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PRELIMINARY INVESTIGATIONS INTO THE YIELD AND NUT QUALITY RESPONSE OF MATURED CASHEW (ANACARDIUM OCCIDENTALE L.) TREES TO FOLIAR APPLICATION OF EXOGENOUS PLANT HORMONES

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Abstract

The declining yields of matured cashew trees in the West African sub-region limit productivity. The application of foliar exogenous plant hormones could enhance cashew production. Four exogenous hormones, gibberellic acid (GA_3), ethephon, Naphthalene Acetic Acid (NAA) and 2,4-D were applied at 0 mg L−1, 50 mg L^{-1}, 100 mg L^{-1}, 150 mg L^{-1}, and 200 mg L^{-1} to a 14-year-old plantation established with clones of Beninese and Ghanaian origin at the Wenchi Agricultural Research Station in Ghana. The trial was laid out in a split plot design with four replications and the trees were evaluated for yield, nut weight and outturn. There were significant hormone × concentration interaction effects on all the traits measured except outturn. The results indicate that application of ethephon and GA_3 at 50 mg L−1 and 100 mg L^{-1} had the highest yield of 17.7 kg/tree and 17.3 kg/tree which was over 100% higher than the yields obtained from the untreated trees respectively. The NAA applied at 100 mg L^{-1} had the highest nut weight with an advantage 5% compared to untreated trees. The results though preliminary emphasize the potential of increasing the productivity of matured cashew plantation through the application of GA_3 , Ethephon and NAA hormones.

Keywords: Cashew, hormone, NAA, GA_3, nut yield

1.0 Introduction

Cashew *(Anacardium occidentale L.)* is an important tropical nut crop of social and economic importance worldwide. It is primarily grown for its kernel being highly nutritive and low cholesterol content. Other commercial and economic benefits of the crop include juice, wine, vinegar, jam, pickle and cashew nut shell liquid (CNSL) for industrial uses. In Africa, where about 67% of the world raw cashew nuts (RCN) are produced, average output per tree is as low as 2 - 3 kg per tree (Aliyu and Awopetu, 2007). Currently, over seventeen countries in Africa are engaged in cashew production and in 2019, the continent produced 2.33 million tons of RCN from an estimated area of 4.7 million ha, with an average productivity of 0.57 tons/ ha (FAO, 2019). Two-thirds of this production in 2019 came from four countries, Côte d'Ivoire (34%), Burundi (12%), Tanzania (10%) and Benin (9%).

In Ghana, cashew is one of the tree crops with a huge potential for increasing foreign exchange and creating employment (GSS, 2005). In spite of economic importance of cashew as a commodity and export-oriented crop with increasing cultivation globally, world average yield is as low as 780 kg ha-1 (FAO, 2008). Heard et al. (1990), therefore suggested that for a sustainable investment and competitiveness in the cashew industry, there must be a substantial increase in production of the trees.

Several factors have been attributed to the problem of low yield of cashew trees, ranging from poor genetic planting material (Foltan and Lüdders, 1995; Chacko et al., 1990; Parameswaran, 1979) poor and irregular flowering, poor fruit set, immature fruit drop and adverse environmental conditions(Bello et al., 2017; ACA, 2011; Rupa et al., 2013; Masawe et al., 1996). Over the past years, application of exogenous hormones (i.e. plant growth regulators) has been reported to significantly improve flowering and fruiting in many crops. The use of various plant growth regulators ranging from cytokinins to auxins also improved flowering and fruit set in citrus (ElOtmani, 1992), coffee (Schuch et al., 1990), grape (Dokoozlian and Peacock, 2001), and mango (Ramírez and Davenport, 2010) . Aliyu et al. (2011) tested the response of two Brazilian dwarf cashew genotypes to application of exogenous hormones and reported that they improved nut yield and quality significantly. This study therefore evaluated four exogenous hormones at different concentrations on the yield and nut quality of a 14-year-old cashew plantation at Wenchi in the transitional zone of Ghana.

2.0 Materials and methods

2.1 Study area:

The study was conducted at the Wenchi Agricultural Station, situated at a latitude of 7.7º North and longitude 2.9º West, with an altitude of 303 min the Bono Region of Ghana.

2.2 Experimental design and treatments:

The trial was laid out in a split plot design with four replications. The hormones were the main plot and their concentrations were the sub plot.

Hormones used were Gibberellic Acid (GA3), Naphthalene acetic acid (NAA), 2,4 Dichlorophenoxy acetic acid (2,4-D) and ethephon. They were applied at 0 mg L^{-1}, 50 mg L^{-1}, 100 mg L^{-1}, 150 mg L^{-1}, and 200 mg L^{-1} on the periphery of each tree with using a motorized spraying machine.

2.3 Data collection and analysis

Data on yield per plot (4 trees plot^{-1}) were estimated from the weight of nuts collected from each plot throughout the 2022 cropping year. Nut sizes were also estimated as the weight of 1 kg of raw cashew nuts divided by the number of nuts and out-turn (%) was estimated as (weight of healthy kernels divided by the weight of raw nuts) × 100 for each plot. The data was analyzed using ANOVA. The means were further separated using Duncan Multiple Range Test at a significance level of 0.05.

Rainfall and temperature data during the period of study were obtained from the Wenchi Meteorological station situated in the Wenchi Agricultural research station.

2.4 RESULTS

Generally, the concentration of 50 mg L^{-1} of the hormones produced the most nuts with GA_3 giving the highest yield. However, the hormones applied at 100 mg/l produced the highest weight. Nut out-turn reduced with increasing hormone concentration (Table 1).

At a concentration of 50 mg L^{-1}, ethephon had the highest nut yield of 17.8kg/tree whereas NAA gave the lowest yield of 10.2 kg/tree. However, at 100 mg L^{-1}, 150 mg L^{-1} and 200 mg L-1, GA_3 had the highest nut yield of 17.3, 17.2 and 15.2 kg/tree (Table 1).

Ethephon and NAA recorded nut yields of 10.9 and 10.1 kg/tree respectively. Comparatively, GA3 had a yield advantage of approximately 50% compared to 2,4-D, Ethephon and NAA and over 100% compared to the control/untreated trees. As the concentration of hormone increase to 100 mg L-1, 150 mg L-1 and 200 mg L-1 yields declined to 10.9, 11 and 11.2 respectively.

For nut weight, a concentration of 100 mg L-1 NAA had nut weights of 6.1 g and ethephon 5.1 g. Meanwhile at a concentration of 200 mg L^{-1}, 2,4-D gave the highest nut weight of 6 g while GA_3 had the lowest nut weight of 5.3 g. Among the exogenous hormones, NAA gave the highest nut weight of 6.8 g compared to ethephon which had the lowest weight of 5.2 g. However, among the concentrations tested, 100 mg L^{-1} recorded the highest nut weight of 5.8 g (Table 1).

Table 1. Mean values of the interactions between four exogenous hormones (2, 4 -D, Ethephon, GA3 and NAA) and five concentrations on nut yield, nut weight and outturn of matured cashew trees.

Trait		Concentration (mg L^{-1})					Mean [2]
	Hormone	0	50	100	150	200	
	2,4-D	8.1a	10.8a	6.2a	8.7a	12.8b	9.6a
	/tree)	6.4a	17.8b	9.2a	7.1a	9.5b	10.9b
Nut yield (kg	GA3	7.2a	14.3a	17.3b	17.2b	15.2b	16a
	NAA	5.7a	10.2a	11a	12a	7.2a	10.1a
	Mean [1]	6.9a	13.3b	10.9ab	11.0ab	11.2ab	
	2,4-D	5.2a	5.3a	6a	5.4a	6a	5.6ab
	ETHEPHON	5.5a	5.5a	5.1b	5a	5.5b	5.2b
Nut weight (g)	GA3	5.5a	5.5a	6a	5.5a	5.3b	5.5ab
	NAA	5.8a	5.7a	6.1a	5.5a	5.8a	5.8a
	Mean [1]	5.5a	5.5a	5.8b	5.4a	5.6a	
	2,4-D	31.9a	30a	30.4a	28.9a	27.3a	29.2a
	ETHEPHON	30.7a	29.8a	29.1a	28.9a	28.1a	29.0a
Outturn (%)	GA3	30.4a	32.6a	30.2a	30.9a	29.5a	30.8a
	NAA	31.8a	31.2a	30.7a	30.9a	29.6a	30.6a
	Mean [1]	31.2a	30.9a	30.1a	29.9a	28.6a	

* Means bearing the same letters are not significantly different.

The analysis of variance (ANOVA) indicated that, there were significant ($p < 0.05$) hormone, concentration and hormone × concentration interaction effects on yield and nut weight but not out-turn (Table 2).

Table 2. Summary ANOVA on yield, nut weight and out-turn

Source of variation	d.f.	Yield	Nut weight	Shelling
Hormone (Main plot factor)	3	113.58*	3.3221*	9.8
Residual	9	23.68*	1.054	9.09
Concentration(Subplot factor)	4	29.95*	88.05*	17.74
Hormone × Concentration	12	43.75*	39.32*	4.81
Residual	44	22.37	22.43	12.69

During the period of experiment, the month of October recorded the highest rainfal of 282 mm over 15 wet days. Out of the 11 months period, December and January recorded no rainfall (Fig. 1). The month of February had the highest temperature of 35.3 oC while August showed the least temperature of 27.7 oC.

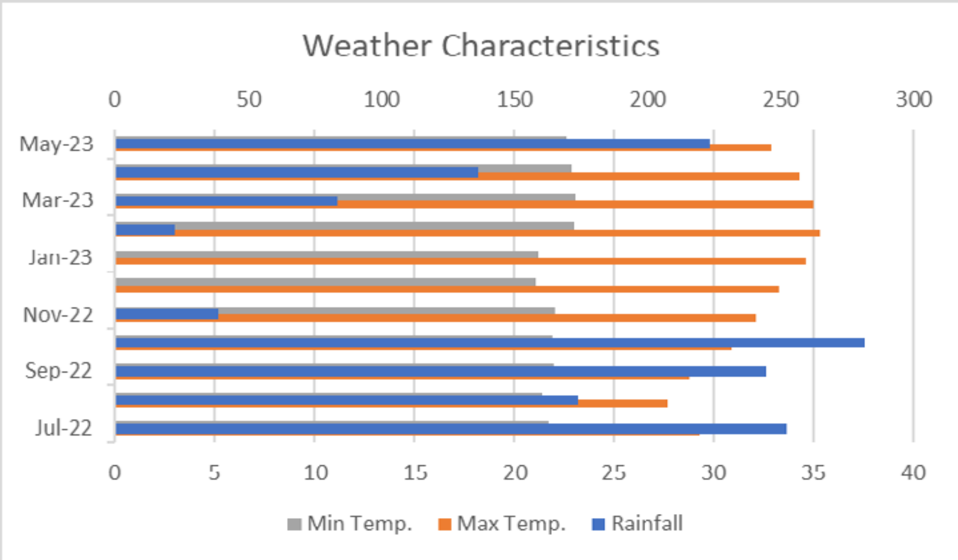

Figure 1: Rainfall and temperature at Wenchi experimental site

3.0 Discussion

In the study, the significant hormone × concentration interaction effects on yield and nut weight of cashew trees indicated that the cashew trees exhibited differences in response to the application of exogenous hormones at different concentrations. It therefore suggests that, nut yield and nut weight response among cashew trees were largely influenced by the hormones applied. In effect, selection and application of the right hormones at the appropriate concentrations could represent one of the best strategies for improving yield. The highest yield obtained for ethephon at 50 mg L-1 and GA3 at 100 mg L-1, 150 and 200 mg L-1 and the highest nut weight obtained from NAA at 100 mg L-1 and 2,4-D at 200 mg L-1 suggest that, cashew trees may respond to more than one hormone for yield at a particular concentration. These findings agree with that of Aliyu et al. (2011) who reported on the significant hormone x concentration interaction effects on nut yield and flowering traits in cashew. Additionally, the range of 100 to 200 mg L-1 of GA3 response to yield in the current study agrees with Aliyu et al. (2011) that foliar application of exogenous GA3 hormone exhibited a broad concentration tolerance for nut yield in cashew (Aliyu et al., 2011). The GA3 hormone treated trees produced 50% more yield than the 2,4-D and 120% more than the control. On the other hand, NAA hormone treatments had 10% higher nut weight than ethephon and 5.2% higher than the control. These findings suggest that cashew productivity could depend on the exogenous hormone type applied. The observations are also consistent with reports by Othman and Leskovar (2022) on foliar application of gibberellic acid. The GA3 and NAA have been found to increase leaf photosynthesis, leaf area, growth rate and N use efficiency compared to non-treated plants (Miceli et al., 2019). While, Aliyu et al. (2011) also highlighted an increase in nuts weights of cashew trees treated with GA3.The current study indicated a significant effect of NAA in improving nut weight of matured cashew trees and the findings are consistent with that of Basuchaudhuri (2016) who reported an increase in the seed weight of rice.

4. Conclusion

The results revealed a significant hormone, concentration and hormone x concentration effects on nut yield and nut weight. Lack of significant hormone, concentration and hormone x concentration interaction effects on outturn in the current study suggest that more hormones need to be explored. The results of our study though preliminary suggest that the application foliar exogenous hormone to matured cashew trees has the potential to increase yield and nut quality for sustainable cashew production.

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EFFECT OF APPLICATION OF N AND K FERTILIZERS ON CASHEW NUT YIELD AND SOIL CHEMICAL PROPERTIES IN OCHAJA, KOGI STATE, NIGERIA

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Abstract

The experiment was conducted at the Ochaja Substation of the Cocoa Research Institute of Nigeria, Ibadan. Plantation soil nutrient requirements were determined prior to applying the required fertilizers. The soil was deficient in nitrogen (N) and potassium (K), with values of 0.41 gkg-1 soil and 0.012 cmolc/kg-1 soil, respectively, at depths of 0–20cm and 20-40 cm. These values were used to calculate cashew fertilization rates of 54 kg N/ha and 84 kg K2Oha-1. Four treatment combinations of two rates of nitrogen fertilizer and two rates of potassium fertilizer were formulated and applied to young cashew trees in the field. Nitrogen fertilizer (Urea) was applied at 0 and 54 kg Nha-1 while the Potassium fertilizer (Muriate of potash) was applied at 0 and 84 kg Kha-1. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The first dose was applied in June while the second dose was applied in September of both 2019 and 2020. Data was collected on crop nut yield and soil nutrient characteristics. Application of N fertilizer significantly increased soil pH at both soil depths of 0-20 cm and 20-40 cm compared to the control. Specifically, application of potassium-based fertilizer, with or without nitrogen fertilizer increased soil pH by 5.4%. Soil N was significantly increased compared to other treatments ($P < 0.05$) by application of K fertilizer. Total N ranged from 0.5 g/kg to 0.7 gkg-1 for fertilizer treatments. N and K fertilizers did not significantly improve available phosphorus (P) across fertilization treatments. Exchangeable K in soil followed a similar trend with available P in different treatments. Yield of cashew nuts was significantly ($P < 0.05$) improved as a result of applying only N fertilizer without K and control. Application of nitrogen-deficient-only nutrients yielded better results in terms of efficiency than extensive application of fertilizers without relying on the natural fertility of the soil.

Keywords: Cashew, Soil, nutrients, deficiency, productivity.

1. Introduction

Cashew is an important commercial crop and has great potential as a source of foreign exchange earnings in Nigeria. Cashew is often planted in poor soils and this hampers its survival and establishment (Topper, et al. 2001). In most cashew plantations, fertilizer is not part of the production input system, so productivity is highly dependent on natural soil abundance (Ibiremo et al., 2017; Agbongiarhuoyi, et al., 2014). As a result, the soil in which cashew is grown has been preserved by inherent nutrient status and the crop may not reach its full harvest potential.

Fertilizers are rarely used in cashew production, and when they are used, they are blanket-applied. This practice leads to over-fertilization in some areas and under-fertilization in others, or results in unbalanced soil nutrient levels (Bruuselma et al. 2012). Fertilization is therefore unavoidable to compensate for the depletion of soil nutrients during the annual harvest of apples and nuts. Site-specific fertilizer management (SSFM) improves nutrient use efficiency and yields higher returns on fertilizer investments (Ortiz-Monasterio and Raun 2007). The soil at Ochaja Substation is deficient in nitrogen and potassium, and for effective soil management, additional nitrogen- and potassium-based fertilizers may increase production. Traditionally, among the few farmers who use fertilizers on their crops in Nigeria, the use of solid fertilizers containing the main nutrients nitrogen, phosphorus and potassium is common. The aim of this study therefore, was to evaluate the effects of N and K fertilizer applications and their effects on soil properties based on soil test values on cashew yield.

2. Materials and methods

The cashew plantation at Ochaja substation used for the experiment were divided into two blocks (A and B) and soil samples were randomly collected within each of the blocks to form the composite samples at 0-20 cm and 20-40 cm soil depths. These samples were processed and analyzed for both physical and chemical properties using standard laboratory procedures based on the IITA Laboratory Manual (1982). Calculated fertilizer rates were based on the result of analysis of soil samples from 0 to 40 cm depths. The results of the soil analysis indicated that the total nitrogen was 0.04g/kg soil which is inadequate to sustain cashew as it requires 1g/kg soil and the available P was adequate while the exchangeable potassium was also deficient having a value of 0.012 cmolkg-1 which is far below the critical of 0.12 cmolkg-1 soil. Four treatment combinations at two rates each of nitrogen and potassium fertilizers using Urea and Muriate of potash as nitrogen and potassium sources respectively were formulated and applied to four years old young cashew trees in the field. Nitrogen fertilizers were applied at 0 and 54 kg Nha-1, potassium at 0 and 84 kg Kha1, treatments were placed in three replicates in RCBD. Cashew nut yield and soil nutrient characteristics were measured. The fertilizers were applied in two split applications. The first dose was applied in June while the second dose was applied in September of both 2019 and 2020. Data collected were subjected to ANOVA and means separated using LSD with 5% probability.

3. Results and Discussion

Pre – cropping soil analysis

The pre-cropping soil properties indicated that the soil was sandy loam, with average values for sand, silt, and clay of 888, 20, and 92 g/kg soil, respectively (Table 1). The pH was slightly acidic and very close to neutral averaging 6.7, and organic carbon (OC) was low averaging 0.82 g/kg soil. Block B OC was higher than Block A OC. Total nitrogen in soil was 0.41 gkg-1 soil, which is below the critical value of 1 gkg-1 soil (Egbe et al. 1989). A deficiency of 0.6 gkg-1 soil required 54 kg N for optimal production, whereas the average available P was 5.28 mgkg-1 soil. This value exceeds the level required by cashew for optimal productivity. The mean potassium value was 0.012 cmolkg-1 soil. A deficit of 0.108 cmolkg-1 requires 84 kgha-1. Exchangeable calcium ranged from 1.26 to 2.26 cmolkg-1 at soil depths of 0 to 40 cm, with an average of 1.68 cmolkg-1. The exchangeable Mg ranged from 0.25 – 0.35 cmolkg-1 soil with an average of 0.29cmolkg-1 soil.

Effects of Nitrogen (Urea) and Potassium (Muriate of potash) fertilizers on the soil pH

The soil pH of the two soil depths (0-20 and 20-40 cm) was significantly ($p<0.05$) affected by the application of nitrogen and potassium fertilizers (Table 2). The Urea (N) and MOP fertilizers increased significantly the pH at both soil depths compared to the control but application of urea (N) alone seemed to enhanced the acidity at the sub-soil (20-40 cm). The decrease in pH may be due to the properties of urea fertilizer that lowers soil pH as observed by Agbede (2009).

Influence of N and K fertilizer application on soil N

The control (T1) and K fertilizer treated plots had a significant ($P< 0.05$) higher N value of 0.07gkg-1 soil than where urea (N) sole and combined with MOP applied.at 0-20cm depth. However, the N value of control and plots treated to sole N and K fertilizers were lower than when N and K were applied together but no significantly difference was observed among the values at 20-40cm depth. Nitrogen is prone to leaching in sandy soil as it is washed by water flow through porous structure (Agriculture Victoria 2023). A high sand content in the soil may support the water and be responsible for the low retention of the applied N which agreed to sandy texture soil generally having limited nutrient holding capacity (Agbede, 2009). This observation therefore contradicted the general observation of Adejumo, (2010) that application of urea increased the total soil N

Effects of N (Urea) and K (MOP) fertilizer application on soil Phosphorus

The application of Urea and potassium fertilizers significantly depressed the amount of available phosphorus in the soil irrespective of the depths (Table 2). The plots without fertilizer application had the highest soil available P relative to the other plots with fertilizer addition. Similar trend was observed at both depths (0 – 20 and 20 - 40cm) with the control plots recording the mean values of 11.17 and 10.35 mg/kg soil respectively (Table 2). The order of available P in the plots was highest (11.17 and 10.35) in the control and lowest (7.39 and 8.98) in plots that received potassium addition (T3) at both depths and was in order of Control (T1) > T2 > T4 > T3 and Control (T1) > T4 >T2 >T3 at 0 – 20cm and 20 - 40cm depths respectively.

Influence of application of Urea and Potassium fertilizer on soil K

Similar trend was observed in the amount of exchangeable K in the soil arising from the effects of applied K and Urea fertilizers. The control plot recorded the highest mean K values relative to the other plots where Urea and K fertilizers were applied irrespective of whether the fertilizers were applied sole or in combination. T2 and T3 recorded similar effects (0.14 cmolkg-1 soil) at 0 - 20cm depth (Table 2). This value was significantly ($p<0.05$) higher than that of T4. At 20 – 40 cm depth, T2 produced a significantly ($p<0.05$) higher K in the soil compared to the rest (Table 2).

Influence of application of Urea and Potassium fertilizer on raw cashew nuts

Application of N fertilizer (Urea) promoted cashew yield, which was reflected in an increase in cashew nut. The Cashew nut yield was significantly ($P < .05$) improved by nitrogen fertilizer application compared to sole and combined potassium fertilizers and control (Figure 1). Relative to other fertilizer type, Cashew plots that were treated with sole Urea fertilizer (T2) performed significantly better to confirm the finds of Adejumo, (2010) and Babu et al., (2015) influence of N and K on vegetative and the reproductive growth of crop. In their separate studies on Nitrogen and potassium application, positive effects on productivity, profitability and nutrient use efficiency of irrigated wheat (Triticum aestivum L.) were reported. Also, Sandeep et al., (2022) revealed that wheat productivity, plant growth and yield attributes, nutrients uptake and use efficiency increased significantly ($p < 0.05$) with N-fertilizer application. This observation is consistent with the results obtained by Adejumo, (2010) that, application of N, P and K fertilizers significantly enhanced the yield of Cashew nuts relative to the control, although the interaction effect of N and K application was statistically not significant ($p<0.05$).

Table 1: Baseline soil physical and chemical properties of the cashew plot

Block	Soil Depth (cm)	Sand gkg^{-1} soil	Silt gkg^{-1} soil	Clay gkg^{-1} soil	pH	O.C gkg^{-1}	Total N gkg^{-1}	Ava.P $mgkg^{-1}$	Exch K+ $Cmolkg^{-1}$	Exch Ca2+ $Cmolkg^{-1}$	Exch Mg2+ $Cmolkg^{-1}$	CEC $Cmolkg^{-1}$	Base saturation (%)
A1	0-20	885.20	22.80	92.00	6.7	0.78	0.07	5.03	0.012	2.26	0.35	2.78	95.83
A2	20-40	895.20	12.80	92.00	6.8	0.66	0.02	5.20	0.011	1.73	0.29	2.18	95.05
B1	0-20	895.20	12.80	92.00	6.6	0.97	0.05	5.35	0.012	1.26	0.27	1.70	92.81
B2	20-40	875.20	32.80	92.00	6.7	0.86	0.02	5.55	0.012	1.34	0.25	1.15	91.62
Mean x		887.70	20.30	92.00	6.7	0.82	0.04	5.28	0.012	1.65	0.29	1.95	93.83

Table 2: Influence of Nitrogen and Potassium fertilizers on some soil chemical properties at Ochaja cashew plot.

