghana

Spacing (m)	Years after transplanting						Cumulative 6-year yield (kg ha ⁻¹)
	3	4	5	6	7	8	
4 m x 8 m (312)	89.2	195.0	236.0	179.0	461.0	753.0	1,913.2
8 m x 8 m (156)	43.0	116.0	73.0	85.0	153.0	563.0	1,033.0
5 m x 10 m (200)	46.6	134.0	63.0	141.0	407.0	518.0	1,309.6
10 m x 10 m (100)	23.9	116.0	52.0	60.0	222.0	290.0	763.0
6 m 12 m (139)	35.0	121.0	66.0	84.0	203.0	352.0	861.0
12 m x 12 m (69)	15.2	60.0	54.0	36.0	207.0	230.0	602.0
F-test	64.8	48.6	145.5	166.6	278.0	394.0	-
CV (%)	100.4	52.8	68.6	97.8	45.2	103.7	-

Note: The values in parentheses are plant population densities (ha⁻¹) associated with the respective spacing.

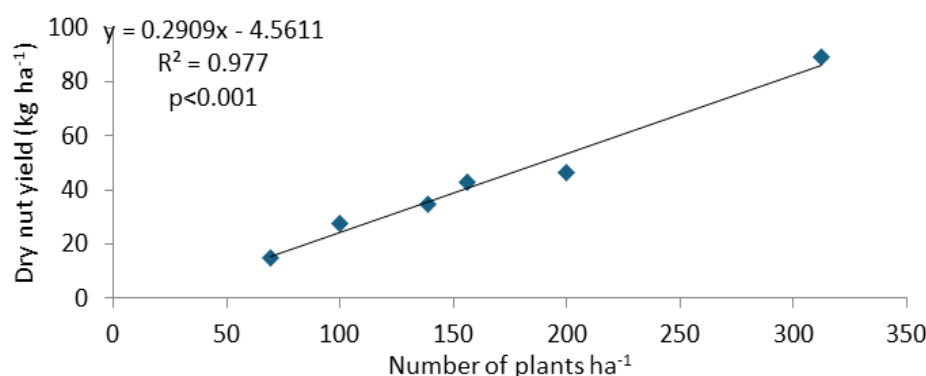


Figure 3: The relationship between plant population density and annual/cumulative dry nut yield (kg ha⁻¹).

CONCLUSIONS AND RECOMMENDATIONS

The growth of cashew trees in the Guinea Savanna zone of Ghana was not adversely affected by high densities resulting from close spacing. Canopy span and individual nut weights were not impacted by tested densities. However, nut production per unit area was greatly improved by plant spacing which led to high-density cashew crop. Cumulatively, high-density cashew crop produced higher dry nuts over six years. Based on the results of this study, it is recommended that cashew clones, established in the Guinea Savanna zones be spaced at 4 m x 8 m, giving a population density of 312 plants ha⁻¹ for early and higher returns to investments.

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POST-HARVEST HANDLING EFFECTS ON THE QUALITY OF FATS IN CASHEW NUTS

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Abstract

Cashew nuts are good sources of proteins, carbohydrates, vitamins, minerals and healthy fats. The fat content of the kernel ranges from 40 to 50 %, comprising 62 % monounsaturated fatty acids, 18 % polyunsaturated fatty acids, and 20 % saturated fatty acids. High unsaturated fatty acid predisposes the cashew nuts to lipid oxidation resulting in oxidative rancidity and rapid deterioration of fats. Peroxide value and free fatty acids are classic indicators of oxidative rancidity in fats and oils. Preliminary studies along the cashew processing line showed that peroxide value (PV) and free fatty acid (FFA) content of processed nuts were higher than the acceptable values ($PV \leq 1.0$ mEq/Kg Fats and $FFA \leq 0.7$ % Oleic acid). The total fat content observed for steamed wet unpeeled kernel was 24.4% with PV and FFA values of 7.1 mEq/Kg Fats and 1.8 % Oleic acid respectively. For dried peeled kernel, the total fat content was 28.1 % with PV and FFA values of 10.8 mEq/Kg Fats and 0.9 % Oleic acid respectively. To ensure the production of high-quality nuts, there is a need to understand the post-harvest processes of the nuts right from the field to the consumption stage. This paper describes the changes in PV and FFA of cashew fats along the processing line.

Keywords: Cashew, lipid oxidation, peroxide value, free fatty acid, rancidity

Introduction

Cashew kernels have been classified as highly nutritious and contain a considerable amount of protein, fat, carbohydrates, phosphorus, calcium, iron, and other mineral elements (Venkatachalam and Sathe, 2006). Cashew kernels contain about 40-50 % fat of which about 80 % is unsaturated fatty acid (Venkatachalam and Sathe, 2006; King et al., 2008; Bai et al., 2018). The fats contain bioactive, health-promoting substances and have long been considered important components of the human diet. In addition, cashew nuts contain antioxidants such as flavonoids, tocopherols, polyphenols, squalene, and vitamins such as A, D, and E which help in fat assimilation and increase immunity levels of humans (Ryan et al., 2006). The consumption of tree nuts may exert several cardioprotective effects, which are speculated to arise from their lipid component that includes unsaturated fatty acids (Miraliakbari and Shahidi F. 2008).

Since lipids constitute more than 40 % of cashew nut kernels (Chandrasekara & Shahidi, 2011), their oxidation is the main cause of its deterioration, resulting in the formation of off-flavours (oxidative rancidity) impairing their acceptability (Wasowicz et al., 2004). Lipid-containing foods are oxidized at different rates, resulting in their sensory and nutritional deterioration. One of the most important parameters influencing lipid oxidation is the degree of unsaturation of fatty acids. The presence of natural compounds with different chemical structures that exhibit antioxidant activity may also affect the oxidation rate (Gutfinger T., 1981). Furthermore, lipid oxidation reactions damage nutritional value because of the oxidation of vitamins, degradation of beneficial antioxidants, and loss of essential fatty acids and amino acids (Decker et al., 2010).

From harvest to consumption, cashew nuts are subjected to technological processes that include drying, storage, roasting or steaming, deshelling, peeling, and then secondary processing like salting, frying, grinding, cooking, and flavouring (Akujobi et al., 2018; Griffin & Dean, 2017; Lima et al., 2015), to satisfy consumer preferences such as colour, size, palatability, flavour, taste, and aroma (Gadani et al., 2017; Lima et al., 2015). To ensure the production of high-quality nuts, there is a need to understand the post-harvest processes of the nuts right from the field to the consumption stage. This paper describes the factors predisposing cashew kernel to lipid oxidation during the processing procedures.

Materials and Methods

Sample collection and processing procedure

Raw nuts were sourced from cashew farms at the Cocoa Research Institute of Ghana (CRIG), Bole. Raw cashew nuts (50 kg each) were steam boiled using a steam boiler (at a pressure of 8 kg/ms²) for 20 minutes. The steamed nuts were air-dried for 24 hours and then deshelled using a manual cashew kernel cutter to obtain wet unpeeled kernels. The unpeeled kernels were then oven-dried at 80°C for 2 hours to allow easy removal of the peels from the kernel. The peeled kernels were then sorted and graded according to different nut sizes. This was followed by roasting at 150-160°C for 20 minutes. Kernel samples were collected from each processing stage and analysed for total fat, FFA contents, and PV.

Determination of total fat

This was determined using the Soxhlet extraction method (AOAC, 1990). Each kernel sample was introduced into the Soxhlet extractor (Brand Biobase BFA-1S) containing 250 ml of petroleum at 60°C for complete oil extraction. The reagents used were of analytical grade. The total fat content was calculated as follows:



Conclusion

This study has shown that the processing of raw cashew nuts plays a significant role in the quality of fats in the cashew nuts. During the processing stages, heat was applied to the cashew kernel which led to changes in the PV and FFA. High levels of PV and FFA were recorded in the kernel which can result in fat deterioration and rancidity. The changes in the fat quality might have started from the field, making it important that the study should be carried out from the field to the consumption of nuts.

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EFFECTS OF DIFFERENT SOIL SUBSTRATES ON GERMINATION EMERGENCE AND GROWTH OF CASHEW VARIETIES (*ANACARDIUM OCCIDENTALE* L.) AT THE ISRA STATION IN SANGALKAM/SENEGAL

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Summary

Cashew tree (*Anacardium occidentale* L.) contributes to the socio-economic development of several West African countries, including Senegal, but several constraints limit its production and productivity. These include lower yields, ageing plantations and the use of non-performing planting material. A great deal of research has been carried out across West Africa to significantly improve cashew production and productivity. However, over the last few decades, the rapid expansion of cashew plantations in West Africa is likely to raise the issue of land availability in the near future, as well as the availability of land that is more suitable for cashew cultivation. Studies on the effect of different soil textures on cashew germination and growth are rare. The aim of this research is to study the germination and growth of two varieties (Vietnamese and local) in 5 different soil textures. Sandy, clay, sandy-clay, clay-sand and dune-sand soils. For this purpose, a split plot system was installed at the ISRA / Sangalkam research station in Senegal. Local (V1) and Vietnamese (V2) varieties were sown on the different textures (dune sand (T0), sandy (T1), clay (T2), sandy-clay (T3) and clay-sandy (T4)). The results showed that the germination rate varied according to variety and time ($P < 0.05$). The V2 variety obtained a germination rate of 56.67% compared with 36.67% for V1, while the emergence time was 26 days for V1 compared with 33 days for V2. Germination rates also varied according to soil texture: T0 (83.33%), T3 (75%), T1 (46.33%), T4 (25%) and T2 (8.33%). Growth parameters varied as a function of time ($P < 0.0001$). The highest height was obtained on T0 (31.7 cm) and the lowest on T3 (26.2 cm) at 90 days after sowing (90 DAS). Diameter and number of leaves varied according to variety ($P < 0.01$). V2 obtained an average of 12 leaves compared with 8 leaves/plant for V1 at 75 days after sowing. The largest diameters were obtained in V2 (0.69 cm) compared with 0.52 cm in V1. The Vietnamese variety on a sandy-clay substrate could help boost national cashew nut production.

Key words: *Anacardium occidentale* L, Substrates, Varieties, Germination, Growth parameters

Abstract

The cashew tree (*Anacardium occidentale* L.) contributes to the socio-economic development of several African countries, including Senegal. Production continues to face several constraints related to a drop in yield, ageing of plantations, high density and the use of non-performing plant material. Several researches are being carried out across West Africa to significantly improve cashew production and productivity. However, in recent decades, the meteoric rise of cashew plantations in West Africa should pose the problem of land availability and land that would be more suitable for cashew cultivation in the near future. It is in this context that Shelter For Life imported a variety from Vietnam in order to test its germination emergence, its adaptability on 5 soil substrates: sandy (T1), clay (T2), sandy-clay (T3), clay-sandy (T4) and dune sand (T0), in order to improve productivity in the SeGaBi zone. On these different substrates, the local (V1) and Vietnamese (V2) varieties were sown, following a split plot system. The results showed that the germination rate varies with variety and time ($P < 0.05$). V2 obtained a germination rate of 56.67% against 36.67% for V1 while the emergence time is 26 days for V1 against 33 days for V2. The germination rate also varies according to soil texture: T0 (83.33%), T3 (75%), T1 (46.33%), T4 (25%) and T2 (8.33%). Growth parameters varied with time ($P < 0.0001$). The highest height was obtained on T0 (31.7cm) and the lowest on T3 (26.2cm) at 90 days after sowing (90DAS). The diameter and number of leaves varied according to the variety ($P < 0.01$). V2 obtained an average of 12 leaves compared to 8 leaves/plant for V1 at 75DAS. The highest neck diameters were obtained in V2 (0.69 cm) compared to 0.52 cm in V1. The Vietnamese variety adapts well to the sandy-clay substrate. The Vietnamese variety on sandy-clay substrate could help boost national cashew nut production. The results obtained reflect only a first trend. Thus, it would be useful to continue the study to have more information on the behavior of the two varieties.

Keywords: *Anacardium occidentale* L, Substrates, Varieties, Germination, Growth parameters

1. INTRODUCTION

Cashew tree (*Anacardium occidentale* L.) is a plant of savannah zones, native to Brazil (Oluyole et al. 2017). It is produced mainly for its fruit, and cashew nuts remain highly prized in international trade. Cashew nuts contribute to the socio-economic development of many rural households around the world through the income they bring in for producers (Assih and Nenonene, 2022). It is a multi-purpose plant (pharmacopoeia, firewood and timber, food, oil, soap, chocolate, etc.) with considerable potential, especially in agroforestry systems (Niang, 2002; Djaha, 2010). World production of raw cashew nuts is estimated at 3,396,680 t for a cultivated area of 3,276,756 ha in 2019 (Semporé et al. 2021). Nut production in Africa is estimated at 2,334,405 t. Africa is the world's leading cashew nut producer and exporter, accounting for more than 50% of production (Semporé et al. 2021). In Senegal, the main production areas are Sédhiou, Kolda, Ziguinchor and Fatick (Nugawela et al. 2006). Today, cashew production is one of the most profitable activities, with a yield of 542 kg.ha⁻¹ (Samb, 2019). This evolutionary dynamic of cashew plantations was observed by Samb et al. (2018). The dependent population represents around

14.80% of the total population of these regions and contributes to feeding 20% of the population of these four regions (Fatick, Kolda, Sédhiou and Ziguinchor) (IRD/CEP 2, 2017). However, yields per hectare, estimated at 542 kg. ha⁻¹ in Senegal, are low compared with those in Guinea Bissau (1,200 kg.ha⁻¹) (Samb, 2019). Better still, out of a total production of 2,200,000 t, Senegal accounts for only 0.8% (Planetoscope, 2019). This situation can be explained by the lack of use of selected and improved varieties, and the ageing of plantations. Indeed, germination is one of the most sensitive stages in the life of a plant (Koochaki, 1991; Ly *et al.* 2015). Cashew growers face enormous difficulties due to several factors such as insufficient technical supervision, the use of low-productivity varieties and unknown origins (Sarr, 2002; Ndiaye *et al.* 2017). This situation of low productivity requires the involvement of research and development structures in order to provide the required solutions. It was against this backdrop that Shelter For Life's LIFFT-Cashew project, in conjunction with the Institut Sénégalais de Recherches Agricoles (ISRA), imported cashew seeds from Vietnam in order to improve quality and productivity in the SéGaBi zone. The aim of this research is to study “the effect of different soil substrates on germination and growth of cashew varieties under controlled conditions”.

The aim of this study is to help improve cashew nut productivity in Senegal.

Operationally, the study explores three specific objectives:

- Assessing the behaviour of a variety from Vietnam in a controlled environment;
- Identify the type of soil best suited to this origin;
- Offer growers the best soil/plant combination for growing this variety.

This research aims to test the hypotheses that:

- H1: the Vietnamese variety has a higher germination rate than the local variety;
- H2: the Vietnamese variety adapts better to the sandy-clay texture;
- H3: Plant growth and development are better in the Vietnamese variety.

2. MATERIALS AND METHOD

2.1 Description of the study environment

The research activities took place at the ISRA experimental station at Sangalkam (Latitude 14° 46' 44.30" N, Longitude 17° 13' 33.65" W, Altitude 19 m), located in the rural community of Sangalkam, which is situated in the Dakar region, Rufisque department (Figure 1).

The climate is sub Canarian, with clay, sand, sandy-clay and sandy-clay soils, rich in organic matter. In the hot, rainy season (June to October), average temperatures range from 25 to 30°C. In the cool season (November to April), average temperatures range from 19 to 23°C. Average annual rainfall varies around 400 mm (Camara *et al.*, 2013).

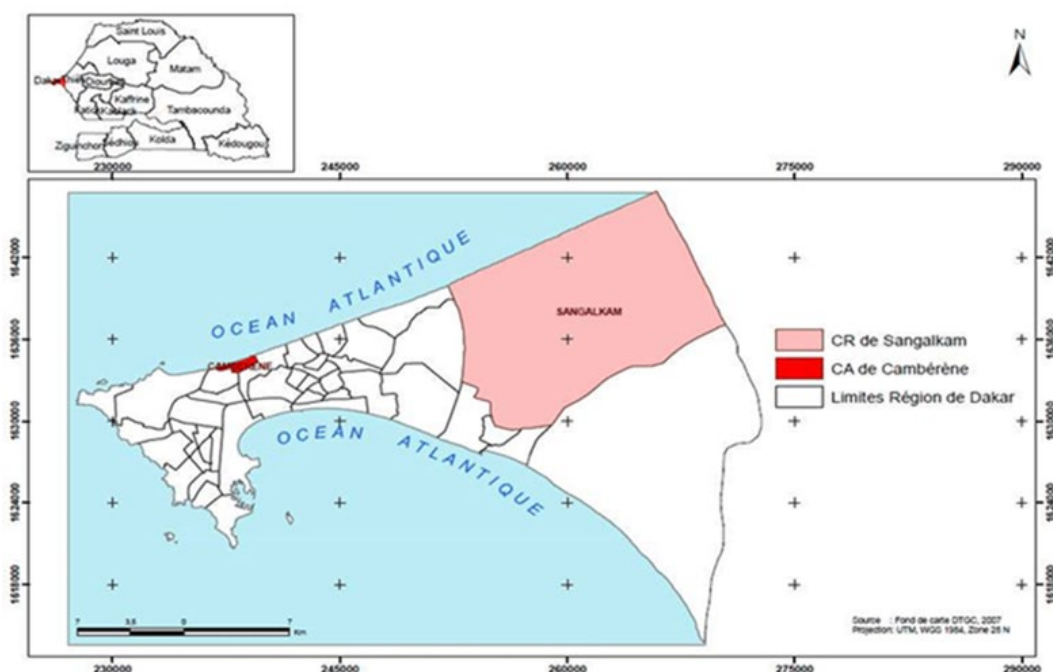


Figure 1 ISRA - CDH research station at Sangalkam in the Dakar region (Camara *et al.* 2013).

2.2 Plant material

The plant material to be tested consists of cashew nuts from Vietnam and a local Senegalese variety.

The cashew variety (PN1) is a new variety imported from Vietnam (V2) that is highly adaptable. The name attributed to this selection is: *SFL/ISRA 30723*. Originating from *TrueCoop /Vietnam*, it has the agronomic characteristics of fruiting from 10 to 15 fruits per cluster-1; a number of nuts between 140-160 grains.kg-1. This variety is already available from several multipliers in the SéGaBi region with pilot

growers, as well as from ISRA-NARI research centres (LIFFT, cashew Project). It is characterised by an upright growth habit, dark green leaves, flowering in bunches and a grey nut. This variety has a potential yield of 2,500-3,000 kg.ha⁻¹ (Le Quy Kha-FR, 2017). Seeds were imported in February 2023.

The nuts of the local variety (V1) used in this study yield between 250 and 400 kg.ha⁻¹ (Ndiaye *et al.* 2017). They were harvested in March 2023 at Keur Martin in the Fatick region of Senegal.

2.3. Experimental set-up

The experimental set-up is a split plot with 2 factors. The main factor studied is the variety with 2 levels; the local variety (V1) and the Vietnamese variety (V2) and the second factor studied is the soil texture with 5 levels; dune sand (T0), sandy soil (T1), clay soil (T2), sandy-clay soil (T3) and sandy-clay soil (T4). This makes a total of 10 treatments. The set-up consisted of 03 blocks spaced 1 m apart. Each block is 3.5 m long and 0.5 m wide, covering an area of 1.75 m². It is divided into 05 sub-blocks corresponding to the 05 soil substrates on which the two cashew varieties are randomised. Each block contained 20 sheaths and one seed was sown in each sheath.

The seeds were sown as shown in Figure 2.

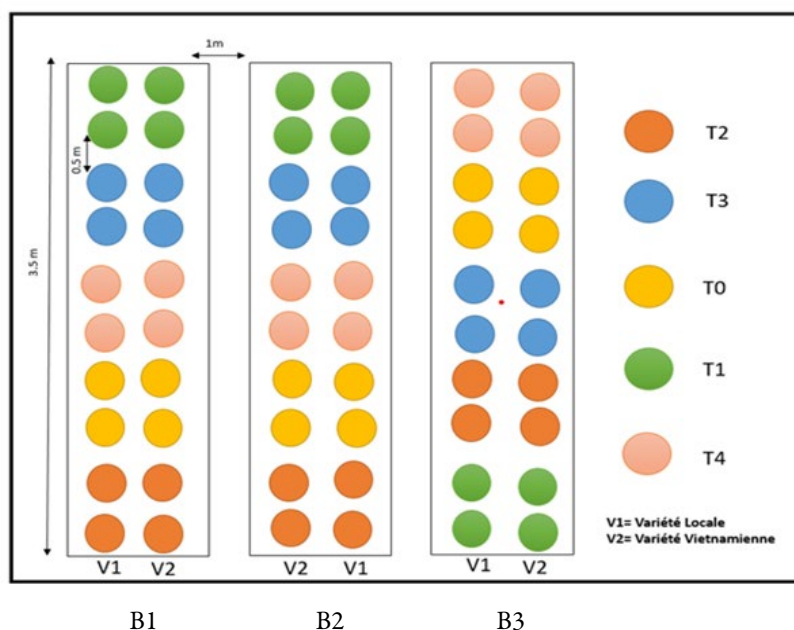


Figure 2 Split-plot experimental set-up

T3: The texture is made up of 2/3 sand and 1/3 clay;

T4: The texture is made up of 2/3 clay and 1/3 sand.

The potting substrate was made up of the following: 2/3 of a texture for 1/3 of well-decomposed manure except for control T₀.

2.4. Sowing nuts and nursery maintenance

The walnuts were sown on 5 September 2023 in the dorsal position and without pre-treatment in the different types of potted substrates in sheaths of the same dimensions (width: 14 cm; length: 24 cm). The nuts were buried in the substrates at a depth of 3 cm. After sowing, the sheaths were sufficiently watered. Manual watering cans were used to water the blocks at a rate of 24 litres per block per day for 30 days after sowing. A shade canopy was installed to limit heat stroke.

2.5. Data collected

Daily observations were made to record the dates of germination emergence and to count the number of germination events during the 30 days following sowing. Subsequently, observations on germination were made on a weekly basis because of the slow germination observed on certain substrates.

The following parameters were assessed:

- Germination rate (GR) = time by which 50% of the seeds have germinated (Come, 1970; Scott *et al.* 1984).
- Germination delay (GD) = time interval between sowing and the first germinated seeds (Bayarassou, 2011; Samb, 2015).

Thirty (30), forty-five (45), sixty (60), seventy-five (75) and ninety (90) days after sowing, measurements of diameter, height and number of leaves were taken in each block. The height of the main stems of the plants was measured using a graduated ruler (cm). The diameter at the collar of the plants was measured using a caliper. The number of leaves on each plant was also determined by counting.

Other observations included mortality after germination and the behaviour of the plants after emergence.

2.6. Data analysis

The final emergence rate (FER), germination speed (GS) and germination time (GT) were determined according to the following formulae:

$$\text{Final emergence rate: FER} = (\text{number of germinated seeds}) / (\text{total number of seeds sowed}) \times 100$$

To assess the vigour of the young plants, a comparison was made of plant height, diameter and number of leaves per individual. According to Alexandre (1977), the height/diameter ratio is an index of the respective vigour of the above-ground and below-ground parts of the plant. According to Devineau (1991), a high height/diameter ratio indicates a predominance of terminal growth over cambial growth and would be due to a defect in energy input. The higher the ratio, i.e. over 80, the more wiry and unkempt the plants (Hamawa *et al.* 2019).

Statistical analysis of the data was carried out using R software version 4.2.1. First, a Shapiro Wilk normality test (Shapiro *et al.*, 1965) was performed before the 4-factor ANOVA to identify the large sets and locate the level of difference between the treatments if the data were normal, and non-parametric Wilcoxon test and Kruskal-Wallis tests for abnormal data. In addition, the Tukey test was used to carry out a multiple comparison of the two means in order to identify the treatments in which a significant difference was noted.

3. RESULTS

3.1 Germination of seeds

3.1.1. Cumulative emergence rate over the 30 DAS (Days after Sowing)

The seeds sown in the experimental set-up were observed daily to monitor emergence after germination. First emergence was observed on the 14th day after sowing in V1. On day 15, first emergence was observed in V2.

During the 30 days after sowing, an emergence rate of 36.67% was obtained for V1 and 50% for V2. The germination rate (GR) was therefore faster with the Vietnamese variety than with the local variety. By 26 days after sowing, 50% of the seeds sown with the Vietnamese variety had germinated. The Wilcoxon test did not detect any significant difference in germination between the varieties (p-value = 0.6448).

The germination rate increased with each day for both varieties. From 26 days after sowing (DAS), no emergence was recorded for the rest of the 30 DAS (Figure 3).

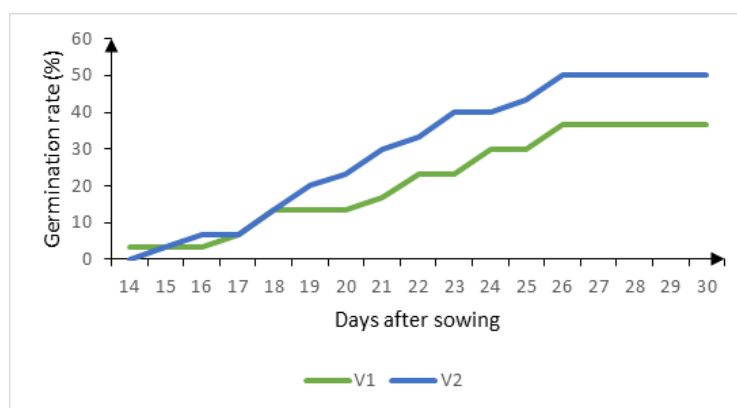


Figure 3 Emergence rate over time as a function of variety

3.1.2. Emergence rate

In total, the recorded emergence rate was 56.67% for V2 and 36.67% for V1. However, the Wilcoxon test showed no significant difference in the number of emergences between varieties for p-value = 0.3238 (Figure 4).