Treatment	pH (H^2O)		Total N (gkg^{-1})		Available P ($mgkg^{-1}$)		Exchangeable K ($cmolkg^{-1}$)	
Soil depth	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm
N_0K_0–T1Control)	5.13	4.94	0.07	0.03	11.17	10.35	0.16	0.10
N_1K_0-T2	5.77	4.77	0.05	0.03	10.22	9.74	0.14	0.11
N_0K_1-T3	5.27	5.17	0.07	0.03	7.39	8.98	0.14	0.09
N_1K_1-T4	5.54	5.37	0.05	0.04	9.37	10.32	0.13	0.10
LSD (P<0.05)	0.19	0.20	0.01	0.02	0.72	0.60	0.01	0.01

Legend: N_0K_0–T1 (Control); N_1K_0-T2, N_0K_1-T3, N_1K_1-T4

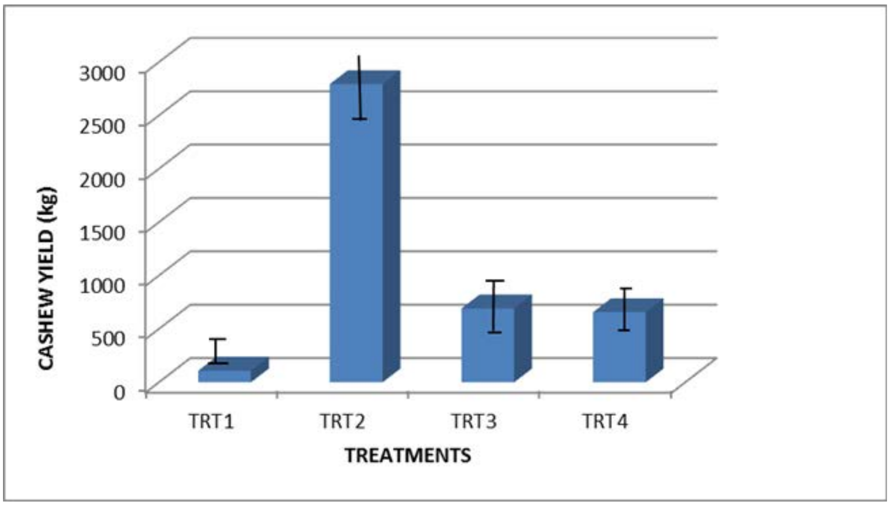

Figure 1: Effects of Nitrogen and Phosphorus based fertilizer on raw cashew yield (kg)

Conclusion

Fertilizer application based on the results of soil test and the needs of the site yields optimal results in terms of efficiency of fertilizer use, better crop yields compared to blanket application of fertilizers without recourse to the inherent nutrients of the soil. Hence, application of Nitrogen (N) fertilizer enhanced nut yield of cashew better than when it is applied in conjunction with K fertilizer. Application of N and K fertilizers increased the soil pH compared to the control.

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CASHEW (*ANACARDIUM OCCIDENTALE* L.) NUT YIELD AS INFLUENCED BY NPK FERTILIZERS AND AGE OF PLANTATION IN NORTHERN GHANA

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Abstract

Cashew cultivation started in Ghana in the 1960's. Due to poor genotypes, early cashew introductions have resulted in large tracts of low yielding farms. This problem is compounded by the harvesting of cashew nuts and apples that gradually depletes the soil of plant nutrients. To reverse this trend, fertilizer application is very crucial to improve soil fertility and increase cashew nut yield. A study was carried out at the Cocoa Research Institute of Ghana sub-station, Bole in the Guinea Savannah agro-ecology of Ghana. The objective was to investigate the effect of different NPK fertilizer formulations on nut yield of cashew plantations of different age categories. Four age categories of cashew plantations of unknown origin and established from seedlings were selected and used for the study. The age categories were 4, 6, 8 and 10 years old, respectively. Six fertilizer formulations viz; F1-Control, F2–100 kg N+40 kg P2O5+40 kg K2O ha-1, F3-125 kg N+60 kg P2O5+60 kg K2O ha-1, F4-150 kg N+80 kg P2O5+80 kg K2O ha-1,F5-175 kg N+100 kg P2O5+100 kg K2O ha-1, F6- 200 kg N+120 kg P2O5+120 kg K2O ha-1, were investigated. The trial was arranged in a 4 x 6 factorial and laid out in a randomized complete block with three replicates. The fertilizers were ring-applied by single application in shallow trenches at the edge of canopies in July each year. Data on nut yield were collected for six consecutive years. Cashew trees that received high amounts of fertilizers, especially F6, gave significantly ($p<0.05$) higher nut yield (329.7- 488.3 kg ha-1) with the control recording the least (163.9-275.8 kg ha-1) in all four age categories. The six-year mean nut yields were highest for the 10 year old plantation (275.8-488.3 kg ha-1) and lowest for the six year old plantation (180.4-329.7 kg ha-1). The result has demonstrated that high cashew nut yield could be obtained with improved or elite planting materials and fertilizer application.

Key words: *Fertilizer formulation, plant nutrients, age categories, cashew*

1.0 Introduction

Cashew cultivation started in Ghana in the 1960's under the then government's savanna afforestation programme which resulted in the establishment of cashew plantations in the coastal savannah belts of the Greater Accra and the Central regions and the forest savannah transition of Brong Ahafo region (Addaquay and Nyamekye-Boamah, 1998). Due to poor genotypes, early cashew introductions have resulted in large tracts of low yielding farms. This problem is compounded by the harvesting of cashew nuts and apples that gradually depletes the soil of plant nutrients. For example, essential nutrient loss attributable to the removal of 1 kg of cashew fruits (nuts plus apples) is estimated to be about 64, 2 and 25 g N, P, K respectively (Bhaskar et al, 1995) and this translate into huge amounts per hectare. These nutrients can be returned into the soil through fertilizer applications. The application of inorganic fertilizers has been reported to significantly increase growth and yield of cashew (Kumar and Sreedharan, 1998; Mahanthesh and Melanta, 1994). However, in Ghana the usual practice is to remove cashew apples and nuts without soil nutrient replacement. A programme to improve cashew production in Ghana was initiated in 2004. A cardinal part of the programme was to renew low yielding farms through canopy substitution or replanting. Before these renewal strategies could be fully operational there is the need to find ways to improve the yields of existing mature cashew. One strategy that can be considered is application of inorganic fertilizers. Compared to other sources of plant nutrients, inorganic fertilizers are concentrated sources of such nutrients, however their use is limited by their high costs. Application of nitrogeneous fertilizer from sulphate of ammonia and organic manure improved the growth of young cashew in Northern Ghana (Opoku-Ameyaw et al., 2000; Arthur et al., 2022). Nitrogen application has the greatest effect of increasing yield when applied during the vegetative growth stage, which was shown to reduce late flowering and nut drop (O'Farrell et al., 2010), while phosphorus and sulphur applications were proven to positively affect plant growth and nut production (Grundon, 1999). The nutrient removed from the soil, due to fruit and pseudo-fruit harvesting, should be factored into planning fertilizer application (Dendena and Corsi, 2014), hence, the application of 500 g N, 125 g P2O5, and 125 g K2O tree-1 annually in two split doses was recommended when assuming an annual average nut yield of 5–10 kg tree-1 (Panda, 2013). A farmer is motivated towards farming when the yearly harvest is high and for this to be achieved; the soil must be well maintained and conserved. Ghana as a whole is faced with a problem of soil management and in particular to the farmers cultivating this commodity crop (cashew) which is faced with a problem of poor crop yield due to the inability of carrying out soil management practices for maintaining the fertility of the soil. So, any measure taken to manage the soil for its fertility will go a long way in improving the growth and yield of this crop and general well-being of the farmers. Considering the significance of this commodity crop in the livelihood of farmers and economy of the nation, a concerted effort on improving its yield and increasing production per unit area is very important. Consequently, an investigation was conducted with the objective to assess the influences of NPK fertilizers on cashew nut yield of trees of different ages that had not received fertilizers since establishment to determine the fertilizer formulation needed to improve the yield.

2.0 Materials and methods

2.1 Study sites

The study was carried out at the Cocoa Research Institute of Ghana sub-station, Bole in the Guinea Savannah agro-ecology of Ghana from 2008 to 2014.

2.2 Soil sampling and analyses

Soil samples were collected at two distinct depths of 0-15 cm and 15-30 cm, respectively before treatments application. The soil samples collected were placed in polybags, labelled properly and sent to the laboratory for the determination of physico-chemical properties. The samples were air-dried, ground and passed through a 2 mm mesh sieve and stored for analyses. The soil pH was determined using Suntex pH/Temp (SP-701) meter in a soil: water ratio of 1:2.5. Soil organic carbon was determined using the modified Walkley and Black wet oxidation method. Soil total N was determined using the Kjeldahl digestion and distillation method, while available P was determined by the Bray P1 method. Exchangeable K, Ca and Mg were extracted with 1 N ammonium acetate solution, and the concentrations were determined using the Atomic Absorption Spectrophotometer (Varian Spectr AA 220 FS). Particle size (sand, silt, and clay) distribution was carried out by the hydrometer method. All methods were referred to Sparks et al. (1996).

2.3 Experimental design and treatments

Four age categories of cashew trees of unknown origin and established from seedlings were selected and used for the investigation. The age categories of cashew plantations used were as follows; 4, 6, 8 and 10 years old. Six fertilizer formulations based on recommendation from various sources (FAO, 2010; Lefebvre, 1973) were investigated as follows:

F1- no fertilizer control

F2 – 100 kgN+40 kg P_2O_5+40 kg K_2O $ha^{-1}yr^{-1}$

F3 – 125 kgN+60 kg P_2O_5+60 kg K_2O $ha^{-1}yr^{-1}$

F4 – 150 kgN+80 kg P_2O_5+80 kg K_2O $ha^{-1y}r^{-1}$

F5 – 175 kgN+100 kg P_2O_5+100 kg K_2O $ha^{-1}yr^{-1}$

F6- 200 kgN+120 kg P_2O_5+120 kg K_2O $ha^{-1}yr^{-1}$

The investigation was a 4 x 6 factorial arranged in randomized complete block with three replicates and 10 trees per replicate within each age category. The fertilizers (Ammonium sulphate for N, triple superphosphate for P_2O_5 and muriate of potash for K_2O) were ring-applied by single application in shallow trenches at the edge of canopies in July each year. Data on nut yield were collected annually for six consecutive years.

2.4 Statistical Analysis

Data on nut yield were subjected to analysis of variance (ANOVA) and least significant difference used to separate significant differences between means. All statistics were performed using GenStat statistical package (edition 12, Lawes Agricultural Trust, Rothamsted Experimental Station, http://www.vsni.co.uk).

3.0 Results and discussion

3.1 Status of soil nutrients

Soil pH values recorded for both depths (6.37 and 6.35) were slightly acidic. These pH values are, however, suitable for the cashew crop, since it has a wide range of tolerance from pH 4.5-8.5 while optimum values are within 5.2-7.5 (Dedzoe et al., 2001). Soil organic carbon (SOC) for the two depths was below the critical value of >2% considered suitable for cashew cultivation (Table 1). The total nitrogen content of the cashew soils was below the 0.1% nitrogen required for cashew cultivation (Aikpokpodion et al., 2010). The low nitrogen content could be due to the low organic matter content of the soil. The calcium content of the soil recorded was above 0.8 cmol kg^{-1} which is the critical value for ideal soils for cashew. Soil potassium and magnesium recorded at the site for both soil depths were within the critical values of 0.12 cmol kg^{-1} and 0.08 cmol kg^{-1}, respectively. Available phosphorus content of the soil was generally low for optimum cashew cultivation since the value recorded was below the optimum value of 10 mg kg^{-1}.

Table 1: Some selected soil chemical properties at the study sites

Location	Soil Depth (cm)	pH	Org C (%)	Total N	Avail. P (mg kg-1)	Exch. K	Exch. Mg	Exch. Ca
						cmol kg-1		
Bole	0 – 15	6.33	1.11	0.07	3.76	0.18	1.13	1.58
	15 -- 30	6.29	0.86	0.05	3243	0.11	0.87	1.02

3.2 Nut Yield

There was no significant (p>0.05) effect of age of trees or its interaction with fertilizers on nut yield as such the results will be discussed based on influences of the NPK fertilizers on nut yield of the different age categories. There was significant increase (p<0.05) in nut yield with fertilizer application in all four age categories of cashew from 2008-2014 as the trees increased in age and size. Fertilizers increased the initial nut yield in 2008 to between two to three folds in 2013 and 2014, whilst the nut yield of the control remained the lowest and differed slightly from the initial level throughout the trial period. The slightly acidic nature of the soil, low organic carbon, and total nitrogen in baseline soil (Table 1) suggests that the low yield of these cashew trees in T1 was a result of low availability and/or uptake of nutrients and that this deficiency was exacerbated by lack of nutrient supply from an external source through fertilizer applications. Cashew crop requires regular application of fertilizer, especially during fruit set and beyond (Nair et al., 1979). The combined application of potassium and phosphorus is indispensable in the initial stages of cashew growth (Parent and Albuquerque, 1972). Continuous application of nitrogen, phosphorus and potassium is beneficial for obtaining healthy trees and increasing cashew yields (Azam-Ali and Judge, 2001).

Table 2: Six-year mean cashew nut yield of trees of different ages as influenced by NPK fertilizer application.

Age	Fertilizer treatment	Mean yield (kg ha^{-1})	Increase over control (kg ha^{-1})	% increase
4	F1	197.9	-	-
	F2	302.7	104.8	52.9
	F3	324.1	126.2	63.7
	F4	366.2	168.2	85.0
	F5	374.7	176.7	89.2
	F6	415.6	217.6	109.9
6	F1	180.9	-	-
	F2	248.2	67.3	37.2
	F3	272.5	91.5	50.6
	F4	290.3	109.4	60.4
	F5	298.5	117.6	64.9
	F6	329.7	148.7	82.2
8	F1	163.9	-	-
	F2	247.5	83.5	50.9
	F3	298.0	134.0	81.7
	F4	323.2	159.2	97.1
	F5	350.5	186.5	113.7
	F6	364.5	200.5	122.2
10	F1	275.8	-	-
	F2	374.0	98.1	35.5
	F3	406.3	130.4	47.2
	F4	410.2	134.3	48.6
	F5	486.6	210.8	76.4
	F6	488.3	212.4	77.0

Cashew trees that received high amounts of fertilizers, especially F5 and F6, gave significantly ($p<0.05$) higher nut yield than trees which received less amount of fertilizer and the control from 2012 in all four age categories. The youngest of the trees (4 years old) when the trial commenced in 2008 had the highest increase in nut yield by fertilizer application, and was followed by, the oldest trees (10 years old) . The mean nut yields for the six-year period, were highest for the 10 year old trees and lowest for trees in the 6 years old farm (Table 2). Irrespective of the rate of application, the nut yields for all trees that received fertilizers were significantly higher than the control. The increase in mean nut yield by fertilizer application over the control was 98-212 kg ha^{-1} (35-77%) for the 10 year old trees, 83-200 kg ha^{-1} (50-122%) for the eight year old trees, 67-148 kg ha^{-1} (37-82%) for six year old trees and 104-217 kg ha^{-1} (52-109%) for four year old trees. The lower and higher ends of the nut yield ranges are for F1 (the lowest) and F6 (highest) fertilizer application rates respectively. This observation is in line with what was reported by Kumar et al. (1995). Thus, as NPK rate increased, the duration of harvesting time and the total percentage of harvested nuts increased significantly. The critical concentrations of N and P in relation to yield were 2.09 and 0.14% as observed in fully matured leaves (Kumar and Sreedharan, 1987). Moreover, higher yields of cashew nuts were obtained with a combination of N, P_2O_5, and K2O equivalent to 200, 75, and 100 g plant-1 per year, respectively (Ghosh and Bose, 1986), while the application of 250, 125, and 125 g $plant^{-1}$ per year of N, P_2O_5, and K_2O, respectively was reported as suitable for significantly increasing the yield of 15-year-old cashew plants (Subramanian et al., 1995).

4. Conclusion and Recommendation

This study has shown that the application of inorganic fertilizers on less fertile soils will greatly benefit the nutrition of cashew plants. Cashew trees which were 10 years old responded well to fertilizer application compared to the 6 year old ones. The possibility and benefit of supplying nutrients to cashew plants by combining NPK (inorganic fertilizer) have been clearly shown in this study. The best yield was recorded for treatment F6 (200 kgN+120 kgP_2O_5+120 kgK_2O $ha^{-1}yr^{-1}$). From its preeminence over the other treatments in promoting yield of cashew, its application would ensure improved growth and yield of cashew trees in less fertile soils.

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ANTIFUNGAL ACTIVITIES OF SOYBEAN EXTRACT AND SYNTHETIC FUNGICIDES ON PATHOGENS CAUSING ANTHRACNOSE DISEASE OF CASHEW IN GHANA

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Abstract

Anthracnose is one of the most important diseases of cashew in Ghana and other African countries. It affects aerial parts of cashew tree particularly the leaves and the fruits, reducing the economic benefit of the crop. The disease is caused by Colletotrichum gloeosporioides complex. There are limited anthracnose disease management options to cashew farmers, especially on the use of organic and inorganic fungicides. In this study, antifungal efficacy of different concentrations of soybean extract and synthetic fungicides (77% Cupric Hydroxide, 6% Metalaxyl-M +60% copper oxide, 4% Pyraclostrobin + 7.2% Dimethomorph) were tested against five isolates of Colletotrichum gloeosporioides complex on agar plates under laboratory conditions for 7 days. Soybean extract at concentration of 50% (V/V) achieved 81.74% inhibition of mycelial growth of C. gloeosporioides isolates and it was almost efficacious as the synthetic fungicide. Meanwhile, fungicide containing 6% Metalaxyl-M + 60% copper oxide completely inhibited all isolates of C. gloeosporioides while fungicides containing 77% Cupric Hydroxide and 4% Pyraclostrobin + 7.2% Dimethomorph inhibited the isolates with percentage inhibition ranging between 86.80-100% and 79.70-100% respectively. This study shows the efficacy of soybean extract as a potential bio-fungicide for field evaluation in the management of anthracnose disease of cashew.

Keywords: Antifungal activity, inhibition, soybean, anthracnose disease *Colletotrichum gloeosporioides*

Introduction

Cashew (*Anacardium occidentale* L.) is an important cash crop in Ghana and by large West Africa, where 45% of the world's Raw Cashew Nut (RCN) is produced (Oliveira, 2008; Dedehou, 2015; Monteiro et al., 2017). Cashew cultivation in Ghana has been on the increase since the inception of the Cashew Development Project (CDP) in 2002, making it second most important tree crop in the country (GBN, 2020). Production of RCN increased from 6.33 tonnes in 2003 to 232,834 tonnes in 2015 (MoFA, 2016). In 2016, Ghana earned US$196.683 million from the export of RCN and this accounted for 53% of the total export earnings derived from non-traditional exports (ISSER, 2017). Income generated from sale of cashew over the years has raised the standard of living of most rural farmers and has brought the much needed foreign exchange for the country.

Diseases are among the important limiting factors of cashew production in all growing areas including Ghana (Kone et al., 2015). They affect both the quality and quantity of cashew nuts and apples produced (Ghini et al., 2011; Monteiro et al., 2015). Disease can affect all parts of the cashew tree such as the leaves, branches, stem and roots (Adeniyi et al., 2011; Dominic et al., 2014). The most common diseases of cashew in Ghana include anthracnose, leaf blight, inflorescence blight, leaf rust, gummosis and root rot (Amoako-Attah et al., 2021). Anthracnose disease caused by Colletotrichum gloeosporioides is one of the most important diseases of cashew and it is estimated to cause 70-100% yield loss (Wonni et al., 2017; Amoako-Attah et al., 2021). The disease commonly affects the nuts, leaves, twigs and flowers (Freire et al., 2002; Nakpalo et al., 2017) leading to severe defoliation, withering of flowers, darkening of apples and nuts (Freire and Cardoso, 2003;Amoako-Attah et al., 2021).

Chemical control has been found to be effective in controlling anthracnose disease of cashew (Filoda, 2008; Silue et al., 2017). In Ghana, synthetic fungicides containing mancozeb or copper oxychloride have been reported to be effective in controlling anthracnose disease of cashew (Amoako-Attah et al., 2021). Other active ingredients including azoxystrobin, trifloxystrobin, benomyl and dithianon have also been reported to be effective against the disease (Menezes et al., 1975; Christian, 2001).

Despite the effectiveness of synthetic fungicides, there are growing concerns on the potential effect of fungicides on non-target organisms, high cost of chemicals and higher residues in crops (Balakumar et al., 2011, Sande et al., 2011; Basco et al., 2017). There is therefore the need to search for alternative control methods such as botanicals which could be used alone or in combination with synthetic chemicals to control the anthracnose disease. Studies have shown that botanicals contain important metabolites which have antimicrobial properties and can be used to control plant diseases (Wang et al., 2010; Villalobos et al., 2016; Bukari et al., 2022). The combination of synthetic fungicides and plant extracts for integrated management of anthracnose disease could lead to reduction in the number of applications in a spraying season as well as the quantity of synthetic fungicides required for the spray. This study therefore evaluated the efficacy of soybean extract and synthetic fungicides (77% cupric hydroxide, 6% metalaxyl-M +60% copper oxide, 4% pyraclostrobin + 7.2% dimethomorph) on mycelial growth of C. gloeosporioides isolates.

Materials and Methods

Soybean extract

Soybean extract was obtained following the methods described in Bukari et al. (2022). The seeds were bought from a local market in Tamale, the capital city of the Northern Region of Ghana. The seeds were thoroughly washed with tap water and rinsed with sterile distilled water (SDW) before drying them under shade for three weeks. The seeds were then ground into fine powder using a blender. Then 5 L of water was added to 1 kg of the powder and incubated at room temperature for one week. The sample was filtered using a muslin mesh and concentrated to drying using a rotary evaporator. A stock solution of 60% (v/v) was prepared by dissolving 60 g of the powder in 100 ml of water for use.

Disease sampling and pathogen isolation

Sampling for anthracnose disease was done in commercial farms in the Eastern, Bono East and Volta Regions of Ghana from October to December 2022. Cashew leaves showing symptoms of anthracnose disease were collected into sterile polythene bags. The geographical coordinates of the sampling locations were recorded. Diseased leaves were surface sterilized with 70% ethanol and rinsed three times in SDW. Diseased parts of the leaves were cut into 5 × 5 mm pieces, placed on water agar and incubated at 25 oC for 3-5 days. Hyphal strands emerging from the fungal growth were transferred onto Potato Dextrose Agar (PDA) media and further incubated at 28oC for seven days. Pure cultures of C. gloeosporioides obtained were kept on fresh PDA plates for use. The pathogens were identified using morphological and microscopic characteristics (Humber 2005; Kirk et al., 2008). The cultures of the pathogens were preserved in SDW inside McCartney bottles and kept at room temperature. Five distinct isolates of C. gloeosporioides (Colle 1, Colle 2, Colle 3, Colle 4, Colle 5) were used for this study.

Bioactivity of the soybean extract and synthetic fungicides under laboratory conditions

The bioactivity of the soybean extract was performed following the method described by Nwosu and Okafor (1995) with some modifications. Different concentrations (50, 20, 10, 1, 0.1%, v/v) of the soybean extracts were added to 100 ml molten PDA. Three synthetic fungicides (77% cupric hydroxide, 6% metalaxyl-M + 60% copper oxide, 4% pyraclostrobin + 7.2% dimethomorph) were tested at their respective manufacturers' recommended rate against all the five isolates of C. gloeosporioides. A 6.67 g of 77% cupric hydroxide, then 3.33 g each of 6% metalaxyl-M + 60% copper oxide and 4% pyraclostrobin + 7.2% dimethomorph were separately added to 100 mL sterilized PDA (45–50 °C). The amended media were poured into Petri plates and allowed to solidify. A 5 mm mycelial disc from pure culture of each of the five isolates was used to inoculate the centres of the PDA plates. Plates containing no extracts served as controls. The Petri plates were incubated for 7 days at 28 ± 2 oC. Radial growths were measured at the end of the 7th day and Percentage Inhibition (PI) was calculated as:

$$PI = (D-T)/D \times 100$$

where D = average diameter of growth in control plates; T = average diameter of growth in test plates

Data analysis

The percentage inhibition of the isolates in response to the synthetic fungicides and soybean extract was calculated. The data was analysed using ANOVA (Genstat 10th edition) at a significance level of 5%. Tukey post hoc test was also done.

Results

Sample location and Isolation of pathogens

The pathogens coded Colle 1, 3 and 4 were obtained from the forest transitional zone whiles Colle 2 and 5 were isolated from the Semi-deciduous zone (Table 1).