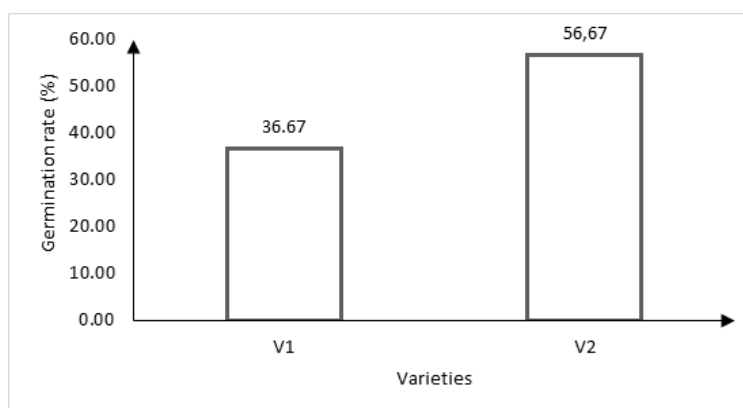


Figure 4 Germination emergence rate as a function of variety

3.1.3 Emergence rates during the 30 DAS (Days after sowing)

The substrates on which the first emergence was observed were T1 (14 days after sowing) followed by T0 (15 days after sowing). T3 recorded its first emergence on 16 days after sowing and T4 on 18 days after sowing.

There was no significant difference between the number of emergences and the texture at $p\text{-value} = 0.07771$. However, arithmetically, T0 recorded the highest emergence rate (83.33%), followed by T3 (75%), T1 (41.67%) and T4 (16.67%). However, it should be noted that no emergence was observed during the 30 days after sowing on T2 (Figure 5).

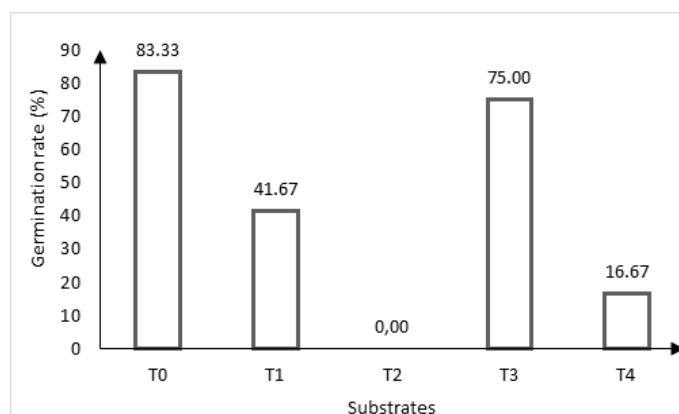


Figure 5 Emergence rate as a function of texture at 30DAS

3.1.4. Emergence after 30 days from sowing

The first emergence of the 100% clay texture was recorded at 33 days after sowing with the Vietnamese variety. In the same week, two emergences were recorded on T1. On T4, emergence was observed the following week.

Figure 7 shows the final emergence rate as a function of substrate, with T0 (83.33%), T1 (41.67%), T2 (8.33%), T3 (75%) and T4 (25%).

The emergence rate did not vary significantly according to substrate ($P=0.2114$). However, arithmetically, the highest germination rates were recorded on T0 (83.33%) and T3 (75%). T2 gave the lowest germination rate (8.33%) (Figure 6).

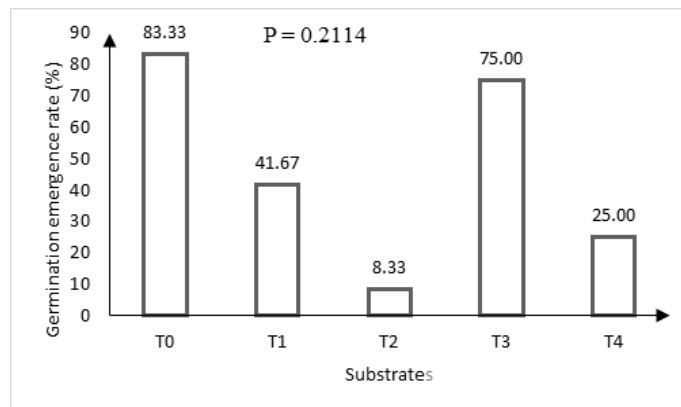


Figure 6 Total emergence rate as a function of texture

The emergence rate varied significantly with time ($P = 0.04677$). The highest emergence rate was obtained in the week of 21-27 DAS (53.57%) and the lowest was obtained in the week of 28-34 DAS (7.14%) (Figure 7).

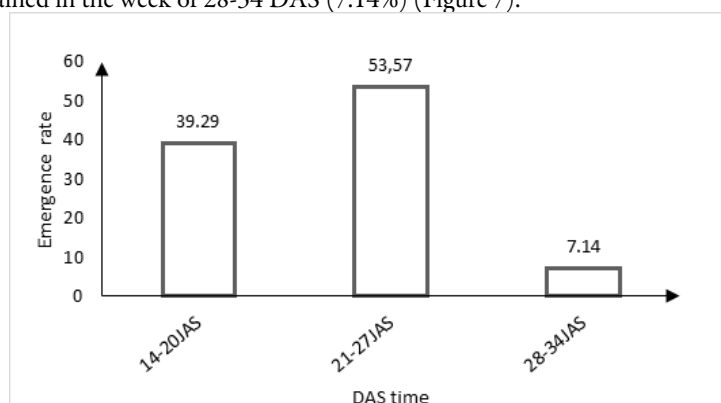


Figure 7. Emergence rate as a function of time

3.1.5. Plant mortality and defects as a function of variety and texture.

A growth defect was observed on T0. A delay in growth was observed with substrates T2 and T4 of the V1 variety. Germination emergence was also interrupted at T1. At 60 days, the mortality rate was relatively low at 14.29% for V1 and 10.71% for V2 (Figure 8b). The highest mortality rates were recorded in substrates T0 (10.71%) and T3 (7.14%) (Figure 8a).

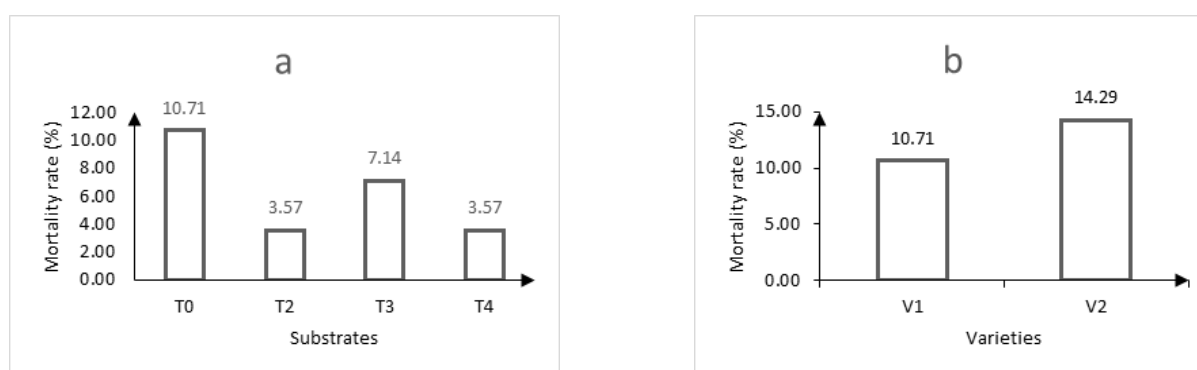


Figure 8 Mortality rates as a function of substrates (a) and varieties (b)

3.2. Variation in plant growth parameters by variety and texture

There was a highly significant difference ($P=0.000728$) between the average heights according to the substrates at 90 DAS. In terms of average height, texture T0 gave the highest (31.57 cm), followed by T1 (29.06 cm) and T4 (28.83 cm), while the lowest height was obtained with T3 (24.62 cm) (Figure 9). Diameter varied very significantly according to variety ($P=0.00413$) and soil texture ($P=0.00111$). The number of leaves showed a very significant difference between varieties ($P=0.00137$).

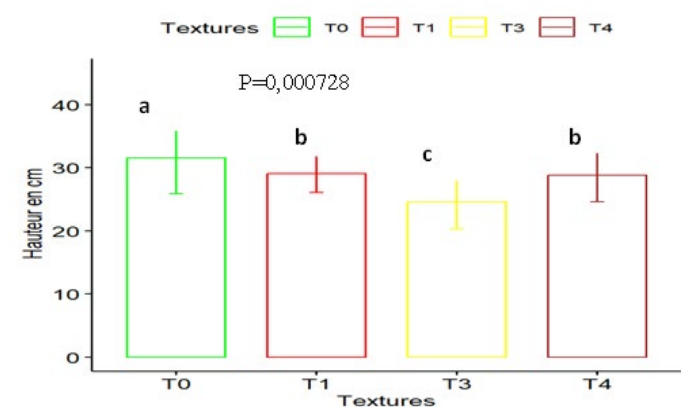


Figure 9 Variation in plant height according to substrate

Diameter varied very significantly according to variety ($P=0.00413$). Plants of V2 had the largest diameters (0.61 cm) compared with those of V1 (0.53 cm) (Figure 10). There was a highly significant difference in diameters between textures ($P=0.00111$). Plants in texture T1 had the largest diameters (0.67 cm on average), followed by those in T4 (0.60 cm) and T3 (0.58 cm). The smallest diameters were obtained with plants of texture T0 at 0.49 cm (Figure 11).

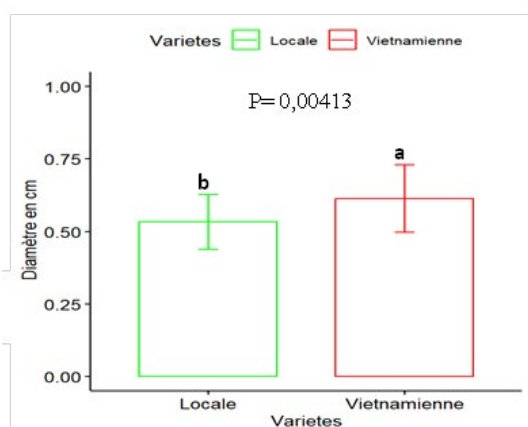


Figure 11 Variation in plant diameter according to variety

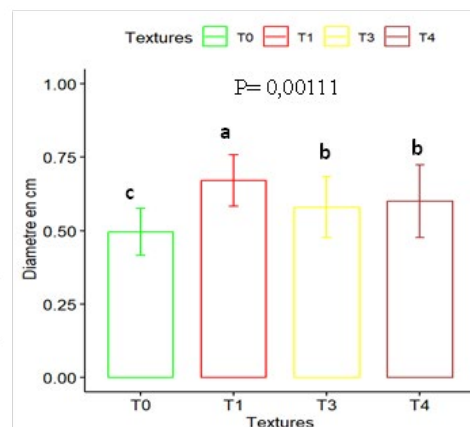


Figure 10 Variation in plant diameter as a function of texture

On average, V2 plants had more leaves (11 than V1 plants (9) (Figure 12).

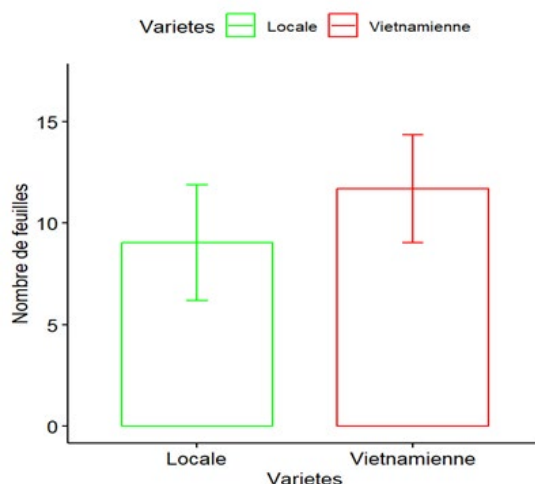


Figure 12 Variation in the number of leaves on plants as a function of variety

3.3. Plant growth parameters by variety and substrate as a function of time

3.3.1. Plant growth by variety at 60, 75 and 90 DAS

Table 1 shows the mean values of the growth parameters as a function of variety at 60, 75 and 90 days before harvest. These results show that there is no significant difference between heights according to variety. Diameter and number of leaves varied significantly according to variety. In fact, V2 had the best averages at 75 and 90 DAS. The H/D ratio of V1 is higher than that of V2, which means that V2 has better vigour than V1 at 90 DAS. However, plants from both varieties have good vigour (H/D less than 80).

Table 1 Growth parameters according to varieties at 60, 75 and 90 DAS

		60 DAS	75 DAS	90 DAS	P-value
Height	V1	27±7.74	27.78±7.74	28.92±7.74	ns
	V2	26.86±7.74	29.14±7.74	29.88±7.74	
Diameter	V1	0.50±0.12	0.52±0.12	0.58±0.12	0.00413
	V2	0.54±0.12	0.62±0.12	0.69±0.12	
Height/Diameter	V1	54.61	53.42	52.63±16.89	0.0425
	V2	51.41	48.18	44.35±16.89	
Number of sheets	V1	8±2	8±2	9±2	0.00137
	V2	11±2	12±2	12±2	

3.3.2. Plant growth as a function of substrate at 60, 75 and 90 days after sowing

Table 2 shows the mean values of growth parameters as a function of texture over time. Analysis of variance revealed a significant difference in height, diameter and H/D ratio as a function of substrate, with p-values of 0.00413, 0.0425 and 0.00137 respectively. The highest mean height was obtained on T0 (30.9 cm; 32.10 cm; 31.70 ±7.74 cm respectively at 60, 75 and 90 days after sowing) and the lowest on T3 (23.17 cm; 24.75 cm; 26.20 cm respectively at 60, 75 and 90 days after sowing).

T1 had the largest mean diameter at 0.61 cm, 0.65 cm and 0.77 cm on 60, 75 and 90 days after sowing respectively, while the smallest mean diameter was obtained on T0 (0.46 cm, 0.51 cm and 0.51 cm on 60, 75 and 90 days after sowing respectively).

The average number of leaves was 12 leaves/plant on T1 substrates at 90 days after sowing and 9 leaves/plant on T0 substrates at 90 days after sowing. The H/D ratio was highest on T0 (67.49) followed by T4 (57.43) at 60 days after sowing. It was lowest on T3 (38.95) and T1 (39.97) substrates at 90 days after planting.

These results show that the plants obtained the best vigour on the T3 and T1 substrates. The plants on substrate T0 had the lowest vigour.

Table 2. Growth parameters as a function of varieties at 60, 75 and 90 DAS

		60 DAS	75 DAS	90 DAS	P-value
Height	T0	30,9±7,74	32,10±7,74	31,70±7,74	0,000728
	T1	27,6±7,74	29,30±7,74	30,57±7,74	
	T3	23,17±7,74	24,75±7,74	26,20±7,74	
	T4	26,50±7,74	29,75±7,74	30,25±7,74	
Diameter	T0	0,46±0,12	0,51±0,12	0,51±0,12	0,00111
	T1	0,61±0,12	0,65±0,12	0,77±0,12	
	T3	0,525±0,12	0,55±0,12	0,67±0,12	
	T4	0,470±0,12	0,64±0,12	0,69±0,12	
Height/Diameter	T0	67,49±16,89	63,26±16,89	63,36±16,89	1,63e-08
	T1	45,40±16,89	44,84±16,89	39,97±16,89	
	T3	44,74±16,89	44,40±16,89	38,95±16,89	
	T4	57,43±16,89	48,46±16,89	43,93±16,89	
Number of sheets	T0	9±2	10±2	9±2	ns
	T1	9±2	11±2	12±2	
	T3	10±2	10±2	11±2	
	T4	10±2	11±2	11±2	

4. Discussion

4.1. Germination as a function of variety and texture

4.1.1. Germination as a function of variety

The present study revealed that germination emergence starts at 14th DAS, as previously observed by Lefebvre (1966) and Djaha et al. (2010). It was observed at 14th DAS in V1 and at 15th DAS in V2.

The germination rate per variety increases with time, remaining constant from 26th DAS. The average germination time for cashew seeds under the experimental conditions was 26 days for variety V1 and 33 days for variety V2. A total of 56.67% germination was observed for variety V2 compared with 36.67% for variety V1. This result confirms hypothesis 1, according to which the Vietnamese variety has a higher germination rate than the local variety. This result can be explained by the fact that the seeds did not undergo pre-treatment or a flotation test. According to Touré *et al.* (2018), germination rate is a function of variety, pre-treatment and the position of the nuts in the soil. Seed storage time could also have an influence on germination, as shown by Lefebvre (1966), according to whom the germination rate of *A. occidentale* seeds varies between 93 and 98% in the first few months after harvest. This rate falls to 55% at 8 months and 45% at 12 months. The observed discontinuity in germination may be explained by the fact that the seeds are not all at the same stage of physiological development at a given time, as observed by Parisot (1988) on mango. Furthermore, the difference in germination behaviour observed between seeds from the two varieties is attributable to differences in intrinsic characteristics (Paulo et al. 2002; Djaha et al. 2010). The difference in emergence rate between the varieties could be explained by the fact that the germination capacity of the Vietnamese variety is higher than that of the local variety. This result is in line with that of Fané (2021) who states that the origin of the varieties influences germination. The results obtained on germination rate are higher than those of Djaha et al (2010) who obtained germination rates of 40.83 and 37.50% respectively for the varieties LAX1432 and LAX2081. However, these results are lower than those of Touré et al. (2018) who obtained the highest germination rates for the varieties James (79.16%) and Henry (63.58%) and the lowest for Costa Rica (51.67%). This difference could be explained by the fact that they performed a germination and flotation test but also by the fact that they used the same type of substrate.

4.1.2. Germination as a function of texture

First emergence was observed around two weeks after sowing (14, 15 and 16 DAS) in substrates T1, T0 and T3. At these dates, there was no emergence in T4 until 18 DAS and T2 until 33 DAS. The emergence rate according to the substrates showed that the highest germination rate was obtained on T0 (83.33%) and T3 (75%), followed by T1 (46.33%). The lowest rates were observed on T4 (25%) and T2 (8.33%). The shortest germination times were obtained with substrates T0, T1 and T3. This result can be explained by the fact that the T0, T1 and T3 substrates are lighter than the T4 and T2 substrates. This is in line with the experience of Lacroix (2003), who states that *A. occidentale* prefers loose, deep soil. He also states that the soil should be sandy or well drained. Cashew likes light, deep soil that is not asphyxiated (Lacroix, 2003). The emergence rates obtained in T0 and T3 could be explained by the fact that the seeds sown in these substrates were more apt to germinate than those sown in T1. In fact, the seeds had not undergone any pre-treatment, which may favour unequal initial characteristics between the seeds in terms of their germinative capacity. The low emergence rates obtained on substrates T4 and T2 could be explained by the fact that the heavy texture does not favour emergence. Cashew enjoys deep, loose, sandy or gravelly soil. It is even used to revegetate coastal dunes to prevent erosion, even though the yield is almost nil. On the other hand, it fears hardened horizons that prevent root penetration (Fine Media, 2017). Joker (2003) and Assih and Nenonene (2022) state that sandy or sandy-loam soils are best suited to cashew nut production because they are generally deep and drain water well. Cashew trees prefer light, sandy, deep, well-drained soils with 25% clay (Lautié *et al.* 2001).

4.2 Plant growth as a function of variety and texture

The study showed that growth parameters varied as a function of time ($P < 0.0001$). The type of variety had an influence on the diameter and number of leaves of the plants ($P < 0.05$). Plants of the Vietnamese variety had the largest diameters, with a mean value of 0.61 cm compared with 0.53 cm for the local variety. Regarding variation in plant height, there was a highly significant difference ($P = 0.000728$) between substrates. The highest height was obtained with T0 (31.57 cm) followed by T1 (29.06 cm) and T4 (28.83 cm), the lowest height was obtained with T3 (24.62 cm). The largest diameters were recorded with texture T1 (0.67 cm), followed by T4 (0.60 cm) and T3 (0.58 cm). The smallest diameters were obtained with plants of texture T0 (0.49 cm). In terms of vigour, the H/D ratio showed that plants of texture T3 had the best vigour (38.95), followed by texture T1 (39.97). The lowest vigour was obtained with plants of texture T0 (63.36). This result can be explained by the fact that the absence of manure in T0 favours plant development in height rather than in diameter, as stated by Smirnov et al (1977), according to whom manure is an organic fertiliser of prime importance, containing all the nutrients required by the plant for its development. The yellowing of the leaves observed on T0 could be caused by the lack of nutrients in the substrate. The difference in diameter between the varieties can be explained by the intrinsic characteristics of the varieties. The H/D ratio of the plants is less than 80, which can be explained by the fact that cashew plants less than two months old are at a stage in their development cycle when growth in height is not favoured over growth in diameter (Frieden et al. 2004). According to Devineau (1991), a high H/D ratio means that terminal growth predominates over cambial growth and is due to a defect in energy inputs. The higher the ratio, i.e. over 80, the more wiry and poorly behaved the plants (Hamawa et al. 2019). These height results are higher than those of Touré et al. (2018) obtained on the yellow Benin variety with the highest height of 13.97 ± 0.32 cm at 90 DAS. The diameter and number of leaves obtained are low compared with the results of Coly (2016), who obtained an average collar diameter of 0.95 cm and an average number of leaves per plant of 12. The difference in growth observed between the varieties may be linked to the adaptive capacity of each variety, especially as the latter is more significant for Sahelian species during the early growth phases (Ado, 2017).

5. Conclusion and Outlook

This study made it possible to evaluate the germination and growth parameters of two cashew varieties of different origins and to determine the best substrate for these parameters. The results show that the origin of the seed has an influence on the germination and growth of cashew seedlings, depending on the texture of the soil. Naturally sown seeds of the Vietnamese variety gave a better emergence rate than the local variety. This difference confirms hypothesis 1, according to which the Vietnamese variety has a higher germination rate than the local variety. The highest emergence rate was recorded on the substrate (T3) for the Vietnamese variety and on T0 for the local variety; this confirms hypothesis 2 according to which the Vietnamese variety adapts better to the sandy-clay texture (T3).

The best substrates for good plant development were the sandy-clay substrate (T3) and the sandy substrate (T1), in which the plants showed better vigour (H/D less than 80). In short, the best vigour was obtained with the Vietnamese variety and the sandy-clay substrate (T3), confirming hypothesis 3, according to which plant growth and development are better with the Vietnamese variety.

However, further studies should be undertaken on the:

- effect of irrigation on germination and growth of cashew varieties;
- effect of temperature on the growth of cashew seedlings in the nursery;
- monitoring of plantations and pathogen attacks on the Vietnamese cashew variety in Senegal;
- effect of grafting local and Vietnamese varieties on plant growth and development;
- effect of clay dose on germination and growth of cashew varieties in Senegal.

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SELECTIVE MEDIA FOR ISOLATION OF ENTOMOPATHOGENIC FUNGI FROM CASHEW INSECT PESTS AND SOILS IN GHANA

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ABSTRACT

Different selective media were developed using basal media; Sabouraud dextrose agar (SDA) and Potato dextrose agar with yeast extract (PDAY) to isolate potential entomopathogenic fungi (EPF) from cashew insect pests and soils in Ghana. The agar media were amended with various antibiotics (chloramphenicol, streptomycin, ampicillin, rifampicin, gentamicin, penicillin) and the antifungal agent nystatin to form the selective media. The selective media developed were SDA with nystatin, ampicillin, and rifampicin (SDAN-AR); SDA with gentamycin (SDA-G); PDAY with chloramphenicol and nystatin (PDAY-CN); PDAY with rifampicin and nystatin (PDAY-RN); PDAY with penicillin and nystatin (PDAY-PN). The selective media were inoculated with soil sourced from different cashew farms in the Eastern Region of Ghana (Begoro, Aframase and Asesewa) for the isolation of potential EPF. Cashew insect pests including coreid bugs (*Pseudotheraptus devastans* and *Anoplocnemis curvipes*), and cashew mosquito bug (*Helopeltis* spp.) collected from these cashew farms were directly plated on the selective media for isolation of potential EPF. Soil was used to bait EPF using fruit fly larvae after incubation at 25 ± 2 °C. SDAN-AR, SDA-G and PDA-RN were the best media for the isolation of potential entomopathogens from soil while suppressing the growth of bacteria and yeast. EPF isolated directly from cashew insect pests and soil included *Beauveria* spp., *Metarhizium* spp., *Aspergillus* spp., *Paecilomyces* spp. and *Fusarium* spp. The use of EPF in cashew plantations will contribute to a sustainable and environmentally friendly way of controlling cashew insect pests.

Keywords: Entomopathogenic fungi, selective media, cashew insect pests, soil baiting, sustainable pest control

1.0 Introduction

Cashew farms in Ghana are often attacked by insect pests such as coreid bugs (*Pseudotheraptus devastans* and *Anoplocnemis curvipes*) and cashew mosquito bug (*Helopeltis* spp.) leading to devastating losses if not curtailed (Dwomoh et al., 2008). These insect pests are normally controlled using synthetic insecticides leading to potential negative effect on the environment and human health (Mazih 2015). Generally, the search for alternative means of controlling pests in agriculture has become necessary because of the adverse effects of using synthetic pesticides (Hallouti et al., 2020). Consequently, using entomopathogenic fungi (EPF) to control cashew insect pests can be considered environmentally friendly and sustainable (Fernandez et al., 2010). The use of EPF as an example of biological control agent has minimal effect on the environment because of the absence of residues and rather tend to enhance network balance of the ecosystem (Fitriana et al., 2021). EPF when applied can spread within the ecosystem and build up populations for sustainable pest control (Scheepmaker and Butt 2010).