Table 1: Sampling locations of anthracnose disease pathogens

Pathogen	Sampling location	Ecological zone	Region	Coordinates of Location
Colle 1	Prusu Nkoranza	Forest transitional	Bono East	Lat: N07o 30.588" Lon:W01o 33.931"
Colle 2	Kpando Gadza	Semi-deciduous	Volta	Lat:N7o1'38.13708"; Lon:E0o218'.48016"
Colle 3	Duabone	Forest transitional	Bono East	Lat:N 7 o 454.92012 Lon:W 1 o 429.75592
Colle 4	Adunasa Nkoranza	Forest transitional	Bono East	Lat:N 7 o6'41.47812" Lon:W 1 o 22'38.3818"
Colle 5	Aframase	Semi-deciduous	Eastern	Lat:N6 o 21'4.75812" Lon:W0 o 4'31.26"

Efficacy of soybean extract

The soybean extract was effective against the isolates of C. gloeosporioides at all the test concentrations with PI ranging from 3.73% to 81.74% (Table 1). None of the soybean extract was able to completely inhibit the mycelial growth of the pathogens. However, it was observed that higher concentrations of the extract achieved greater reduction in mycelial growth of the pathogens. For all the isolates, the highest PI was obtained with 50% concentration of the extract. The highest PI of 81.74% was recorded on plates inoculated with Colle 4 at 50% concentration of the soybean extract. The value was significantly different ($p<0.001$) from the PI recorded for all the other isolates. At 20% concentration, there were no significant differences in PI obtained for Colle 3 (52.33%), Colle 4 (55.45%) and Colle 5 (51.67%). Also, the PI of Colle 1 and Colle 2 were not significantly different at 20% concentration of the extract. Similarly, the PI of all isolates at 1% and 2% concentrations of the soybean extract were not significantly different from each other.

Table 2: Percentage inhibition of the mycelial growth of Colletotrichum isolates on PDA amended with different concentrations of soybean after 7 days of incubation (28 ± 2°C).

Pathogen	Extract concentration (%)				
	50	**20**	**10**	**1**	**0.1**
Colle 1	53.70^{e}	37.41^{b}	30.93^{b}	9.63^{a}	6.48^{a}
Colle 2	75.99^{b}	42.52^{b}	29.91^{b}	13.95^{a}	3.73^{a}
Colle 3	68.78^{d}	52.33^{a}	40.26^{a}	11.49^{a}	6.14^{a}
Colle 4	81.74^{a}	55.45^{a}	31.27^{b}	5.68^{a}	3.74^{a}
Colle 5	71.11^{c}	51.67^{a}	37.96^{a}	8.90^{a}	4.63^{a}

Values with the same letter within the same column are not significantly different

Efficacy of synthetic fungicides

All five isolates of C. gloeosporioides were very sensitive to the three fungicides used. Metalaxyl-M +60% copper oxide fungicide completely inhibited (100%) the mycelial growth of all the isolates (Table 3). Also, fungicide containing 4% pyraclostrobin + 7.2% dimethomorph completely (100%) inhibited the growth of all the isolates except Colle 1 (79.77%). Colle 2 and Colle 3 were completely inhibited by all the test fungicides. Colle 1, Colle 2 and Colle 4 were also completely inhibited by 77% cupric hydroxide fungicide.

Table 3: Percentage inhibition of the mycelial growth of Colletotrichum isolates on PDA amended with different synthetic fungicides after 7 days of incubation (28 ± 2oC).

Isolates	Synthetic fungicides		
	77% Cupric hydroxide	**6% Metalaxyl-M + 60% Copper oxide**	**4% Pyraclostrobin + 7.2% Dimethomorph**
Colle 1	100^{a}	100^{a}	79.77^{b}
Colle 2	100^{a}	100^{a}	100^{a}
Colle 3	90.50^{b}	100^{a}	100^{a}
Colle 4	100^{a}	100^{a}	100^{a}
Colle 5	86.80^{b}	100^{a}	100^{a}

Values with the same letter within the same column are not significantly different

Discussion

All the concentrations of the soybean extracts had inhibitory effects on the isolates of *C. gloeosporioides* and this confirms works done by other researchers on the antimicrobial properties of soybean extract. For instance Bukari et al. (2022) reported a PI of 80.4 and 86.8% when Erythricium salmonicolor and Marasmiellus scandens where grown in plates amended with soybean extract. Wang et al., 2010, also noted that soybean extract degraded the quantity of both DNA and RNA of Staphylococcus aureus by 66.47 and 60.18% respectively. The highest PI of 81.74% was recorded on plates amended with 50% of the soybean extract. However, work done by Igboabuchi and Llodibia (2018) on Aspergillus niger and E. coli showed a PI of 62.2% and 68.8% respectively on plates amended with soybean extract. The results of the study showed that the extent of inhibition of the isolates was dependent on the concentration of the extracts. The rate of mycelial inhibition increased with an increase in extract concentration. This trend has been reported in other studies (Bukari et al., 2022; Velazquez- Nuenez et al., 2013.). A lower PI of 10.9% to 61% was observed when glyceollins (200 and 600 μg/disk) isolated from soybean seeds were tested against Fusarium oxysporum and Botrytis cinera (Hyo et al., 2010), an indication that the soybean extracts works better on C. gloeosporioides.

The antimicrobial properties in soybean extracts can be attributed to the presence of phytochemicals such as phenols and alkaloids (Villalobos et al., 2016; Dahanukar, 2000; Cowan, 1999). Wang et al. (2010) attributed the inhibition of Staphylococcus aureus to isoflavones in soybean extract. These isoflavones inhibit the synthesis of nucleic acids in S. aureus. Also Morais et al. (2013) reported that soybean toxin, isolated from soybean inhibited the development of nutrient uptake system in Candida albicans.

The high efficacy of the fungicides against isolates of *C. gloeosporioides* has been demonstrated. The metalaxyl-M +60% copper oxide fungicide completely inhibited the mycelial growth of all the isolates. The lowest PI obtained on the synthetic fungicide was 79.77%.

Patrice et al. (2021) reported a PI of 100% when 5 mg/ml of Mancozeb was tested against isolates of C. gloeosporioides. The authors also reported PI ranging from 50-100% when 0.5 mg/ml of Mancozeb was used. Carbendazin and Prochloraz fungicides have also been reported to totally inhibit growth of *C. gloeosporioides* (Nakpalo et al., 2017). Metalaxyl+ copper oxide fungicide have been reported to inhibit spore germination of *C. gloeosporioides* by 82.86% (Patrice et al., 2021). The use of soybean extract and synthetic fungicides in an integrated disease management system could reduce the over reliance on synthetic fungicides to control anthracnose

Conclusion

The antifungal effects of the synthetic fungicides and soybean extract have been demonstrated in this study. After 7 days of incubation, the soybean extract (50% V/V) and the fungicides inhibited mycelial growth of C. gloeosporioides by a PI of 81.74 % and 79.77-100% respectively. Fungicides containing 6% Metalaxyl-M + 60% copper oxide completely inhibited all isolates of C. gloeosporioides. The combination of both extracts and fungicide in an integrated disease management strategy could reduce the amount of synthetic fungicides needed to control anthracnose disease of cashew in the field.

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CONSTRAINTS TO SUSTAINABLE PRODUCTION AND MARKETING OF RAW CASHEW NUTS FOR IMPROVED FARMER LIVELIHOOD IN ABIA STATE, NIGERIA

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Abstract

For sustainable cashew sector in Nigeria, a number of things have to be put in place for the raw cashew nut (RCN) market to flourish. This study was carried out in Abia state, Nigeria. Structured questionnaire was used to elicit information from 120 cashew farmers using the multistage sampling technique in three cashew producing local government areas of Umumeneochi, Isikuwato and Abia North local government areas. The study identified the constraints to cashew production and examined the level of awareness of production/ marketing practices among cashew farming households. Data collected included socio-economic characteristics of farmers, constraints to cashew production and marketing, the level of awareness of practices in cashew production and the factors that determine cashew production and marketing. Data collected were subjected to descriptive and inferential analysis.

The results showed that the majority of the farmers are males (63.8%), with 52.4% having secondary education, operating on small-medium scale farmlands of 4.38±2.05 ha. Most of them (75%) acquired the land through inheritance with low adherence to good agricultural practices and no organized markets for RCN in the state. About 28.6% have over 20 years of cashew farming experience with 81% of the farmers belonging to associations. Constraints to production and marketing of cashew include high taxes and unfavourable government policy (82%), climate change effects (89%), inability to access government assistance in marketing (87%), poor access to inputs and chemicals (86%), poor access to improved planting materials (81%), low level of training on post-harvest handling (92%), incidence of pest and diseases (90%), poor access to credit facility (90%) and herdsmen disturbance (92%). Production practices among farmers showed low levels of awareness on the research advances in cashew production, recommended planting population, appropriate marketing channels, climate change mitigation and adaptation techniques. Access to land ($p<0.05$), age of farmers ($p<0.01$), access to inputs ($p<0.05$), training on GAP ($p<0.05$) and disturbance by herdsmen ($p<0.05$), climate change ($p<0.05$) and access to credit ($p<0.01$) are positively significant for sustainable cashew production. This study recommends that cashew farmers in Abia State be assisted and trained to mitigate the constraints in cashew production.

Keywords: Constraints, Awareness, Cashew, Sustainable production, Nigeria

Introduction

Cashew (Anarcardium occidentalae) is an economic crop in Nigeria which is grown in plantations in almost every state because of the ease of cultivation and need for minimum attention. It is a major cash crop with high potential to generate foreign exchange and to create employment, as well as curb desertification in Nigeria. The crop is an important industrial raw material with rising demand in the confectioneries, food, and beverage industries. The three main cashew products traded in the international market are raw cashew nuts (RCN), cashew kernels and cashew nut shell liquid (Azam-Alli and Judge, 2001). Cashew nut production trends have varied over the decades with an increase in its importance as an export oriented cash crop (FAO 2013, INC 2013). It contributes over 10% of Nigeria's GDP based on export data of 2022. Nigeria is a leading exporter of premium quality (RCN), with an average of 48 kernel yield out-turn (Abubakar, 2023). Also, Nigeria is the world's 6th largest producer of cashew fruits, with annual production volume of about 120,000 tonnes. The Cashew Industry also provides about 600,000 jobs and a total annual trade worth N24 billion, thus making the sector a major contributor to Nigeria's non-oil GDP (Ajanaku, 2021). It is widely grown in the southern states of Nigeria, especially in the Enugu, Oyo, Anambra, Kogi, Osun, Abia, Ondo, Benue, Cross River, Imo, Ekiti, Ebonyi, Kwara. Understanding the key factors that influence cashew product quality and effective marketing strategies is crucial for maximizing the industry's potential. This paper examines the awareness levels among stakeholders regarding sustainability and identifies key constraints that hinder sustainable production and marketing efforts.

Methodology

Using a multistage sampling technique, primary data were collected from 120 cashew farmers from three Local Government Areas (LGAs) of Abia State using well-structured questionnaire. Abia State was purposively chosen because it has a large number of cashew farmers. Three high cashew growing LGAs (Umumeneochi, Isikuwato and Abia North) were selected randomly and four communities were selected from a list provided by Abia State Agricultural Development Programme (ABSADP) per LGA with 10 farmers per community. Data collected were subjected to both descriptive and inferential statistics. The data on socio-economic characteristics were subjected to descriptive analysis to determine the frequencies, percentages, mean and standard deviations. Also, the other data collected like the farm /farm operation characteristics on awareness and constraints were analyzed using the descriptive analysis while the determinants of production and marketing was determined using multiple regression analysis.

Results and discussions

The minimum and maximum ages among the farmers were 25 and 74 years respectively with the mean age at 50±13.35 years (Table 1). This indicates that the cashew farmers are young and in their active and productive years which is good for the sustainability of the industry. The farming experience ranged from 6 to 49years with a mean of 22±9.93 years, implying that the cashew farmers have wealth of experience in the business and probably along the value chain that could help them succeed. Also, the number of persons per household was from 2 to 14 with a mean of 8±2. More than half of (56%) of cashew farmers in the study area use labour from within their families while 6.6% use hired labour. This indicates that the households with larger families may have more hands (family labour) to use on the farms.

The cashew farm sizes were from 1 to 7 hectares, with a mean of 4.38±2.05 hectares. This implies that the cashew farmers are actually smallholder farmers in the state and these calls for expansion of cashew farms due to the young ages of the farmers.

Table 1.0 Descriptive statistics of cashew farmers in the study area

	Minimum	Maximum	Mean	Std. Deviation
Age(years)	25	74	50.00	13.346
Years in cashew farming Experience	6	49	22.00	9.925
Household Size	2	14	8.11	2.657
Size of cashew farm	1	7	4.38	2.050

Source: Field Survey, 2021

Males dominated (63.3%) cashew farming in the study area and this makes it necessary to encourage more females to engage in cashew farming in the state (Table 2). The result revealed that 52.5% of the farmers sampled have secondary education and which indicates the farmers ability to read and write. They can therefore participate effectively in marketing and production trainings on cashew. About 80.1% of the farmers belong to one association or the other where they get information on production and marketing of their produce. The result further revealed that most of the farmers plant their cashew seeds in-situ as only 38.3% have nursery where they raise their nuts to seedlings for planting. About 76.7% of the farmers do not test their soils for suitability before planting. Out of the few that tested, only 7.1% used scientific methods for soil testing. In terms of Good Agricultural Practices (GAPs), 81% of the farmers carry out rehabilitation. Out of this, 52.5% do coppicing of old trees and 27.5% do replanting. For other GAPs, 78.33% did pruning with 95.8% of them pruning annually. Weeding was done by 90% of the farmers with 95.12% weeding once and 4.88% weeding twice . Majority of the farmers (92.7%) do not apply fertilizers on the assumption that their soils are fertile. A good number of the farmers (90.27%) applied herbicide for clearing of weeds.

Table 2: Distribution of the respondents by socio-economic characteristics in study area

Characteristics		Frequency	%
Gender	Male	76	63.3
	Female	44	36.7
Level of Education	No formal Education	17	14.2
	Primary	16	13.3
	Secondary	63	52.5
	Tertiary	24	20.0
Membership of association	Yes	97	80.1
	No	23	19.9
Land acquisition	Inheritance	90	75.0
	Purchase	11	9.2
	Lease	10	8.3
	Gift	7	5.8
	Through government	2	1.7
Source of Labour	Family	68	56.7
	Hired	8	6.6
	Both	44	36.7

Do you keep nursery	Yes	46	8.33
	No	74	61.67
Do you test your soil before planting	Yes	28	23.34
	No	92	76.66
If yes, how do you test the soil	Manually	22	78.57
	Other farmers	4	14.29
	ADP	2	7.14
Do you carry out rehabilitation	Yes	98	81.67
	No	22	8.33
Rehabilitation methods	Total replanting	33	27.5
	Coppicing	63	52.5
	OTHERS	24	20.0
Do you prune	Yes	94	78.33
	No	26	21.67
If yes, how regular?	Once a year	90	95.74
	Once in 2 years	3	3.19
	Once in 3 years	1	1.06
Method of weeding	Manual	108	90.00
	Chemical	12	10.00
Frequency of weeding/annum	Once	78	95.12
	Twice	4	4.88
Fertilizer usage	Yes	5	7.35
	No	63	92.65
Use of Herbicides	Yes	10	8.73
	No	93	92.65
Use o pesticides	Yes	24	20.00
	No	96	80.00

Source: Field Survey, 2021

The study shows that the farmers were very much aware of the use of agrochemicals, cashew farm sanitation, varieties of cashew, stakeholders in the value chain, and good agricultural practices (Table 3). However, they did not know of practices like planting population, research advances in cashew production, marketing channels, and mitigation/adaption to climate change. This calls for quick attention through proper training of the stakeholders along the value chain.

Table 3.0 Level of awareness of practices in cashew production/marketing

Variables	**Very much aware (%)**	**Not aware(%)**
Use of agrochemicals	75%	25%
Cashew farm sanitation practice	89%	11%
Varieties of Cashew	87%	13%
Planting population	10%	90%
Research advances in cashew production	24%	76%
Marketing channels	8%	92 %
Stakeholders in the value chain	92%	8%
Good agricultural practices	94%	6%
Mitigation/adaption to climate change	13%	87%

Source: Field Survey, 2021

High taxes and unfavourable government policy (82%), climate change effects (89%), inability to access government assistance in marketing (87%), poor access to inputs and chemicals (86%), poor access to improved planting materials (81%), low level of training on post-harvest handling (92%), incidence of pest and diseases (90%), poor access to credit facility (90%) and herdsmen disturbance (92%) are constraints in the cashew value chain (Table 4).

Table 4.0: Constraints to the production and marketing of cashew

Perceived Constraints	Highly important (%)	Less important (%)
Inadequate information on cashew production	22%	78%
High taxes and unfavourable government policy toward cashew	82%	18%
Climate change effects on cashew production	89%	21%
Inability to access government assistance on production	22%	78%
Inability to access government assistance in marketing	87%	13%
High risks and uncertainty in Agric	46%	54%
Poor access to inputs and chemicals	86%	14%
No access to improved planting materials	81%	19%
Need of training on post-harvest handling	92%	8%
Incidence of pest and diseases	90%	10%
Poor access roads to cashew plots	19%	81%
Poor access to credit facility	90%	10%
Herdsmen disturbance	92 %	8%

Source: Field Survey, 2021

Determinants of production and marketing among cashew farming households in Abia state Nigeria

Access to land is a significant ($p<0.05$) determinant of production in the state as there is land scarcity and its availability is germane for economic production. Age is also a significant ($p<0.01$) factor which motivates production as corroborated by the socio-economic characteristics. Access to inputs is negatively significant ($p<0.05$) for production in the study area and this agrees with the constraints indicated in Table 4. Training on GAP is positively significant ($p<0.05$) for production in the state. This result is in consonance with the work of Akpomie and Ojeh (2018) who found that knowledge gaps highlight the need for targeted capacity-building programs and extension services to raise awareness and promote sustainable RCN production and marketing. Disturbance by herdsmen is negatively significant ($p<0.05$) for production and marketing. The herdsmen usually interfere with production and marketing activities. Poor access to credit facility significantly ($p<0.01$) reduces the ability of farmers to increase production, market their raw cashew nuts and to invest in sustainable technologies and practices. This result confirms works of Chukwu and Nwokocha (2019) that highlighted the need for investment in infrastructure development to ensure the preservation of RCN quality and facilitate efficient marketing.

Conclusion and recommendation

This study conclude and recommends that the youths and females be encouraged into cashew production and marketing processes along the value chain in the state to ensure sustainable production and marketing; while it was also found imperative that land for production, training on GAP, adequate access to credit and production inputs be made available in the state to boost sustainable production and marketing of RCN among producing households in Abia State, Nigeria.

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CASHEW (*ANARCADIUM OCCIDENTALE* L.) NUT AND APPLE PROCESSING: IMPROVING THE LIVELIHOOD OF THE RURAL POOR IN CASHEW PRODUCING AREAS IN GHANA

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ABSGTRACT

Cashew production has become very important in Ghana over the past two decades and it is supported by the Government of Ghana and non-governmental organizations (NGOs) such as Competitive Cashew Initiative (ComCashew), African Cashew Alliance (ACA) and Technoserve. Many developing countries have not been able to exploit the economic value of cashew despite the importance of the nut on international markets and the high nutritional value of the apples. In Ghana, lots of efforts have been made to upgrade cashew production through improved production techniques. However, with all the efforts being made to promote a competitive cashew nut processing industry, processing of the nuts continues to remain very low with over 90% of the nuts being exported. The apples are also left on the farm floor to rot. To generate more income from cashew, the need for value addition cannot be overemphasized. Cashew production is concentrated in the transitional savannah and the northern savannah zones, which are known to be among the poorest areas in Ghana. In order to reduce poverty in these areas and to improve on the livelihood of the people, it is imperative to evaluate the benefits of cashew processing and also develop strategies to promote processing through the local consumption of cashew. In this paper, cashew nut and apple processing are discussed in detail to show their importance to the Ghanaian economy. The processing cost analysis of the cashew fruit (nut and apple) has been elucidated in the paper. The prospects, opportunities and challenges as well as strategies to mitigate these challenges in the processing of the fruit are also discussed.

Keywords: Prospects, challenges and opportunities, production cost, SWOT analysis

INTRODUCTION

Cashew has become an important agricultural commodity in many countries. However, Ghana is yet to tap into the potentials of this cash crop which has great benefits for the country as a whole. Its production is concentrated in the transitional savannah and the northern savannah zones, which are known to be among the poorest areas in Ghana. It is a smallholder activity with individual holdings varying from 0.8-3.0 ha per farmer (Osei Akoto, 2022). As a resilient and drought resistant tree that is adaptable to poor soil conditions, cashew offers environmental benefits in the prevention of deforestation and soil erosion, especially in Sub-Saharan Africa (Cambon, 2003). The tree has been found to have medicinal and non-food uses from the bark, leaves, and apple juice. Bark teas were used for diarrhoea and malaria treatment, and the caustic shell oil was used to treat skin infections, warts, worms, and botfly larvae beneath the skin (Davis, 1999). Most importantly, its cultivation and exploitation are regarded as economically promising for both rural growers and urban industrial processors in terms of employment generation and value addition to emerging economies.

Cashew apple, which is an excellent source of nutrition, contains vitamin C five times higher than an orange (Barros et al., 2001). It also has more calcium, iron and vitamin B1 than other fruits such as avocados and bananas. However, they are highly perishable and can be eaten fresh or juiced. In Brazil, fresh cashew apples are packed in trays and marketed in retail fresh produce outlets (Filgueira and Alves, 2001). Currently in Ghana, the apples are normally left on the farm floor to rot. At the Cocoa Research Institute of Ghana, protocols have been developed on the production of juice drink, jams and marmalades, alcoholic beverages such as wine, gin and brandy from the apples. The objective of this paper is to evaluate the prospects, challenges and opportunities of cashew processing, particularly in the rural areas of Ghana.

Production and marketing of raw cashew nuts (RCN) in Ghana

The average yield of cashew production in Ghana currently stands at 800-1,500 kg/ha (Osei Akoto, 2022). The total production of cashew for the year 2022 was 200,000 MT and Ghana is set to produce 300,000 MT by 2030, according to Osei Akoto, 2022. Since 1992, Ghanaian cashew production has grown by 5.1 percent each year. Originally nuts were sold to buyers from Cote d'Ivoire, at low prices. However, in the early 1990s Ghanaian companies began purchasing nuts for export and the first RCN of 15 MT were exported in 1991 (Dannson, 2002). The crop is marketed through farmer cooperative societies, traders and agents. Over 90% of harvested nuts are sold for export to India, where they are processed into kernels and sold to Europe, Asia and the US. Cashew nut trade in Ghana has rapidly increased over the last few years. However, part of Ghana's export is derived from cross-border trading from Cote d'Ivoire and Bourkina Faso. Cashew international trade is still young compared to other commodities, starting about 70 years ago (Beyadi, 2008).

Marketing of cashew nuts have begun to take centre stage in the economic development of Ghana. The chain from producer to exporter suffers from severe price fluctuations and this is due to a combination of internal and external factors (CDP, 2007). Internally, the flow of information on marketing and pricing of cashew nut between producers and exporters is inadequate. The external factors include unstable international currency markets and variations in global production of cashew. In some years, production may suddenly decline to about half of the previous year's level (Quenum, 2001). Generally, prices of cashew nuts at the beginning of the season are very low but wind up higher by the end of the season. This may be due to the fact that buyers or processors in India may not have established contracts with exporters in West Africa (Cambon, 2003). Farmers who are short of cash early in the season are also forced to sell their produce at very low price. Prices vary between neighbouring villages and this is due to the lack of strong farmer co-operatives that could agree on a good minimum price for the season. Farmers in remote areas also receive lower prices due to higher costs of transportation. Price of raw cashew nuts also depends on the origin of production (Cambon, 2003). All these indicate that activities along the marketing chain of RCN are not regulated. Therefore, the creation of the Tree Crop Development Authority (TCDA), regulatory institution, in the year 2020 is timely.

Cashew nut processing in Ghana

India pioneered the modern processing of nuts, and had been consistently the world's leading producer for decades prior to 2002. Processing of cashew starts with the collection of nuts on the farm and drying of the nuts in the sun on mats for about 3-4 days until they rattle in the shell. The processing operations include roasting/steaming of nuts, cooling of steamed nuts, shelling, drying of kernels, peeling, sorting, grading and packaging. Cashew nut processing is the most difficult of all nuts because of the caustic cashew nut shell liquid (CNSL) in the shell. The CNSL can contaminate the nuts and cause blisters on the human skin. There are three processing modules, the manual, semi-mechanized and fully-mechanized processing technologies (ACi, 2015). In Ghana, the processing operations are performed mostly by the manual module, which requires a lower capital base and has greater output in terms of kernel yield and the quantities of wholes produced as compared to the mechanized one. However, it requires a relatively large number of workers who work at the risk of exposure to CNSL.

Most of the processing factories are small and employ between 10-100 people depending on the capacity of the plant. One of the biggest costs is stockpiling RCN to keep the factories running throughout the year. The cashew-harvesting season is only about 60 days, so that if a plant which processes 500 kg raw nuts per day should be kept running for 200 days in a year, it will require a stock of about 100,000 kg of RCN. Efforts are being made to develop the local processing industry for value addition to raw nuts, but the sector is still significantly less developed than in other commodity processing industries.