Entomopathogenic fungi can be obtained directly from insect cadavers, soils or plant rhizosphere through serial dilutions or baiting using selective media (Singh et al., 2016). Soils tend to serve as the natural habitat for EPF (Hallouti et al., 2020) and harbour the inoculum of these desirable pathogens. The essence of using selective media for pathogen isolation from insect cadavers and soils is to suppress the growth of undesirable yeasts and bacteria while promoting the growth of potential EPF (Fernandez et al., 2010). That is, selective media must contain the essential nutrients for the growth of targeted EPF and the right amounts of antimicrobial agents (antifungal and antibiotic) to prevent undesirable organisms from growing (Luz et al., 2007). The isolated EPF can then be used for bioassay to assess efficacy against insect pests of interest. The effective EPF can subsequently be mass produced for field application in controlling insect pests. EPF as a biological control agent is often incorporated into integrated pest management system (IPMS) for sustainable pest control. This would reduce over reliance on synthetic pesticides and the avoidance of potential residues for healthy foods.

It is reported that temperature is a key factor in determining the pathogenicity of EPF against a particular insect pest (Tesfaye and Seyoum 2010). Temperature and relative humidity tend to vary from region to region. Consequently, obtaining indigenous EPF from a specific environment is essential in ensuring its effectiveness against the insect pests of interest within that environment (Sayed et al., 2019). Therefore, the effectiveness of exogenous EPF can be influenced by the prevailing environmental conditions and may even pose as an ecological risk to native species (Jaronski, 2010; Goble et al., 2011). In effect, using an indigenous EPF as a biocontrol agent enhances the chances of effective pest control (Goble et al., 2011). This study therefore aims at identifying selective media for the isolation of indigenous EPF from cashew soils in Ghana and insect cadavers for the management of cashew insect pests.

2.0 Materials and Methods

2.1 Development of selective media

Sabouraud dextrose agar (SDA) and Potato dextrose agar with yeast extract (PDAY) were prepared according to the manufacturer's recommendations as basal media for the development of the various selective media. Antibiotics and antifungal agents were then added to

form a specific selective medium. SDA and PDAY media without antibiotics and antifungal agents were used as control plates.

PDAY-CN

PDA (CMO 139, Oxoid Ltd) was prepared using the concentration recommended by the manufacturer (39 g/L). Yeast extract (1 g/L) and chloramphenicol (0.5 g/L) were then added to the agar solution. The solution was autoclaved at 121 °C for 15 minutes. The medium was left on the bench to cool to 45-50 °C and nystatin (50 mg/L) was added. About 30 mL of the molten PDAY-CN medium was then poured into Petri dishes in a flow cabinet. The PDAY-CN plates were placed in sterile bags and kept in the fridge at 4 °C for use later.

PDAY-RN

PDA with yeast extract was prepared as previously described without chloramphenicol. The solution was autoclaved at 121 °C for 15 minutes and allowed to cool to 45-50 °C. Rifampicin (10 mg/L) and nystatin (50 mg/L) were then added to the molten medium to form PDAY-RN selective medium. About 30 mL of the molten medium was poured into Petri dishes and stored at 4 °C for use later.

PDAY-PN

PDA with yeast extract (PDAY) was prepared as previously described without chloramphenicol. The solution was autoclaved at 121 °C for 15 minutes and allowed to cool to 45-50 °C. Penicillin G (0.4 g/L) and nystatin (50 mg/L) were then added to the molten medium to form PDAY-PN selective media. The plates were poured and stored as previously described.

PDAY-AN

PDAY was prepared as previously described. The media solution was autoclaved at 121 °C for 15 minutes and allowed to cool to 45-50 °C. Ampicillin (200 mg/L) and nystatin (50 mg/L) were added to the molten media to form PDAY-AN selective media. The plates were poured and stored as previously described.

PDAY-GN

PDAY was prepared as previously described. The solution was autoclaved at 121 °C for 15 minutes and allowed to cool to 45-50 °C. Gentamicin (0.05 g/L) and nystatin (50 mg/L) were added to form PDAY-GN selective media. The media were poured and stored as previously described.

SDAN-AR

SDA was prepared according to manufacturer's recommendations (65 g/L) and autoclaved at 121 °C for 15 minutes. The molten media was allowed to cool to 45-50 °C. Nystatin (50 mg/L), ampicillin (200 mg/L) and rifampicin (10 mg/L) were then added to form SDAN-AR selective media. The media were poured and stored as previously described.

SDA-G

SDA was prepared as previously described and autoclaved at 121 °C for 15 minutes. The molten media was allowed to cool to 45-50 °C and Gentamicin (0.05 g/L) was added to form SDA-G selective media. The media were poured and stored as previously described.

2.2 Collection of soil from cashew farms

Soil samples were collected from cashew farms in the Eastern Region of Ghana; Begoro (Lat: 6° 23' 29.8536" N and 0° 22' 46.3584" W), Aframase (Lat: N 6°21'4.75812" & Lon: W0°4'31.26") and Asesewa (Lat: 6.399516, & Lon: -0.141748). At each location, soil samples were collected randomly from three spots (up to 10 cm) and bulked.

2.3 Inoculation of soil onto selective media

Serial dilutions of soil from each location were carried out using sterile distilled water (SDW) at the CRIG Mycology laboratory to produce different soil dilutions (101, 102, 103, 104, 105 and 106). Aliquot (100 µl) of each soil dilution was used to inoculate the various selective media. The inoculated plates were incubated at 25 °C for 7 days. The number of fungal, bacterial and yeast colonies growing on the plates was recorded at the end of the incubation period. The microbial colony counts of the different selective media and locations were compared using Microsoft Excel (Office 365 2023).

2.4 Soil bating

Soil samples from the same sources in the Eastern Region were sieved to remove unwanted materials such as stones and debris. The fine soil samples were placed in a 50 mL plastic cup and moistened with SDW. Five larvae of fruit fly (*Drosophila* spp.) were placed in each soil sample and covered with net to enhance aeration. The inoculated soil samples were incubated at room temperature (25±2 °C) for 3-7 days. Fungal organisms growing on dead larvae after the incubation period were isolated onto antibiotic amended SDA media plate for storage and identification.

2.5 Isolation of EPF from insect

Cashew insect pests (*Pseudothrips devastans*, *Anoplocnemis curvipes*, and *Helopeltis* spp.) randomly collected from cashew farms in the Eastern Region (Begoro, Aframase and Asesewa) were kept at CRIG insectary until death. The insect cadavers were surface sterilized with a 1 % sodium hypochlorite solution for 3 minutes and dried under the flow hood for approximately 30 minutes. The insect cadavers were individually placed on the various selective media and incubated at 25 °C for 3-7 days until growth was observed on plate. Potential EPF were isolated onto clean antibiotic amended SDA plate for storage and used later.

2.6 Identification of EPF

To obtain pure cultures of the potential EPF, mycelial colony growing on the agar plates were sub-cultured twice onto antibiotic amended SDA media plate using single hyphal tip method. Culture morphology and microscopic characteristics of pure cultures were used to identify the isolates with the aid of identification manuals (Mathur and Kongsdale, 2003; Humber, 2005; Kirk et al., 2008).

3.0 Results

3.1 Development of selective media

Seven selective media containing different antibiotics and antifungal agents were developed (Table 1).

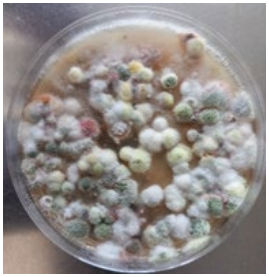
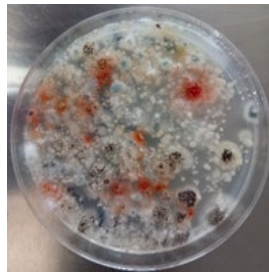
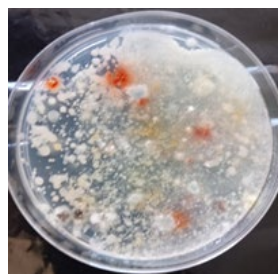
Table 1: Selective media developed containing different agar and antibiotics.

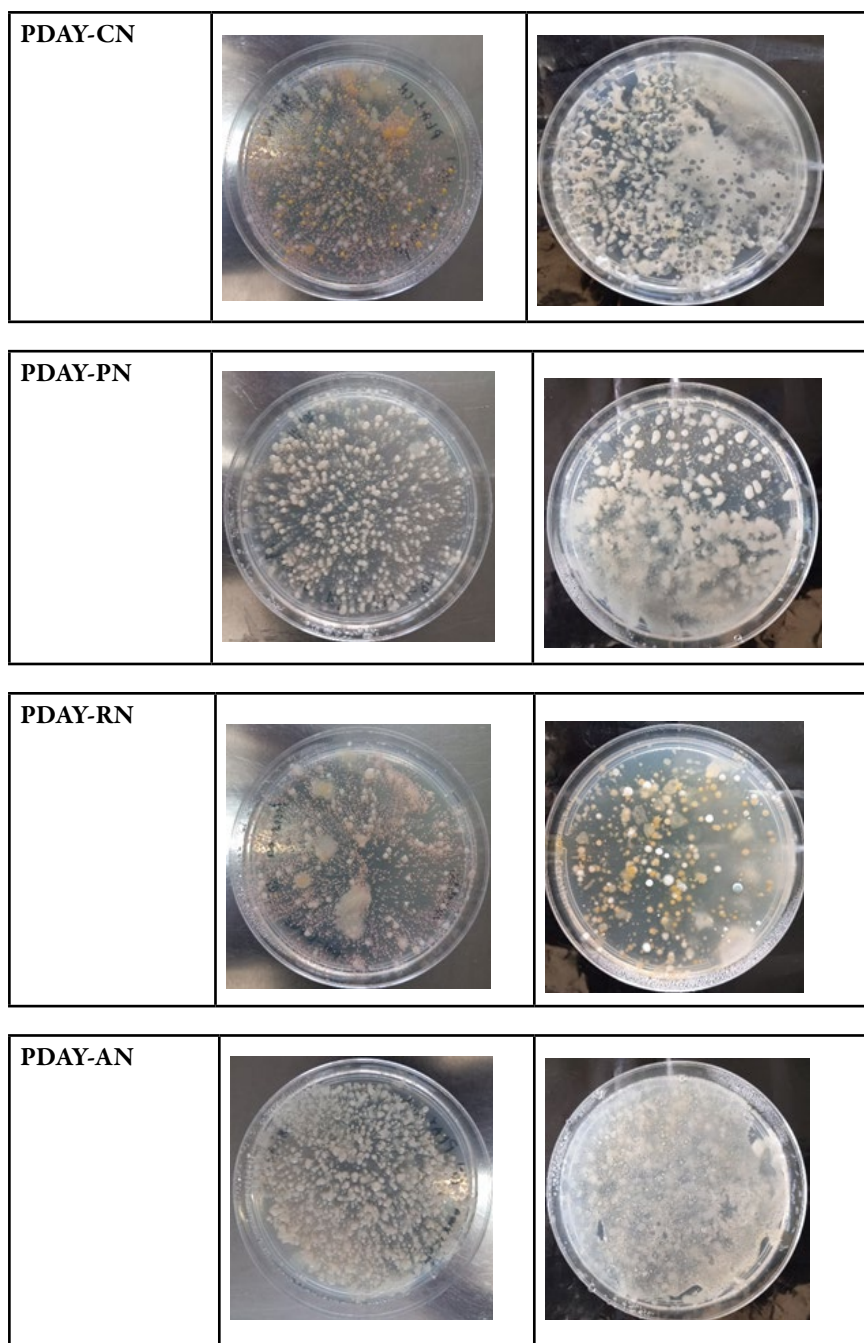
Selective media	Constituent
PDAY-CN	Potato dextrose agar, yeast extract, chloramphenicol and nystatin
PDAY-RN	Potato dextrose agar, yeast extract, rifampicin and nystatin
PDAY-PN	Potato dextrose agar, yeast extract, penicillin G and nystatin
PDAY-AN	Potato dextrose agar, yeast extract, ampicillin and nystatin
PDAY-GN	Potato dextrose agar, yeast extract, gentamicin and nystatin
SDAN-AR	Sabouraud dextrose agar, ampicillin, rifampicin and nystatin
SDA-G	Sabouraud dextrose agar and gentamicin

3.2 Selection of optimum selective media for EPF isolation

Inoculating different selective media with soils from different cashew farms resulted in growth of mainly fungal, bacterial and yeasts colonies. Generally, antibiotic and nystatin amended PDAY plates were dominated by bacteria and yeasts colonies in comparison with that of SDA plates which had mainly fungal colonies (Table 2). SDA amended plates promoted fungal growth while PDAY ones promoted more bacteria and yeasts growth. This was consistent with Aframase and Asesewa soil inoculated plates (Figure 1).

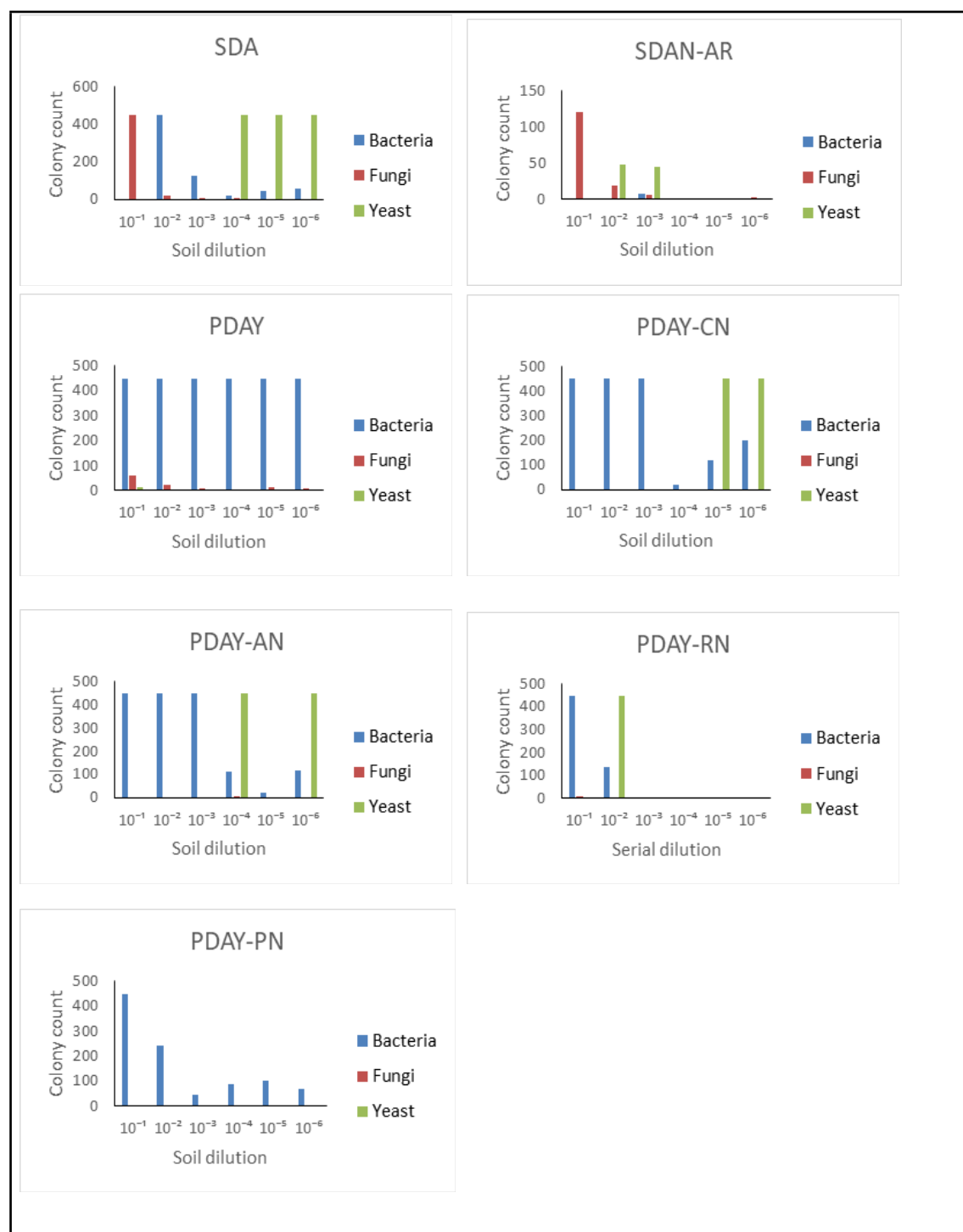
Table 2: Colonies of microorganisms growing on different selective media of 101 dilution soil from two cashew farms in the Eastern Region.

Media	Asesewa	Aframase
SDA		
SDAN-R		
PDAY		

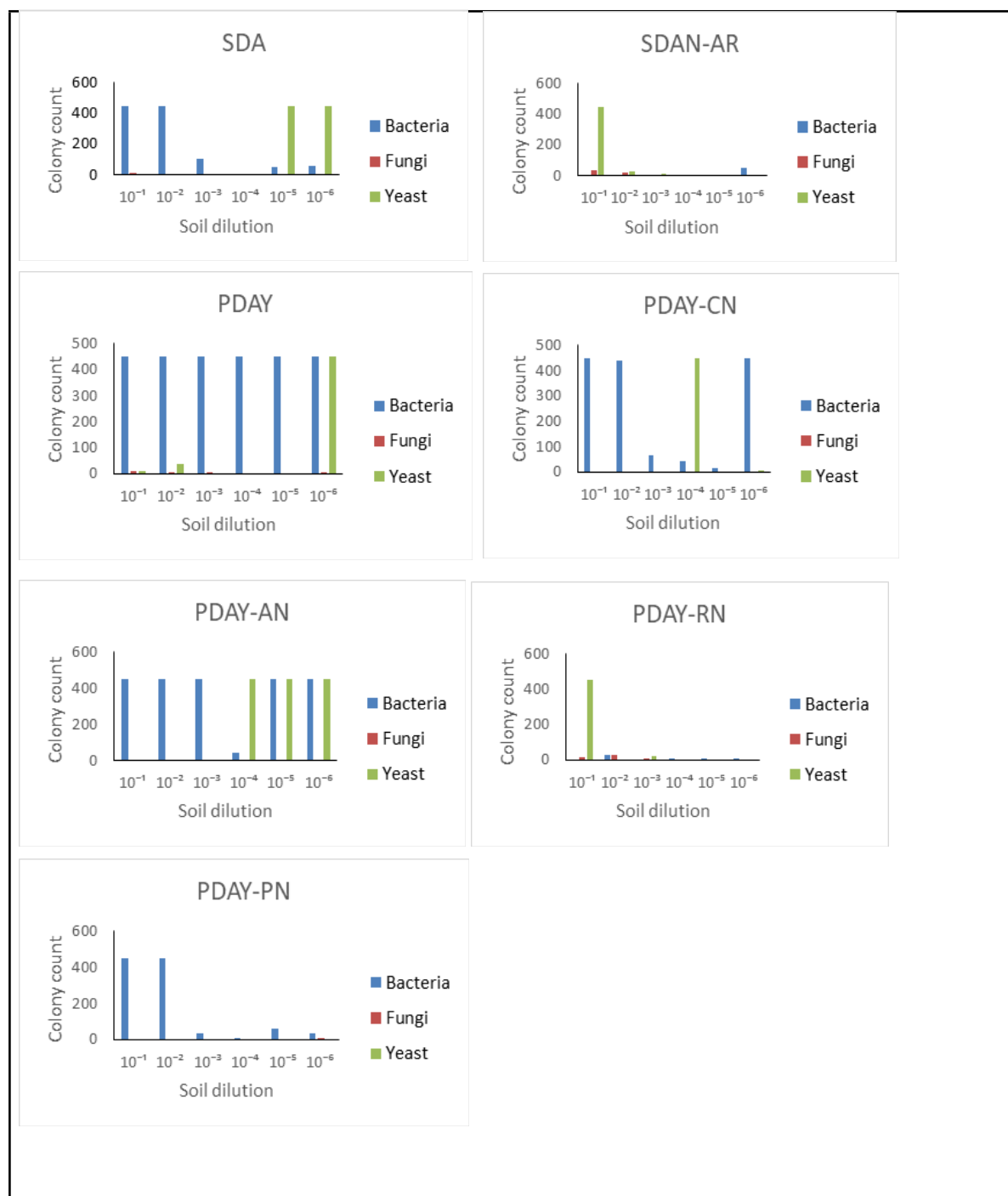


SDAN-AR was the best media for isolating potential EPF from Asesewa and Aframase soils (Figure 1). However, PDAY-RN and SDA-G promoted fungal growth of Begoro soil samples. Although PDAY-GN promoted fungal growth of Begoro soil it did not inhibit bacteria and yeast colonies. In contrast, SDA-G, SDAN-AR and PDAY-RN completely inhibited bacterial and yeast growth while promoting fungal growth for all dilutions of Begoro soil.

(A)



(B)



(C)

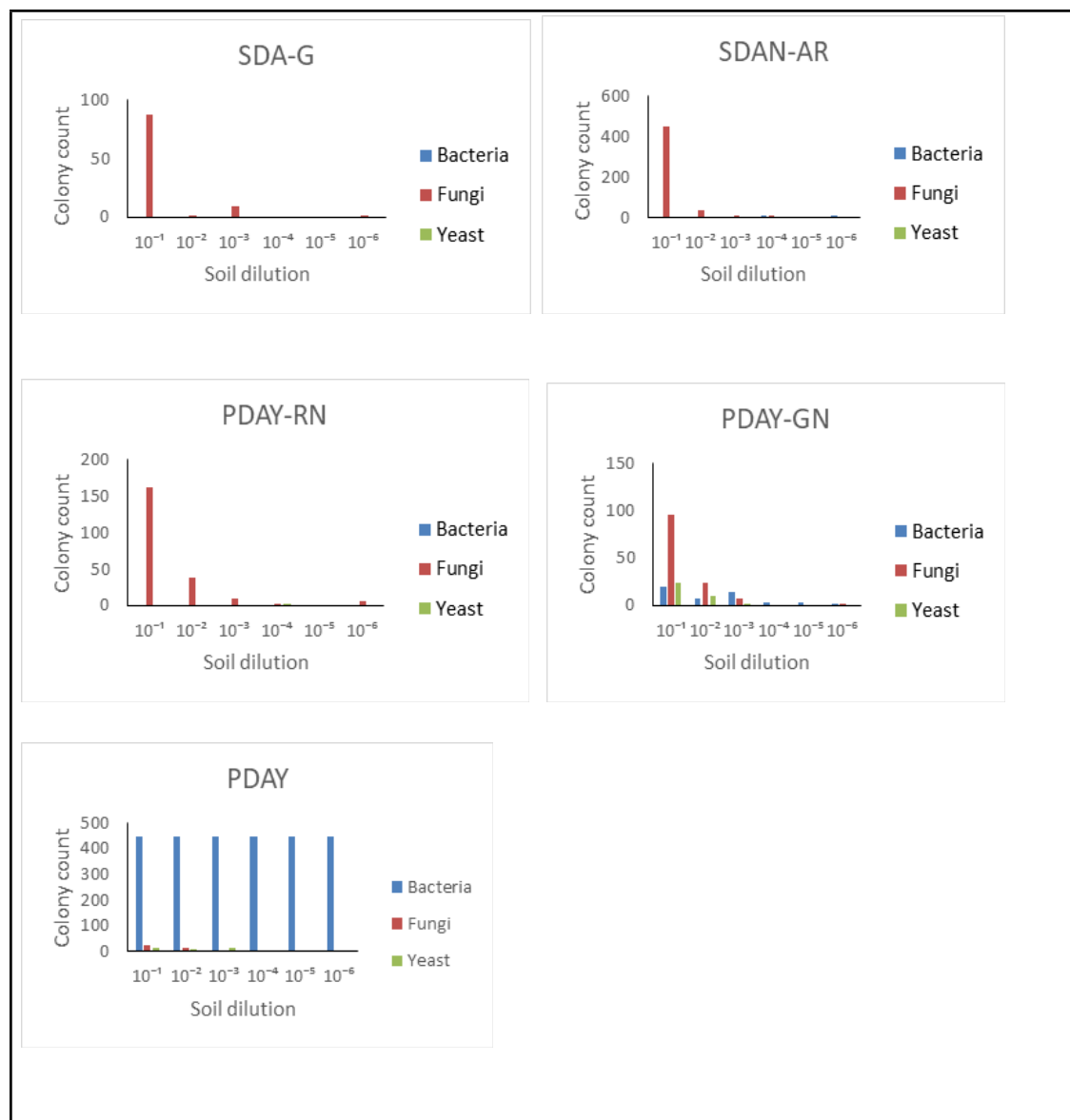


Figure 1: Colony count of soil samples from cashew farms in Asesewa (A), Aframase (B) and Begoro (C) after inoculation of selective media and incubation at 25°C for 7 days. Begoro soil samples were not necessarily exposed to the same type of selective media as with Aframase and Asesewa. The maximum colony count was restricted to 500 for ease of comparison.