A Profile of cashew nut processors in Ghana

Over the past two decades, seventeen (17) processing factories have been built in Ghana (Table 1). These factories vary in size and may be classified into large-, medium- or small-scale enterprises. They may also be grouped into cooperatives, urban and rural-based factories. Each factory is a combination of the above categories. The combinations are the urban-based large/medium/small enterprise, the rural-based large/medium/small enterprise and the rural-based cooperative. There are 2 large-scale, 4 medium-scale and 11 small-scale processors in Ghana (Table 1). The large- and medium-scale factories primarily produce kernels for export while the smaller plants target the domestic market. The 4 largest processors are foreign direct investments (FDI) with the rest being local investments. Out of the seventeen factories, ten (10) are out of business and have closed down mainly due to problems associated with cost of RCN, labour and difficulty in accessing finance.

Table 1: Raw Cashew Nut Processing Units in Ghana as at 2022

Scale of production	**Name of company**	**Location**	**Installed capacity (RCN MT/year)**	**Status**
Large scale >15,000	Usibras	Prampram	35,000	Active
	Rajkumar	Techiman	15,000	Closed
Medium scale 1,000-15,000	Mim Cashew & Agricultural Products Ltd.	Mim	7,000	Active
	Chinese Factory	Sampa	3,000	Closed
	Kona Agro Processing Ltd	Awisa	1,800	Closed
	Muskan Ghana Ltd	Sampa	1,500	Closed
Small scale <1,000	NASAKA	Kabile	200	Active
	NASAKA	Sampa	20	Closed
	NASAKA	Nsawkaw	100	Closed
	ShopBest Company Ltd	Accra	25	Closed
	Nsuro	Accra	10	Closed
	CRIG	Bole	100	Active
	Winker Agro Processing Co.	Afienya	500	Active
	Cash nut Foods Ltd	Faaman	750	Closed
	Jelana Company Ltd	Jamera	250	Closed
	Innovative Organic Cashew Ltd	Frante	600	Active
	Nafana Agro Processing Ltd	Sampa	100	Active

CRIG Processing Factory

This is the first and the only cashew nut processing unit in the five Northern Regions of Ghana and was established by the Cocoa Research Institute of Ghana (CRIG) in the year 2005, with the support of the then Ghana Cashew Development Project. It is a small-scale factory with manual operations, which started operating in March, 2006. It is currently being run with a total of 25 workers, made up of a supervisor, steam and oven attendants who are all males as well as 22 females. The female workers consist of 10 cutters, 8 peelers and 4 graders. The unit has a processing capacity of 100 MT of raw nuts per year and it is fed with nuts from CRIG's cashew experimental plots. The saleable kernels obtained from the factory are sent to the New product Development Unit of CRIG for further processing and marketing. Processing cost analysis for RCN in the factory is shown in Table 2. The start-up and operational costs could vary dramatically depending on one's situation.

The basis and presumptions of the analysis are as follows:

i. Average annual production of RCN from CRIG plots is 350 bags (28 MT)

ii. Picking, drying and storage are done during the main harvesting season, late-December to March ending.

iii. The wages for picking, drying and storage are by piece meal.

iv. There are 4 RCN processing days in a week with a processing rate of 4 bags/day

v. Processing is done continuously for six months.

vi. The wages for skilled workers are taken as per prevailing rates at CRIG.

vii. Costs of equipment are based on average prices of equipment.

viii. Quantities of saleable kernels obtained forms about 14% of total RCN processed (3,920 kg)

ix. 85% of saleable kernels are wholes (3,332 kg)

Table 2: Cost of Analysis for processing 28 MT of RCN

Item	**Cost (GH ¢)**
a. Primary processing	
Direct labour for picking and storage	55,060.08
Direct labour for processing	112,520.16
Inputs for production and processing	5,000.00
Sub-total	**172,580.24**
Selling price of wholes	80.00/kg
Selling price of broken	50.00/kg
Total Revenue generated	**295,960.00**
Gross profit (%)	**71.5**
b. Secondary processing	
Inputs for roasting	47,350.00
Labour for roasting	29,922.17
Sub-total	**77,272.17**
Selling price of roasted wholes	150.00/kg
Selling price of roasted broken	100.00/kg
Total Revenue generated after roasting	**558,600.00**
Gross profit (%)	**124**

*The figures are estimates in Ghana cedis (Currently the cedi to dollar rate is Gh ¢12.00 to $1.00).

An estimated annual gross profit of 71.5% could be made on the primary processing of RCN into kernels at CRIG while as high as 124% could be realized after secondary processing (Table 2). The analysis indicates that despite having a total installed processing capacity of 100 MT, the factory is processing around 28 MT annually.

The Market for Processed Kernels in Ghana

Cashew consumption in Ghana has been very marginal. In 2014, Ghana produced a total of 1,250 MT of kernels and only 9% of this was consumed locally with the remaining 91% exported (ACi, 2015). Kernels consumed locally are mainly produced by the small-scale factories and are sold to roasters who do the final processing and package in plastic bags and jars for the domestic market. The final products are mostly sold in supermarkets and fuel station convenience shops. There are about thirty (30) cashew kernel processors in Ghana. These are mainly roasters and a couple of artisanal chocolate makers who use the kernels in chocolate confectioneries. At CRIG, roasted kernels are sold in a small shop within the premises. Table 3 presents the quantities and sales of roasted cashew kernels sold by CRIG from 2015 to 2020. This is an indication that there is a local demand for roasted cashew kernels and its derivatives. Although CRIG is already working on the benefits of processing and promoting the local consumption of cashew, this is still not enough. It is therefore important to make a collective effort to promote processing of raw nuts in the developmental phase of the industry.

Table 3: Sales of roasted cashew kernels and its derivatives at CRIG

Year	**Production (kg)**	**Amount (GH ¢)**
2015	3086	98,380.88
2016	2095	115,296.00
2017	1414	109,282.00
2018	1924	49,604.00
2019	2072	175,824.00
2020	1830	148,224.00
Total	12,421	796,610.88

Source: CRIG Annual Progress report (2015-2020)

Cashew apple processing in Ghana

With the current cashew nut production in Ghana, an estimated amount of 1.8 million MT of the apples is wasted. Juice from the apples from the northern part of Ghana have significant amounts of sugars, minerals such as K, Ca, Mg, Zn and Fe, vitamin C as well as polyphenols (Lowor and Agyente-Badu, 2009). In order to add value to cashew apples, CRIG has developed products such as fresh juice drink, jams and marmalades (Gyedu-Akoto, 2011). These products are highly nutritional and have been reported to contain appreciable amounts of minerals (Gyedu-Akoto, 2011). Alcoholic beverages such as gin, brandy and wine have also been developed from cashew apple juice. Wine from cashew juice also contains high levels of minerals as well as polyphenols (Gyedu-Akoto et al, 2021). The economic viability of these products has also been studied and has shown that there is a local demand for such products and their production is also profitable (Gyedu-Akoto et al, 2013). Processing cost analysis of cashew apples for juice drink and wine production are shown in Table 4.

The basis and presumptions of the analysis are as follows:

i. Average of 120 kg of fresh cashew apples are picked from CRIG plots daily and this yields about 80 L of fresh juice

ii. Picking and processing into fresh juice are done during the main harvesting season (approximately 70 days).

iii. The wages for picking and processing are taken as per prevailing rates at CRIG (12 workers/day).

iv. Costs of equipment are based on average prices of equipment.

v. Total quantity of apple juice extracted during the period is 5,600 L

Table 4: Production Cost Analysis of cashew wine

Item	**Cost (GH ¢)**
a. Production of juice drink	
Direct labour for picking and juice extraction	36,531.60
Direct labour for processing of juice drink	41,600.16
Inputs for processing	10,763.67
Sub-total	**88,895.43**
Selling price/L	25.00
Total Revenue generated	**140,000.00**
Gross profit (%)	**57.5**

b. Production of wine	
Direct labour for picking and juice extraction	36,531.60
Direct labour for processing of wine	41,600.16
Inputs for processing	44,121.00
Sub-total	**122,252.76**
Selling price/750 ml	40.00
Total Revenue generated after roasting	**298,666.67**
Gross profit (%)	**144**

Just like nut processing, an estimated annual gross profit of 57.5% could be made from processing cashew apples into juice drink and as high as 144% could be realized from wine production (Table 4). Apart from CRIG, there are only five cashew apple processors in Ghana and all of them fall in the cottage industry category. They are Natu, Daff, C-cash, Wangariba and Bansam companies. Bansam produces alcoholic beverages while the others produce natural juice drinks from the apples.

Potentials/Benefits of processing

Apart from value addition, cashew processing, creates employment and the existence of a local market for cashew products. Most of the nut processing factories, both active and inactive, as well as apple processors are sited within cashew growing communities in Ghana, therefore, serving as a source of employment for the rural communities. These factories employ people from the communities they are operating in, thus, creating a certain sense of familiarity. One important aspect to note of the employment generated is the high percentage of female employment. Many of these women are farmers who only work on their farms to provide food for themselves and their families. Women are preferred to men because they have been found to be more reliable and serious workers. Their neat handiwork is also seen in the peeling and grading of kernels. The benefits are not limited to mere wages and employment for community members but they find it exciting working in their communities and earning some wages. It gives them a sense of pride that a new activity apart from farming is on-going.

The other benefits from the cashew fruits (both nuts and apples) include their high nutritional values. Kernels from some cashew growing areas in Ghana have protein contents ranging from 26 to 29% and fat content from 44 to 50% (Gyedu-Akoto et al., 2014). About 82% of the fat in cashew kernels is made up of polyunsaturated fatty acids, which can help reduce the levels of low density lipids (LDL) or bad cholesterol (Visalakshi et al., 2015). They are also a good source of minerals and vitamin E (Rico et al., 2015). The apples are equally a good source of minerals, vitamin C as well as polyphenols such as flavonoids, tannins and phenolic acids (Chung et al., 1998; Lowor and Agyente-Badu, 2009). Polyphenols in cashew apple contribute to the astringency, colour, flavour and odour. They also possess antioxidant and antimicrobial properties with a long medicinal history. The vitamin C in the apple aids in immunity.

Cashew processing may minimize apple waste, ensure food security and the making of profits in the short term. It is also an additional source of income for farmers, especially women farmers. Cashew processing may also help in product diversification as well as extended availability of traditional and non-traditional products from cashew. Table 5 presents strengths, weaknesses, opportunities and threats (SWOT) analysis for cashew fruit processing in Ghana

Table 5: SWOT Analysis of cashew (apple + nut) processing

Strengths	**Weaknesses**
• Relatable scale of business, not too big • Fits with rural culture • Friendly environment • Available local demand for products particularly processed kernels • High cost/profit ratio • Cashew production is growing steadily in Ghana	• Large startup costs • Consumer education and awareness is low • Low purchasing power of consumers • Limited access of products to consumers • Fledgling industry, needs assistance • Level of competitiveness is low • Inadequate funds for stockpiling of RCN by processors
Opportunities	**Threats**
• Ghana's population of about 29 million provides a huge market for cashew products • Agritourism • Job creation for rural population which is in line with poverty alleviation and economic growth	• High international market demands for RCN • High prices of cashew products on the local market, particularly the kernels • High RCN exports in Ghana • Inaccessibility of finance

Strategies for mitigating challenges

The local cashew processing industry, particularly nut processing, is gradually collapsing and will only survive if there is proper management of the sector. With the creation of TCDA, Government and all stakeholders along the cashew value chain must make a collective effort to promote the processing and consumption of the cashew fruit, both nut and apples, since this will help develop a well-established local market for cashew products. This could be done through the following:

1. Create awareness and educate people on the benefits of cashew processing to the rural poor and the Ghanaian economy as a whole. This could be done as part of curriculum for schools and universities. For instance, the Ghana Skills Development Initiative (GSDI) in cooperation with the Commission for Technical and Vocational Education (CTVET) and GIZ is developing a curriculum for cashew value chain for all levels of certificates, from National Proficiency to Bachelor of Technology for the Technical Universities.

2. Efforts should be made by government in collaboration with the mass media and other stakeholders to provide space and time to create awareness of the utilization and health benefits of cashew fruit.

3. There is a sizeable number of cashew farmers in Ghana and most of them do not know the uses and health benefits of the cashew fruit. Thus, creating awareness of cashew processing at farmers' rallies and on their community radio programmes is important.

4. Create strong processor groups (including roasters) at local and national level to give them a better negotiating power to be able to deal with farmers, traders, equipment suppliers, credit givers, among others.

5. Roasters should be encouraged to package cashew products in attractive and affordable retail sizes for sale in schools, on the streets, in farmer communities and other vantage points.

6. Processors should be encouraged to organize fairs and exhibitions of their products as part of awareness creation.

7. Hoteliers and chefs should be encouraged to include cashew products in their recipes and menus.

8. Corporate organizations, Ministries, Agencies and Departments should be encouraged to serve cashew products at meetings, seminars and conferences.

9. Government could also institutionalize a National Cashew Day as in cocoa.

10. Access to credit and service providers should be made available to processors to increase cashew processing to help alleviate poverty in rural communities in Ghana.

11. With the current closure of cashew processing factories, efforts should be made to create enabling environment for existing processors as well as prospective ones. For instance, developing innovative incentive incentives for farmers to sell their RCN to processors and increase loyalty.

12. Training programmes on cashew apple and nut processing should be organized for farmers, existing processors as well as prospective ones.

13. Farmers should be encouraged to sell their RCN to processors to avoid price fluctuations.

CONCLUSION

The processing of both cashew apples and nuts locally have been found to be highly profitable with estimated gross profits ranging from 57.5-144 and 71.5-124% respectively. It also serves as a source of employment for the rural communities, particularly women. With the insufficient number of processing units in Ghana, there is the need to attract investors, in the form of associations, local cooperatives, small- and medium-scale private business operators, into the industry to reduce the export of raw nuts as well as create incomes for both farmers and other people in the rural communities. One of the key strengths of cashew processing is the availability of local demand and the opportunities include agritourism, which is now becoming popular in the agricultural sector in Ghana, as in cocoa. Some weaknesses within the processing sector are large startup costs, low purchasing power of consumers and distance of products to consumers. Strategies to mitigate some of these weaknesses include creating the awareness and educating the masses of the economic benefits of cashew processing to the business community in Ghana as well as providing access to finance and service providers to processors in order to promote a competitive processing industry. Grouping processors together is also vital to help carry out marketing campaigns and increase bargaining power.

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BIOASSAY OF ENTOMOPATHOGENS ASSOCIATED WITH THE MAJOR INSECT PESTS OF CASHEW (*ANACARDIUM OCCIDENTALE* L.) IN GHANA

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Abstract

Control of insect pests on cashew in Ghana is achieved mostly by using conventional insecticides which are effective but comes with environmental and health consequences. The objectives of this study were to identify entomopathogens associated with the major insect pests of cashew in Ghana and to exploit such pathogens to manage the pests. This is to address the problem of the environmentally hazardous nature of conventional insecticides currently in use. The study found several fungal pathogens associated with the major insect pests on cashew but Beauvaria bassiana was the only entomopathogen identified. Three spore concentrations (101, 103 and 105 spore mL-1) of B. bassiana proved efficacious against Pseudotheraptus devastans, Helopeltis schoutedeni, Anoplocnemis curvipes and Analeptes trifasciata compared to the control. The number of days to death of insects after applications of treatments ranged from 5 to 8. The days to regrowth of entomopathogen from the insects after death (cadavers) ranged from 3 to 7. Percentage re-isolation of pure cultures of the B. bassiana tested, ranged from 0 to 85%. The study indicates the efficacy and potential use of this entomopathogen for cashew insect pest management. However, there is the need to evaluate B. bassiana isolates under field conditions to verify their efficacy on the pests and effect on non-target organisms.

Key words: Cashew, *Beauvaria bassiana*, fungi, isolate, insecticides, cashew insect pests

1.0 Introduction

Cashew is a major tropical tree crop in Ghana and it is traded internationally providing the needed foreign exchange (Wongnaa and Ofori 2012; Mensah et al., 2021). Cashew nuts production in Ghana a decade ago was 27,000 tonnes and this was increased to 86,000 tonnes in 2019(FAOSTATS 2021). However, cashew yield still remains below optimal levels (Wongnaa and Ofori 2012; Danso-Abbeam et al., 2021). The effect of insect pests on the crop is one of the factors accounting for the relatively low yield. Pests of economic importance include the mosquito bug (Helopeltis schoutedeni) and the coreid bugs (Pseudotheraptus devastans and Anoplocnemis curvipes) (Dwomoh et al., 2007; 2008). These sap-sucking insects cause severe damage to the flushing shoots, inflorescence and developing fruits. Flushing shoot stop growing and fruit deforms especially after coreid bug attack. Trunks and branches of the tree are also attacked by stem girdlers (Analeptes trifasciata), and borer (Apate terebrans) (Dwomoh et al., 2007; 2008). Management of these pests has been achieved by using insecticides such as lambda-cyhalothrin, chlorpyriphos and endosulfan in the past (Dwomoh et al., 2007; Maruthadurai et al., 2012). Because of pesticide use regulation in the European Union, molecules like chlorpyriphos and endosulfan are no longer permitted for use on the crop. This is in response to biodiversity impact and residue issues related to the use of such active ingredients. Pesticide usage though effective in pest management has some constraints. Insecticide contamination of nuts and fruits could cause serious environmental and human health problems hence the need to investigate into relatively safer pest control methods.

Entomopathogenic fungi (EPF) are pathogens that exist as absolute parasites and induce disease symptoms on host insects (Bamisile et al., 2018). They have been reported to be effective biopesticides in controlling the populations of myriad of insect pests (Bamisile et al., 2018). Some Metarhizium anisopliae isolates demonstrated considerable mortality to early immature stages of Spodoptera frugiperda (Akutse et al., 2019). Entomopathogenic fungi including Beauveria bassiana, Isaria fumosorosea and other Metarhizium spp. have been formulated into commercial biopesticides for the management of pests of some crops like cotton (Chandler et al., 2005).

The EPF are generally host-specific and provide little to no threat to non-target organisms or beneficial insects (Shahid et al., 2012). On the other hand, when used with selective insecticides, entomopathogens increase the efficiency of pest control and reduce the amount of insecticides applied (Neves et al., 2001). This makes entomopathogens suitable for inclusion into an existing integrated pest management (IPM) system on a crop. Entomopathogens could decrease crop damage below the economic threshold by causing host pest infection. This is achieved through reduction in pest feeding, oviposition, physiological development and mating for population growth (Thomas et al., 1997). Biological control accomplished by entomopathogens, is an important technique in IPM programs as a pest population density reduction factor (Zimmerman, 2007). Therefore, the search, identification and conservation of entomopathogens, naturally occurring or introduced, to control insect pests is timely. The environmental benefits of using fewer chemical insecticides in any IPM system with entomopathogens necessitated the need for this study on cashew. This practice would minimize environmental contamination, chemical residues in produce and the expression of pest resistance to insecticides. Cashew can therefore be produced in a relatively more sustainable manner with less reliance on chemical pesticides.

Materials and methods

Collection, rearing and incubation of insect

A total of 296 insects were collected from cashew farms at different locations (Tafo, Akorley, Aseseeso, Bunso, Wenchi, Sampa, Drobo, Techiman, Kintampo and Brekum) in Ghana (Fig. 1) and brought to Cocoa Research Institute of Ghana for rearing. Insects that were alive at the time of arrival were kept at the insectary, fed and monitored until death and incubated for possible emergence of pathogens. Dead insects were collected daily and the number recorded. They were then washed in two changes of Sterile Distilled Water (SDW) and transferred onto Petri dishes lined with moistened filter papers. Pathogen (mainly fungus) growths originating from dead insects were sub-cultured onto different growth media (Sabouraud Dextrose Agar (SDA) and Potato Dextrose Agar (PDA) for sporulation and identification using standard reference manual (Imperial Mycological Institute, 1983). The EPF identified were further studied for their bio-efficacies.

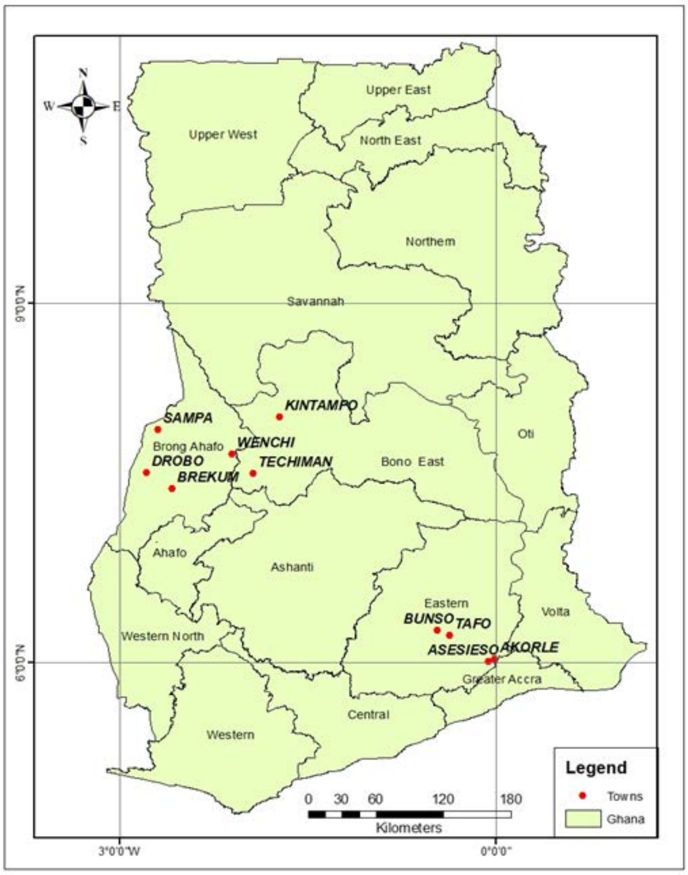

Fig. 1: Insect collection sites

Bio-efficacy test

The entomopathogen B. bassiana, was used in the bio-efficacy test on the four major cashew insect pests (P. devastans, H. schoutedeni, A. trifasciata and A. curvipes) in Ghana. The bioassay was set up as a completely randomized design with three different spore concentrations (1×105; 1×103; 1×101 mL-1) plus a control containing SDW and replicated 10 times. Mortality data were expressed as percentages (number of dead insects / total number of insects per treatment for each target insect pest). After 8 days of evaluation of the bioassay, the data was analyzed using the analysis of variance tool in GenStat (version 11) after arcsine transformation. The Standard Error of the Difference of the means (SED) was used to separate treatment means.

Results

Sampling location, field observation and disease symptoms

Identification of fungal pathogens

A total of nine fungal pathogens were identified from the insect collections, with Fusarium spp. (38%), Aspergillus spp. (28%) and B. bassiana (17%) being the three most abundant (Table 1). In some cases (29%), two different pathogens were isolated from the same insect (Table 1). Three species of Fusarium and four of Aspergillus were encountered namely F. oxysporum, F. equiseti and F. semitectum and, A. niger, A. flavus, A. wentii and A. tamarrii (Table 1). The only EPF isolated and identified was B. bassiana.

Table 1: Frequencies of occurrence of fungal species associated with insects collected on cashew

Pathogens	Total number isolated (%)
Fusarium (oxysporum, equiseti and semitectum)	113 (38.2)
Aspergillus (niger, flavus, wentii and tamarrii)	82 (27.7)
Mucor plumbeus	5 (1.7)
Colletotrichum gloeosporioides	4 (1.4)
Botrytis cinera	4 (1.4)
Penicillium digitatum	1 (0.3)
Rhizopus stolonifer	4 (1.4)
Arthrobotrys oligospora	1 (0.3)
Beauvaria bassiana	51 (17.2)
Fusarium oxysporum / Rhizopus stolonifer	1 (0.3)
Aspergillus niger / B. bassiana	1 (0.3)
B. bassiana / Rhizopus stolonifer	2 (0.6)
Fusarium semitectum / Mucor plumbeus	1 (0.3)
Fusarium oxysporum / Aspergillus wentii	23 (7.8)
Arthrobotrys oligospora / Fusarium equiseti	3 (1.0)
Total	296

Fusarium and *Aspergillus* spp. were present at all locations except Aseseeso which did not record the latter (Table 2) (Fig. 1). Arthrobotrys oligospora and Penicillium digitatum were recorded only at one site each. A pathogen was recorded at a minimum of three different sites except, Colletotrichum gloeosporioides that was recorded at two sites (Table 2).