3.3 Isolation and identification of EPF from different sources

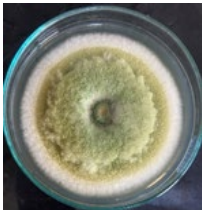
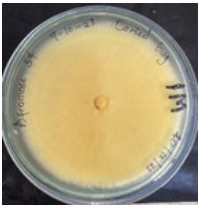
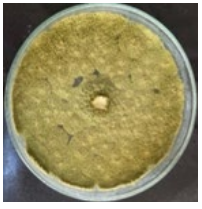
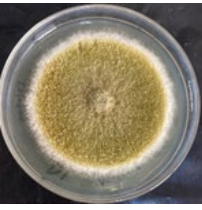
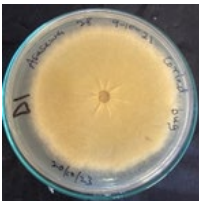
Potential EPF were isolated directly from insect cadavers growing on media after incubation. Similarly, putative EPF were isolated from larvae of fruit fly after inoculating on soils and incubation (Figure 2).

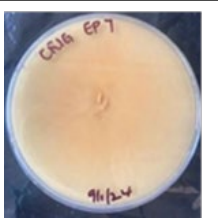
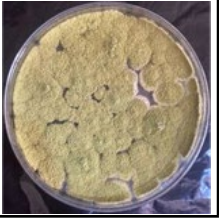


Figure 2: (A) Potential EPF growing directly on cadaver of cashew coreid bug after direct inoculation on SDAN-AR and (B) Soil baited with fruit fly larvae showing initial growth of putative EPF.

The EPF cultures isolated from cashew insect pests and soils had different characteristics on SDA plates. Isolates with greenish mycelia and whitish margins were identified as *Aspergillus* and *Paecilomyces* (Table 3). *Fusarium* isolates had fluffy and cottony mycelium with pinkish colour on the reverse plate. Isolates identified as *Metarhizium* had greenish-brownish mycelium while *Beauveria* cultures were powdery and whitish on SDA.

Table 3: Identity and culture features of EPF isolated from different sources.

Identified organism	Source town	Isolation method	Morphology	
			Front	Reverse
<i>Aspergillus</i>	Aframase	Insect		
<i>Metarhizium</i>	Asesewa	Insect		
<i>Paecilomyces</i>	Asesewa	Insect		
<i>Beauveria</i>	Aframase	Insect		
<i>Beauveria</i>	Asesewa	Insect		
<i>Beauveria</i>	Asesewa	Insect		

<i>Fusarium</i>	Aframase	Insect		
<i>Metarhizium</i>	Begoro	Soil baiting		
<i>Metarhizium</i>	Aframase	Soil baiting		
<i>Fusarium</i>	Asesewa	Soil baiting		

4.0 Discussions

Entomopathogens are becoming increasingly important in combating insect pests in a sustainable way to reduce negative effect of synthetic pesticide on the environment and human health (Fernandez et al., 2010). The effort to isolate potential EPF from insects and soils is often hampered by the presence of undesirable yeasts and bacterial colonies in culture plates inhibiting the growth of targeted pathogens of interest (Luz et al., 2007). Consequently, finding the media which would allow potential EPF to grow while suppressing that of undesirable microorganisms is of great importance. Screening soils from three different cashew farms in the Eastern Region of Ghana showed that antibiotic and antifungal amended SDA media generally promoted fungal growth than PDAY. This is consistent with Deb et al. (2017) who reported SDA amended media as the best in supporting vegetative growth of EPF in comparison with other agar media. That is SDA amended media tend to promote growth of potential EPF if the appropriate concentrations of antifungal and antibiotic agents are present. In contrast, the PDAY plates were often dominated by bacteria and yeast colonies inhibiting potential entomopathogens. Meanwhile, Rangel et al. (2010) used PDAY agar media amended with gentamicin and dodine to isolate several EPF from contaminated environments. The difference with our current study was their inclusion of the antifungal agent dodine in the selective media which is well known to control undesirable yeasts and other contaminants when isolating EPF from soils (Beilharz et al., 1982; Chase et al., 1986; Fernandes et al., 2010).

For Asesewa and Aframase soils, SDAN-R selective media promoted more fungal growth while inhibiting bacteria and yeast. Consequently, SDAN-R was the best media for isolation of potential EPF from soil. Similarly, SDA-G, SDAN-AR and PDAY-RN were the best selective media for isolation of potential EPF from Begoro soil. Clearly for all the three locations, SDAN-AR was consistent in promoting fungal growth while suppressing bacteria and yeast. SDAN-AR media were subsequently used for isolation of potential EPF from the direct plating of cashew insect pest cadavers and fungal isolates from soil baiting. The isolated EPF from direct plating of insect cadavers and larvae included *Beauveria* spp., *Metarhizium* spp., *Aspergillus* spp., *Paecilomyces* spp. and *Fusarium* spp. These isolates have been widely reportedly as effective entomopathogens against insect pests of various crops (Fitriana et al., 2021; Idrees et al., 2021; Sayed et al., 2019). For instance, Idrees et al. (2021) demonstrated the use of *B. bassiana* and other EPFs to control fall armyworm (FAW), *Spodoptera frugiperda*, a devastating pest of maize in China and other parts of the world including West Africa. Similarly, Yan et al. (2022) used pathogenic *Aspergillus fijiensis* to effectively control Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) on mandarin orange (*Citrus reticulata*) in a study in China. Meanwhile, known EPFs such as *Beauveria* and *Metarhizium* have been mass produced into commercial microbial pesticides for easy field application in agriculture to control crop insect pests (Fen et al., 1994; Lomer et al., 2001; Sahayaraj, K. and Namasivayam, 2008).

Consequently, the isolates from the current study are being evaluated against cashew insect pests of economic importance in Ghana; coreid bugs (*Pseudotheraptus devastans* and *Anoplocnemis curvipes*) and cashew mosquito bug (*Helopeltis* spp.) in a bioassay and semi-field conditions. It is hoped that using entomopathogens to control cashew insect pests would enhance the sustainable development of the sector in Ghana by reducing the over reliance on synthetic pesticide in cashew orchards with its associated health implications.

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CASHEW TREE HEALTH STATUS IN NIGERIA: SURVEY OF DISEASES AND INSECT SPECIES

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Abstract

A West African sub-region project to map the health of cashew plantations was carried out in Nigeria between November 2023 and April 2024. The activities targeted inventory of diseases and insect species of cashew trees at different phenological stages. The health map activity was conducted in four major cashew producing states in Nigeria, Oyo (South West), Kwara, Kogi (North Central) and Enugu states (South East). The field data were collected from selected farms based on disease symptom, and insect damage on different parts of cashew. The diseases identified include dieback, leaf rust, bacterial leaf spot, anthracnose, bacteriosis and blight. Suspected cases of powdery mildew were also detected. The insect species identified were leaf miner (*Eteoryctis gemoniella*), cashew mosquito (*Helopeltis* spp.), *Helopeltis schoutedeni*, termites (*Nasutitermes* spp.), *Anoplocnemis curvipes*, *Analeptes trifasciata*, *Dysdercus* sp. and stem borer (*Apate terebrans*). However, bees, spiders, red ants (*Oecophylla longinoda*), and black ant were identified as beneficial insects on the farms. The health status of cashew farms in Nigeria varied from state to state.

Key words: Cashew, pre-flowering, post-flowering, fruiting, diseases, insect species

Introduction

Cashew is a commodity of international trade and values with huge foreign exchange earnings for the producing countries. In spite of its economic importance, cashew is faced with some challenges, which have over the years threatened productivity or compromised yield and quality. There has been declining trend in productivity and quality of raw cashew nut across growing ecologies of Nigeria as occasioned by complexes of prolong drought, temperature fluctuations, hazy weather resulting from climate change related factors. These factors have been prominent recently leading to resurgence and emergence of insect species and pathogens.

In West Africa, preference is given to cashew nut but often neglected is the apple as an important source of livelihood (Va

yssieres et al., 2019). It is known that, more than half of fruit crops are lost to pests every year (Vayssieres et al., 2019). The damages caused by different insect species and pathogens on cashew at the same time is a complex which poses significant challenges to the sector, affecting the quality and quantity of cashew nuts. The vegetative organ and fruits of cashew trees are severely affected by many insect species (Dwomoh et al., 2009; Agbeton et al., 2014; Anato et al., 2015). The Hemiptera pests belonging to the families Miridae damage the annual flush, Coreidae-Alydidae, damaging nuts and apples, Bostrichidae, affecting the branches and trunk and Thripidae and Gracillariidae which damages the leaves; resulting into losses of cashew nuts annually thus reducing the expected productivity from growers.

This complex also refers to the simultaneous or sequential occurrence of multiple insect species and pathogens which complicate management strategies. Factors contributing to this complexity include interlocking canopies, unmanaged farms, high humidity and poor soil drainage fostering the growth of multiple pathogens, making it difficult to control one disease without inadvertently exacerbating another (Onifade and Olorunfemi, 1998; Adeigbe et al., 2015). In addition, paucity of cashew varieties resistant to major diseases (Adeniyi and Olufolaji, 2006) and lack of technical know-how of proper agronomic practices which can mitigate disease spread (Baba and Eka, 2014) also contribute to the complex. There have been rare cases of pest management measures practiced by cashew farmers during production in Nigeria. Moreover, climate change related issues and resurgence of pests and diseases require drastic measure to save the crop. Understanding the impact of pests on cashew productivity and quality is crucial for sustainable cultivation, in Nigeria.

Materials and Methods

The disease and insect pest survey for the cashew health update was conducted in four cashew major growing states in Nigeria. The selected study states were identified as having high volume of raw nut production in Nigeria and were spread across the North central (Kogi and Kwara states), South East (Enugu state) and South West (Oyo state). Major cashew growing communities in Kogi, Kwara, Enugu and Oyo states were identified and five farms that were sparsely located were randomly selected and surveyed depending on the consent of farmers. The study involved a total of twenty farms evaluated for the update of cashew health study. The selected surveyed cashew farm sites were shown in figure 1 with their geographical coordinates. The cashew trees were observed and evaluated through assessment of the symptoms and expressions of diseases as well as the damages caused by insect pests on the cashew leaves, flowers, twigs, apple, nuts and the trunk.

These evaluations were carried out at the pre-flowering, flowering/fruiting, and post fruiting stages of cashew. A one-hectare of cashew trees was mapped out on each farm, ten trees were randomly selected through a zig-zag movement through the farms and the selected trees were tagged. Physical observation, evaluation and inspection of the farms and trees for pest infestation damages and expressions of disease incidences were carried out on the tagged trees. A one-square meter quadrant was used and the pest evaluation carried out on cashew twigs, leaves, apples, nuts within the quadrant and the pest identified based on cashew part affected. The quadrant was placed by hanging on the peripheral twigs of tagged trees one at a time and rotating the quadrant from the east and west sides of the tree. GPS.

Results

Records of disease expressions and insect species identified on cashew trees and parts in study farms and locations were catalogued in figure 2a and 2b.

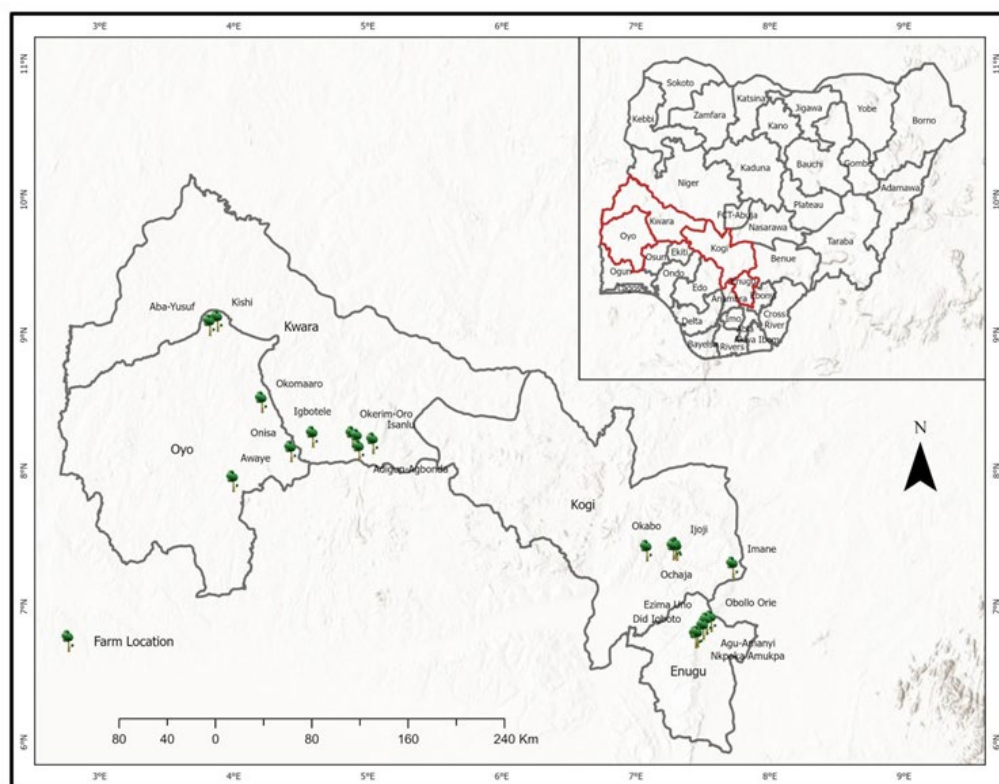


Figure 1: Map of Nigeria showing cashew health study states and farm sites

The outcome of field survey showed incidence of sixteen disease expressions on the various cashew parts evaluated. These diseases identified included anthracnose, leaf spot, chlorosis, dieback, rust and suspected case of powdery mildew. Different severity levels of panicles and nut blights were observed in most farms (figure 1b). Diseases on cashew trees vary from farm to farm in the study.

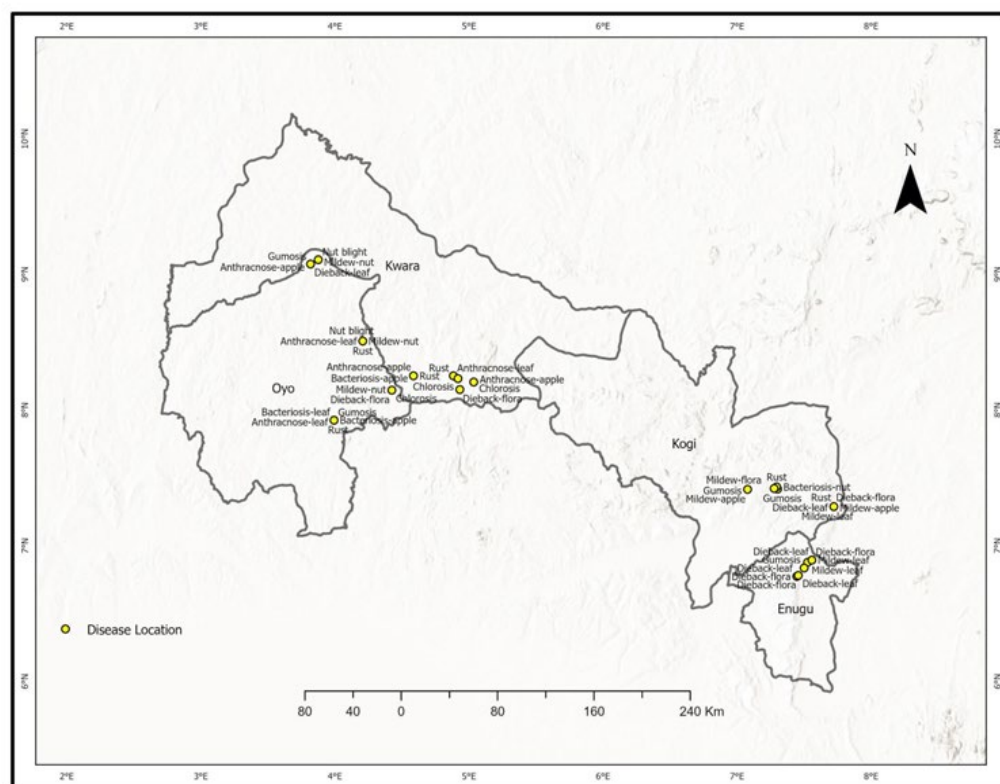


Figure 2a: Map of study states showing spread of diseases in study farm sites

A total of fourteen insect pests were identified from the field survey. Figure 1c indicates the cluster of insect species distribution in the selected study farm sites. Insect pests that were commonly found in most farms were the caterpillars, grasshoppers, *Helopeltis shoutedeni*, *Eteoryctis gemoniella* and termites. Some other insect pests such as *Anoplocnemis curvipes*, *Analeptes trifasciata* were found. Spider and some butterfly species were also found on the farms. Other beneficial insects such as bees and ant complex were present.

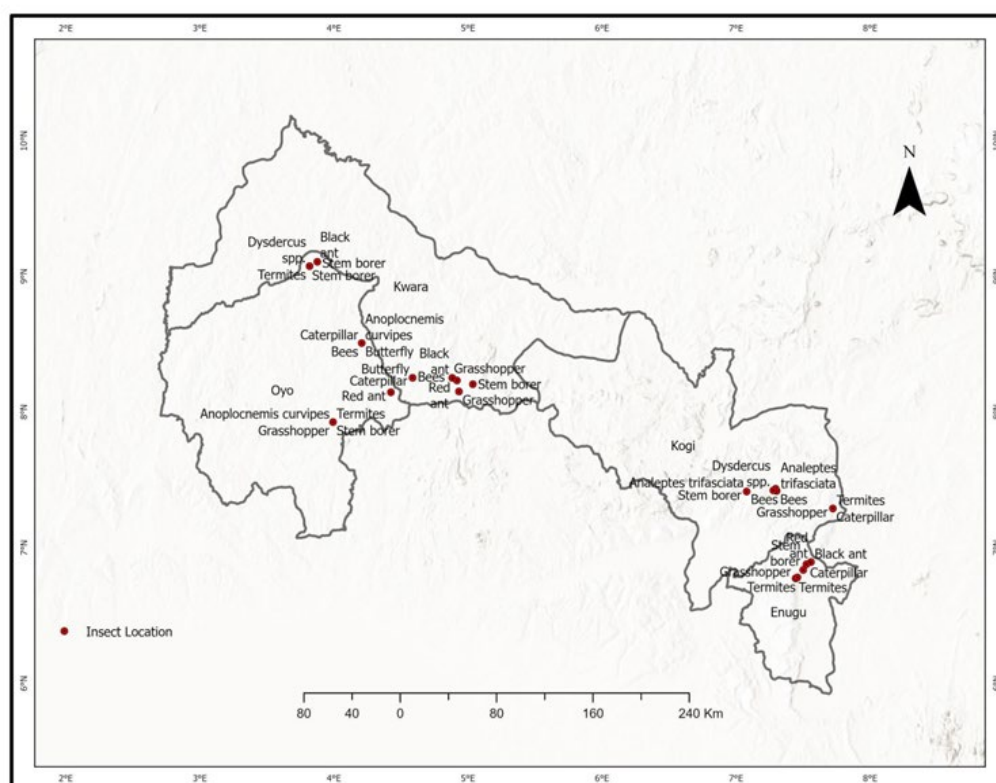


Figure 2b: Map of study states showing distribution of insect species in study farm sites



Figure 3: Expression of anthracnose on cashew leaves



Figure 5: Expression of chlorosis on cashew leaves



Figure 4: Expression of bacterial leaf spot



Figure 6: Expression of rust on cashew leaves



Figure 7: Suspected fresh infection of powdery mildew on leaves (A) and flower (B)



Figure 8: Suspected advance powdery mildew situation on leaves



Figure 9: Dieback situation on flowers (A) and twig (B) of cashew



Figure 10: Suspected powdery mildew situation on apples



Figure 11: Anthracnose on cashew apple



Figure 12: Expression of Bacteriosis on cashew apples



Figure 13: Suspected powdery mildew on young nuts



Figure 14: Cashew nut blight

The incidences of gummosis with exudation of gum on cashew branch and trunk were localized in the study locations, holes on affected parts were observed and gum exudation recorded on the trees (figure 15).



Figure 15: Gum exudation on infected cashew trees

The study recorded thirteen insect species both pest and beneficial on the surveyed farms. *Analeptes trifasciata* (figure 16) was found present in farms through the sawing damage on branches and tree trunk, likewise were live insects with typical appearance in pairs and their regular black and pink body colour. Also was the infestation of *Apate terebrans* commonly called stem borers (figure 17). Stem borer was not common in many farms but localized to particular farms.



Figure 16: *Analeptes trifasciata* and damages cause to cashew tree



Figure 17: Exudate flow from bores (A) and holes created by stem borers (B)

The infestation by *Helopeltis* spp. on cashew leaves, twigs and apples was identified by damages caused. Affected leaves were curled, folded and wrinkled while the infested twigs resulting into dieback, turn brown and withered (figure 18 & 19). However, *H. schoutedeni* damages the apples by piercing both the young green and mature apples, some live insects were found (figure 20).



Figure 18: Wrinkled and folded cashew leaves caused by *Helopeltis* spp.



Figure 19: Curled cashew leaves (A) and twig dieback (B) by *Helopeltis* spp.X



Figure 20: Apple deformation by *Pseudotheraptus devastans* (A) and *Helopeltis schoutedeni* (B)

The incidence of leaf miner on cashew leaves was observed in many farms in study areas and it is common to all cashew growing ecologies with very few exceptions. The infestation by *E. gemoniella* was identified by the brown leathery patches on leaves resulting into perforations at advance stage (figure 21).



Figure 21: Leaf miner on cashew leaves caused by *Eteoryctis gemoniella*

The infestation of cashew farms by termites (*Nasutitermes* spp.) was a common site in many farms. Termites were identified by presence of termite runways on cashew trunks, branches and termitaria also present in the farms (figure 23).



Figure 22: *Dysdercus* sp. on cashew leaves



Figure 23: Termite infestation on cashew tree (A) and termitarium on farm (B)

Figure 24 shows the presence of caterpillar – worm found on cashew leaves but also localized in the affected farms.

3.2. Results of field data collected

3.2.1. Infestation rate

Mean infestation rates of *Apate terebrans* in all orchards were significantly different (kruskal wallis chi-squared = 13.923; df=4; p-value = 0.007546). The most infested orchards were Mangacounda (80%) and Sindima (66%), followed by Goudomp (40%) and Djibanar (33). The lowest infestation rate was recorded in Terembasse (28%) (Table 1). Comparison of the averages between orchards reveals a significant variation in the infestation rate between the Djibanar, Mangacounda and Sindima orchards and a similar attack rate between the Djibanar, Goudomp and Terembasse orchards (Figure 11).

Table 1: Shapiro and kruskal wallis test for infestation rate in orchards



Figure 24: Leaf perforation and destruction by caterpillar worms

The presence of adult grasshoppers and damages done to cashew leaves are shown in figure 25, perforating the leaves resulting into defoliation and reducing the photosynthetic potentials of the tree. They also feed on both young green and mature ripe apples by scrapping the surface thereby reducing its economic value (figure 26).



Figure 25: Perforation of cashew leaves by grasshopper



Figure 26: Grasshopper and damage habit on apple

Anoplocnemis curvipes was intercepted on cashew cluster and identified by the damage effect on the hanging nut in figure 27. The insect pierces the succulent green and young cashew nut creating a dark brown mark on the. This damage can also stain the cashew kernel thereby reducing the market value.



Figure 27: Damage by *Anoplocnemis curvipes* on young nut

Figure 28 shows collections of insect species found on a particular farm during the cashew health study. The occurrence of these species varies from farm to farm and the cashew parts that hosted the insect species also differs.



Figure 28: Collection of insects: *Dysdercus* spp. (A), Spider (B), Grasshopper (C), Black ant nest (D)

Some beneficial insect species were recorded in the farms. These includes red ants (*Oecophylla longinoda*), butterflies and bees (figure 29 & 30).

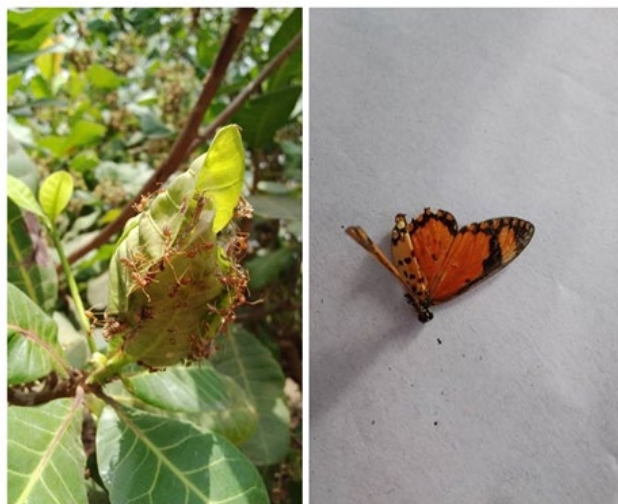


Figure 29: Beneficial insect *Oecophylla longinoda* and butterfly on sampled from a cashew farm



Figure 30: Beneficial red weaver ants and bees on cashew

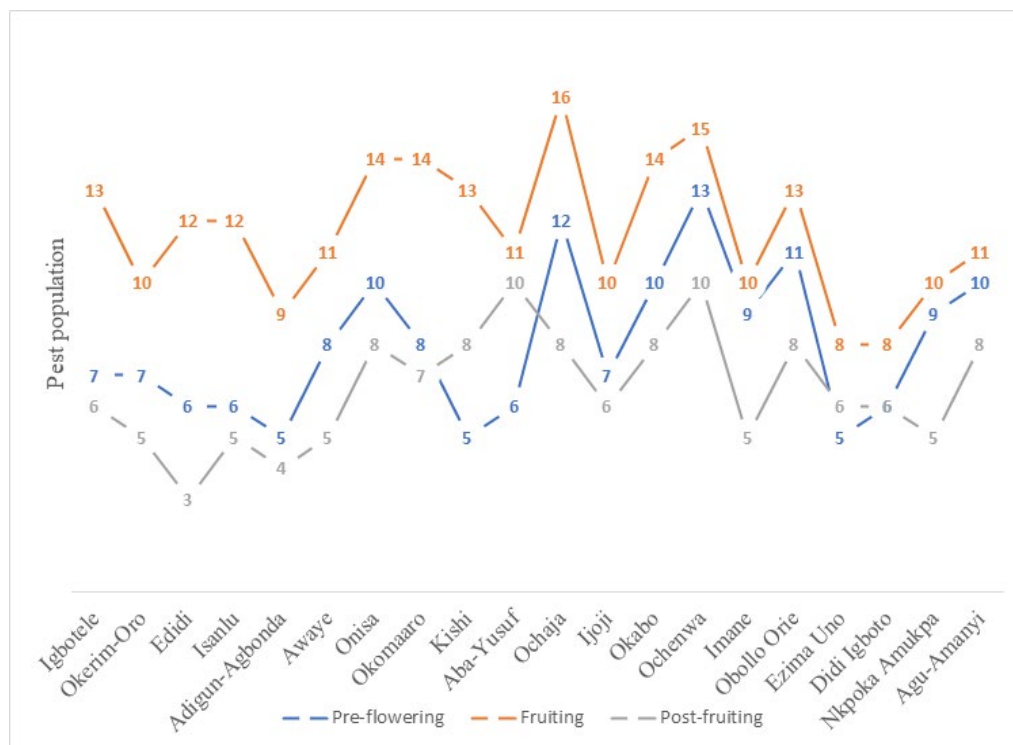


Figure 31: Pest population and distribution in study farms

Figure 31 shows the distribution of insects and diseases on cashew farms from the study locations according to the phenological stages of evaluation. The presence of pests was not evenly dispersed in farms and varied with phenological stage of growth. Ochenwa and Ochaja, both in Kogi state were similarly high in number of pest population at pre-flowering fruiting stages. This trend was common to other farm sites in Kogi, Onisa in Oyo and Agu-Amanyi in Enugu state at pre-flowering and fruiting stages. Cashew farms at Adigun-Agbonda (Kwara), Kishi (Oyo) and Ezima Uno (Enugu) hosted the least number of pests intercepted at pre-flowering stage while fruiting stages recorded least pest population at farms at Ezima Uno and Didi Igboto but closely followed by farm at Adigun-Agbonda (figure 30). All the farms surveyed recorded more insects and disease infestation during the fruiting stage followed by the pre-flowering stage with exception of cashew farms at Kishi and Ezima Uno which recorded more pest at post fruiting than pre-flowering. Figure 32 showed that incidence of disease and insect infestation were low in farm sites on high topography as recorded in Edidi, Okerimi and Adigun-Agboda.. Moderate infestations were common across different farm altitudes in study locations but high infestations by pests were common in farms at low elevations such as Ochaja, Ochenwa, Okabo, Obollo Ori, Agu-Amanyi, but at few high altitudes farms at Kwara and Oyo boundary recorded high pest infestation.

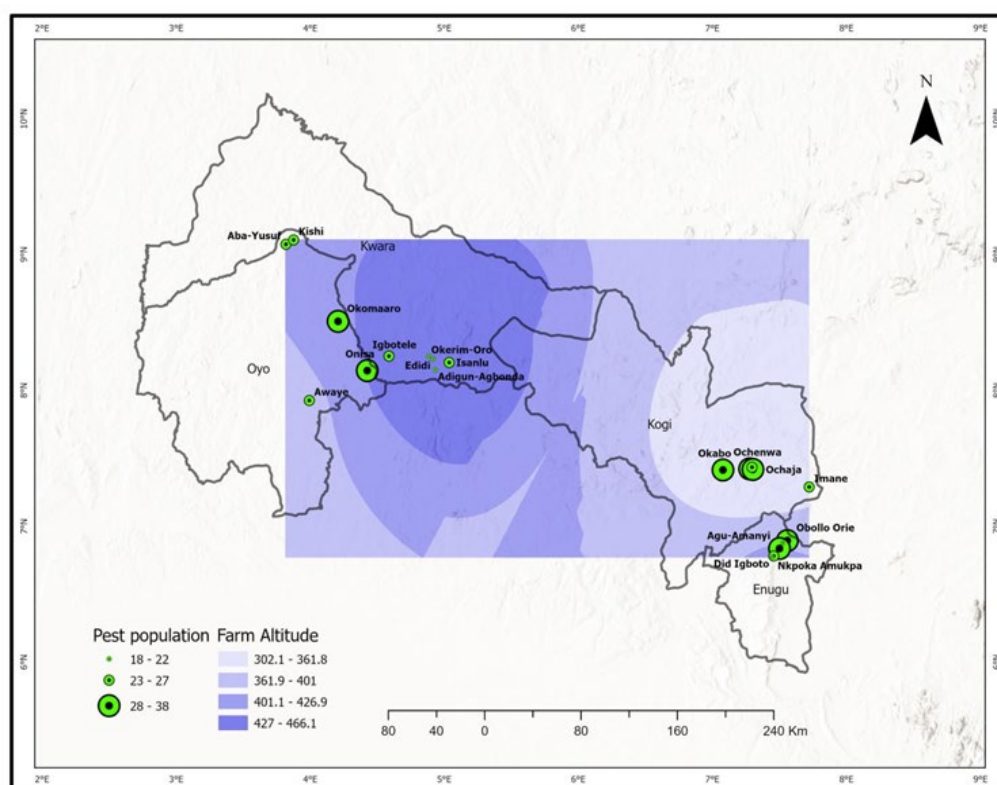


Figure 32: Correlation of the pest population with altitude of the study farm sites

Discussion

The diseases and insect species affected cashew trees at varied phenological stages in study farms. Prominent among the diseases are anthracnose (leaf, apple), bacteriosis (leaf, apple), inflorescence blight and dieback on twigs across the study areas. This variation was also similar across ecology and farms. Bacteriosis and anthracnose on leaves and rare cases of same on apples were found to be recurring in many farms than other expressions, however bacteriosis occurrence on farms was more prominent. Similar trend was observed in flora dieback and chlorosis in the farms but the later was often localized. Dieback, rust, suspected cases of mildew and gummosis were variedly distributed in study farms. The resurgence of disease condition depicting presence of obligate fungal causing powdery mildew disease, on cashew leaves, flora panicles and apple were found also common to many farms and a major risk of devastating productivity decline as reported in countries with major incidences.

The diseases have caused considerable damage to cashew, affecting both yield and quality of the raw nuts. The spread of Anthracnose caused by *Colletotrichum gloeosporioides*, across cashew growing ecologies affecting leaves, apples, nut formation and leading to significant yield losses as reported by Adeigbe *et al.*, (2015); Adeniyi, (2012). Baba and Eka, (2014); Adeniyi & Olufolaji, (2006) reported that powdery mildew disease caused by *Oidium anacardiae* was characterized by a white powdery growth on leaves and flowers. This is prevalent in the humid and semi-humid regions of Nigeria, notably in Kogi and Oyo states. This report was in consonant with this study that recorded significant presence of powdery mildew situation in cashew farms in Kogi and Oyo states. The effect of anthracnose and powdery mildew include reduction in the photosynthetic function of the leaves, affecting flower and nut development, which leads to lowered yields. Infections can cause discoloration and deformities in nuts, making them less marketable and directly impacting their economic value (Adeniyi, 2012). Earlier findings have also reported fruit rot (*C. gloeosporioides*) and gummosis of the fruit and trunk respectively caused by *Lasiodiplodia theobromae* (Cardosa *et al.*, 2004; Cysne *et al.*, 2010; Oduwole *et al.*, 2001). Additionally, diseases such as leaf and nut blight, rust, and bacterial leaf spot diseases have been reported by Majune *et al.*, (2018). Diseases like dieback and root rot also lead to the complete loss of trees, which has long-term economic implications due to the time required to re-establish orchards (Adeigbe *et al.*, 2015).

The presence of the insect species: *E. gemoniella*, *Helopeltis spp.*, *termites*, *A. curvipes*, *grasshopper*, *A. trifasciata*, stem borer, corroborate the earlier report of Adewale *et al.*, (2013) and Adeigbe *et al.*, (2015) that highlighted major pests in cashew plantations. Beneficial insects like bees, spiders, red ants), butterflies, and black ant were also identified in this study. There was evidential devastating effect and damages by the long-horned beetle *A. trifasciata* on stems and branches with its girdling activities on the farms. This result into yield losses by destroying branches carrying flower panicles, nuts and apples. However, this was not the situation in all farms, but only in some areas. *Apate terebrans* also refer to as black borer or trunk borer/ stem borer has been reported to be a serious biotic constrain to the good prospect of cashew production. It is classified as an important wood-boring beetles that infest cashew trees in Nigeria, Benin (Agboton *et al.*, 2014) and likewise in many cashew producing countries in West Africa (Dwomoh *et al.*, 2008; Wagners *et al.*, 2008; Vasconcelos *et al.*, 2014). Stem borer is native to Africa and Madagascar but now widely spread into Arabian Peninsula, Central and South America and now reported in Austria, Georgia, Spain and the United Kingdom on the European continent (Agboton *et al.*, 2019). As the case observed on cashew trees in the study area, adult *A. terebrans* attacks cashew trunk and branches by boring holes; whereas larvae are found developing inside felled and moribund trees (Agbeton *et al.*, 2017) and same situation was found in this study where the stem borer are found attacking living cashew trees regardless of its physiological state either healthy or not (Agbeton *et al.*, (2019). Stem borer also have preference for new trees rather than previously infested trees whose nutrients potential has somewhat been depleted. This wood tissue damages increases the risk of stems, branches and even trees breaking off during storming season.

The use of red ants as natural control agents in protecting cashew trees has been shown in Australia (Peng *et al.*, 1997), Vietnam (Peng *et al.*, 2014) and recently in many Africa countries as reported in the control of fruit fly in West Africa (Vayssieres *et al.*, 2016). Red ants are dominant predator that feed on insects especially crop pest such as cashew bugs. They are common in area with abundant rainfall and luxuriant perennial vegetation. Red ants' colony constantly interact and work together in their own territory by way of different types of pheromones, living in a society in leaf-made nest woven by their larvae and chase off other invertebrates over several hundred square metres (Vayssieres *et al.*, 2017). Red ants' controls *A. curvipes*, *H. schoutedeni*, *Psuedotheraptus devastans*, *P. wayi*, *Tupalus fasciatus*, *Mirperus jaculus* (Dwomoh *et al.*, 2008; Aidon, 2009; Oluthu *et al.*, 2013; Abdullah *et al.*, 2016; Anano *et al.*, 2015). The presence of beneficial insect species is crucial for natural pest control and for maintaining the ecological balance within the farms (Waliyar *et al.*, 2006).

Conclusion

Cashew farms is facing varied challenges of which infestation of insects and diseases are major factor affecting productivity and quality. However, the overall impact of pest is currently mitigated only by ecological factors and physiological response of the tree. This study also provides valuable insights into current health status of cashew farms and a guide to future research strategies to improve cashew productivity and quality. Enhancing biodiversity in cashew farms and adopting better agronomic practices could further improve the health and productivity and quality of cashew. Research into organic, eco-friendly and climate-resilience management techniques need to be developed for cashew pest management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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THE HEALTH OF CASHEW ORCHARDS IN GHANA: A SURVEY OF INSECT SPECIES AND DISEASES

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Abstract

As part of a project to map the health of cashew orchards in the West Africa sub-region, a survey of insect species and diseases occurring on cashew trees in Ghana at the pre-flowering, flowering and fruiting stages of the crop was carried out. The surveys were conducted in 8 of the major cashew growing districts selected from the Savannah (Bole and Sawla), Transition (Wenchi and Techiman) and Semideciduous (Aframase, Aseesewa, Aseeso and Begoro) zones of Ghana. Pyrethroid knockdown and visual assessment methods were used to collect data on insect species on the crop while plant parts (leaves, inflorescences, bark, apple and nuts) were assessed for disease infection. The major insect pests identified include sup-sucking bugs (*Helopeltis* sp., *Pseudotheraptus devastans*), stem girdler (*Analeptes trifasciata*), termites and fruit eaters (*Diplognatha* and *Pachnoda*). Beneficial insects identified include spiders, the ant complex (*Oecophylla*, *Camponotus*, *Pheidole* and *Crematogaster*), bees, praying mantids, lacewings, ladybug beetles and butterflies. The diseases identified include Anthracnose, Leaf Blight, Leaf Rust, Leaf Spot, Inflorescence Blight and Twig Die Back. Generally, cashew orchards in Ghana showed good health with minimal diseases and a good number of natural enemies as against insect pests. There is the need to harmonize pest and disease control protocols to ensure sustainable production of cashew within the West Africa Sub-region.

Key words: Cashew, insect pests, diseases, natural enemies, pre-flowering, flowering, fruiting

Introduction

In Ghana, cashew was introduced by the Government for afforestation and land reclamation programmes in the savanna, coastal savannah and forest-savannah transition zones (Dwomoh, 2008). Annual production of cashew nuts, the most economically important component of the crop, stood at 86,000 MT in 2019, an increment from 27,000 MT over a decade (Wongnaa and Ofori 2012; FAOSTATS 2021; Mensah et al. 2021). Despite gains in cashew production, yields are below optimum levels (Wongnaa and Ofori, 2012; Danso-Abbeam et al., 2021). Factors accounting for the sub-optimal yields include the effect of insect pests and diseases at each developmental stage of the crop.

Insect pests of economic importance include mosquito bug, *Helopeltis schoutedeni* Reuter, coreid bugs, *Pseudotheraptus devastans* (Distant), and *Anoplocnemis curvipes* (Fabricious) (Dwomoh et al. 2007; 2008). These sucking insects cause severe damage to the flushing shoots, inflorescence, developing fruits and trunks of the tree (Dwomoh et al. 2007; 2008). For mature cashew, Anthracnose, Leaf Blight, Inflorescence Blight, Gummosis and Twig Die Back are important diseases (Amoako-Attah., et al. 2020). At the nursery, damping off, seedling blight and root/nut rot are also considered important (Amoako-Attah., et al. 2020). These diseases also affect flushing shoots, inflorescence, developing fruits and trunks of the tree resulting in crop loss.

As part of a West Africa project to map the health of cashew orchards in the sub-region, a survey of insect species and diseases occurring on cashew trees in Ghana at different phenological stages of the crop was conducted. This report documents insects (both pests and beneficial insects) and diseases on cashew orchards in surveyed farms in Ghana.

Materials and methods

Study sites

The survey was conducted in Wenchi, Techiman, Bole, Sawla, Begoro, Aseesewa, Aframase and Aseeso districts. The locations of these districts from which farms were assessed for cashew pests and diseases at the different phenological stages is presented in Figure 1. Five (5) farms were assessed in each district making a total of 40.

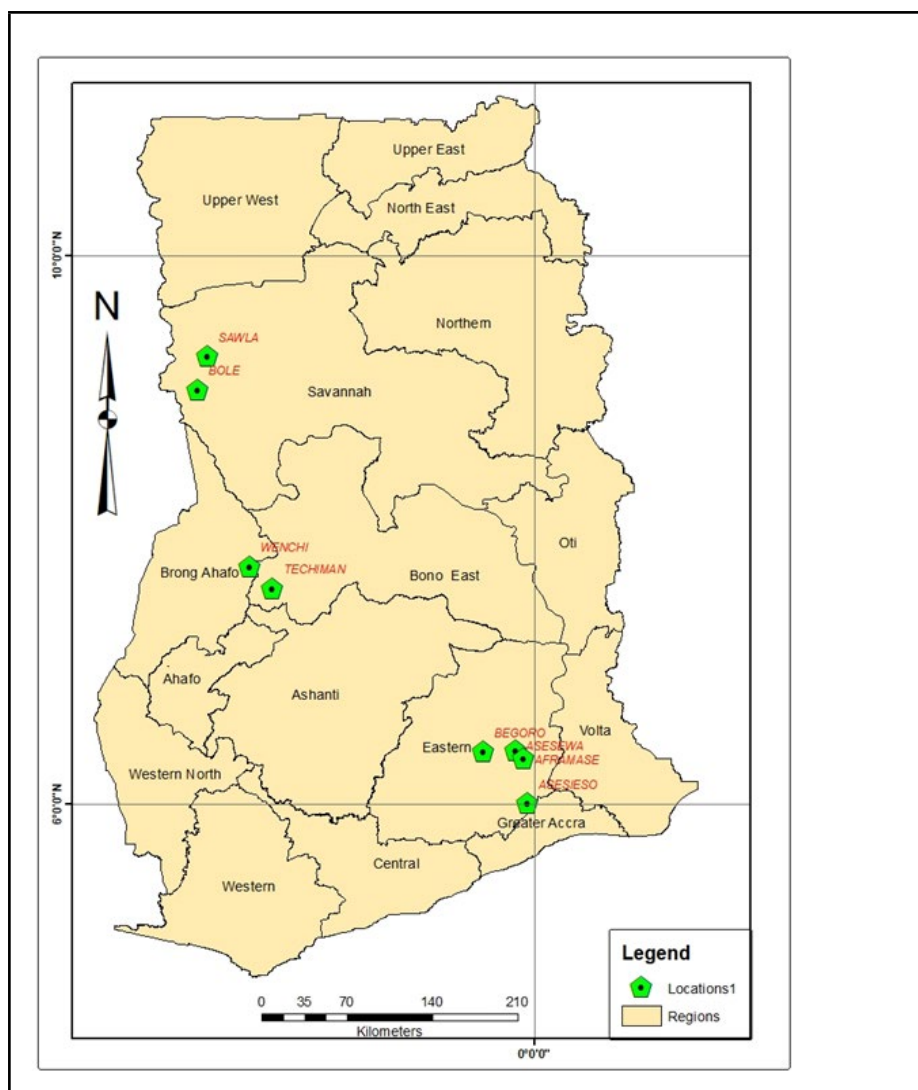


Fig. 1: Surveyed sites

Insect assessment

Assessment was conducted at both young (<5 years) and matured farms (>5 years). Two sampling methods, the pyrethroid knockdown and visual examination, was used. Pyrethroid knockdown method was used to determine insect species distribution and their relative abundance on mature cashew trees (>5 years) (Dwomoh et al., 2008). Plants below five (5) years old were assessed with the visual examination method. A one-hectare plot was demarcated in each selected farm in the different agroecological zones for the assessment. At each data collection event, five (5) trees were randomly selected from each field and sprayed thoroughly with a pyrethroid insecticide, using a motorized mist blower. The sprayed trees were vigorously shaken 30-60 minutes later and all insects that dropped on white cloth spread underneath were collected for counting and identification.

Ten trees were also randomly selected for flower and fruit assessment. Twenty (20) panicles (inflorescence) and 20 fruits (young and mature apples and nuts) was sampled per tree and observed for insect species and their damage. By means of a ladder, the 20 panicles and 20 fruits were first examined in situ on each tree and later plucked by hand. Each sample was then carefully examined and incubated for the presence of insects and their damage at the CRIG insectary, New-Tafo Akim. All developmental stages of insects (eggs, larvae, nymphs, pupae and adults) were recorded. Panicles and fruits (apples and nuts) would be considered damaged when there are symptoms of brownish and watery lesions, necrotic lesions, dieback and fruit deformation with scars (Amoako-Attah., et al. 2020). In addition, all the trees in selected farms were assessed on their stems, branches and twigs for fresh entry and exit points of stem and twig borers.

Disease assessment and pathogen isolation

Cashew trees in selected farms (approximately 1 ha) were visually inspected along two diagonal transects and 10 diseased trees were randomly selected for disease incidence studies. Assessment was done on four sides of the cashew tree: North, South, East and West. Approximately one-meter square area on each side was selected and the number of leaves, shoots or flowers showing disease symptoms were recorded.

Pathogens from the infected parts were isolated following standard mycological methods. Pieces of infected tissues (5 to 10 mm) were surface sterilized in 3 % sodium hypochlorite solution for 2 minutes and subsequently rinsed in sterile distilled water. The sterilized tissues were placed on Water Agar (WA) and incubated at 28°C for five days. Hyphal strands emerging on the WA were transferred onto Potato Dextrose Agar (PDA) and incubated for five days. Fungal pathogens were identified using morphological characteristics (Mathur and Kongsdale, 2003; Kirk et al., 2008).

Data analysis

Descriptive statistics was used to present the presence and number of the different insect species for each location. Percentage disease incidence was determined by the number of diseased parts (shoots, leaves, flowers) divided by the total number of unaffected parts multiplied by 100.

Results

Pre-flowering stage

Insect assessment

Different insect species (both pests and beneficial insects) were observed, identified and their numbers recorded (Table 1). The insect pests identified include *Helopeltis schoutedeni* (cashew mosquito), *Apate terebrans* (cashew stem borer), *Anoplocnemis curvipes* (Aeroplane Bug), *Analeptes trifasciata* (cashew stem girdler) and termites. Beneficial insects (natural enemies and pollinators) identified include bees, the ant complex (*Oecophylla*, *Crematogaster*, *Macromischoides* and *Camponotus* spp), wasp and praying mantis. Details of the abundance of the different insect species sampled across cashew farms in the surveyed districts is presented in Table 1.

Table 1: Pyrethrum knockdown collection of insect species in cashew farms showing abundance and diversity

Common name	Scientific names/ description	Locations/ insect numbers							
		Eastern Region				Bono Region	Bono East Region	Savanna Region	
		Aframase	Asesewa	Begoro	Aseseeso	Wenchi	Techiman	Bole	Sawla
Cashew mosquito	<i>Helopeltis schoutedeni</i>	20	45	1	30	12	10	12	10
Red Weaver Ants	<i>Oecophylla longinoda</i>	180	0	0	0	92	90	85	110
Desert Cockroach	<i>Arenivaga investigata</i>	2	1	0	1	0	0	0	2
Grasshopper	<i>Caelifera</i>	35	6	11	5	47	32	40	35
Cotton Stainer	<i>Dysdercus supersticiosus</i>	1	0	0	0	3	0	3	1
House Cricket	<i>Acheta domesticus</i>	9	0	0	0	15	0	15	9
Spider	<i>Aranee</i>	11	4	4	6	25	18	20	15
Brown beetle	<i>Latridiidae</i>	3	2	1	2	0	1	0	3
Bee	<i>Apis mellifera</i>	1	0	0	0	10	8	12	10
Praying Mantis	<i>Mantis religiosa</i>	0	1	3	2	13	8	15	13
Black Ant	<i>Lasius niger</i>	0	0	10	1	1	1	1	1
Black beetle	<i>Amara aulica</i>	2	0	0	0	0	0	0	2
Houseflies	<i>Musca domestica</i>	4	3	0	3	0	0	0	4
Coreid Bug	<i>Pseudotheraptus devastans</i>	0	3	0	3	3	0	3	0
Potter wasp	<i>Eumenes fraternus</i>	1	1	0	1	0	0	0	1
Hornets wasp	<i>Vespa crabro</i>	0	1	0	1	0	0	0	0
Hydrophilus beetle	<i>Hydrophilus triangularis</i> Say	0	1	0	1	0	0	0	0
Clavigralla	<i>Clavigralla tomentosicollis</i> Stal	0	1	0	1	0	0	0	0
German Cockroach	<i>Blattella germanica</i>	1	0	0	0	0	0	0	1
Cashew stem girdler	<i>Analeptes trifasciata</i>	4	3	0	0	0	0	0	0
Stem borer	<i>Apate terebrans</i>	0	3	0	0	0	0	0	0
Aeroplane Bug	<i>Anoplocnemis curvipes</i>	1	1	0	0	0	1	0	1
Butterflies	<i>Lepidoptera</i>	20	13	22	19	24	21	24	20
Termite	<i>Isoptera</i>	10	13	18	20	24	11	24	15
Leaf Miner (Damage)	<i>Acrocercops Syngamma</i>	<1%	0	<1%	<1%	<1%	0	<1%	<1%
Crematogaster	<i>Crematogaster clariventris</i>	6	10	4	3	18	5	18	9
Macromischoides	<i>Macromischoides aculeatus</i>	0	1	0	0	6	1	6	3
Camponotus	<i>Camponotus acvapimensis</i> Mayr	0	1	0	1	0	0	0	0
Pheidole	<i>Pheidole megacephala</i>	19	16	11	13	20	21	20	10

Disease assessment and identification

Different diseases were observed, identified and percentage disease incidence determined (Table 2). The diseases identified include Anthracnose, Leaf spot and Rust, Inflorescence blight, Gummosis and Twig die back.