Table 2: Fungal species associated with insects collected on cashew from different locations

Pathogens	Wenchi	Drobo	Kintampo	Sampa	Techiman	Akorley	Bunso	Brekum	Aseseeso	Tafo
Fusarium spp	23(41.8)	33(50.8)	13(32.5)	24(38.1)	4(44.4)	1(50.0)	7(20.6)	3(23.1)	4(57.1)	1(50.0)
Aspergillus spp	15(24.6)	17(26.2)	11(27.5)	11(17.5)	5(55.6)	1(50.0)	17(50.0)	4(30.8)	0(0.0)	1(50.0)
Mucor plumbeus	0(0.0)	1(1.5)	2(5.0)	2(3.2)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Arthrobotrys oligospora	0(0.0)	1(1.5)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Colletotrichum gloeosporioides	0(0.0)	1(1.5)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	3(8.8)	0(0.0)	0(0.0)	0(0.0)
Botrytis cinera	0(0.0)	1(1.5)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	2(5.9)	1(7.7)	0(0.0)	0(0.0)
Penicillium digitatum	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	1(2.9)	0(0.0)	0(0.0)	0(0.0)
Rhizopus stolonifer	1(1.6)	0(0.0)	1(2.5)	0(0.0)	0(0.0)	0(0.0)	2(5.9)	0(0.0)	0(0.0)	0(0.0)
Beauveria bassiana	16(26.2)	4(6.9)	10(25.0)	21(33.3)	0(0.0)	0(0.0)	10(27.0)	0(0.0)	0(0.0)	0(0.0)

*Numbers in brackets are percentages

Efficacy of B. bassiana as an entomopathogen

Both location and location*spore concentration interaction were not significant, so the effect of the spore concentrations of the B. bassiana tested is presented. P. devastans recorded its first death 5 days after inoculation (DAI) with the highest spore concentration of 1× 105 mL-1. At this concentration, B. bassiana gave 40% mortality 5 DAI but increased to 80% on the eighth day. On the other hand, the lower concentrations of 1× 101 mL-1 and 1× 103 mL-1 achieved 15% and 30% mortality 8 DAI, respectively. However, the control treatment had no (0%) mortality of P. devastans throughout the study period (Table 3). Re-growth of the EPF was observed 3 days after death of the insects treated with 1× 105 mL-1 with re-isolation frequency of 85% but, the lowest concentration took 7 days with 5 % re-isolation (Table 3). No fungal isolations were made from the non-inoculated (control) insects. Similarly, B. bassiana induced up to 70% mortality in Helopeltis schoutedeni at 1× 105 mL-1 8 DAI with the lower doses achieving less than 50% mortality (5% to 30%). Though regrowth of B. bassiana spores was recorded 5 days after the death of the insects, no fungus was re-isolated at 1 x 101 mL-1 (Table 4). Anoplocnemis curvipes mortality ranged from 0 to 60% with 1× 105 mL-1 giving the highest mortality at 8 DAI and 70% re-isolation efficiency. The control treatment had 5% mortality of A. curvipes but no fungus was re-isolated from the cadavers (Table 5). At 1× 105 mL-1 spore concentration, Analeptes trifasciata had 75% mortality 8 DAI with 70% re-isolation whereas the control treatment had 5% mortality but with no fungus re-isolated (Table 6). Generally, there were significant differences ($P < 0.05$) in the performances of 1× 105 mL-1 B. bassiana spore concentration compared with the two lower concentrations and the control on all four insects evaluated (Tables 3 - 6). It took 3 to 7 days for B. bassiana to regrow on all the insects studied (Tables 3 - 6).

Table 3. Mortality of Pseudotheraptus devastans induced by B. bassiana under laboratory conditionsTable 3. Mortality of Pseudotheraptus devastans induced by B. bassiana under laboratory conditions

Percentage mortality at different days after inoculation						
Treatment (mL^{-1})	5DAI	6DAI	7DAI	8DAI	DPG	PBR
Control	0	0	0	0	0	0
1 x 10^1	5	5	10	15	7	5
1 x 10^3	10	15	15	30	5	20
1 x 10^5	40	50	50	80	3	85
SED	10	15	15	20	1	20

DAI: Days after inoculation

DPG: Number of days to pathogen growth after death of insect

PBR: Percentage B. *bassiana* re-isolated

Table 4. Mortality of Helopeltis schoutedeni induced by B. bassiana under laboratory conditions

Percentage mortality at different days after inoculation						
Treatment (mL^{-1})	5DAI	6DAI	7DAI	8DAI	DPG	PBR
Control	0	0	0	5	0	0
1 x 10^1	0	10	10	15	5	0
1 x 10^3	10	15	15	30	7	10
1 x 10^5	20	40	60	70	3	55
SED	10	15	15	20	1	10

DAI: Days after inoculation

DPG: Number of days to pathogen growth after death of insect

PBR: Percentage B. bassiana re-isolated

Table 5. Mortality of Anoplocnemis curvipes induced by B. bassiana under laboratory conditions

Percentage mortality at different days after inoculation						
Treatment (mL^{-1})	5DAI	6DAI	7DAI	8DAI	DPG	PBR
Control	0	0	0	5	0	0
1 x 10^1	0	0	10	15	7	0
1 x 10^3	5	10	15	20	5	20
1 x 10^5	40	50	50	60	3	70
SED	10	15	15	20	1	20

DAI: Days after inoculation

DPG: Number of days to pathogen growth after death of insect

PBR: Percentage B. bassiana re-isolated

Table 6. Mortality of Analeptes trifasciata induced by B. bassiana under laboratory conditions

Percentage mortality at different days after inoculation						
Treatment (mL^{-1})	5DAI	6DAI	7DAI	8DAI	DPG	PBR
Control	0	5	5	5	0	0
1 x 10^1	10	10	20	20	7	10
1 x 10^3	5	15	20	20	5	20
1 x 10^5	30	50	60	75	3	60
SED	10	15	15	20	1	20

DAI: Days after inoculation

DPG: Number of days to pathogen growth after death of insect

PBR: Percentage B. *bassiana* re-isolated

Discussion

Numerous entomopathogens including species of Beauveria, Metarhizium and Trichoderma have been associated with insect pests (Islam et al., 2021; Sala et al., 2019). The present study focused on screening insects found in cashew orchards for growth of possible entomopathogenic fungus that could effectively reduce the populations of the major cashew insect pests in Ghana. This is important for developing biopesticides for use against insect pests on the crop. B. bassiana, Fusarium and Aspergillus sp. were the most common fungi found associated with insects in nearly all locations sampled. B. bassiana, a known entomopathogen (Bamisile et al., 2018; Islam et al., 2021), when tested at three different spore concentrations caused significant mortality with the highest concentration causing 60 - 85% mortality in the four insect pests evaluated. This agrees with findings by many researchers including Devi et al., (2008), Idrees et al., (2021), Bamisile et al., (2018) and Islam et al., (2021) of the effectiveness of B. bassiana as an entomopathogen. Specifically, B. bassiana has shown promise as a good mycoinsecticide against cashew insect pests from this study. B. bassiana at 250 g/tree reduced cashew stem and root borer (Plocaederus ferrugineus) infestations significantly in India (Sahu and Sharma 2008). Smitha et al., (2019) and Navik et al., (2015) evaluated entomopathogens including B. bassiana and some botanicals against tea mosquito bug (Helopeltis antonii), an insect pest of cashew and found it to be pathogenic to the pest. These suggest that B. bassiana may play an important part in IPM programmes for cashew insect pests.

B. bassiana is an effective EPF that infects and kills a wide range of insect pests including fall armyworm (Spodoptera frugiperda), striped rice stem borer larvae (Chilo suppressalis), Cotton bollworm (Helicoverpa armigera) and mirids (Helopeltis spp.) (Islam et al 2021; Devi et al., 2008; Manimaran et al., 2019; Smitha et al., 2019; Navik et al., 2015). The fungus attacks insects by penetrating the cuticle with the hypha. This breaks the insect's body, resulting in hemorrhage, immobility and rendering it unable to feed and eventually death. On the other hand, Aspergillus spp. are typically pathogenic organisms associated with agricultural crops such as corn, peanuts, tree nuts, cereal grains, and fruits (Wilson et al., 2002; Palencia et al., 2010). Some of the species have been reported as entomopathogenic. For instance, A. flavus have been found to infect and kill Spodoptera litura; A. oryzae against Locusta migratoria; and A. nomius against Dolichoderus thoracicus (Karthi et al., 2018; Zhang et al., 2015). Similarly, Fusarium, primarily recognized as a disease-causing plant pathogen, also exhibited entomopathogenic properties in some insects (Munkvold 2017; da Silva Santos et al., 2020). Interestingly, all the three Fusarium spp. (F. oxysporum, F. equiseti and F. semitectum) identified in this study, have some entomopathogenic effect on insects though at low efficacy rates (da Silva Santos et al., 2020). In previous experiments, da Silva Santos et al., (2020) used Fusarium spp. as entomopathogens against insects including Planococcus ficus, Bemisia tabaci, Platypus quercivorus and Eldana saccharina. However, the effectiveness of Aspergillus and Fusarium species tested as entomopathogen over the years have been low. The present study therefore concentrated on B. bassiana which has proven very effective in the management of insect pests on cashew and other crops.

An important consideration for the effectiveness of an entomopathogen is dependent on the time it takes for an insect to die after inoculation. Generally, entomopathogens are designed to be effective at controlling pests by causing relatively gradual paralysis of affected targets and eventually resulting in death from starvation or a breakdown in the skeletal or nervous system of the insect. Unlike our observation of 5 to 8 days, Kaur et al., (2014) observed mortality in Corcyra cephalonica 24 h after inoculation with 2.02 × 108 spores/mL and 48 to 72 h after inoculation with 4.05 × 106 and 1.49 × 105 spores/mL of B. bassiana. However, similar to our findings, Adane et al., (1996) observed that 1.0 × 104 conidia/mL B. bassiana took up to 8 days to cause mortality in Sitophilus zeamais. Navik et al., (2015) recorded 4 g L-1 B. bassiana to cause 91.67 % mortality in H. antonii after 10 days. This suggests that the time for an entomopathogen to cause mortality varies depending on several factors, including the entomopathogen used, the target insect species, environmental conditions, and the dose or concentration of the spores or metabolites assessed. The current investigations also revealed dose-dependent mortality of B. bassiana on the four cashew pests. The highest concentration of 1× 105 spore mL-1recorded the highest mortalities in all four cases with the control recording as low as 5%. This suggests that the higher the fungal spore concentration, the higher the effectiveness. Hence, it can be speculated that, 100% mortality of our test insects could be achieved with spore concentrations higher than 1× 105 spore mL-1. Again, higher spore concentrations could also reduce the days to death after inoculation of the insects. Evaluation of higher concentrations of B. bassiana spores is needed to confirm and possibly recommend a minimum effective concentration for field evaluation. Efficiency of biocontrol of insect pests with entomopathogenic fungi is mainly due to their capacity to produce epizootics from the infected cadavers. Re-isolation of an entomopathogen from a dead insect therefore becomes an important indicator of the efficacy of the pathogen against the target pest because insects that die from entomopathogens often produce visible signs on the insect's body, such as fungal growth or spore production. This confirms that the entomopathogen was indeed responsible for the insect's death, rather than other factors. It also provides valuable information about the persistence and activity of the pathogen within the target pest population. Hidalgo et al., (1998) explains that at death, the cadaver of insects produces large numbers of infective agents (spores) by internal and external sporulation, replenishing inoculum wherever the insects have perished. These cadavers act as a source of inoculum and thus further disseminate microbial agent within their environment to cause more death to the other insect pests (Islam et al., 2021).

Conclusion

The mortality due to B. bassiana was effective against all four insect pests of cashew tested given that over half of the tested populations died. Again, pathogen growth on the dead insects provides a good evidence of the potency of the fungus and its ability to spread out in an insect population.

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SEASONAL DAMAGE INDUCED BY ANALEPTES TRIFASCIATA (COLEOPTERA: CERAMBYCIDAE) ON CASHEW AND ITS' IMPLICATION ON YIELD

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Abstract

Analeptes trifasciata, commonly known as the cashew stem girdler, is an economic insect pest of cashew in most producing nations. In Nigeria, it causes up to 26% annual yield loss. As part of concerted efforts to manage this pest, seasonal damage was studied for 2 years on cashew farms at Ibadan-Oyo State and Ivbiaro-Edo State (Derived savannah and Rain forest agro-ecologies respectively) in Nigeria. Observations on damage intensities were recorded at monthly intervals and correlated with weather variables. The earliest emergence and girdling activities were typically detected in May, while girdling activities were prominent between August and February in Ibadan. The damage level was pronounced between July and January in Ivbiaro. Mean monthly count of total girdled branches caused by A. trifasciata was 1.5/tree and 1.6/tree in Ibadan and Ivbiaro respectively. Branch damage reached 4.25/tree in January at Ibadan. In Ivbiaro, damage by A. trifasciata was highest in October with 2.05 stems damage/tree. Rainfall (t (22) =2.45, $p<0.05$ with r= 0.46) significantly influenced the girdling activities of A. trifasciata on cashew in Ivbiaro. Girdling is usually done on mature cashew branches. The periods of observable girdled branches coincided with the fruit maturation/development stage, which has implication on yield. The findings and implications of this study will be useful towards developing a decision support system for timely intervention.

Key words: cashew, damage, girdling, seasonal, stem

Introduction

Analeptes trifasciata Fabricius (Coleoptera: Cerambycidae) is an important pest that is widely distributed in Nigeria (Eguagie, 1973). It is also found in the Savannah and rainforest regions of many West African countries (Topper et al., 2001). The insect, which is also called cashew stem-girdler or long-horned beetle, occurs in 27 states with varying levels of infestations in seven agro-ecologies where cashew is grown in Nigeria (Oroh, 2005; Asogwa et al., 2011). The cashew stem girdler also attacks many trees in the family Bombaceae such as *Bombax costatum* (bombax), *Adanisonia digitata* (African baobab) and *Ceiba pentandra* (silk cotton tree). Other alternate hosts include *Mangifera indica* (mango) and *Spondias mombin* (yellow mombin) (Igboekwe, 1984; Adeyemo and Okelana, 1989). *Mangifera indica* and S. *mombin* belong to the same family as the major host, *Anacardium occidentale* (cashew) - family Anacardiaceae. The stem girdler does not feed on or cause damage directly to panicles, nuts and pseudo-apples. However, the girdling activity of the cashew stem-girdler damages the vascular tissues, affects the movement of plant sap and causes drying up of twigs and leaves, which are eventually shed off. Symptoms of the attack are deep ring-barking and the presence of girdled portions on stems and branches. A survey on the occurrence of the beetle in Ibadan (Oyo State) and Ochaja (Kogi State) showed that almost all the sampled cashew trees (n=300) were attacked with varying levels of infestation (Asogwa et al., 2011). A 2-year study conducted on incidence of A. trifasciata showed between 53 to 75% girdled branches in selected locations in Ibadan, Ochaja and Ugbenu in Nigeria; out of which 16% of their stems were destroyed (Ndubuaku, 1997). A previous study by Akesse et al. (2018) showed that the fluctuation of the stem girdler population is influenced by some weather factors.

The dearth of relevant and requisite information about A. *trifasciata* and its damage intensity has undermined its successful management. Most authors usually assess damage done by the stem girdler by calculating proportion of girdled trees. This only provides a superficial estimate but does not indicate the damage intensity per tree. The evaluation of crop damage due to pests is critical as well as assessing efficacy of crop protection practices for improvement of production systems. The widespread ecological distribution of A. trifasciata makes it crucial to evaluate its damage potential, which is necessary for estimating the attendant economic impact. In addition, in an earlier research survey and training of farmers in Edo North agro-ecological zone by CRIN, all the cashew farmers unanimously claimed that the stem-girdler was a major constraint to cashew production in the area and were willing to partner with CRIN towards achieving sustainable solutions. This study was therefore conducted to provide information on the damage intensity of the stem girdler on cashew, the seasonality of the damage and abiotic factors that influence damage.

Methodology

Description of experimental sites

The study was conducted on cashew farms at two locations which were Cocoa Research Institute of Nigeria (CRIN) headquarters, Ibadan, Oyo State and Ivbiaro, Owan East Local Government Area, Edo State. The first site, CRIN Ibadan, is located in the derived savanna ecosystem with mean solar radiation of 18 mJ/m2/day. It lies between the latitude 7o30'N and longitude 3o 54'E at an altitude of 200 m above sea level. It has annual rainfall of 200 cm with a tropical wet and dry climate. Wet season runs from March to October while dry season runs from November to February. The mean maximum temperature is 26.4 °C, mean minimum temperature is 21.42 °C and relative humidity is 74.5% (Durowoju et al., 2021). The second site, Ivbiaro, is characterized by a tropical climate which ranges from humid to sub-humid at different times in the year. However, it is mainly humid in the forest zone and lies between latitude 7o 58'N and longitude 6o16'E at an altitude of 253.2 m above sea level. The mean annual rainfall is 252-254 cm, with mean minimum and maximum temperatures of

24°C and 33°C, respectively (https://tcktcktck.org/nigeria/edo/auchi). It experiences wet season between April and November and dry season from December to March. Soil type is generally red-yellow feral soils. The second study area was purposively selected because it is a well-known area for cashew production in Edo State.

Experimental set-up

Analeptes trifasciata-induced damage was assessed on a 2.5- hectare cashew plantation at the Cocoa Research Institute of Nigeria, (CRIN), Ibadan between May, 2017 and April, 2019. The cashew plantation was established in 2005 and planted in geometry of 6 m by 6 m with a total of 278 stands. The size of the field was 60 m x 255 m and was made up of eight blocks. Each block measuring 60 m x 24 m contained 40 trees, was separated by 9 m border row of oil palm trees. From each block, a plot size of 12 m x 12 m containing four trees was marked out and replicated three times. The plot was separated between replicates by 12 m border row of cashew trees. The experimental site at Ivbiaro was located in a one-hectare 15 to 20 years old cashew plantation planted approximately at 6 m x 6 m. The size of the field was 60 m x 60 m. Four plots were carved out with each measuring 30 m x 30 m and containing 25 trees represented the replicates. Each plot was separated from one another by a border made up of rows of cashew trees at 6 m x 6 m.

Data collection

Four randomly selected trees per plot were inspected for damage symptoms and presence of the stem-girdler at monthly intervals. Data were taken on their damage characteristics on the cashew trees such as total number of girdled branches, girdled and hanging branches; and girdled but fallen branches. To assess intensity of damage, three types of girdled attacks were defined:

Type 1 - Girdled branch: this was made up of girdled branch where only the bark has been attacked

Type 2 - Girdled and hanging branch: this included branch on which attack has reached the sapwood but the branch remained attached to the tree though hanging.

Type 3- Girdled and fallen branch: attacks included cut branch which had fallen and laid strewn on the ground.

Damaged branches were counted per tree using the following calculation:

Intensity of attack=NGS/TNST

Where NGS- number of girdled branch (es)

TNST = total number of sampled trees

Data on weather parameters such as temperature, relative humidity and rainfall pattern were obtained from the CRIN Automatic weather station, Ibadan and NASA Power Prediction of Worldwide Energy Resources. The coordinates were obtained via GPS.

Figure 1: Girdled branch

Figure 2: Girdled and hanging branch

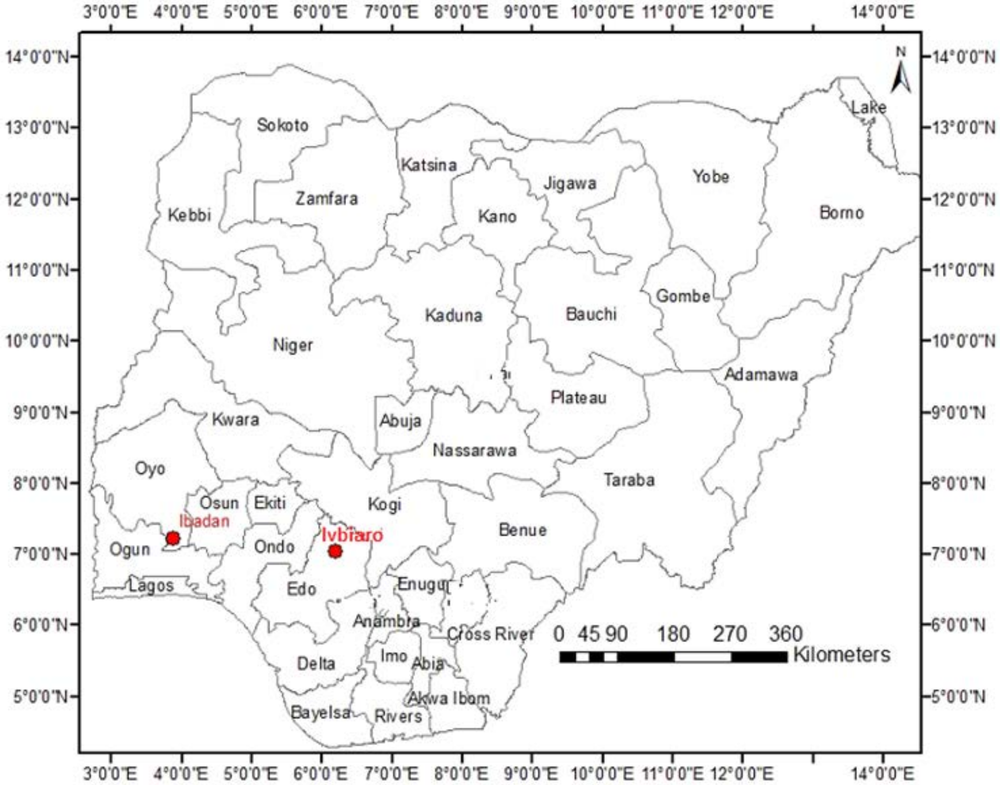

Figure 1: Map of Nigeria showing the experimental locations in Ibadan, Oyo State and Ivbiaro, Edo State.

Source: GIS Laboratory, CRIN (2020)

Statistical analysis

All the data were analyzed using GenStat Package (GenStat version 12.1) (GENSTAT 2009). Data obtained on damage intensity was subjected to analysis of variance and means separated by Student-Newman-Keuls (SNK) test. Correlation and regression analyses were also conducted between weather data and pest damage. All analyses were conducted at an error level of 0.05%.

Results and Discussion

In the first year, at Ibadan, girdling of branches started in October 2017, built up to a peak of 1.5 girdled branches/tree in January 2018 and declined until it was no longer observed in April 2018 (Figure 2). This coincided with the period of the pest incidence, which is usually between September and December. Hanging and fallen branches were observed throughout the year. This is usually as a consequence of uncontrolled infestation in the previous year and harbors the stem girdler. The cumulative damage was very pronounced in May 2017, September 2017 and January 2018. Quali-N'Goran et al., (2020) reported that the Diastocera trifasciata (=A. *trifasciata*) attacks were observed from September to January which coincided with the preflowering to flowering stages in Cote D'Ivoire. Cumulative damage by A. trifasciata which is characterized by girdled, hanging or fallen branches was highest in January 2018 with 4.25 branches damage/tree and declined considerably from February with minor fluctuations for the rest of the year (Figure 2). The monthly count of total girdled branches caused by A. trifasciata was 1.5/tree (Table 1). In the second year, girdled branches were only observed between August and November 2018. While hanging branches were noticeable throughout the year with fluctuations. Cumulative girdling activities were pronounced in April 2019 (0.6 / tree) and November 2018 (0.4 /tree) (Figure 3). In Cote D'Ivoire, peak of attacks was observed in November, while no attack was recorded from February to September (Quali-N'Goran et al., (2020). Mean monthly counts of girdled branches, girdled and hanging branches and girdled and fallen branches were 0.02/tree, 0.2/tree and 0.01/tree respectively. The total damage level was 0.2/tree on a monthly basis which was lower compared to the previous year (Table 1). In Ivbiaro, girdling of branches started from May 2018 and continued throughout the year with a peak observed in September 2018. The highest counts of fallen branches per tree were observed in February 2018 (1.03), May 2018 (1.12) and July 2018 (1.07). Quali-N'Goran et al., (2020) recorded 0.97/ tree, 0.55/tree and 0.46/tree fallen branches in three different cashew locations over a 2-year study period. Girdled branches only, girdled and hanging, and girdled and fallen branches recorded monthly mean of 0.2/tree, 0.6/tree and 0.8/tree respectively in the first year. And on a monthly basis, an average of 1.6/tree was recorded as total branch damage per tree (Table 1). The girdling activities of A. trifasciata also followed a similar pattern of the pest abundance. The highest level of damage infestation (1.8/tree) was recorded in September 2018 (Figure 4). The seasonal damage intensity was polynomial at 6th degree with coefficient of determination R2 = 0.3535, thus indicating that there were several factors responsible for the fluctuation. In the second year, cumulative girdling activity was highest in October with a mean of 2.05/ tree and lowest in March and January (0.7/tree). The total girdled branches was predominant between August and October which coincided with the period of the pest occurrence. Thereafter the girdling activities dropped considerably reaching 0.7/ tree in January (Figure 5). Over the two years of study, the total number of damaged branches irrespective of girdling intensity was 1,958 and 3,295 branches in Ibadan and Ivbiaro respectively. On average, the cumulative damage was 0.85 stem per tree in Ibadan and 1.43 branch per tree in Ivbiaro (Table 1).

The beginning of girdling of branches typically suggests the emergence or entry of the stem girdler into the cashew plantation thus requiring timely intervention in the form of control. Girdling is usually done on mature stems with diameters of 4.1-5.99 cm and at heights of 3.64 - 5.31 m which is far from hand height (Ndubuaku, 1997). Stems of diameters within this range and beyond are usually the fruit-bearing stems, which constitute large portions of the canopy. The young larvae tunnel beneath the fallen stem bark where they feed on the wood, receive nourishment and grow. The wood also provide protection for the developing larvae against insecticide sprays, they complete their lifecycle in the dead wood and are seldom detected until emergence of adults after 6-7 months. The implication is that as the number of girdled branch increases likewise will the number of eggs laid on such branches thereby leading to growth in the pest population in the following season. All of these stages may occur on the farm without the knowledge of the farmer and unfortunately most cashew farmers do not practice farm sanitation. More so, since A. trifasciata is a low density insect pest, the farmer is not aware of the extent of damage and therefore the need to curtail its incidence. Usually, these damaged stems are left hanging on the tree or strewn around the farm, this is the farmers' practice over the years. As a result, the pest problem persists and becomes amplified season after season. This study has highlighted the extent of damage which is most noticeable from the flowering to the maturation stages, unfortunately this is capable of affecting cashew yield with huge economic implication.

Correlation between branch damage and weather factors

In Ibadan, there was no significant correlation between mean number of damaged branches and the weather factors ($p>0.05$) (Table 2). However, there was a significant and positive correlation with rainfall in Ivbiaro, $t(22) = 2.45$, $p<0.05$ with $r = 0.46$. In Ivbiaro, rainfall was the only factor that significantly influenced the girdling activities of A. trifasciata on cashew. Rainfall may have restricted movement and other activities such as walking, fighting and oviposition; thereby causing the stem-girdler to engage more time on gnawing the wood tissues, which would have been softened by the rains. Besides, the local micro-climate conditions during the rains characterized by decrease in temperature which has been observed to influence rise in stem-girdler population (Akessé et al. (2018)) would inevitably lead to increasing stem damage as observed. Rainfall might likely have some direct and negative effects on their natural enemies thereby reducing predation risk of A. trifasciata. Fink and Volkl (1995), demonstrated a significant reduction in the foraging activity of some natural enemies (parasitoids) during the wet season.

Previous studies have shown that weather factors also affect the nutritional quality of the host plant such as the C: N ratio, encouraging insect pests to feed more (Musser and Shelton, 2005). Chen et al. (2019) also reported that sugar concentration in black mustard, Brassica nigra reduced in response to rainfall prior to insect feeding. These assertions probably explain the positive relationship between rainfall and damage level of A. trifasciata on cashew.

Conclusion

The girdling activities of A. trifasciata were prominent between August and February in Ibadan; and between July and January in Ivbiaro. Mean monthly count of total girdled branches caused by A. trifasciata was 1.5/tree and 1.6/tree in Ibadan and Ivbiaro respectively. Branch damage reached 4.25/tree in January at Ibadan. In Ivbiaro, damage by A. trifasciata was highest in October with 2.05 branches /tree. Rainfall significantly influenced the girdling activities of A. trifasciata on cashew in Ivbiaro. The study has provided useful information on the period of attack, which is necessary for timely management of A. trifasciata. Consequently, hanging and fallen stems should be removed and burnt regularly to control re-infestation. The study also underscored the extent of damage due to A. trifasciata on cashew tree which has implication on yield, thus requiring development of appropriate management tools.

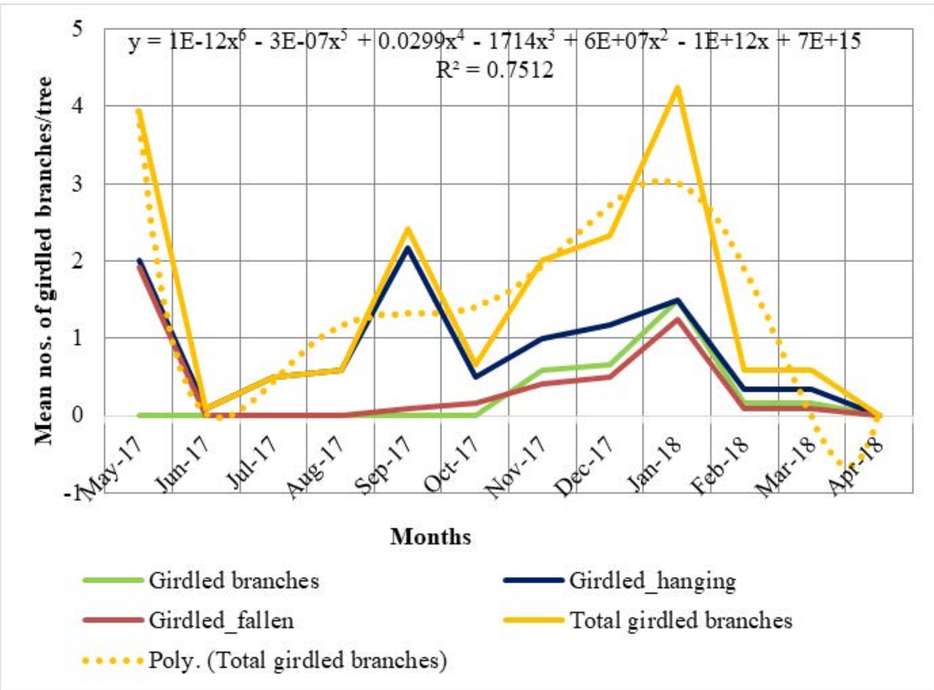

Figure 2: Seasonal damage intensity of Analeptes trifasciata on cashew branches at Ibadan in 2017/2018

Table 1: Mean monthly girdling intensities of Analeptes trifasciata on cashew trees for two years in Ibadan (2017-2019) and Ivbiaro (2018-2020)

Locations/Year	Girdled branches	Girdled and hanging branches	Girdled and fallen branches	Total Girdled branches
Ibadan				
2017/2018	0.3	0.8	0.4	1.5
2018/2019	0.02	0.2	0.01	0.2
t-value	0.10	0.008*	0.06	0.01*
Ivbiaro				
2018/2019	0.2	0.6	0.8	1.6
2019/2020	0.2	0.5	0.6	1.2
t-value	0.97	0.02*	0.01*	0.02*
Cumulative girdling intensities for two years				
Ibadan	0.14	0.51	0.19	0.85
Ivbiaro	0.18	0.55	0.69	1.43
t-value	0.63	0.73	5.06X10-5*	0.03*

*T- value is significantly different at p<0.05

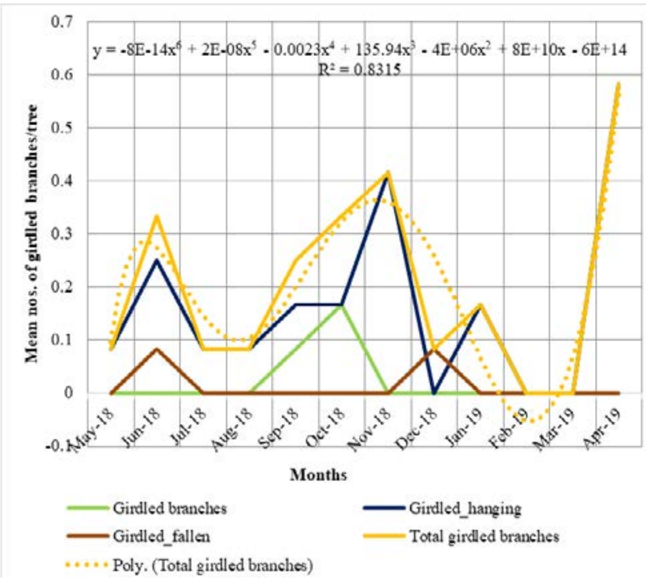

Figure 3: Seasonal damage intensity of Analeptes trifasciata on cashew branches at Ibadan in 2018/2019

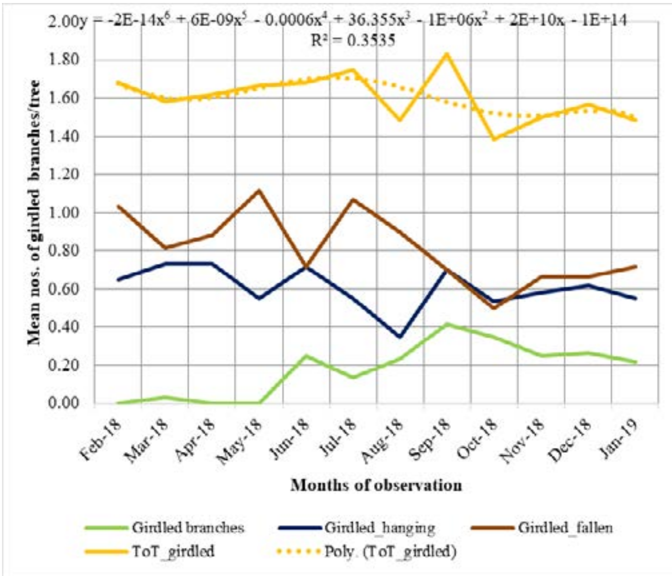

Figure 4: Seasonal Damage intensity of Analeptes trifasciata on cashew branches at Ivbiaro in 2018/2019

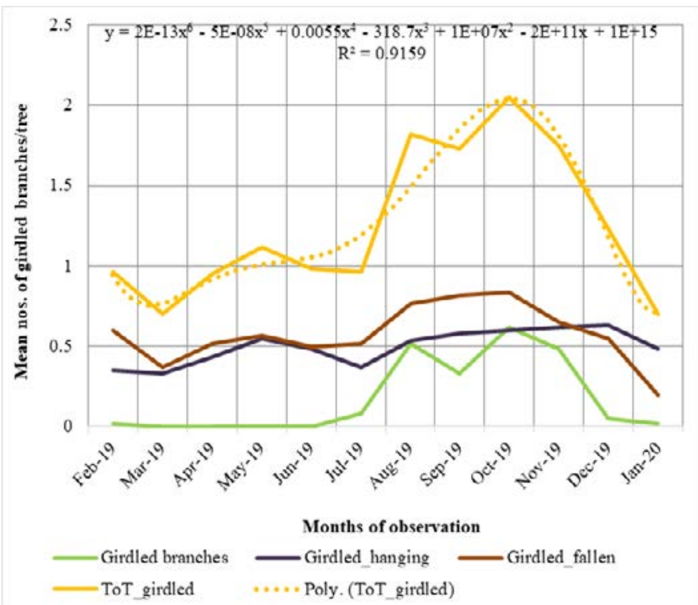

Figure 5: Seasonal damage intensity of Analeptes trifasciata on cashew branches at Ivbiaro in 2019/2020

Table 2: Correlation between branch damage of Analeptes trifasciata and weather factors

Weather Parameters	Correlation Coefficient (r)	Coefficient of determination (R2)	Regression Equation
Ibadan			
Average temperature	0.19NS	0.04	Y= (-7.64) + 0.33x
Relative Humidity	0.37NS	0.13	Y= 7.91+(-0.08)x
Rainfall	0.004NS	1.3x10-5	Y = 0.84 + (5.41x10-5)x
Ivbiaro			
Average temperature	0.17NS	0.03	Y =3.34 +(- 0.08)x
Relative Humidity	0.39NS	0.15	Y= (-0.002)+0.02x
Rainfall	0.46*	0.21	Y = 1.23 + 0.001x

NS= Not-significant. *Correlation is significant at $p<0.05$.

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IDENTIFICATION OF CASHEW (*ANACADIUM OCCIDENTALE* L.) CLONES WITH IMPROVED TOLERANCE TO FIELD ESTABLISHMENT STRESS

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Abstract

High seedling mortality resulting from the annual drought stress after transplanting limits cashew establishment. Sustainable production requires the identification of clones with improved tolerance to field establishment stress for the development of varieties resilient to climate change. Nine cashew clones of Ghanaian (SG and BL), Beninese (BE) and Tanzanian (TAN) origins were evaluated in 2020 to 2021 for stem diameter, height, leaf chlorophyll content and survival. The trial was laid out using a randomized complete block design (RCBD) with 2 replications on farmers fields at Aframase (near optimal environment) and Gbefi (sub-optimal environment) in the Semi-deciduous ecology of Ghana There were no significant ($p > 0.05$) genotype × environment interaction effects, however, the effects of genotype and environment were significant. Survival ranged from 30 - 90% and it was lower at Gbefi by 51% compared to Aframase. The higher soil carbon, magnesium and nitrogen levels recorded at Aframase than Gbefi could be the driver of this environmental effect. Heritability for survival was lower (h2bs - 0.01) in sub-optimal environment compared to the near optimal environment (h2bs - 0.46). However, stem diameter, height and chlorophyll content had higher heritability (h2bs >0.60) in both environment. Survival correlated positively with height ($r = 0.78$, $p < 0.01$), stem diameter ($r = 0.84$, $p < 0.001$) and chlorophyll content ($r = 0.77$, $p < 0.01$). Clones TAN 039, TAN 250, and BE 360 were superior and comparable to the Ghanaian standard clones (BL 175 and SG 278) for survival. The study suggests that widening the cashew gene pool could constitute a viable strategy to sustain production. In addition, selecting vigorous cashew clones with high chlorophyll content under drought stress could lead to the identification of clones tolerant to field establishment stress.

Key words: Drought, establishment, clones, heritability and cashew

Introduction

Cashew is an important nut globally and in terms of supplying nourishment based on kernels to humans, it ranks third after almonds and walnut (Shahbandeh, 2022). Currently, over 45% of the raw cashew nut (RCN) produced globally comes from West Africa (Monteiro et al., 2017). In Ghana, cashew is the leading agricultural non-traditional export (NTE) commodity and contributed over US$ 250 million in 2020 (GEPA, 2022). This represented 58% of US$ 443 million received from the total agricultural NTE sub-sector in 2020. The potential of the crop in boosting rural development and alleviating poverty in developing countries have been highlighted (Dendena and Corsi, 2014; Chivandi et al., 2015).

Cashew is successfully grown within 25° North and South in the tropical and sub tropical regions of the world (Ohler, 1979). In Ghana, the cashew belt extends from the Semi-deciduous zone in the south through the Transitional zone in the middle belt to the Savannah zone in the north. Cashew is reputed for being drought tolerant requiring an annual rainfall range of 1500 - 2000 mm (Sys et al., 1993) and 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 grows best on well drained, deep, light to medium textured soils (Dedzoe et al., 2001) with a pH range of 4.5 - 6.5 (Dendena and Corsi, 2014).

Drought limits the productivity of many crops including cashew (Adu-Gyamfi et al., 2022; Acuna-Soto et al., 2002). The harmful effect of drought occurs at several levels of plant functions, leading to a drastic reduction in growth rates and the death of seedling. In leaves, the photosynthetic form is recognized as sensitive to elevated temperatures (Ceylan et al., 2018; Okatan, 2018). Photosynthesis may be inhibited as a result of the loss of chlorophyll and reduced carbon fixation and assimilation. Therefore leaf chlorophyll content is strongly connected to soil nutrient stress with drought tolerant genotypes having high chlorophyll content (Maharajan et al., 2018).

Recently, the high cashew seedling mortalities resulting from the annual drought stress at 6 months after planting has been highlighted (Adu-Gyamfi et al., 2022). This has been attributed to the use of unimproved planting materials (Oliveira et al., 2006; Dadzie et al., 2014b) and drought (Armah et al., 2011). The projected climate change for cashew is expected to increase production variability (ACA, 2011) and research is vital if production is to be sustained.

Drought is a complex trait under polygenic control with low heritability and high genotype x environment interaction effects (Liu et al., 2023). In tree crops such as cashew, changed management, improved agronomy and better genetics and synergy among these elements have significantly improved seedling survival and yield under drought stress (Adu-Gyamfi, 2016). The seedling stage of cashew is the most susceptible to drought as well as the most expensive for the farmer and genotypes with improved tolerance in similar tree crops have been associated with high vigour, low canopy temperature and high chlorophyll content (Padi et al., 2013; Rashid et al., 1999; Ali et al., 2023). Improving cashew seedling survival for better field establishment will therefore require understanding of the genetic basis and relationship among morphophysiological traits that control seedling survival under sub-optimal environmental conditions. The resilient genotypes identified could be introduced into the pedigree of recommended varieties to improve resilience to drought stress and sustain production under sub-optimal environments.

The Ghana Cashew Breeding Research Program has assembled over 2000 cashew accessions of both local and exotic origin (Adu-Gyamfi et al., 2019; Dadzie et al., 2014a) and the objectives of this study were to (i) assess the genotype × environment (G × E) interaction effect on seedling survival and (ii) determine the relationship between morpho-physiological traits and seedling survival on farmers' fields.

Materials and Methods

Plant materials

Nine cashew germplasm clones were selected and clonally propagated by grafting scions harvested from mother trees to 2.5 months old rootstocks raised from open pollinated seeds. This selection comprised two (2) high yielding (≥ 7 kg/tree) local clones (BL 175 and SG 278) and seven (7) high yielding (≥ 7 kg/tree) exotic clones from Benin (BE 059, BE 072 and BE 360) and Tanzania (TAN 039, TAN 100, TAN 250 and TAN 992).

Field evaluation and plant culture

The experiments were conducted on farmers' fields at Aframase and Gbefi in the Eastern and Volta Regions of Ghana respectively. These testing sites were located in the Semi-deciduous ecology of Ghana with mean annual rainfall of 1500 mm and mean temperature of 25 °C. Baseline soil samples were randomly collected from the 2 sites at a depth of 0 - 15 cm. The trial was laid out in a randomized complete block design with two (2) replications involving 8 trees per clone per replication and clones were transplanted in June, 2020 at a spacing of 10 m × 10 m (100 plants per hectare). In July 2020, each cashew plant was fertilized with nitrogen supplied as ammonium sulphate because of the low levels of fertility of the soil used for the experiment. The application of agro-pesticides followed recommended agronomic practices for cashew production in Ghana. Essentially, cyperderm (active ingredient - cypermethrin) @ 150 mL ha-1 was used to control insect pest from August - October annually.

Data collection

Traits evaluated in this study included seedling survival (%), plant height (m), stem diameter (mm2) and leaf chlorophyll content. The stem diameter of young cashew plants was measured at 15 cm above the graft union with electronic callipers at one year after planting. Leaf chlorophyll meter (SPAD) was use to measured the chlorophyll content of five fully expanded leaves at 6 months after planting. Plant height was measured by placing a meter rule against the plant and measuring from the base of the plant (soil surface) to its apex at 12 months after planting. Plant stem diameter was also estimated from the tree trunk diameter using veneer digital callipers at 12 months after planting. Survival for each genotype was estimated at 12 months after planting using equation 1 below: .

$$\text{Survival (\%)} = \frac{\text{Number of plants per plot surviving at 12 months after planting}}{\text{Total number of plants planted per plot}} \quad (1)$$

Statistical analysis

Analysis of variance based on best linear unbiased prediction (BLUP) using REML was carried out with Genstat Statistical Package with environments considered a random effect and germplasm clones as fixed effects. The following model was used for combined location analysis.

$$Yijk = \mu + Bj + Gj + Lk + GLjk + \mathcal{E}ijk$$

Where,

Yijk = observed trait value of genotype j in block i of Environment k, μ=grand mean, Bi=block effect, Gj=effect of genotype, Lk= Environmental effect, GLjk = the interaction effect of genotype j with Environment k and $\mathcal{E}$ijk = error (residual) effect of genotype j in block i of environment k. The differences among means were tested by least significant difference (LSD) at 5% probability level. The analysis on growth (plant stem diameter and plant height) utilized the recordings made on the clones at 12 months after planting.

Results

Soil characteristics

Our study indicated that, the soils were of acidic reaction with pH values in the range of 5.7 - 6.5 (Table 1). Aframase consistently had high contents of organic carbon, nitrogen, phosphorus and magnesium than Gbefi. The available magnesium content at Aframase (1.4.1 cmolc kg-1) was twice that of Gbefi (0.77 cmolc kg-1). Compared to the critical values, the Soil pH, organic carbon and phosphorus levels at both sites were lower, however, the total nitrogen and magnesium levels at Aframase were within the normal range. Based on the soil chemical composition, the soils appeared to be more fertile at Aframase than Gbefi.

Table 1. Soil characteristics of the two trial sites

Parameter	Location		Critical values
	Aframase	Gbefi	
pH	6.54	5.75	5.2-7.5
Organic C (%)	1.03	0.94	2%
Total N	0.10	0.07	0.10%
Avail. Phosphorus (ppm)	5.52	5.17	>10ppm
Exch. Mg (cmolc kg-¹)	1.41	0.77	0.8 cmolc kg-1

Genotype and environment

There were no significant (p> 0.05) G × E effects on all traits, however, the effects of genotype and environment were significant on survival, stem diameter, height and leaf chlorophyll content (Table 2). Environmental effects were greater than 70% compared to the genotype effects for all the traits tested.

Table 2. Mean sum of squares for stem diameter, height, leaf chlorophyll and survival of 9 cashew germplasm clones evaluated at Aframase and Gbefi.

Source of variation	d.f.	Stem diameter	Height	Chlorophyll	Survival
Clone	8	118.3*	2346.7*	15.6*	526.3*
Environment	2	1831.2**	11087.1**	65.8*	5892.3**
Clone x Environment	4	61.4	943.8	15.4	263.1
Residual	13	28.9	570.2	5.5	213.4

*, **, ***Significantly different at $p \leq 0.05$ $p \leq 0.01$and $p \leq 0.001$, respectively

Seedling survival rate

Across the two environments tested, survival rate was significantly lower by 51% at Gbefi compared to Aframase. Similarly, plant stem diameters and heights were also lower by 54% and 29.3% at Gbefi compared to Aframase respectively. Additionally, a reduction in leaf chlorophyll content by 11% was recorded when comparing Gbefi to Aframase. Gbefi could be considered as a relatively sub-optimal environment due to its low soil nutrient levels (Table 3).

Among the clones at Aframase, TAN 039 had the highest survival rate of 90.1% (Table 3). This was closely followed by BE 360 and BL 175 (standard clone) with survival rates of 77.1% and 77.1 % respectively. The lowest survival rate of 50.5% was recorded in TAN 100. However, at Gbefi, TAN 250 had the highest survival rate of 45.1% and this was comparable to the standard clone (SG 278) with a survival rate of 41.6%. At this site, TAN 039 recorded the lowest survival rate of 30% which was similar to TAN 992 with survival rate of 30.1%.

Table 3. Seedling survival (%) of 9 cashew clones evaluated at Aframase and Gbefi

Clone	Location	
	Aframase	Gbefi
BE 059	64.2	-
BE 072	-	31.0
BE 360	77.1	-
BL 175 (Standard)	77.1	31.0
SG 278 (Standard)	-	41.6
TAN 039	90.1	30.0
TAN 100	50.5	37.2
TAN 250	77.1	45.1
TAN 992	64.2	30.1
Mean	55.6	27.3
h2 bs	0.46	0.01
SED (genotype)	10.3	
SED (location)	5.8	

Assessment of growth parameters

At Aframase, TAN 039 had the highest stem diameter of 44.5 mm (Table 4). This was comparable to TAN 250 with stem diameter of 40.4 mm. Clone BE 059 gave the lowest stem diameter of 26 mm. At Gbefi, TAN 100 recorded the highest stem diameter of 24.6 mm and was closely followed by BL 175 and TAN 992 with stem diameter of 23.7 and 23.3 respectively.

Table 4. Plant stem diameter (mm) of 9 cashew clones evaluated at Aframase and Gbefi

Clone	Location	
	Aframase	Gbefi
BE 059	26.0	-
BE 072	-	10.7
BE 360	29.6	0.0
BL 175 (Standard)	42.2	23.7
SG 278 (Standard)	-	18.3
TAN 039	44.5	13.4
TAN 100	35.6	24.6
TAN 250	40.4	18.9
TAN 992	36.8	23.3
Mean	36.4	16.6
h2 bs	0.79	0.70
SED (genotype)	3.8	
SED (location)	2.1	

At Aframase, the tallest plant was BL 175 (187.2 cm) and this compared well with TAN 250 (183.5 cm). Clone BE 059 recorded the lowest height of 109.8 cm (Table 5). At Gbefi, BL 175 was the tallest plant (140.1 cm) and this was closely followed by TAN 992 (124.2 cm). At Gbefi, BE 072 recorded the lowest height of 62.5 cm.