Table 2: Disease incidence of surveyed cashew farms in the different districts

Disease	Locations/disease incidence							
	Bono Region	Bono East Region	Savanna Region		Eastern Region			
	Wenchi	Techiman	Bole	Sawla	Aframase	Asesewa	Begoro	Aseseeso
Anthracnose	27.2	29.0	40.5	27.3	11.5	9.2	10.9	6.6
Leaf spot	35.1	26.3	23.3	20.8	13.4	4.7	12.7	12.7
Leaf blight	10.2	9.4	37.8	27.9	13.3	10.1	5.5	2.9
leaf rust	14.6	13.9	6.2	4.4	0.8	3.3	1.4	2.1
Inflorescence blight	0.3	0.6	0.9	0.4	0.0	0.0	0.0	2.3
Gummosis	0.6	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Twig Die Back	0.0	3.3	0.9	1.8	0.2	0.0	0.0	3.2

Flowering and fruiting stage

Insect assessment

The insect pests identified include *Anoplocnemis curvipes* (Aeroplane Bug), *Helopeltis schoutedeni* (cashew mosquito), *Apate terebrans* (cashew stem borer), *Analeptes trifasciata* (cashew stem girdler) and termites (Table 3). The prominent apple eaters identified were *Diplognatha gagates*, *Pachnoda cordata* and *Pachnoda marginata*. Beneficial insects (natural enemies and pollinators) identified include green lacewing (*Chrysoperla rufilabris*), bees, the ant complex (*Oecophylla*, *Crematogaster*, *Macromischoides* and *Camponotus* spp), praying mantis and wasp (Table 3).

Table 3: Pyrethrum knockdown collection of insect species in cashew farms showing abundance and diversity

Common name	Scientific names/ description	Locations/ insect numbers							
		Eastern Region				Bono Region	Bono East Region	Savanna Region	
		Aframase	Asesewa	Begoro	Aseseeso	Wenchi	Techiman	Bole	Sawla
Green lacewing	<i>Chrysoperla rufilabris</i>	6	4	1	0	7	8	4	1
Apple eaters	<i>Diplognatha gagates</i>	18	20	10	12	6	5	8	4
Apple eaters	<i>Pachnoda cordata</i>	10	12	11	2	5	3	4	2
Apple eaters	<i>Pachnoda marginata</i>	6	4	5	3	9	7	4	4
Cashew mosquito	<i>Helopeltis schoutedeni</i>	10	12	0	6	8	9	5	3
Red Weaver Ants	<i>Oecophylla longinoda</i>	500	200	150	100	300	450	200	150
Desert Cockroach	<i>Arenivaga investigata</i>	4	3	10	4	3	1	4	12
Grasshopper	<i>Caelifera</i>	35	6	11	5	47	32	40	35
Cotton Stainer	<i>Dysdercus superstitionis</i>	1	5	4	7	3	6	3	3
House Cricket	<i>Acheta domesticus</i>	10	10	7	7	11	2	10	7
Spider	<i>Aranee</i>	11	4	4	6	25	18	20	15
Brown beetle	<i>Latridiidae</i>	6	4	6	9	2	5	3	7
Bee	<i>Apis mellifera</i>	5	6	3	2	10	8	11	21
Praying Mantis	<i>Mantis religiosa</i>	4	6	7	9	15	9	25	15
Black Ant	<i>Lasius niger</i>	0	0	10	1	1	1	1	1
Black beetle	<i>Amara aulica</i>	2	1	1	5	4	6	1	5
Houseflies	<i>Musca domestica</i>	5	3	1	3	1	0	0	5
Coreid Bug	<i>Pseudotheraptus devastans</i>	2	3	5	4	7	3	1	1
Potter wasp	<i>Eumenes fraternus</i>	1	1	0	1	0	0	0	1

Hornets wasp	Vespa crabro	0	1	0	1	0	0	0	0
Hydrophilus beetle	Hydrophilus triangularis Say	0	1	0	1	0	0	0	0
Clavigralla	Clavigralla tomentosicollis Stal	0	2	1	1	1	1	1	0
German Cockroach	Blattella germanica	1	0	0	0	0	0	0	1
Stem borer	Apate terebrans	0	3	0	0	0	0	0	0
Aeroplane Bug	Anoplocnemis curvipes	1	1	0	0	0	1	0	1
Butterflies	Lepidoptera	20	13	22	19	24	21	24	20
Termite	Isoptera	10	13	18	20	24	11	24	15
Leaf Miner (Damage)	Acrocercops Syngramma	<1%	0	<1%	<1%	<1%	0	<1%	<1%
Crematogaster	Crematogaster clariventris	10	12	16	12	20	15	23	11
Macromischoides	Macromischoides aculeatus	2	5	6	4	8	5	19	12
Camponotus	Camponotus acvapimensis Mayr	3	0	0	12	2	1	1	3
Pheidole	Pheidole megacephala	21	17	18	20	19	23	26	21
Cashew stem girdler	Analeptes trifasciata	2	2	4	2	1	1	0	3

Disease assessment and identification

The dominant diseases identified include Leaf spot and Rust, Inflorescence blight and Anthracnose (Table 4).

Table 4: Disease incidence of surveyed cashew farms in the different districts

Disease	Bono Region	Bono East Re-gion	Savanna Region		Eastern Region			
	Wenchi	Techiman	Bole	Sawla	Aframase	Asesewa	Begoro	Aseseeso
Anthracnose	23.8	21.9	26.5	31.8	9.1	10.8	13.4	5.2
Leaf spot	21.2	18.2	15.1	23.9	15.8	7.8	8.7	15.5
Leaf blight	8.1	3.6	39.9	22.9	5.3	8.1	6.3	1.4
leaf rust	8.5	9.8	16.4	6.9	2.8	8.8	5.5	1.0
Inflorescence blight	4.8	5.4	8.3	5.0	69.3	0.0	2.5	4.5
Gummosis	0.0	1.1	0.0	0.0	1.0	0.3	0.0	0.0
Twig Die Back	0.0	2.5	0.0	0.0	0.0	0.0	0.0	3.02

Post fruiting stage

Insect assessment

The insect pests identified include Anoplocnemis curvipes (Aeroplane Bug), *Helopeltis schoutedeni* (cashew mosquito), *Apate terebrans* (cashew stem borer), *Analeptes trifasciata* (cashew stem girdler) and termites (Table 5).

The prominent apple eaters identified were *Diplognatha gagates*, *Pachnoda cordata*, *Pachnoda marginata*. Beneficial insects (natural enemies and pollinators) identified include green lacewing (*Chrysoperla rufilabris*), bees, the ant complex (*Oecophylla*, *Crematogaster*, *Macromischoides* and *Camponotus* spp), praying mantis and wasp (Table 5).

Table 5: Pyrethrum knockdown collection of insect species in cashew farms showing abundance and diversity

Common name	Scientific names/ description	Locations/ insect numbers							
		Eastern Region				Bono Region	Bono East Region	Savanna Region	
		Aframase	Asesewa	Begoro	Aseseeso	Wenchi	Techiman	Bole	Sawla
Green lacewing	Chrysoperla rufilabris	5	4	1	0	7	8	4	1
Apple eaters	Diplognatha gagates	2	1	2	3	1	3	1	0
Apple eaters	Pachnoda cordata	2	4	1	1	2	0	0	0
Apple eaters	Pachnoda marginata	2	0	1	0	0	1	0	0

Cashew mosquito	Helopeltis schoutedeni	3	2	0	1	1	2	0	1
Red Weaver Ants	Oecophylla longinoda	300	100	50	70	150	200	30	15
Desert Cockroach	Arenivaga investigata	3	1	2	1	1	1	3	1
Grasshopper	Caelifera	12	2	4	1	7	5	10	12
Cotton Stainer	Dysdercus supersticiosus	1	5	4	7	3	6	3	3
House Cricket	Acheta domesticus	2	4	2	3	5	2	3	2
Spider	Aranee	6	1	2	2	15	8	2	4
Brown beetle	Latridiidae	6	4	6	7	2	5	3	7
Bee	Apis mellifera	5	6	3	2	8	8	9	9
Praying Mantis	Mantis religiosa	4	6	7	9	15	9	10	4
Black Ant	Lasius niger	0	0	5	1	1	1	7	4
Black beetle	Amara aulica	2	1	1	5	4	6	1	5
Coreid Bug	Pseudotheraptus devastans	2	4	3	5	4	0	0	0
Potter wasp	Eumenes fraternus	2	1	1	1	0	2	1	1
Hornets wasp	Vespa crabro	1	2	0	1	1	3	0	4
Hydrophilus beetle	Hydrophilus triangularis Say	3	3	0	1	3	0	4	0
German Cockroach	Blattella germanica	3	4	2	2	5	3	3	1
Stem borer	Apate terebrans	2	0	1	0	0	0	1	0
Aeroplane Bug	Anoplocnemis curvipes	1	1	0	0	0	1	0	1
Butterflies	Lepidoptera	5	3	6	12	4	11	9	4
Termite	Isoptera	9	14	18	23	25	12	21	16
Leaf Miner (Damage)	Acrocercops Syngamma	<1%	0	<1%	<1%	<1%	0	<1%	<1%
Crematogaster	Crematogaster clariventris	13	14	17	5	6	5	8	9
Macromischoides	Macromischoides aculeatus	2	5	6	4	8	5	19	12
Camponotus	Camponotus acvapimensis Mayr	3	0	0	12	2	1	1	3
Pheidole	Pheidole megacephala	20	7	8	9	10	13	16	9
Cashew stem girdler	Analeptes trifasciata	2	2	5	2	1	1	0	3
Pheidole	Pheidole megacephala	21	17	18	20	19	23	26	21
Cashew stem girdler	Analeptes trifasciata	2	2	4	2	1	1	0	3

Disease assessment and identification

The dominant diseases identified include Leaf spot and Rust, Inflorescence blight and Anthracnose (Table 6).

Table 6: Disease incidence of surveyed cashew farms in the different districts

Disease	Locations/disease incidence (%)							
	Bono Region	Bono East Region	Savanna Region		Eastern Region			
	Wenchi	Techiman	Bole	Sawla	Aframase	Asesewa	Begoro	Aseseeso
Anthracnose	14.4	16.0	15.9	20.2	6.9	3.4	12.3	3.5
Leaf spot	19.9	19.7	23.5	20.8	7.7	8.9	8.7	8.0
Leaf blight	6.8	2.5	32.2	27.9	9.0	5.2	3.2	2.5
leaf rust	8.6	2.3	3.1	4.4	0	2.6	0	2.8
Inflorescence blight	0	0	0.7	0.4	0	1.2	0	0
Gummosis	0	0	0.8	0	0	0.5	1.4	0
Twig Die Back	0	0	0	1.8	1.0	1.9	1.6	3.0

Discussion

The present study identified several insect species on cashew in Ghana. Most of these insect species have previously been reported by Dwomoh *et al.*, (2008). In this survey, insect species identified include the coreid bugs *P. devastans* and *A. curvipes*, *Helopeltis* spp, *D. supersticiosus*, *S. rubrocinctus*, *H. schoutedeni*, *A. trifasciata* and the ants *P. megacephala*, *C. clariventris*, *M. aculeatus*, *C. acvapimensis* and *O. longinoda*.

The majority of these insect species found have previously been reported in Ghana, Nigeria, Cote Ivoire, Guinea Bissau and Guinea (Eguagie, 1972; Topper *et al.*, 2001; Dwomoh *et al.*, 2008). This suggests similarities in the insect species associated with cashew in the West Africa sub-region. Similarities in climatic conditions coupled with genetic diversity of planting materials and farm management practices could contribute to similarities in insect diversity. Even though this phenomenon of similar insect species among cashew growing countries in West Africa can be exploited for the integration and harmonization of pest management protocols, it also comes with the danger of sub-regional pest outbreak in the event of any serious pest surge. It is important to note that only a small proportion of insects identified are pests. The majority of insects found in cashew plantations are beneficial insects with the ant complex dominating. Other insects whose ecological role are unknown or undocumented in the cashew landscape in Ghana such as the German cockroach and House cricket were found. Most of the insects identified were found in all the study sites during the period of assessment. However, differences in insect populations in cashew plantations were observed at the different phenological stages of the crop. For instance, *Oecophylla longinoda* populations were more prominent in the flowering and fruiting stages as compared to the other phenological stages of the crop (Tables 1,3 and 5). Even though cashew mosquito, *H. schoutedeni*, and the coreid bugs are all sap sucking bugs, *H. schoutedeni* was more prominent than the latter during the pre-flowering and flowering phases of the crop. This is because *H. schoutedeni* feeds freely on newly developing flush points by sucking its sap relative to the coreid bugs who prefer fruits (immature nuts and apples). This sucking feeding habit results in the drying of growing tip of cashew plants (Dwomoh *et al.*, 2008). However, at the fruiting phase of the crop across all locations, the coreid bugs numbers were similar to that of *H. schoutedeni*. The coreid bugs also feed on growing tips of cashew plants but prefer fruits (apples and nuts) causing them to deform extensively (Dwomoh *et al.*, 2008). These sap sucking bugs have previously been reported on cashew across the entire West African Sub-region (Boakye 1995; Dwomoh *et al.*, 2008; Eguagie, 1972; Topper *et al.*, 2001). The cashew stem girdler, *Analeptes trifasciata*, is also an important insect pest found in all the study locations. This pest girdles around the stems and branches of cashew plants causing them to fall. Their numbers are known to be significantly high in poorly maintained farms (Amoako-Attah *et al.*, 2020). The survey identified a number of fruit eaters that occur during the fruiting period of the crop. These fruit eaters were mainly *Diplognatha gagates*, *Pachnoda cordata* and *Pachnoda marginata* and have previously been reported by Dwomoh *et al.*, (2008).

Different ants have been reported to serve as natural enemies to most insect pests on many crops including cashew (Vanitha *et al.*, 2017; Abdulla *et al.*, 2017). The ant specie *Oecophylla longinoda* observed in cashew plantation in this study have been reported to reduce insect pest populations on cashew (Dwomoh *et al.*, 2009). This study showed that they are the most abundant ant species in cashew plantations in Ghana. Other ant species found and also previously reported on the crop include *C. striatula*, *C. olivieri* and *P. megacephala*. These ants complex on cashew help to minimize insect pest populations on the crop (Vanitha *et al.*, 2017; Vanitha, *et al.*, 2022; Abdulla *et al.*, 2017).

Apart from the ant species, the study has revealed a number of natural enemy species in cashew plantation in Ghana. These natural enemies include *Eumenes fraternus* (Potter wasp), spiders, *Mantis religiose* (Praying mantis) and *Chrysoperla rufilabris* (Green lacewing). Some of these natural enemies have been reported by Sundararaju (1984) and In Kyine Khaing *et al.*, (2004). The main natural enemy reported against cashew insect pests is *Oecophylla longinoda* (Red weaver ants) (Dwomoh *et al.*, 2009). The bee, *Apis mellifera*, which serves as a pollinator was also identified in cashew plantations across the various locations. The natural enemy complex on cashew during the flowering and fruiting phases of the crop is significantly more than that observed at the pre-flowering and post-fruiting phases of the crop. The pre-flowering and post-fruiting phases of the crop may not harbour a lot of pests due to the absence of feeding and breeding sites. This phenomenon will therefore reduce natural enemy populations in cashew plantations since their prey populations are low. As a result of the presence of natural enemies on the crop during the flowering and fruiting phase of cashew, care must be taken to apply only recommended insecticides and at the right time to avoid reducing natural enemy populations. In a balanced cashew ecosystem, insecticide application may reduce the natural enemy complex present in the plantations. Indiscriminate application of insecticides during the fruiting period of the crop may also lead to chemical contamination of fruits.

Cashew diseases have been reported to affect the production of the crop in all growing regions including Ghana (Amoako Attah *et al.*, 2021, Kone *et al.*, 2015; Freire, *et al.*, 2002; Monteiro *et al.*, 2022). Diseases affect the quality and quantity of the cashew nuts leading to loss of revenue to the farmer.

Anthraxnose, leaf spot, leaf blight and leaf rust were the dominant diseases identified. These diseases have earlier been reported to affect cashew trees in Ghana (Amoako-Attah *et al.*, 2021; Muntala *et al.*, 2021). Anthracnose disease caused by *Colletotrichum gloeosporioides*, is a major disease of cashew in Ghana and many producing countries in the sub-region. It affects the nuts, twigs and flowers of the cashew tree leading to yield loss of 70-100% if not controlled (Amoako-Attah *et al.*, 2021; Wonni *et al.*, 2017; Freire *et al.*, 2002). Incidence of anthracnose diseases ranged from 6.63-40.46%, 5.24-31.78% and 3.48-20.18% during the pre-flowering, fruiting/ flowering and post-fruiting stages respectively. Soro *et al.*, (2021) reported anthracnose disease severity of 4.52-51.96% during a survey of anthracnose disease in some cashew growing arrears of Côte d'Ivoire. Leaf blight disease caused by a fungal complex of *Lasiodiplodia* spp., *Pestalotia* spp. and *Colletotrichum* spp. is characterized by irregular patches of brick red colour on leaf margins which later coalesce to silvery grey colouration (Agyare *et al.*, 2022). The disease incidence during this current study ranged from 2.89-37.84%, 1.4-39.90% and 2.84-32.24% during the pre-flowering/ flowering/fruiting and post fruiting phases respectively. Nene and Sijaona (2015), reported cashew leaf blight disease incidence of 1-70% in the southern production areas of Tanzania. However, the disease causal agent in Tanzania is different from that of Ghana. Leaf spot and leaf rust diseases although dominant across the surveyed areas are regarded as minor diseases of cashew in Ghana and as such cause minimal damage to the crop (Amoako Attah *et al.*, 2021; Muntala *et al.*, 2021). Inflorescence blight, gummosis and twig die back diseases were less severe in the farms surveyed. Inflorescence blight disease incidence during the flowering/fruiting stage ranged between 0 and 8.24%. This disease, although less severe can cause loss of flowers leading to low yield if not controlled.

Disease incidence was very low in the semi-deciduous areas (Eastern region) as compared to the other zones. This could be as a result of the variation in environmental conditions across the different agro-ecological zones. The diseases encountered during this study have been reported in other growing areas in the West Africa sub-region. Wonni *et al.*, (2017) reported the presence of anthracnose, leaf spot and gummosis as the major cashew diseases in Burkina-Faso. In Tanzania, leaf rust and anthracnose were the dominant diseases with yield loss of 70 to 100 % (Otuonye *et al.*, 2014). Anthracnose disease has also been reported to be a serious threat to cashew production in Mozambique (Uaciquete *et al.*, 2013) whilst in Benin, leaf spot, leaf rust and anthracnose diseases continue to be among the dominant diseases (Afouda *et al.*, 2013). Control of these important cashew diseases is crucial to the survival of the cashew industry in Ghana and all producing countries. Cultural practices and application of fungicides have been used effectively to control cashew diseases (Amoako-Attah *et al.*, 2021; Christian 2001; Menezes *et al.*, 1975; Zhongrun *et al.*, 2014).

The use of resistant planting materials and plant-based products have shown promise in the control of cashew diseases (Adeji *et al.*, 2021; Nene *et al.*, 2017).

Conclusion

The survey has showed that a number of insect species and diseases occur on cashew in Ghana. Insects attack cashew through sap-sucking, defoliation, stem or branch girdling. Others also bore stems, fruits and nuts. Some insect species identified were natural enemies to pests and others serve as pollinators to the crop. The dominant diseases on cashew in Ghana include Anthracnose, Leaf spot, Leaf blight, Inflorescence blight, Leaf rust, Gummosis and Twig die back insect pests and diseases identified in this study were found to be similar to those identified in other West African countries. It is therefore recommended that a sub-regional pest and disease quarantine center be established to deal with indigenous and exogenous pests. Consequently, there is the need to harmonize pest and disease control protocols to ensure sustainable production of cashew in the West Africa Sub-region.

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Why choose West African cashew?

Supply Chain

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traceable, organically
produced

Logistics

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cost, reduced carbon
footprint

International Certifications

HACCP, BRC,
Kosher, ACA

Sufficient Supply

1.6 million MT of
raw cashew nut per
annum

Social Impact

Major contribution
to job creation
for women and to
national GDP



FACTORS IN THE ADOPTION OF CASHEW CULTIVATION BY FARMERS IN THE BÉNOUÉ DEPARTMENT OF NORTHERN CAMEROON

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Summary

In Cameroon, the challenges of cash crop diversification have recently led to the extension of cashew cultivation in five regions of the country, including the northern region, which was dominated by cotton cultivation. This article sheds light on the factors influencing the adoption of cashew nut cultivation by farmers in the Bénoué Department of northern Cameroon. Surveys were conducted from April to May 2022 among producers who had adopted cashew nut cultivation, spread across 3 of the 12 districts of the Bénoué (Demsá, Pitoa, and Garoua 3). These respondents were selected using the purposive sampling technique. Data were collected from 137 cashew nut producers and three managers from the Cotton Development Company (SODECOTON). The data were analysed thematically and descriptively. It was found that the actors involved in cashew nut extension in Bénoué are SODECOTON, the Departmental Delegation of Agriculture and Rural Development, the GIZ and the municipality. Most of them use technical guidance on production itineraries to popularise cashew nut cultivation. The majority (96%) of cashew growers in Bénoué are men aged between 36 and 45. The majority (68%) are educated to at least secondary level. Several factors favourably influence the adoption of cashew by producers. These include economic factors, such as the attractive market price of cashew nuts, and socio-cultural factors, such as the organoleptic and medicinal qualities of cashew trees, which are used to treat a number of illnesses including malaria and cardiovascular diseases. The increased fertilisation of soils by cashew trees and their use as shade are also factors contributing to their adoption. These growers face a number of difficulties, particularly conflicts with herders, difficult access to water for watering the plants in the dry season and delays in the supply of cashew seedlings by promoters. However, growers have developed various strategies, such as hedgerows, watering points and the construction of mini-nurseries to replace dead plants. The study recommends reinforcing the technical capacities of adopting producers.

Key words: adoption, cashew tree, Bénoué, North Cameroon.

1. Introduction

Agriculture is one of the key sectors of the Cameroonian economy. The National Institute of Statistics [INS], (2017) estimates that the agricultural sector contributes more than 22.9% to the country's GDP. This figure accounted for around 23% of the country's total exports in 2013. According to a report by the Ministry of Agriculture and Rural Development (2016), the agricultural sector is the leading provider of employment with 62% of the working population in Cameroon, although only 15.4% of land is arable. The importance of the agricultural sector is based mainly on the cash products sub-sector, which covers cocoa, coffee, bananas, rubber, wood, palm products and cotton. Cameroon's cotton-growing zone covers a large part of the North and Far North, excluding the northern areas close to Lake Chad (the Logone and Chari departments). Cotton plays an important role in rural and economic development in northern Cameroon. The sector is mainly supported by the Cotton Development Company (SODECOTON), the main agro-industrial company in the region, which was set up in 1974 (Devèze, 1996) to continue the work of the Compagnie Française de Développement des Textiles (CFDT). As part of the Growth and Employment Strategy Paper (GESP), Cameroon intends to launch a vast programme to increase agricultural production in order to meet not only the food needs of the population, but also those of the agro-industry. The aim is to modernise the production system by making production factors such as land, water and agricultural inputs accessible and available; by promoting access to technological innovations through strengthening the link between research and extension; and by developing the competitiveness of production sectors such as cashew nut production, which is beginning to expand and to be seen as 'white gold' on the international market. The cashew tree (*Anacardium occidentale*) is a multi-purpose tree that was introduced to Cameroon's three northern regions in 1975, where several thousand hectares were planted with the aim of avoiding over-dependence on cotton. This objective was never fully achieved, as the sector remained underdeveloped for a long time. However, the government is reaffirming its commitment to the cashew tree with a view to contributing to the socio-economic development of the cotton basin with an annual production of 108 tonnes of cashew nuts (MINADER, 2018).

According to the National Cashew Nut Value Chain Development Strategy 2019-2023, the Cameroonian government is constantly reiterating the need to bring about a genuine "Agricultural Revolution" by modernising the means of production and processing agricultural products. This would enable the country to consolidate its status as the breadbasket of Africa. In the current context of seeking to diversify sustainable sources of income for producers and develop value chains, the government has given its backing to the formulation of a consensual vision concerning the need to support the development of the cashew nut industry. The economic importance of this sector, which was ignored for a long time, has now been recognised, with strong international demand for its by-products. Alongside cotton, coffee and cocoa, cashew nuts can play a key role in economic growth and the development of poor countries.

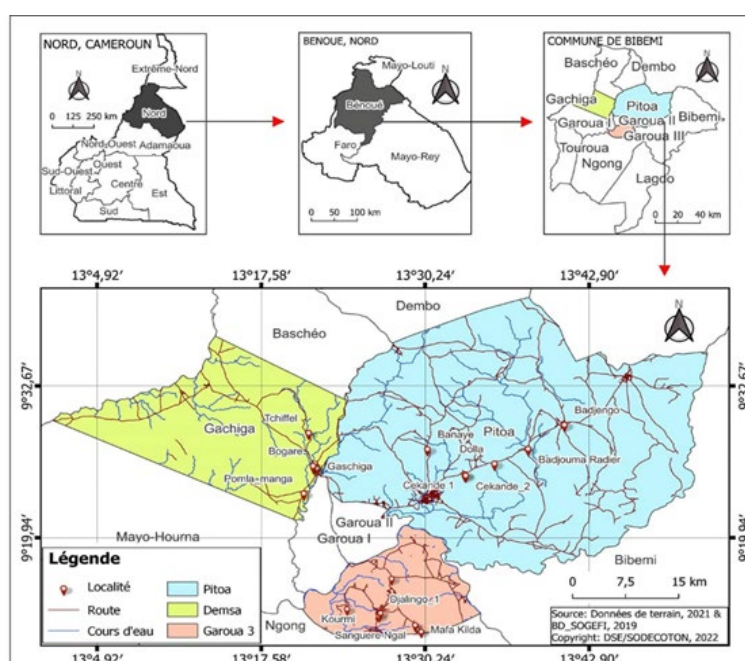
Despite its importance in increasing producers' incomes and diversifying crops, the cashew nut is a promising product for Cameroon in economic, environmental and social terms. Its by-products, such as cashew nuts, white and roasted cashew kernels and cashew apples, are consumed directly, but are also used to make juice, jam or alcohol (National Cashew Nut Sector Value Chain Development Strategy Document in Cameroon (2019-2023)).