Table 5. Seedling height (cm) of 9 cashew clones evaluated at Aframase and Gbefi

Clone	Location	
	Aframase	Gbefi
BE 059	109.8	-
BE 072	-	62.5
BE 360	127	-
BL 175 (Standard)	187.2	140.1
SG 278 (Standard)	-	103.8
TAN 039	171.5	96.4
TAN 100	111	105.4
TAN 250	183.5	105.6
TAN 992	154.2	124.2
Mean1	149.2	105.5
h2bs	0.87	0.71
SED (g)	16.8	
SED (l)	9.3	

Clone BE 059 at Aframase had the highest leaf chlorophyll contents of 43.8 (µmol-2) and this was closely followed by TAN 039 with 42.4 (µmol-2) (Table 6). TAN 100 gave the lowest reading of 37.5 (µmol-2). But at Gbefi, SG 278 and TAN 992 recorded the highest leaf chlorophyll content of 38.1 (µmol-2) whereas TAN 039 recorded the lowest content of 31.9(µmol-2) respectively.

Table 6. Leaf chlorophyll content (µmol-2) of 9 cashew clones evaluated at Aframase and Gbefi

Location	Aframase	Gbefi
BE 059	43.8	-
BE 072	-	35.1
BE 360	41.9	-
BL 175 (Standard)	38.9	36.5
SG 278 (Standard)	-	38.1
TAN 039	42.4	31.9
TAN 100	37.5	36.5
TAN 250	38.9	36.7
TAN 992	40.0	38.1
Mean[1]	40.5	36.1
h^2 bs	0.52	0.69
SED (g)	1.6	
SED (l)	0.9	

Comparatively, clones TAN 039, TAN 250, BE 360, BL 175 and SG 278 which gave high survival rates were vigorous with high chlorophyll content.

Heritability of traits

Broad sense Heritability (h2bs) estimates varied between the two environments tested (Table 7). Aframase recorded higher heritability estimates for survival (h2bs = 0.46) than Gbefi (h2bs = 0.01). For stem diameter, heritability estimates were higher at Gbefi (h2bs = 0.80) than Aframase (h2bs = 0.70), whereas estimates for height were higher at Aframase (h2bs= 0.87) than Gbefi (h2bs= 0.71). Regarding chlorophyll content, heritability estimates were lower at Aframase (h2bs = 0.52) compared to Gbefi (h2bs = 0.70).

Correlation among traits

There were significant positive correlation between survival and height ($r = 0.78$, $p < 0.01$), stem diameter ($r = 0.84$, $p < 0.001$) and chlorophyll content ($r = 0.77$, $p < 0.01$).

Table 7. Correlation among traits of clones tested

Trait	Chlorophyll content	Stem diameter	Height
Stem diameter (mm)	0.62*		
Height (cm)	0.47	0.88***	
Survival (%)	0.77**	0.84***	0.74**

Discussion

Over the past years, cashew has been considered to be drought tolerant. However, high seedling mortalities leading to poor field establishment on farmers' fields has been highlighted in many studies (Balogoun et al., 2015; Adu-Gyamfi et al., 2019). In the present study, environment was found to have a stronger effect (>70%) on all the traits assessed. The variation among environments was more than 7 fold higher than genotypes. The higher values obtained for stem diameter measured at Aframase could be attributed to the higher soil nutrient levels. This implies that even within the same agro-ecological zone, the performance of cashew seedlings could depend on the soil nutrient levels. Observations made in this study are consistent with other studies, where greater soil nutrient level affected cashew seedling growth and establishment (Bezerra et al., 2007; Babatunde et al., 2023; Amorim et al., 2023).

The low genetic effects (< 15%) on survival among the clones could explain the difficulty in using breeding approaches to obtain varieties with superior performance for field establishment. This may be attributed to the limited number of clones evaluated in the study. Nevertheless, the superior performance of clones BE 360, TAN 039 and TAN 250 suggest that they could also possess alleles that ensure higher water and nutrient-use efficiency under drought stress. This is in concurrence with the report of Adu-Gyamfi et al. (2019). They could therefore serve to broaden the genetic base of donors (Padi et al., 2017; Adu-Gyamfi et al., 2021; Ofori et al., 2014). The comparatively low to moderate heritability (h2bs = 0.01 - 0.46) for survival observed in the two environments, could indicate high environmental influence on the expression of this trait and this may limit the selection process in cashew breeding programs. Nevertheless, Jansky (2009) has emphasized that significant genetic improvement in such trait is achievable if progeny testing and phenotypic recurrent selection approaches are employed. Again, the relatively low heritability for survival in Gbefi (h2bs < 0.01) compared to Aframase (h2bs < 0.46) are consistent with the report of low heritability in poorer environments (Charmantier and Garant, 2005). Hence, more genetic gains can be expected from the selection for survival in near optimal environments compared to sub-optimal ones. On the other hand, the moderate to high heritability estimates (h2bs = 0.50 - 0.87) obtained for stem diameter, height and chlorophyll and their strong correlation with survival imply higher genetic control and more genetic gains can be expected from the selection of these traits to improve field establishment. Besides, the observed heritability estimates for stem diameter and plant height in this study were comparable to earlier reported range of 0.30 - 0.85 for stem diameter and 0.46 - 0.80 for height respectively (Sethi et al., 2016; Adu-Gyamfi et al., 2019).

Plant size (estimated as stem diameter and height) may have positive influence on the survival of seedlings during periods of dry weather and the role of stem reserves in supporting re-growth after drought have been highlighted (Padi et al., 2013). In this study, the significant positive correlation observed between leaf chlorophyll content and stem diameter ($r = 0.84$, $p < 0.001$) and survival ($r = 0.74$, $p < 0.01$) implies that, drought tolerant cashew clones may display higher chlorophyll content to maintain faster growth and establishment. The results further support the reports of Adu-Gyamfi et al. (2022) that cashew clones may grow faster to evade moisture deficit and ensure survival.

Aliyu (2006) emphasized that hybridization and recurrent selection approach could improve cashew productivity without compromising quality. The identification of potential clones in this study allows breeders to speculate about potential crosses to improve productivity. Therefore crosses involving clones BE 360 and TAN 039, TAN 250, SG 278 and BL 175 may produce resilient progenies which could be evaluated under different agro-ecological zones.

Conclusion

Overall, our study suggest that while widening the gene pool of cashew could lead to the identification of clones with improve tolerance to field establishment stress, there were low genetic effects (<10%) on survival in our study which implied that more experimentation with a wide array of clones is critical in order to identify consistent genetic variability. Nevertheless, clones BE 360 and TAN 039, TAN 250 together with their standards (SG 278 and BL 175) were superior for survival and their potential could further be validated as progenies in different agro-ecological zones. Environmental effects on survival in our study was large (>70%), suggesting that even within the same agro-ecology, differences in soil nitrogen, carbon and available magnesium could reduce cashew seedling survival rate by 50%. Further, heritability estimates recorded for survival was low ($h2bs < 0.10$) in sub-optimal environment (Gbefi) but moderate ($h2bs > 0.40$) in the near optimal environment (Aframase). Contrastingly, heritability estimates were moderate to high ($h2bs = 0.50$ - 87) for stem diameter, height, chlorophyll content and their significant positive correlation with survival suggested that, the combined selection for vigour and chlorophyll content among cashew clones might lead to the identification of superior varieties with improved tolerance to field establishment stress.

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FORECASTING CASHEW PRODUCTION IN NIGERIA: ARIMA ECONOMETRIC MODELLING APPROACH

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ABSTRACT

Cashew is one of the major agricultural exports in Nigeria. The crop has been a major foreign exchange earner for more than fifty years. Cashew production forecasting is of utmost importance in the choice of agricultural diversification strategy to be employed by the government as well as the livelihood of cashew farmers in the coming years. The study examined the trend of cashew production in Nigeria from 1982 to 2021. The study also forecasted cashew production in Nigeria from 2022 to 2030 using ARIMA model. The automated analytical procedure on E-views 10 software package indicated that ARIMA (1,1,12) is the combination with the least Akaike Information Criteria (AIC) and Sigma square as well as the highest adjusted R-square amongst other structures, hence, it is the most appropriate for forecasting. The trend analysis result revealed that cashew production in Nigeria was at its peak in 2009 with 800,000 tonnes. However, there was a decline in cashew production after 2009. The forecast result revealed that cashew production will rise gradually from 2022 to 2030 where it is expected to reach a decade high of 526,176 tonnes. This is still below the 2009 production level. The study recommends that cashew farmers should be given financial and technical incentives in order to ensure that the forecasted level can be attained and even surpassed as well as to improve the livelihood of cashew farmers. The government should also prioritize cashew production and encourage export during the development of agricultural policies aimed at diversifying the economy.

KEYWORDS: Agricultural Exports, Diversification Strategy, Policies, Trend

INTRODUCTION

Nigeria is one of the major producers of cashew nuts globally, known for its significant contribution to the cashew industry. The country's favourable climate and suitable growing conditions have made it an ideal location for cashew cultivation. Nigeria is consistently ranked as one of the top cashew-producing countries in the world. According to the Food and Agriculture Organization (FAO) of the United Nations, Nigeria was the fourth-largest cashew producer in 2019, with a production volume of approximately 172,000 metric tons (MT) (FAOSTAT, 2019). The Nigerian Export Promotion Council (NEPC) reported that the country produced about 220,000 MT of cashew nuts in 2020, indicating an increase in production compared to previous years (NEPC, 2021). Cashew production plays a vital role in Nigeria's agricultural and economic sectors. The country is a significant exporter of cashew nuts, generating foreign exchange earnings and contributing to employment and rural development.

Nigeria earned about USD350 million from cashew exports in 2020, making it the country's leading agricultural non-oil exports (NEPC, 2021). The cashew industry has also attracted investments and created opportunities for value addition, including processing and packaging, leading to the establishment of cashew processing factories in Nigeria (Onwuka et al., 2021).

Nigeria is highly dependent on oil exports, which account for 90% of government's revenue. The heavy reliance on oil led to economic recession in 2016 due to the sharp decline in global oil prices (Ikechi and Anthony, 2020). Nigeria, as an oil-dependent economy, has recognized the need to reduce its reliance on oil and develop other sectors, with agriculture being a key area of potential growth. Cashew industry as a sub-sector can indeed serve as a means of diversifying the Nigerian economy. Nigeria is already a major player in the global cashew market, but there is significant potential for further growth and development in this sector. According to Nigerian Investment Promotion Commission (NIPC) (2020), cashew production offers several advantages, including job creation, export revenue generation, and poverty reduction. In light of the above this study sought to carry out a nine-year forecast to project the prospects of future cashew production.

METHODOLOGY

The study adopted annual cashew production in Nigeria from the FAO statistical database for a period of 39 years ranging from 1982 to 2020. The study used both descriptive and inferential statistics. Descriptive statistics adopted was in the form of graphs used to examine the trends of cashew production and the properties of Auto-regressive Integrated Moving Average (ARIMA) model. Inferential statistics was employed in the form of ARIMA modelling to forecast cashew production in Nigeria.

ARIMA MODELLING

According to Box et al. (1974), ARIMA is the most frequently used stochastic time series model. It helps in the identification, estimation and diagnostics of models where time is the major independent variable (Ajetomobi and Olaleye, 2019). The model is suitable for large time series data with an observable historical pattern. ARIMA is usually specified using three order parameters, p, d and q. The auto-regressive component of the model refers to the use of past values to predict the observed values. The auto-regressive parameter, p, refers to the number of lags allowed in the model. A generalized AR model is expressed as thus:

$$y\_t=\beta_0+\beta_1 y_{(t-1)}+\beta_2 y_{(t-2)}+\dots\beta_k y_{(t-k)}+\varepsilon_t \qquad (1)$$

β_0 to β_k are the parameters in the model

The integrated component of the model represented by d refers to the degree of differencing which is determined by the stationarity of the model. The moving average (q) component of the model refers to the lagged errors in the model i.e. the error term as a function of past errors terms:

$$y_t = \theta_0 + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_k \varepsilon_{t-q} + e_t \quad (2)$$

The full ARIMA model consisting of the auto-regressive, differencing and moving average is linearly stated below:

$$y_t = c + \beta_1 y_{dt-1} + \beta_2 y_{dt-2} + \ldots \beta_k y_{dt-k} + \theta_0 + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_k \varepsilon_{t-q} + e_t \quad (3)$$

Where y_d is y differenced d times and c is a constant.

RESULTS AND DISCUSSION

Trend analysis of cashew production in Nigeria (1982-2020)

Cashew production in Nigeria varied overtime (Fig. 1). There was a stable but low production and yield between 1982 and 1990. This low output in cashew could be attributed to liberalization of the commodity market in the early 1980s. This was followed by a gradual growth in cashew production between 1991 and 1998. According to Ogunwolu et al. (2022), the growth in production during this period can be directly attributed to the increase in cashew cultivation across the country. Production and yield increased by more than 100% between 1999 and 2009 with the highest production of 800,000 tonnes in 2009. The increase in yield was due to the introduction of improved agricultural practices and planting materials. However, there was a production decline from 2010 to 2014 due to reduction in nut quality. Adeigbe et al. (2015) cited poor storage conditions as the main cause of the low quality of nuts. After 2014, cashew production and yield relatively stabilized up to 2021 with average production and yield of 103,409 tonnes and 7303 ha/hg respectively. The decline from 800,000 to an average of 103,409 tonnes could be attributed to inadequate technical incentives in the form of training, input subsidy as well as inadequate financial incentives (Olukunle, 2022; Olomu et al., 2020).

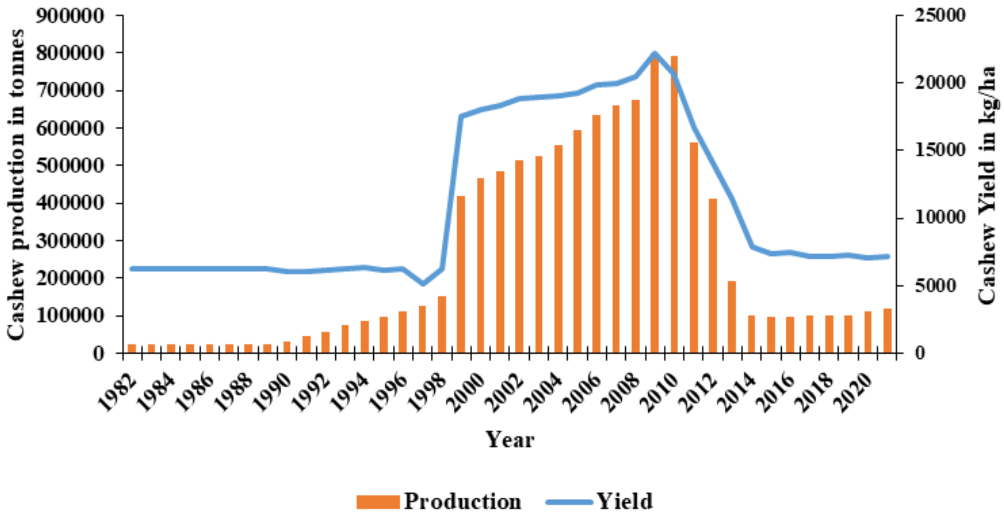

Figure 1: Cashew Production and Yield in Nigeria

Source: FAOSTAT (2022)

Stationarity Test

One of the requirements for fitting an ARIMA model is that the series in question must be stationary, hence Augmented Dickey Fuller (ADF) unit root test was carried out to ascertain the stationarity of cashew over time. The result of the ADF unit root test as presented in Table 1 shows that cashew production is only stationary at after first differencing at 10% level of significance. The implication of this is that the d component of the ARIMA model is 1.

Table 1: ADF Unit Root Test

	T-Statistics	Lag Order	P-value	Comment
Levels	-1.480735	1	0.8183	Non-stationary
First Difference	-3.422568	1	0.0637	Stationary

Model Identification

After the order of integration (d) has been identified, the next stage in the ARIMA modelling process is the identification of the optimal model (finding the optimal order of AR(p) and MA(q)) using the Auto-correlation Function (ACF) and Partial Auto-correlation Function (PACF). Figure 2 shows the graph for the ACF and PACF from which three ARIMA models were identified. They were ARIMA (1,1,1), ARIMA (1,1,12) and ARIMA (12,1,1) models. According to Satrio et al. (2021), the model with the smallest sigma square and Akaike

Information Criterion (AIC) is considered the optimal model. Therefore ARIMA (1, 1, 12) is considered as the optimal model and therefore adopted for forecast (Table 2).

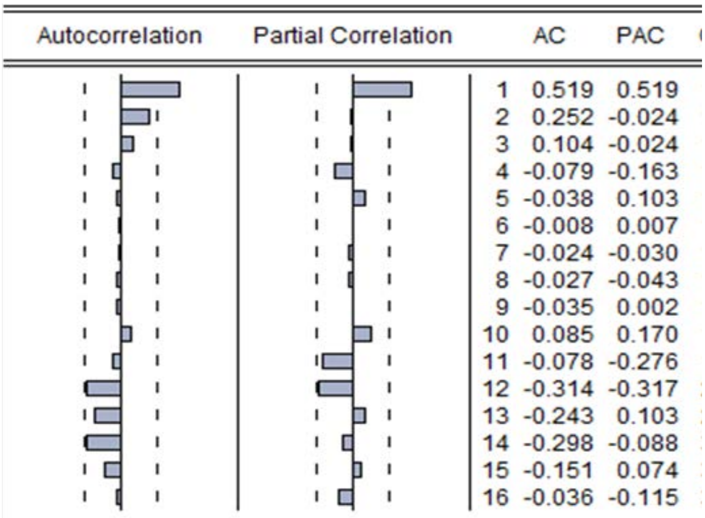

Figure 2: Auto-correlation Function and Partial Auto-correlation Function for cashew production in Nigeria

Table 2: ARIMA Optimal Model Selection Result

MODELS	AIC	Sigma Sq.	Decision
ARIMA (1,1,1)	25.22986	4.29E+09	Not optimal
ARIMA (1,1,12)	25.08035	3.41E+09	Optimal
ARIMA (12,1,1)	25.12337	3.63E+09	Not optimal

Model Diagnostic Checking

There is a need to carry out diagnostic check for the model adopted to ensure that the order of the parameters and the structure of the model are correct before proceeding to forecast. Depicted in Figure 3 are the residual auto-correlation and partial-correlation plots. It can be deduced from the plots that there exists no significant auto-correlation in the model. It can be observed from the Figure that the residual ACF and PACF lies within the 90% confidence interval. Hence, we can conclude that the model is correctly specified.

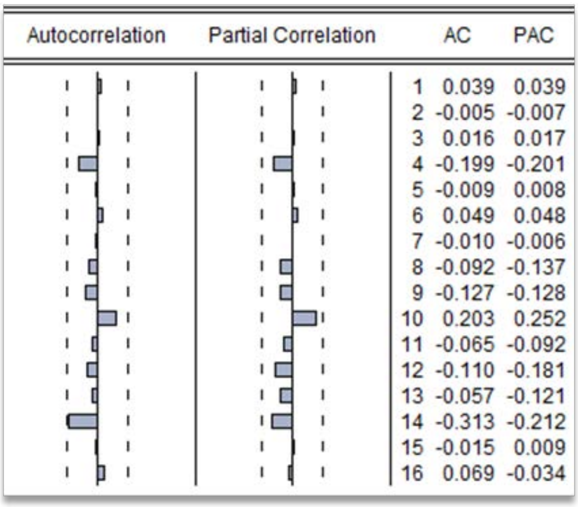

Figure 3: Auto-correlation Function and Partial Auto-correlation Function of cashew production residuals

FORECAST

According to Oni et al. (2020) a well fitted ARIMA model has the ability to adequately forecast a tested time series data. From the forecast results in Table 3 and Figure 4 it can be observed that cashew production will rise gradually from 2023 to 2030. Cashew production in Nigeria will rise at an average rate of 24% from 2022 to 2026. However, this growth will diminish between 2027 and 2030 to an average annual production rate of 1.5%. According to the forecast result, cashew production will reach a decade peak in the year 2030 with 526,176.5 tonnes. However, this is still below the production volume obtained in 2009 which was 800,000 tonnes.

Nigeria possesses favourable agro-ecological conditions for cashew production, including suitable climate, rainfall patterns, and diverse soil types. These factors contribute to the country's potential for large-scale cashew cultivation and increase in future production levels (Ogundele et al., 2020). Furthermore, cashew is a highly sought-after commodity worldwide due to its nutritional value and versatile uses in various industries. According to Ayodeji et al. (2020), Nigeria has a competitive advantage in meeting the increasing global demand for cashew kernels. This could be a reason behind the potential increase in cashew production in the years to come. Cashew production contributes significantly to Nigeria's economy by generating employment opportunities, foreign exchange earnings, and rural development. The cashew value chain has the potential to boost economic growth, improve farmers' livelihood and reduce poverty in the long run (Ugwu et al., 2019). According to Okoye et al. (2021), some of the major factors affecting cashew production are inadequate access to extension services and improved planting materials.

Table 3: Cashew production forecast

YEARS	CASHEW PRODUCTION IN TONNES	PERCENTAGE INCREASE (%)
2022	158253.4	33
2023	237588.1	50.13
2024	320037.9	34.70
2025	439349.5	37.28
2026	494253.2	12.50
2027	507991.4	2.78
2028	515754.7	1.53
2029	520477	0.92
2030	526176.5	1.10

CONCLUSION AND RECOMMENDATIONS

The result of the analysis revealed that cashew production in Nigeria is highly likely to rise from 2023 to 2030. However, despite the positive forecast result, literature identified inadequate financial and technical support, inadequate extension contact and lack of improved planting materials as issues which could derail the forecast results. Based on these challenges, the following recommendations are made:

1. The government should consider cashew industry in the quest for diversification as it holds potentials for expansion
2. Cocoa Research Institute of Nigeria and other cashew industry stakeholders in Nigeria should work towards the development of improved planting materials which are high yielding
3. Government and other cashew industry stakeholders should endeavour to make available more financial and technical support for cashew farmers.

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REACTIONS OF CASHEW GRAFTED SEEDLINGS TO DIFFERENT FORMULAS OF MINERAL AND ORGANIC FERTILIZERS AS BOTTOM DRESSING IN PLANTATION

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Abstract

The yield of raw cashew nuts in Benin remains relatively low, mainly because of the planting material used by farmers. Indeed, cashew tree producers use the nuts all-from previous years for the installation of plantations. The use of grafted seedlings is today an alternative, to improve the yield of new plantations. However, grafted plants are fragile and don't survive easily the dry season of the year in which they are planted, with a high mortality rate due to their fragility. This research conducted on tropical ferruginous soils in Central Benin aims to evaluate the reaction of grafted cashew seedlings to different formulas of mineral and organic fertilizers applied as bottom fertilization. For the study, a Randomized Complete Block Design with three repetitions was installed. Each repetition consists of 11 treatments. The generalized linear model (glm) was used to perform the analysis of variance with SPSS v21 software which to compare the effects of the treatments. The organo-mineral formulas N40P80K72 + 2 kg of poultry droppings and N40P80 + 2 kg of poultry droppings applied as bottom manure allowed for better results in terms of recovery and growth parameters of grafted plants installed in the field. These fertilizer formulas allowed the grafted cashew plants to survive 85% and 80% respectively after installation. They also improved height growth, vigor and the ability to emit many leaves. To reduce the mortality rate of cashew transplants, these fertilizer formulas can be suggested to growers for the establishment of new plantations.

Keywords: Bottom manure, Cashew transplants, Poultry Droppings, Mineral fertilizers, growth parameters, cashew grafted seedlings survival.