The Cameroonian government, via MINADER (the Ministry of Agriculture and Rural Development), plans to establish cashew nuts as the second export crop in the Sudano-Sahelian zone, thereby diversifying producers' sources of income and ensuring that part of the population break out of the poverty cycle. Since then, many other players have taken up the cause, working alongside MINADER to popularise cashew cultivation. Immediately, several producers decided to start producing this crop. With this in mind, this article looks at the spread of cashew nuts in the northern part of the country, more specifically in the Bénoué department. The aim is to analyse the factors influencing the adoption of cashew nut cultivation by producers in the Bénoué department of northern Cameroon. The aim is to identify the actors involved in cashew extension in Bénoué and the extension approach used for cashew dissemination, to present the socio-economic characteristics of cashew growers in Bénoué, to identify the factors influencing the adoption of this crop by growers and finally to identify the problems faced by cashew growers in the Bénoué department.

2. Methodology

2.1 Choice of study area

This study was carried out in three of the twelve districts (Demsas, Pitoa, and Garoua 3) of the Bénoué department in the northern Cameroon region. This region is one of the main cashew nut production and distribution areas in Cameroon, as shown by Fadimatou (2021). Northern Cameroon is the leading cashew nut production basin in the country. It is one of the most favourable agro-ecological zones (Sahelian zone) for cashew cultivation. Figure 1 shows a schematic representation of the Department of Bénoué, more specifically the districts of Garoua 3, Demsa and Pitoa.



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Figure 1: Location map of the study area: Bénoué Department

Source: Field data 2021 and BD_SOGEFI, 2019

2.2 Sampling technique, data collection and analysis

The data were collected from April to May 2022. The sample, based on the unit of analysis, included producers who had adopted cashew trees and managers from the Cotton Development Company (SODECOTON). Using the purposive sampling and snowball sampling techniques, 137 cashew nut growers and 3 SODECOTON managers were selected and interviewed using a questionnaire and an interview guide. The qualitative data obtained were analysed thematically and the quantitative data were analysed using Statistical Package for the Social Sciences (SPSS) version 23.0 and Excel 2016.

3. Descriptive Analysis of Data

3.1 Stakeholders involved in the extension of cashew cultivation in the Bénoué department

The extension of cashew tree cultivation in the Bénoué department involves the collaboration of several players, each contributing their expertise and resources to support local producers. As part of the revival of the cashew industry, the distribution of cashew seedlings to producers in the Bénoué department began in 2018, when the first seedlings were put in the ground. The various players involved in disseminating cashew crops in the Bénoué department are the departmental agriculture delegation, SODECOTON, GIZ and the municipality.

3.2 The Bénoué Departmental Delegation for Agriculture

The Departmental Delegation for Agriculture, a decentralised service of the Ministry of Agriculture and Rural Development, is at the centre of all agricultural projects at local level. This is the case for the PADF-Cashew (Cashew Development Support Project) project, which is represented in five (5) regions of Cameroon, including the northern region.

The Bénoué departmental delegation plays an essential role in the promotion and dissemination of cashew cultivation through support for production, support for extension, organisation of stakeholders and monitoring and evaluation. Through technical guidance, it supports the establishment of orchards, the training of nurserymen, and the production and sale of seedlings (300 CFAF each). It is also involved in training producers and raising their awareness of good cashew-growing practices by organising workshops, meetings and campaigns to encourage cashew planting and the sustainable management of orchards. When supplying seedlings to growers, priority is given to those with their own plots of land.

3.3 SODECOTON

SODECOTON's agricultural projects division handles projects such as the cashew project. Although mainly focused on cotton production, SODECOTON supports MINADER in disseminating and raising awareness of cashew cultivation among cotton growers. It also contributes to cashew tree extension by providing free seedlings produced by the CNPC to farmers with their own plots. It also raises awareness among farmers about the benefits of cashew trees, and shares its expertise in agricultural management and the value chain with growers. SODECOTON works on the basis of the budget provided by the government for the cashew project. However, its interest in cashew growing is based on a very specific objective. That is, to increase the income of cotton growers by diversifying their sources of income, cashew being seen as an asset, a source of income that complements that of cotton.

3.4 GIZ

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), a German international cooperation organisation, is working with local stakeholders to promote cashew tree cultivation by providing technical knowledge, training and resources to improve cashew tree cultivation practices. The GIZ is involved in environmental education and awareness-raising, forest management and restoration.

The Non-Timber Forestry Project deals with the processing of non-timber forest products such as cashew nuts. The cashew tree is considered to be a forest tree, so its nuts can be processed into cashew oil and kernels. To do this, GIZ only works with cashew growers who have cashew orchards of at least 10 plants. To ensure the harvest of good seed, it identifies trees with high production potential from producers with cashew orchards that are 5 to 6 years old. These orchards must be homogeneous, i.e. well drained and single-cropped, with plant spacing of at least 10 metres. Only orchards meeting these criteria are purchased by GIZ for the harvest of fruit by the kilogram per tree. Given the importance of this crop, the GIZ supports cashew growers throughout the entire process, from the preparation of the plot to the harvesting of the fruit.

3.5 The municipality

As a decentralised local authority, the Bénoué Municipality supports other stakeholders in promoting cashew tree cultivation through various initiatives, such as raising awareness among producers, setting up training courses on best agricultural practices, and supplying seedlings from the IRAD (Agronomic Research Institute for Development) or the departmental agriculture delegation. It also facilitates exchanges between growers.

The distribution of cashew seedlings in the Bénoué Department is carried out by several stakeholders, some of whom work together to encourage growers to adopt cashew cultivation. These stakeholders use technical guidance on the production itinerary to popularise cashew to growers. They use tools such as technical sheets to show the cashew tree's technical production itinerary, awareness-raising and training for relay growers, who are responsible for passing on the information to other growers. Transmission takes place directly in the plots of the producers who are members of the farmers' organisation (FOs), and it involves learning by doing. Producers do not receive training and monitoring directly from the promoters, but rather from the leaders of their FOs, who have been trained beforehand. Only nursery growers receive training directly from technicians or engineers sent by the promoters. Nevertheless, more and more producers in the Bénoué department are investing in cashew cultivation, which they consider to be their second cash crop after cotton, or 'retirement' crop, as one producer put it. He justifies this by saying that at a certain age, he will no longer have the strength to grow cotton, but his cashew tree will still be able to produce fruit effortlessly. As part of the revival of the sector in the Bénoué region, the first seedlings were planted 5 years ago, and some farms have cashew trees dating back to the 70s and 80s, when cashew trees were first introduced in the northern part of the country.

3.6 Socio-economic characteristics of cashew growers and their farms

Presenting the socio-economic characteristics of the producers and their farms is of great importance in this study, as it enables the contextualisation of cashew tree adoption factors in the Bénoué department. Variables such as age, sex, level of education, household size and main activity help to understand contexts and motivations. Farm size and agricultural practices can directly influence cashew tree adoption.

Table 1: Distribution of cashew growers according to their socio-economic characteristics and those of their farms.

Variables	Producers	Percentages (%)
Sex	Male	96
	Female	4
Age	Under 25	4
	] 36-45[	51
Level of education	Not enrolled	27
	Primary	34
	Secondary	35
	University	4
Main activities	Agriculture	29
	Farming	71
Marital status	Married	95.70
	Single	1.40
	Widowed	2.90
Workforce	Family	82.60
	Paying	17.40
Surface area of the farm	Less than 1ha	76.47
	] 1-1.5 [	20.59
	] 2-8 [	2.94
Membership of a farmers' organisation (FO)	No FO	28
	GIC, Coop, association	72

The sample of 137 cashew growers in the Bénoué department shows that the majority (96%) are men, most of them (51%) aged between [36-45], with a high level of education (73%). This result contradicts those of Koffi and Oura, 2019, who showed that 80% of cashew nut producers in the Côte d'Ivoire cotton basin were illiterate. The main activity of producers in the Bénoué is livestock farming (71%), and the workforce is mainly (82.60%) family-based. The size of their farms varies from less than one hectare to 8 hectares, with the majority (76.47%) having a farm of less than one hectare. Most of them belong to a farmers' organisation, either a joint initiative group (5%), a cooperative (64%) or an association (3%).

The survival incomes of farmers in the Bénoué department depend mainly on agriculture and livestock farming, especially cotton, which is one of the crops with the greatest economic potential in the area. These producers grow cotton in association. Because of its ability to combine with food crops, cashew is playing an increasingly important role in the new structuring of the agricultural landscape and is becoming a cash crop that complements cotton and food crops (Koffi and Oura, 2019). In addition to cashew and cotton, farmers in the Bénoué department also grow market garden crops (tomato, black nightshade) and food crops (groundnuts, maize, millet, sorghum). Livestock and poultry (sheep, cattle, goats, village chickens, broilers and ducks) are also farmed.

The high rate (87%) of producers using family labour can be explained by the fact that they have fairly large households, with an average of 10 people per household. Based on the differentiation criteria (farm size, use of hired labour, crop specialisation) of the farm typology according to Lamarche (2001), cashew growers in the Bénoué department operate on a family survival basis.

4. Results and discussion

4.1 Factors influencing the adoption of cashew cultivation by farmers in the Bénoué Department

The adoption of a new crop by growers depends on several factors that influence the process. In the Bénoué Department, there were several reasons why growers decided to start growing cashew. The table below shows the distribution of growers according to the factors that led them to adopt cashew cultivation.

Table 4: Breakdown of cashew growers according to cashew adoption factors

Categories of factors	Factor specificity	Percentages (%)
Economic factors	Profitability	36.49
Socio-cultural factors	Organoleptic and medicinal qualities	56.95
Environmental factors	Enhancing soil fertility	6.56
TOTAL		100

4.1.1 Economic Factors

The cashew nut sector has experienced spectacular growth in adoption by farmers because of the crop's commercial value (Djaha et al., 2012). The profitability of cashew cultivation is one of the factors motivating 36.49% of producers in the Bénoué department to adopt this crop. Indeed, cashew has become attractive to some producers because of the favourable market price of cashew nuts. Producers in Bénoué are seeking to maximise their income by growing this crop, which is capable of generating substantial financial resources thanks to the profitability of the cashew nuts and apple (fruit), which can be marketed in their raw state or processed into almonds, crisps or groundnuts, juice, wine, whisky and jam for marketing.

Producers are keen to grow cashew trees because, as well as being drought-resistant, the crop provides substantial financial income for farmers (Timite, 2023). In the Bénoué department, the nuts are bought back by retailers and SODECOTON for processing or export. Cashew nut oil is extracted by women and then resold. Profitability is also seen in the long term, as some producers see cashew cultivation as a crop for the future that they will be able to exploit even when they are tired, hence the term “retirement crop” used by some producers.

4.1.2 Socio-cultural factors

The organoleptic qualities, its culinary use and the medicinal benefits of cashew nuts are the factors that motivated the majority, 56.95%, of producers in Bénoué to start growing cashew nuts. Indeed, they find the taste of cashew particularly exquisite, its juicy and delicious fruit crunchy, tender and creamy, with a slightly sweet flavour. Some producers claim to combine the hand-pressed cashew fruit with the local fermented drink made from red millet, also known as “bili bili”, which is sold. Their customers particularly appreciate this drink because the cashew fruit is juicy and gives a special flavour to this local drink, which attracts more customers.

Its culinary value is well established, with producers in the Bénoué region claiming that cashew nuts go well with many local dishes. And thanks to its medicinal properties, it is used by naturopaths in the Bénoué department to treat a range of illnesses, including malaria and gallstones. Its bark is also used to disinfect snake bites and to make concoctions to treat cardiovascular disease. Its leaves are crushed and mixed with other plants to treat diabetes and hypertension, and it is used as a dewormer to eliminate intestinal parasites. It also has laxative properties and contains numerous vitamins.

4.1.3 Environmental factors

The adoption of a new crop by growers depends on several factors that influence the process. In the Bénoué Department, there were several The cashew tree helps to improve soil fertility thanks to its leaves and organic waste. 6.56% of farmers in the Bénoué department say they have adopted the cashew tree because of its ability to boost soil fertility and its use as shade in hot weather. Enhancing soil fertility means supporting plant growth and optimising crop yields.

Producers report that the soil in the northern part of the region has become very poor (leached) due to the intensive use of synthetic plant protection products, which destroy the plant flora. Certain forest trees with protective and fertilising properties, such as the cashew tree, are of vital importance to them, as they help to boost soil fertility (plant flora). In other words, cashew plants strengthen the soil and help to fix carbon. The cashew tree therefore helps to improve soil fertility thanks to its leaves and organic waste. Given the variations in climate and temperature in the northern part of Cameroon, more specifically in the northern region, cashew trees play an important role for farmers during the day. They take shelter under these trees to get some fresh air during group meetings or when shelling groundnuts, as the temperature is pleasant.

4.2 Difficulties encountered by cashew growers in the Bénoué department

Cashew nut growers in the Bénoué department face a number of difficulties. The major difficulties faced by all producers in the Bénoué department are essentially agro-pastoral conflicts with livestock breeders, difficulties in accessing water and delays in the supply of cashew seedlings to producers by promoters.

The adoption of cashew trees leads to farmer-herder conflicts and helps to exclude herders (Konan et al., 2016). Agropastoral conflicts are caused by animal damage to agricultural plots. These conflicts between herders and producers are mainly the result of poor behaviour by herders when grazing and watering their animals. During the rainy season, the majority of livestock farmers are in search of good pasture, which is most often found on fallow land. When they are on the move, the animals destroy the crops, causing enormous damage to the farmers' fields, which are often unfenced.

Producers in the Bénoué department have difficulty accessing water because of the long drought, which has considerably reduced availability, affecting crop irrigation. Growers lack the water they need to water their plants, and the distance and lack of equipment (watering cans, jerry cans, lack of nearby water wells, lack of means of transporting water to farm plots, etc.) do not make it easy for growers to access water. This water problem is one of the causes of transhumance, which leads to agro-pastoral conflicts.

Cashew growers in the Bénoué department are facing delays in the supply of cashew seedlings. These delays are sometimes linked to a lack of coordination between suppliers, drought which affects the seedlings and makes it difficult to supply suppliers with seeds and seedlings. This delay undermines the planting season, affects the value chain and causes producers to lose money.

Although cashew tree cultivation has been relaunched thanks to the cashew project, there is still a lack of cashew nut processing units in the Bénoué department. Processing is done in the traditional way by some producers, and this limits the added value and income opportunities for them. Cashew trees are also susceptible to certain diseases (rust and anthracnose) and pests, which requires preventive and control measures to protect crops and manage insects, birds, caterpillars, termites and locusts. However, producer training has not been updated to deal with these problems.

Lack of or inadequate funding for farming activities, difficulties in accessing credit and agricultural inputs, the isolation of the roads leading to the farms (which results in the loss of seedlings due to the distances between plots and the state of the road), poor choice of plot, the

arduous nature of the work, lack of mastery of production techniques, natural disasters (flooding, drought, bush fires, etc.) and crop theft are all difficulties faced by farmers in the Bénoué department.) and crop theft are just some of the difficulties facing farmers in the Bénoué department.

To alleviate these problems, producers in the Bénoué department are taking specific measures. Faced with theft and destruction of their plots by animals, cashew growers are building fences all along their agricultural plots. Some plant hedges around their plantations to protect the seedlings. Faced with delays in the supply of seedlings, some growers set up small nurseries at home to replace seedlings that have dried out or been destroyed by animals. For these growers, a number of measures need to be taken to overcome some of the difficulties they face, including an in-depth analysis of the industry in the locality to better understand the organisation and operation of the value chain; anticipating changes in the industry and, above all, facilitating the structuring of the cashew nut industry in the Bénoué department; facilitating better access for producers to training and information on cashew tree cultivation, risk management and processing; and, lastly, training local nurserymen to produce seedlings on site in the Bénoué department in order to make seedlings accessible to producers.

4.3 Discussion

The high male representation among cashew nut growers in the Bénoué department and their relative maturity in terms of age could demonstrate a lack of interest among young people in perennial crop plantations. The majority age group observed is close to that recorded by Lawal et al (2010) who showed that the average age of producers is 56 years in Nigeria. The low involvement of women (6%) in cashew cultivation can be explained by traditional and customary rules that still restrict women's access to land rights.

The results of the study showed that cashew nut growers face real problems of agropastoral (farmer-herder) conflict. The dry season is not only the time when nuts are harvested, but also the time when it is difficult to find fresh grass for the animals. As a result, animals roam all over the unfenced plots. This result is in line with that of Tuo (2007) in his study on "Analysis of the Cashew Sector in Côte d'Ivoire: development strategies and addressing poverty", who believes that farmers consciously set their animals free because they appreciate cashew apples, which are very rich in animal feed.

5. Conclusion

As part of the revival of the cashew industry in the northern part of Cameroon, the extension of cashew cultivation in the Bénoué department involves the collaboration of several stakeholders, in particular the departmental delegation of agriculture, SODECOTON, the GIZ and the municipality. The majority of cashew growers in the Bénoué department are educated men who belong to a farmers' organisation. The factors that motivated them to adopt cashew cultivation are economic, linked to the profitability of cashew nuts, socio-cultural, linked to the organoleptic, culinary and medicinal qualities, and environmental, linked to the enhancement of soil fertility. These producers face a number of difficulties, particularly agropastoral conflicts, difficulties in accessing water, delays in the supply of cashew seedlings to producers by promoters, and lack of financial resources. The popularisation and adoption of cashew cultivation in the Bénoué department is helping to transform the agricultural landscape, given that cashew is increasingly becoming the second cash crop in the Bénoué department.

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IMPORTANCE OF HONEYBEES (*APIS MELLIFERA*) IN CASHEW NUT (*ANACARDIUM OCCIDENTALE* L.) PRODUCTION IN THE NORTHWEST OF MADAGASCAR

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Abstract

The cultivation and processing of cashew nuts began in 1982 on the island of Madagascar. The sector, since then has faced constraints including low yields over the past decade. Therefore, a new strategy is needed to improve nut production. The main objective of this research was to directly enhance nut yield through using *Apis mellifera* as pollinators. After conducting inventories and studying competition from native pollinators of cashew trees, the study focused on comparing production systems with and without colonised beehives. The study evaluated floral ratios, cashew nut yield, and the caliber of nuts. It was conducted over three years (2018, 2019 and 2020) in two planting zones. The experimental plots were selected based on their homogeneity, with each plot measuring approximately 3 hectares. Five (5) plots without beehives and five (5) plots each equipped with a beehive positioned in the center, were chosen in each zone. The colonized beehives were installed in the cashew plantations two months before the flowering period. Five (5) main families of pollinating insects, of which Apidae, Formicidae, Drosophilidae, Muscidae and Nymphalidae were identified in the study. Plots with beehives recorded higher floral ratios, averaging 7.6 % compared to 5 % in plots without beehives. Cashew nut production in plots with beehives averaged 14.7 kg per tree, compared to 5.9 kg per tree in plots without beehives. Bees in cashew plantations significantly improved nut quality, with KOR (kernel outturn ratio) values around 25.4 kg compared to 17.4 kg in plantations without beehives. So, the installation of active beehives in a cashew plantation plot has shown a positive impact on the monitored factors compared to plots without beehives. Therefore, establishing an appropriate beekeeping/cashew production system could enhance sustainable production in Madagascar.

Key words: Beekeeping, cashew tree, pollinators, nut, Madagascar.

1. Introduction

Cashew (*Anacardium occidentale* L.) is a fruit tree native to tropical regions, particularly along the coasts of Brazil (Merabtine, 1998). Its cultivation has expanded due to the global demand for cashew nuts, which has been steadily increasing, leading to higher commercialization. Since 2015, West Africa has dominated cashew nut production with 1.35 million tonnes, while East Asia produced 1.3 million tonnes (PADEC, 2015). Cashew production is a key factor for socio-economic development both for producers and their countries. In Benin, cashew production yields financial and economic returns of 58,85USD/Ha and 111,37USD/Ha respectively (Tchéhouéya, 2012).

In Madagascar, cashew trees were introduced around the 15th century by the Arabs and Portuguese from the African coast (Lefebvre, 1966). Despite its potential, the cashew sector remains relatively small in Madagascar, and the annual national production is insufficient compared to demand. The exportation reaches an average of just under 10,000 tonnes of raw cashew nuts per year, primarily to India. In the Ambilobe district, the price of raw cashew nuts currently ranges from 2 000 to 5 000 Ariary per kilogram (between 0.50 USD and 1.21 USD) depending on the quality (Mahefa, 2023). Cashew production, therefore, if enhanced, has the potential to create jobs and boost the economy of the country. Currently, only two licensed exporters handle cashew nuts locally. Thus, local producers and farmers are being encouraged to cultivate cashew as an alternative to cocoa, vanilla, and cloves cultivation. Like other types of agro-industrial plantations, integrated agroecological systems have consistently shown promising results. According to African Cashew Alliance (ACA) in 2013, introducing beekeeping in cashew orchards increased production by 116.7% in Ghana and 212.5% in Benin. Therefore, the main objective of this research is to directly improve cashew nut yield and quality through the introduction of beekeeping in plantations. To achieve this study, a comparison of cashew nut production with and without bee pollination was conducted in two Communes in the Ambilobe district (Antsoha and Beramanja). This region is the second-largest producer of cashews in Madagascar after Marovoay; the Ambilobe district boasts a vast cashew orchard estimated at 11,000 hectares (Raheriniaina, 2020). Agriculture is the primary activity for the populations of Antsoha and Beramanja Communes, with cashew cultivation being a cornerstone of the regional economy.

2. Materials and methods

2.1. Study area

The study took place from 2018 to 2020 in two locations in cashew growing areas within Antsoha Commune (Latitude: -13.2465, Longitude: 48.9908) and Beramanja Commune (Latitude: -13.3436, Longitude: 48.8762) (Figure 1), located 157 km south of Antsiranana city, in the Ambilobe district. The cashew plantation in each Commune covered an area of about 46 ha minimum.

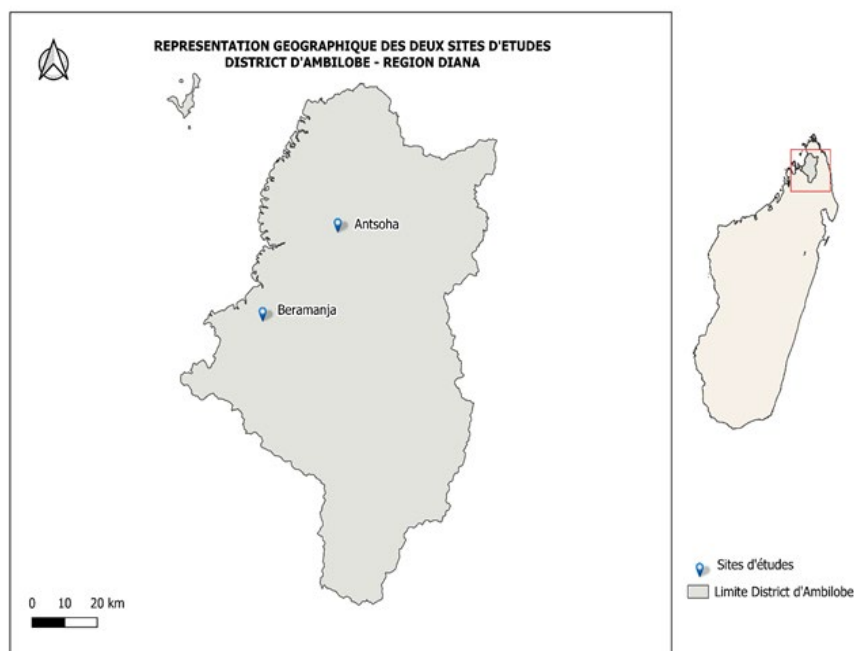


Figure 1: Mapping of study areas

2.2. Experimental setup

2.2.1. Inventories of native pollinators of cashew trees

Ten cashew trees in full bloom were monitored for this study with two replicates in each of the two neighboring communes. Periodic observations of flower-visiting insects on cashew trees were conducted during the flowering season from May to November. Observation dates were randomly selected during the flowering period of *Anacardium occidentale* (Reddi, 1993). Each observation day consisted of six (6) different observation periods, with 15 minutes per tree, totaling 90 minutes of observation per tree per monitoring day and per person. All the panicles were observed in an area of 1 m² on each side or orientation (North, South, East, and West). Additionally, some observations were conducted at night using a flashlight to check for nocturnal flower visitors. Specifically, observations were divided into two (2) in the morning (8AM and 10AM), two (2) in the afternoon (2PM and 4PM), and two (2) at night sessions (7PM and 9PM). The relative abundance of visiting insects was calculated by dividing the total number of visits by the number of flowers available on the panicles during that period. Abundance was averaged across the ten sampled trees. During monitoring, the number of visits by each type of insect were recorded. Insect capture sessions, targeting potential pollinators, were conducted at multiple locations within the cashew orchard and systematically to obtain a representation of the diversity in the studied area. Some species were identified morphologically in the field by the team from the University of Antananarivo. The identification of specimens was carried out using the identification keys developed by Triplehorn et al. in 2005. In contrast, flower-visiting insects that could not be identified on-site were captured using an insect net (sweeping the net through the panicles) or an insect vacuum (sucking insects off the surfaces of the panicles) and preserved in 70 % alcohol or in envelopes for flying insects. They were then sent to the Entomology Laboratory at the Centre National de Recherches sur l'Environnement (CNRE) in Antananarivo, Madagascar, for morphological identification up to the family or species level by following the keys established by the California Academy of Sciences on AntWeb in 2020 were applied.



Figure 2: Visits of insects to flowers

2.2.2. Evaluation of the impact of beekeeping on cashew cultivation and productionst

In total, twenty (20) monoclonal type blocks with a minimum area of 3 hectares each were monitored for this study. In each Commune, five (5) plots without hives and five (5) plots each equipped with a colonised hive positioned centrally in the plots were established. Within each plot, twelve (12) trees were selected for observation and marked within a radius of 150 m. The selection of this radius is based on the plantation size and the mobility of bees, which can travel distances of over 350 meters (Fougeroux et al., 2017). In each plot, cashew trees were evenly distributed in the four cardinal directions (North, East, West, and South) within the 150-meter radius, resulting in four (4) trees per orientation. In plantations without hives, the setup was similar except for the arbitrary selection of the reference point for installation.

However, the first tree was chosen based on the orientation determined in the plantation with hives, with subsequent trees selected following the same orientation scheme. In total, 240 cashew trees were monitored. These trees were geolocated and marked according to the experimental setup described above.

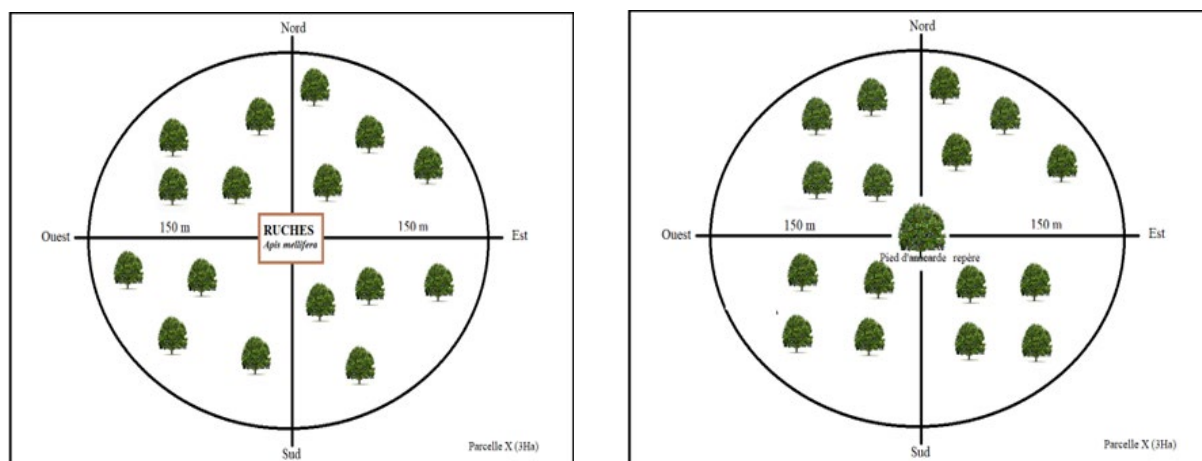


Figure 3: Experimental setup of trees with and without hives

For the evaluation of pollination effectiveness, a flower marking technique was employed for each type of visitor. Flower buds on panicles were isolated to assess their effectiveness as pollinators. This method also highlights the importance of pollinating insects in production and their impact on fruiting (Figure 4). Control panicles were covered with packaging paper, with openings protected by cotton soaked in alcohol to ensure they remained untouched by foreign bodies. Sampled panicles, on the other hand, were simply wrapped with packaging paper. Each covering was labeled or marked to track newly opened hermaphrodite and male inflorescences until fruit set. It's important to note that abnormal flowers were removed from the panicle to facilitate counting.



Figure 4: Setting up caps for pollinated flower panicles and control groups

2.2.3. Evaluation of nut yield and quality

This involved determining the exact number and weight of nut harvests from the plots with hives and comparing them with those of plots without hives. Grading was done by grouping nuts into small piles of ten (10), counting the number of these piles, and any additional nuts. Foreign materials are then removed and weighed before counting. Furthermore, the fruit set rate was calculated by dividing the number of fruits formed by the number of blossomed flowers.

Qualitative analysis: After the grading calculation above, it is also necessary to calculate the defect rate (DR) using the following formula:

$$TD = \frac{(\text{Weight of nuts rejected at 50\%} + \text{Weight of nuts rejected at 100\%})}{\text{Total weight of the nut sample}} \times 100$$

As part of the quality control, the ACA method (2019) which involves measuring the quality of cashew nuts was adopted. However, for this study, two lots were formed: the first lot consisted of plantations with hives and the second lot consisted of plantations without hives. For the determination of KOR (Out Turn), raw nuts were sampled from the aforementioned 240 observation trees, totaling 941 kg of raw nuts. The samples were sun-dried for seven days to reduce moisture content to approximately 7 to 10 %. Divided into four lots, each was carefully mixed and then subdivided into four roughly equal portions. Each portion is referred to as a "quarter," resulting in four opposing pairs of quarters. Thus, the first quarter opposes the third quarter, and the second quarter opposes the fourth quarter. Each sample must come from two opposing quarters. This results in the following diagram:



Figure 5: Sampling process (ACi, 2016)

The basic calculation of the Out Turn (KOR) is obtained by the following formula:

$$\text{KOR (Out Turn)} = (\text{Useful nuts} \times 80) / 454$$

With: AU (Useful nuts) = Total weight of obtained nuts+ Husks of healthy nuts + [(Total weight of obtained almonds + husks of nuts rejected at 50 %) / 2]

2.2.4. Statistical analyses

The data were analyzed using XLStat 2014 version. The Shapiro-Wilk test (1965) was applied to all studied variables to check for normality of the obtained data. Mean comparisons were tested using parametric tests such as the Friedman test and Newman-Keuls test to verify the existence of differences, and the Kruskal test for Out Turn (KOR). Fruit set rates were compared between treatments using a chi-square test.

3. Results

3.1. Inventories and competitive analysis of native pollinating agents of cashew trees

Four types of behaviors were observed: insects flying around trees, insects moving from one panicle to another on the same tree, insects flying to another panicle on a neighboring tree, and insects moving along the vegetative parts of the same tree. The results provided here show the total number of specimens identified both at the University (106 specimens) and at the CNRE (296 specimens). In total, 402 specimens of insects were captured during the monitoring of the fields covering thirty-six (36) collection sessions. Moreover, the morphological identification of each captured specimen resulted in three (3) different insect orders: Hymenoptera, Diptera, and Lepidoptera. These include: *Apis mellifera* sp. (APIDAE) and *Crematogaster* sp. (FORMICIDAE), *Drosophila* sp. (DROSOPHILIDAE), *Musca* sp. (MUSCIDAE), *Danaus chrysipus*, and *Acraea horta* (NYMPHALIDAE). The activity pattern of pollinating insects on cashew flower from the beginning of the flowering season was largely dominated by *Apis mellifera* (APIDAE). Meanwhile, the other families show nearly equal visitation rates but with low populations, except for *Drosophila* sp., which was represented by just five (5) individuals.

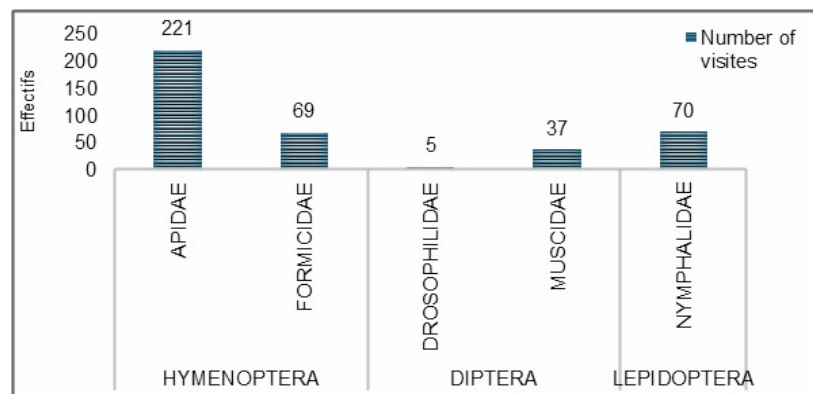


Figure 6: Number of insect individuals captured based on their visits to flower panicles at both sites

3.2. Floral characterization of cashew trees

For the twenty plots studied in the two Communes, Antsoha and Beramanja, the cashew orchards had an average age of 5.5 years. From the 256 inflorescences sampled, the analysis of floral ratio distribution in both communes shows that the floral ratio varies between 5.01% and 11.0% in Antsoha, and between 4.51% and 11.4% in Beramanja. Comparatively, the ratio between plots with hives and plots without hives averages 7.6% versus 5% (Figure 7). This trend confirms the consistency of the floral ratio in the orchards under study. This result is supported by variance analysis between sites, which shows no significant difference ($p = 0.51$) in floral ratio. Indeed, the results indicate an increase in cashew nut production in plantations with hives, averaging 14.7 kg/tree compared to 5.9 kg/tree in plantations without hives across both sites.

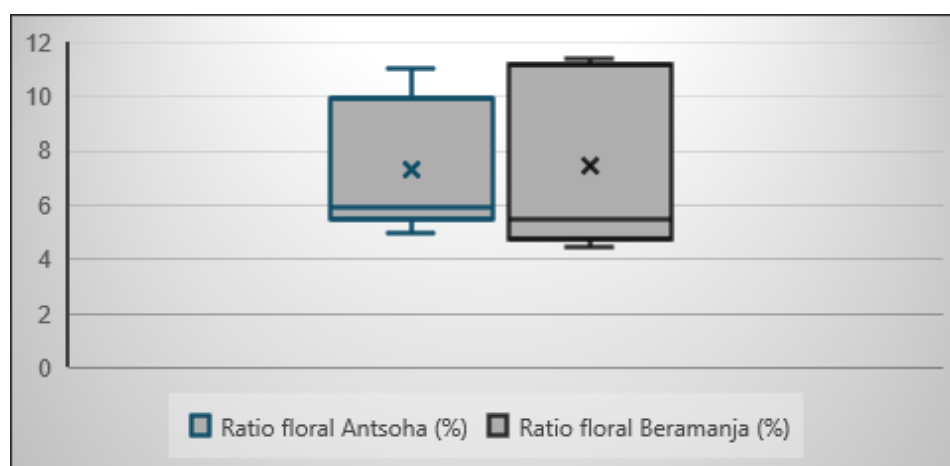


Figure 7: Distribution of floral ratio between Antsoha and Beramanja

3.3. Effect on cashew production

Based on observations, each sampled panicle on average produced five (5) well-formed nuts, half of which were for controls. The descriptive analysis of these results is shown in Figure 8.

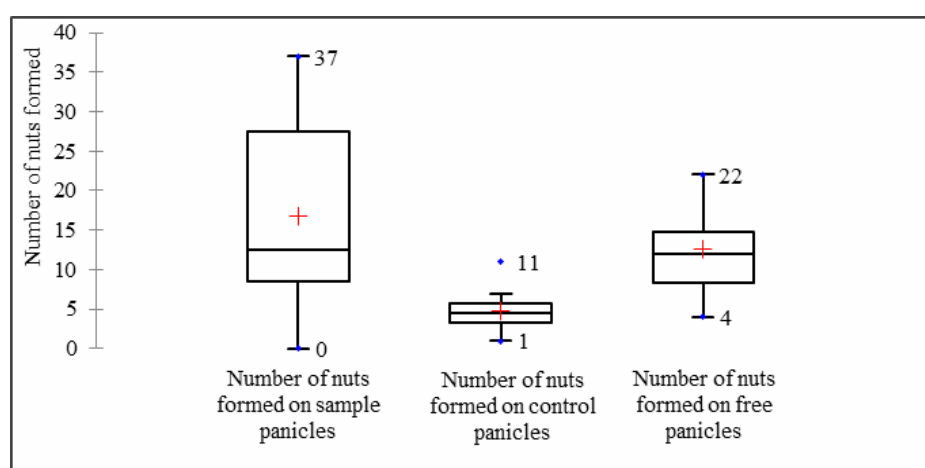


Figure 8: Formed nuts according to observed types of panicles

Firstly, the mean and median of formed nuts on control panicles are around 4 nuts. Overall, the minimum number of nuts formed is 1 and the maximum is 11 nuts. Secondly, on sampled panicles where pollinators are favored visitors, the average number of harvested nuts is 16 nuts per panicle. The Figure 8 shows that the data distribution for nuts is concentrated in the lower section of the median (12 nuts). Lastly, for free panicles without insect pollination, the average number of formed nuts is identical to the median (12 nuts). The maximum nuts formed is around twenty-two (22), and the minimum number of nuts formed under this condition is 4 for the free panicles.

This difference is confirmed by statistical testing comparing the variance of the three samples, which requires us to accept the null hypothesis with ($F = 3.3$ and $p\text{-value} = 0.0004$) and reject the alternative hypothesis with a risk of 0.04%. Therefore, panicles pollinated by *Apis mellifera* have better fruit set than unpollinated flowers (controls).

3.4. Characteristics of nuts and nut quality

A comparison of the average weights of nuts from flowers pollinated by bees and non-pollinated flowers across seasons revealed that pollinated nuts were generally heavier than non-pollinated ones ($F = 8.01$; $p = 0.004$). Although there was no difference among pollinated nuts across the three seasons (Holm-Sidak test; $t = 1.17$; $p = 0.17$). Indeed, nuts formed after pollination were larger than those obtained without their intervention. Cashew nut production in plantations with hives averaged 14.7 kg/tree compared to 5.9 kg/tree in plantations without hives. The highest yields were consistently achieved in orchards with hives throughout the trials in both Communes. Significant yield improvements of 40 % were observed. Result on the nut characteristics and quality are shown in Table below:

Table 1: Results of the evaluation of nut quality

Sites	Types of plantations	Grading	Assessment of quality	TD	KOR (kg)
Antsoha	Plantations without hives (60 Trees)	201	Average	12,2	25,4
	Plantations without hives (60 Trees)	229	Acceptable	14	18,9

Beramanja	Plantations with hives (60 Trees)	212	Below average	11,9	23,2
	Plantations without hives (60 Trees)	222	Acceptable	13,2	17,5

Determination of nut characteristics showed nuts with beehives were larger than those without beehives in Beramanja but was in the other way around in Antsoha (Table 1). Between the two plantation sites, Beramanja showed better grading, both in hived plantations, whereas in Antsoha, non-hived plantations had higher nut counts. In both sites, plantations with hives had an out-turn (KOR) between 25.4 kg to 23.2 kg compared to 17.5 kg to 18.9 kg for plantations without hives.

4. Discussion

The specific characteristic of cashew flowers, with a high proportion of male flowers selected compared to hermaphrodites, justifies the need for the multiplication of pollinators. Autogamy is difficult due to the structure of hermaphrodite flowers with high stigma placement relative to the stamens (Bhattacharya, 2004). The inventory of pollinating agents has provided a number of indigenous insects that have the capacity to pollinate cashew trees at both study sites. Their identification allows us to gain insights into various possible aspects for future studies. Among the recorded visitors, ants and bees are the most abundant. This demonstrated that domestic or wild bees were indeed present in the field during the flowering period. Bees visit flowers for extended periods and generally move short distances. The more abundant the flowers, the greater the number visited, leading to effective pollination. During observations, other visiting insects were noted but not captured during collection. The low number of captured insects may be explained by the difficulty in capture due to strong winds called "Alizé" that coincide with the flowering period in this area. It is highly likely that other specimens remain undetermined at this time. The null hypothesis was therefore rejected because the duration and abundance of insect visits are not influenced by the time of day, likely due to the high daily temperature (27 °C) in the plantation areas of Antsoha and Beramanja, which keeps pollinators active from morning till evening. The frequency of visits to particular flowers from one tree to another is known to be primarily influenced by the quality of pollen and nectar (Abou-Shaara, 2014). Nonetheless, the presence of other diverse insect families indicates their participation in both autogamy and allogamy phenomena.

The analysis of cashew nut yield under the two treatments (with and without beehives) highlights the importance of pollinator activity. Cashew is recognized as a melliferous tree, as in other countries. A significant difference was observed between the number of nuts produced by panicles deprived of pollinator agents and those pollinated panicles. There is a substantial disparity in the number of nuts formed compared to controls and also against natural fertilization (free panicles). This underscores the value of integrating cashew farming with apiculture. The yield in cashew nut production from the aforementioned study, 14.7 kg/tree in the hive plot versus 5.9 kg/tree in plots without hives, were close to findings by Jocelyn (2016), who reported that a tree can produce an average of 15 kg of fruits per season throughout its life, peaking around the tenth year at 30 kg/tree. In contrast, cashew nut production in India can reach up to 48 kg/tree (Samal et al., 2003), highlighting lower yields here due to inadequate pollinator presence. This is supported by Klein et al. (2011), emphasizing the importance of pollinators in ensuring quality production through insect pollination. In 2013, Aidoo demonstrated that introducing apiculture into cashew orchards increased production by 116.7% in Ghana and 212.5% in Benin. It is conceivable that various physical characteristics of cashew pseudo-fruits (the apple) or nuts could be improved due to the intervention of *Apis mellifera* for cross-pollination of the species (Hermann et al. 2020). However, it should be noted that other factors are also likely to influence the characteristics and yield of nuts between open-air treatments and controlled samples.

Regarding the quality of the nuts, the analysis of results shows that the kernel out-turn (KOR) varies between 201 to 212 nuts/kg for plots with hives and 222 to 229 nuts/kg for plots without hives. This variation underscores the importance of the presence of bee pollinators, which has an effect on nut quality. The KOR values in both sites are also attributed to the presence of bees, with an average KOR of 23.2 kg to 25.4 kg for pollinated plantations compared to 17.5 kg to 18.9 kg for plots without hives. These values obtained in plantations with hives are considered good out-turn as per standards, which stipulate that it should be above 50 lbs. In Madagascar, no studies on this case have been published yet, hence no local KOR comparisons have been made. However, referring to other countries like Benin, according to Pal (2016), the average KOR in Benin, Côte d'Ivoire, and Nigeria is 21.7 kg, 21.6 kg, and 20.6 kg respectively. KOR is a crucial indicator in the international trade of raw nuts, influencing global market prices. Therefore, in our study, the good KOR value of raw nuts obtained after pollination by bees underscores its importance in productivity and improving nut quality here in Madagascar.

5. Conclusion

In summary, six (6) species of pollinator agents belonging to five (5) insect families were identified during this study in the two communes of Ambilobe. Each species showed a specific preference level for cashew trees, but their effectiveness was influenced by their numbers. It was only pollination by *Apis mellifera* unquestionably contributed to improving the fruit set rate as well as the quality of nuts and kernels. This approach directly contributes to increasing the productivity of farmers and the country's economy. Besides significantly increasing hive numbers, it is important to conserve natural ecosystems around plantation fields to benefit from the essential service provided by wild bees.

6. Acknowledgements

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Linking Infrastructure Finance & Farms to Cashew (LIFFT Cashew)

The SeGaBi Cashew Production Zone

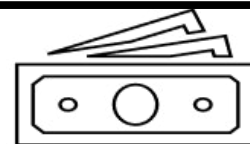
The cashew production area of Senegal, The Gambia, and Guinea-Bissau (SeGaBi) in West Africa stretches from Fatick in northern Senegal through The Gambia to Guinea-Bissau. The work is made possible by the U.S. Department of Agriculture, Shelter for Life is implementing the LIFFT-Cashew (Linking Infrastructure, Finance, and Farms to Cashew) project in the SeGaBi area to promote and improve the value chain linkages

Activities

- **Infrastructure:** construction and rehabilitation of rural roads to facilitate the flow of cashew nuts combines both heavy machinery and manual labor to create employment opportunities. To date 136,24 KM of feeder roads constructed and 4,640 jobs created. Increase in installed storage capacity (dry or cold storage) 38,768 MT
- **Access to finance:** : working with financial institutions to increase financial services to cashew producers and processors through the Cashew Fund. Collaboration with financial institutions (microfinance institution, Bank), traders and exporters to increase access to financial services. \$207,577,164 for access to finance components in financial transactions and micro-finance loans to cooperatives and farmers. 11 processors were financed to the amount of \$3,975,00 and \$1,597,084 public private investment leveraged by investors for cashew processing for the Cashew Fund (A4) in terms of loans and pre-financing.
- **Market access:** The establishment of a win-win contractualization system between producers and buyers, the promotion of business relationships, the strengthening of negotiating power and the impetus of grouped marketing. - Many partnerships were forged with cashew producer cooperatives, traders, processors and financial institutions to facilitate collective sales for better marketing by 27 cooperatives. Mass sensitization of cooperatives was supported, reaching at least 34,043 cashew producers.
- **On-Farm Practices:** Improvement of agricultural techniques and establishment of cashew demonstration farms. Training on good agricultural practices was provided to 20,163 cashew producers through pre-selected cooperative members as trainers/facilitators, who attended thematic train-the-trainer modules on pruning, thinning, nut separation, drying, storage, organic standards, and new plantation.

Period Of Performance: 2017 - 2025
Implementer: Shelter for Life International Total
Agreement Value: \$38 Million
US Commodities Monetized: Crude Oil Soy Bean
Direct Beneficiaries: 46,743 individuals
Indirect Beneficiaries: 327,201 individuals

SeGaBi – Raw Cashew Nut Trade



\$259,128,98

Value of sales of
beneficiaries who
received USDA
assistance



302,806 MT

Volume of commodities
sold by beneficiaries who
received USDA
assistance



46,743

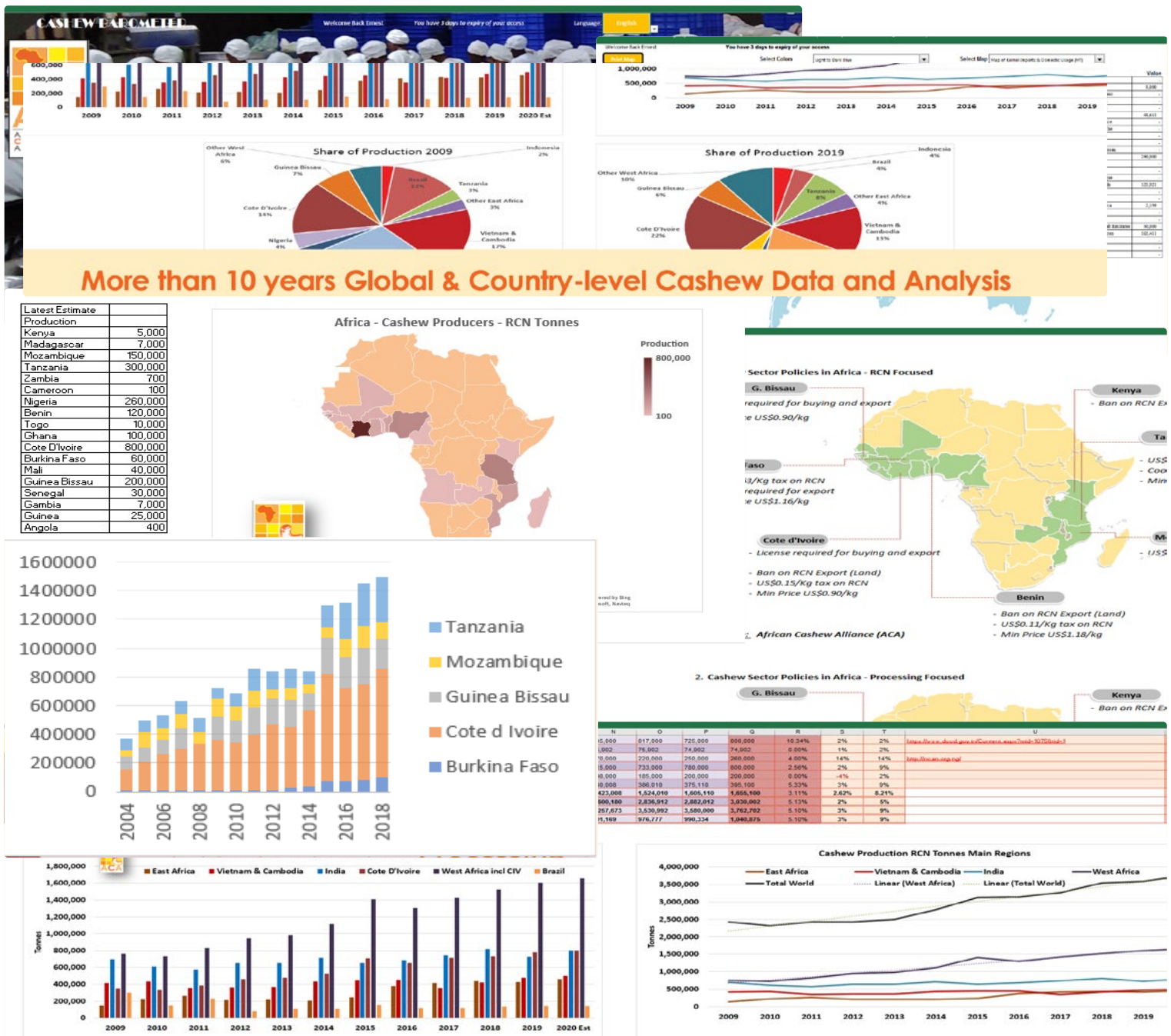
Number of individuals
who have benefitted
directly because of USDA
assistance



119,707 ha

Number of hectares
under improved
technologies

Cashew Barometer



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For more than 10 years Global & Country-level Cashew Data and Analysis, covering:

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