Introduction

The cashew tree (Anacardium occidental L.) is a cash and export crop in West African countries including Benin and helps to solve environmental and socio-economic problems in production areas (Hammed et al.2008; Dwomoh et al., 2008). The importance of the cashew tree in Benin is increasing since the cotton crises of 1999-2000, which again revealed the fragility of the Beninese economy (Rondeux, 1999). Therefore, the Beninese state has taken to heart the diversification of sectors including that of cashew, and producers and economic operators have become aware of the importance of this sector, which has meanwhile been neglected. The cashew tree is now an engine of economic development that creates services and generates income for producers (Adegbola et al., 2011). In Benin, raw cashew nut represents the second agricultural export product after cotton and the third economic pillar (Issaka, 2019). This sector thus represented eight per cent of the total value of exports in 2008, 7% of agricultural GDP, 3% of national GDP and 24.87% of agricultural export income (Tandjiékpon, 2010). The annual cashew production in Benin is estimated at 110,117.41 tonnes, according to the yield survey report (DSA, 2017), with an average yield of 377 kg/ha, despite the efforts made by public authorities, for the promotion of the cashew sector, the yield (2-4 kg/tree) remains relatively low, compared to that of other countries such as Tanzania where the average yield is 15-20 kg / tree (Kodjo et al., 2016). These low yields are justified by the use of all-round planting material and unsuitable cultivation practices, in particular the lack of control over diseases and pests, the lack of maintenance of orchards, poor practices in the fields and post-harvest operations. To this must be added the very advanced age of the trees and the decline in soil fertility. Maintaining fertility is a challenge that producers face. The soils under cashew groves have phosphorus deficiencies, ranging from 31 to 44 %, and potassium deficiencies ranging between 17 and 53 % (INRAB / CCA-CORAF, 2016). To correct the deficiencies and deficiencies in these two main nutrients, tests of formulations and doses of NPK mineral fertilizers were conducted in the minicipalicity of Parakou in North Benin. These tests made it possible to determine two formulations and two optimal doses appropriate to the cashew age classes of three to five years and seven to nine years, with a view to better management of soil fertility and improvement the cashew nut yield in plantations (INRAB / CCA- CORAF, 2016; N'Djolossè et al., 2018). These results are only avenues for improving the yield of young cashew plantations while the question of taking back in the field the new plant material (grafted plants) developed has not yet been resolved. Indeed, mortality rates of more than 73% and 68% were recorded, respectively in 2018 and 2019, according to the survey report of the URCPA-AD 2018 and 2019. The present study was initiated with a view to contributing to the reduction of mortality rates of grafted cashew trees after transplantation.

MATERIALS AND METHODS

Study environment

The work was carried out in the town of Save located at 8 ° 01 '59' 'North latitude and 2 ° 49' 01'' East longitude, at an altitude varying between 200 and 300 meters (Figure 1). Save District enjoys a tropical Sudanese- type climate marked by a rainy season and a dry season of 6 months each. The average rainfall is 1100 mm per year (Amadou, 2008). The heaviest rainfall occurs from June to September, with 587 mm of rain. The topography is marked by the presence of numerous rocky outcrops that appear in the form of domes. The vegetation is made up of savannah dotted with trees and shrubs. The average temperature in Save is 32°C throughout the year. The soils are tropical ferruginous soils which, due to human exploitation, give way in places to infertile lateritic soils. Hydromorphic soils are also observed in lowlands and in valleys (Amadou, 2008). The commune of Save is part of the communes of the Pole 4 Territorial Agency for Agricultural Development whose locomotive sector is cashew.

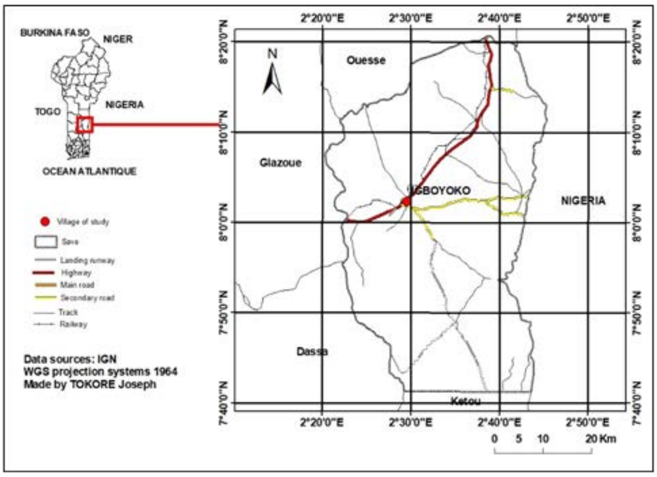


Figure 1 : Map of the study area

Methods

The trial was conducted in the open field for two consecutive years (2019 and 2020). Soil preparation and planting were carried out in May and June, respectively, each year. After cleaning the plot, the plant debris were burnt off the site, to prevent the decline in fertility by burning organic matter and microorganisms in the soil. The stakes were then set. The hole was made in June, at the level where the stakes were set up, measuring 50 cm in depth and in diameter. During this operation, the surface soil and the deep soil were deposited separately. The holes were filled with the mixture of topsoil and different types of fertilizer in the upper third of the holes two weeks after the holes were made to promote decomposition and mineralization of the organic matter. The deep soil layer served to complete the filling of the holes with dome formation. Holes with the appearance of a slight abutment are indicated by a stake placed in their center. The seedlings were planted in the center of the filled holes at the location of the stakes, two weeks after filling. To do this, a hole was regrooved in center, to the size of the polyethylene bag, then the base of the bag which contains the seedling was torn. To avoid injuring the plants, the holes have not been too tightly packed, taking care not to leave a hollow in the collar to avoid water stagnation that can cause root rot. The stakes were put back in place after planting in order to better locate the young plants installed. The maintenance of cashew trees was limited to regular weeding and phytosanitary treatment with Lambda-cyhalothryne and Acetamipridto to fight against pests. Before the application of fertilizers (ten form of solide fertilizer formulation), soil samples were taken from five points of the plot, following the diagonals, using an auger, to depths of 15 cm and 45 cm per collection point. The different samples were then mixed and the composition of the soil in organic matter, nitrogen (N), organic carbon (C), phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na +) and potassium (K +) was determined in the Soil laboratory of the University of Abomey Calavi. The table of Igué et al. (2013), was used to assess the mineral content of the soil. In addition, rainfall data were recorded monthly to determine the amount of water that fell during the entire study period.

Experimental design

The experimental design is a randomized complete block with three replications. The treatments consisted of elementary plots of 10 plants each. A total of 110 plants were used per replicate and 330 for the entire trial. The 11 treatments were as follows:

- T0: without chemical fertilizer or organic manure (Control);
- T1: N1P1 or N20P40 (basic manure, single dose);
- T2: N2P2 or N40P80 (basic manure, double dose);
- T3: F1 (chicken manure added to basic manure, single dose);
- T4: F2 (chicken manure added to basic manure, double dose);
- T5: N1P1 + F1 or N20P40 + F1 (organo-mineral basic fertilizer, single dose);
- T6: N2P2 + F2 or N40P80 + F2 (organo-mineral basic fertilizer, double dose);
- T7: N1P1K1 or N20P40K36 (single dose basic manure with single dose of K);

-T8: N2P2K2 or N40P80K72 (double dose basic fertilizer with double dose of K);

-T9: N1P1K1 + F1 or N20P40K36 + F1 (single dose basic organo-mineral fertilizer with single dose of K);

-T10: N2P2K2 + F2 or N40P80K72 + F2 (double dose of organo-mineral basic manure and K).

The doses of fertilizer that made up the treatments are as follows:

Basic doses used per plants:

- N1: Nitrogen 20 grams of N (43.5 grams of Urea at 46%)
- P1: Phosphorus 40 grams of P_2O_5 (182 grams of 22% PCaS)

- K1: Potassium 36 grams of K2O (60 grams of 60% KCl)
- F1: 20 grams of N + 16 grams of P2O5 + 20 grams of K2O (1kg grams of chicken manure) (British Chamber of Agriculture, 2006)
- F2: 2F1
- P2: 2P1
- K2: 2K1
- N2: 2N1

Data collected

In order to assess the effect of fertilizers on the growth parameters of cashew seedlings after transplantation, the root collar diameter (DC) and height (H) of the plants were measured each month. These data made it possible to calculate the following parameters: the vigor (Vi) and the robustness (Ro) of the plants. The formulas used for this purpose are those developed by Deleuze et al. (2015), for the calculation of the robustness while for the calculation of the vigor of the plants, the formula of Alexandre, (1977) was used. Plant height (H) is measured using a tape measure from root collar to apical bud each month. The root collar diameter (DC) of the plants is also determined using a caliper each month.

The formulas used are as follows:

$Ro=(\sqrt{CC})/H$ et $Vi=H/DC$

Vigor (Vi) is said to be good when the H/DC ratio is less than 80. The most vigorous plant is the one whose value of the ratio (H/DC) is lower. The hardiest plants are those with high hardiness values.

The length and width of five new leaves per plant per month are measured to calculate the leaf area of young plants. Five new leaves per plant were randomly selected. The length (L) of the leaves corresponds to the length of the leaf blade following the main vein (from the gland to the tip). The measurement of the width (l) is made on the widest part of the leaf and perpendicular to the main vein. The formula: SFT = NF x SF from Murthy et al. (1984) was used to calculate the total leaf area of plants with SFT = Total Leaf Area; NF = Number of Sheet; and leaves area of a leaf determined by the following relationship SF = 0.21 + 0.69 P with P = L x l ; the number of resumed / successful plants to calculate the success / resumption rate by taking the number of successful plants out of the total number of plants planted.

For vegetative growth parameters, the data are expressed as growth rates calculated according to the following formula:

Growth rate for period i = (Xi-X0)/X0 with xi denoting the measurement at one collection period (each month) and X0 the initial measurement before the application of fertilizers (data from the first week represent the reference data X0).

In order to assess the precocity of recovery and the development of the plants, the following data were collected: the number of leaves emitted per month by simple counting; the rate of appearance of the leaves calculated as the ratio between the total number of leaves and the number of months; the number of viable transplants to calculate the viability rate (Tv) or survival rate after plant establishment. The success rate is the ratio between the number of successful plants (alive) and the total number of plants transplanted: Ts = NPR/NTP (NPR = Number of successful plants and NTP = Total number of plants transplanted in the field). The following formula is used to calculate the survival rate: Tv=NPENF/NTPEV (with NPENF = the number of plants having produced new leaves, NTPEV = the total number of plants planted).

Statistical analysis

The data collected were entered and coded using the Excel 2013 spreadsheet. The spreadsheet was also used to produce the graphs and histograms. The data collected and the parameters calculated were subjected to statistical analyzes with the SPSS version 21 software for the analysis of variance following the generalized linear model. In particular, the repeated measures ANOVA made it possible to compare the means of the data collected on several dates. In addition, the Pearson bivariate correlation coefficients and Spearman Rho made it possible to highlight the existing relationships between the parameters studied. The significance level for all the tests is 5 %.

RESULTS

Physico-chemical characteristics of soils in the Savè area

The results of the analyzes of the soil samples taken are shown in Table 1. The acidity of Savè soils increases with depth. Also, the composition of organic matter and total nitrogen are greater at the surface (0-15cm) than at depth of 45 cm. In addition, the clay content is lower and the sand content is higher. However, it is loamy at depth of 45 cm. As for mineral elements, surface soils were rich in phosphorus, calcium, magnesium and nitrogen, while at a depth of 45 cm, the soil was richer in potassium. In sum, the analysis revealed that at a depth of 45 cm, acidity is important in the soil of Save as well as the proportions of clay and silt. At 15 cm deep, on the contrary, the soils are rich in calcium, magnesium, sodium, nitrogen, potassium and organic carbon. After comparison with the characterization matrix of Igué et al. (2015), it can be concluded that the soils of the municipality of Save have severe deficiencies in organic carbon (C), nitrogen (N) and phosphorus (P) while they are rich in potassium (K), especially when going from the surface to deeper horizons.

Table 1 : Physico-chemical characteristics of the different soil layers

Grand depth	pH		Corg	Nt	A	L	S	P ass	K	Ca	Mg	Na
	H20	KCl	%	%		%		Ppm	(meq/100g)			
0-15 cm	6,03	5,55	1,12	0,46	6,00	11,40	80,94	11,63	1,12	5,57	8,11	4,97
0-45 cm	5,97	5,39	0,92	0,45	6,80	13,80	79,26	10,74	2,48	3,90	6,90	4,71

Legend: pH : Hydrogen potential ; Corg : Organic carbon ; Nt : Total nitrogen ; A : Clay ; L : Limon ; P ass : Assimilable phosphorus ; K : Potassium ; Ca : Calicium ; Mg : Magnesium ; Na : sodium ; H20 : water ; KCl : Sodium chloride

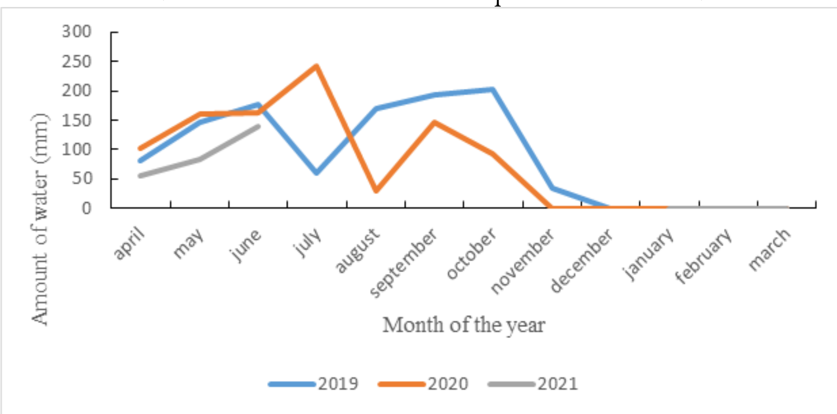
Rainfall variations in the town of Savè.

Figure 2 below shows the evolution of rainfall in the municipality of Save during the experiment, from April 2019 to June 2021. The rainy season starts from April and end in October with only a few rainy days in November and / or December. The rest of the months (november to march) of the year are dry. The peaks of the quantities of water fallen are observed between September-October in 2019 while they are observed in June for the year 2020. These changes from one year to another shows the changing state of the climate of this Save area.

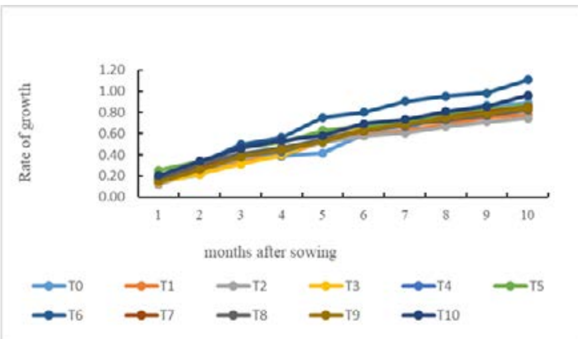
Figure 2 : Rainfall evolution of the municipality of Save 2019-2021

Variation in root collar diameters and height of grafted cashew seedlings depending on the fertilizer formulas applied.

The analysis of variance showed that the different fertilizer formulas significantly improved the diameter and height of the plants ($P \leq 0.05$). The best average growth rates of the diameter at the root collar of the plants were obtained with the T6 treatment (0.71) followed by the

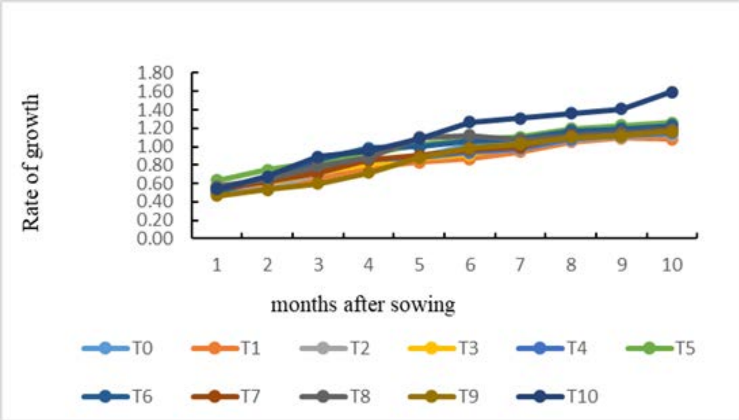


T10 treatment (0.62). On the other hand, the lowest values were obtained with the T2 (0.5), T1 (0.51) and T0 (0.53) treatments. Figure 3 shows that the best growth rates in height of the plants were obtained with T10 (1.11 cm), T5 (1.00 cm) and T6 (0.97 cm) while the lowest rates were obtained with the T1 and T0 treatments. In summary, the T10, T6 and T5 fertilizer formulas resulted in larger diameters and taller plants. The T1, T2 and T0 treatments produced smaller diameters and smaller size plants. T6 was the treatment which favored the best stem growth of the plants starting from the 4th month of planting (figure 4).



Legend : T0 : control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 3 : Evolution of the root collar diameter of the plants during the first 10 months after planting.

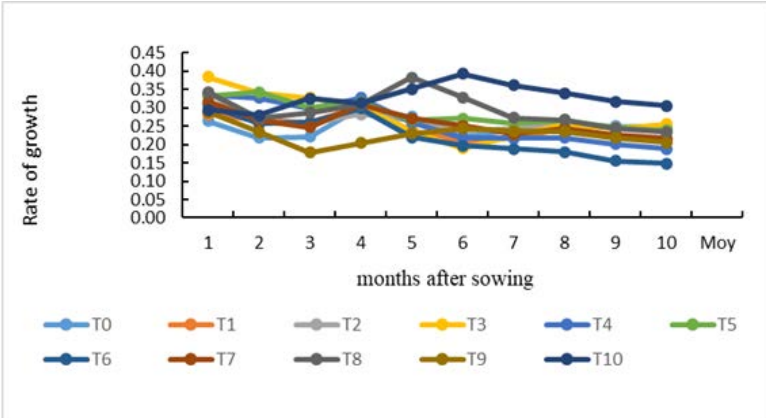


Legend : T0 : Control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 4 : Heights of cashew seedlings planted in the field according to the fertilizer formulas 10 months after planting.

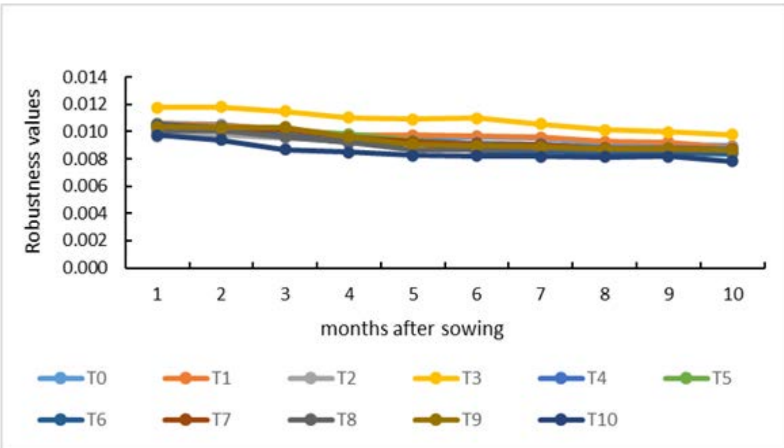
Robustness and vigor of young cashew trees depending on the fertilizer formulas.

There is at least one significant difference between the different fertilizer formulas applied, for the vigor and robustness variables (P ≤ 0.05). All the plants used for this experiment are vigorous (vigor less than 80). Three to four months after transplanting the plants to the field, the best vigor was obtained with the T9 treatment followed by the T0 and T2 treatments respectively. From the 7th to the 10th month after planting the plants, the T6 treatment presented the most vigorous plants (Vi = 22) against the T10 and T4 treatments which presented the less vigorous plants even if the value Vi = 0.33 is less than 80 (Figure 5). Regarding the robustness of the plants (figure 6), it was the T3 (0.011), T0 (0.010) and T1 (0.010) treatments that made it possible to obtain the most robust plants, unlike the T10 (0.009) treatment.



Legend : T0 : control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 5 : Vigor of cashew seedlings planted in the field according to the fertilizer formulas tested.



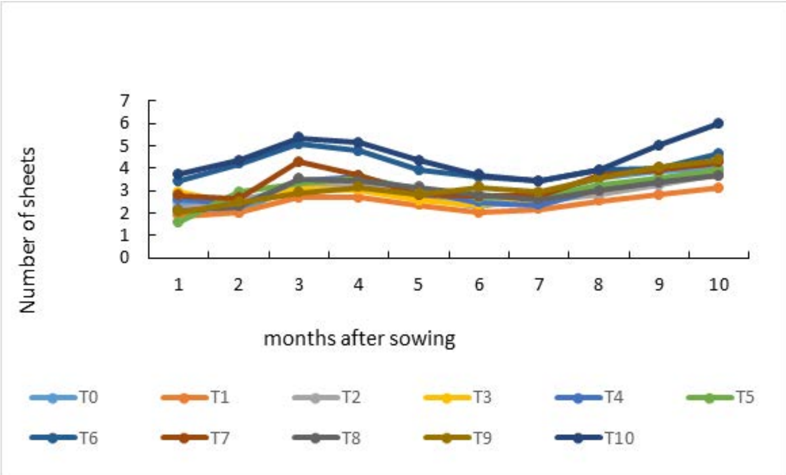
Legend : T0 : Control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 6 : Variation in the robustness of cashew seedlings planted in the field depending on the fertilizer formulas applied

Rhythm of leaf appearance and total leaf area of the plants according to the different fertilizer formulas

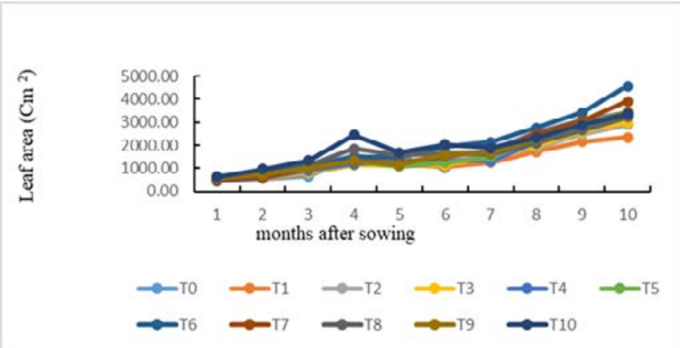
At least one significant difference (P ≤ 0.05) existed between treatments regarding the rates of leaf appearance and the leaf surfaces of cashew trees grafted from the second month of vegetation. We noted a highly significant difference (P ≤ 0.001) from the 4th month after planting, for the leaf area even if this trend was observed from the 3rd month with regard to the rate of leaf appearance. The best rate of leaf appearance was obtained with the T10 and T6 treatments (Figure 7) while the lowest rate was obtained with the T1 and T2 treatments. Plants from T10 and T6 treatments produced an average of four leaves per month (figure 7).

The largest leaf area was obtained with the plants which underwent the T10 treatment (figure 8). They were followed respectively by those who received the T8 and T6 treatments. After 7 months of growth, it is the plants which received the T6 treatment (2 038.84 cm2) which had the largest leaf areas. They were followed by those who underwent the T10 treatment (1 955.63 cm2). However, the smallest leaf areas were obtained with the T3, T0 and T1 treatments. It should be noted that the treatments, which made it possible to obtain the best rates of leaf appearance, are the same ones which led to the obtaining of the largest leaf areas.



Legend : T0 : control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 7 : Variation in the rate of leaf appearance of cashew seedlings planted in the field depending on the fertilizer formulas tested

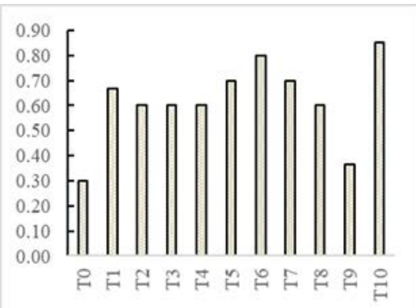


Legend : T0 : Control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

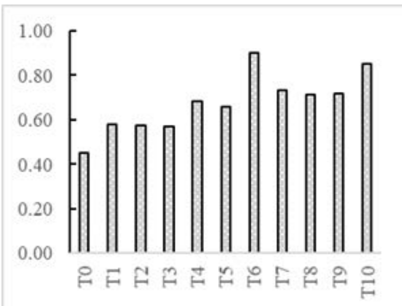
Figure 8 : Variation in leaf area of cashew seedlings planted in the field according to the fertilizer formulas tested.

Success and survival rates of cashew seedlings after planting according to the fertilizer formulas

The analysis of figure 9 a&b shows that there is at least one significant difference ($P \leq 0.05$) between the different fertilizer formulas tested on the success and survival rate of grafted cashew seedlings after planting. The best rates of success and survival after planting were obtained respectively with the T10 and T6 treatments, while the lowest rates of success and survival after planting were obtained with the control. The T10 and T6 treatments made it possible to obtain 85 % and 80 % of live plants respectively after the dry period which followed the year of installation of the plants. Regarding the survival rate after planting, it is rather the T6 treatment which has a better survival rate (90 %) followed by T10 (85 %). The lowest survival (45 %) and success (30 %) rates were obtained with the control treatment. From all the above, it emerges that the T6 treatment allowed the majority of the plants to survive after emitting new leaves, unlike the other treatments.



(a) : Success rate after planting



(b) : Survival rate after planting

Legend : T0 : Control ; T1 = N20P40 ; T2 = N40P80 ; T3 = F1 ; T4 = F2 ; T5 = N20P40 + F1 ; T6 = N40P80 + F2 ; T7 : N20P40K36 ; T8 : N40P80K72 ; T9 : N20P40K36 + F1 et T10 : N40P80K72 + F2

Figure 9 : Success rate after planting (a) and survival (b) of grafted cashew seedlings planted in the field according to the fertilizer formulas tested

Correlations between the growth parameters studied.

Correlation analysis revealed the existence of a significant correlation ($P \leq 0.05$) between the parameters studied. There is a strong positive correlation between collar diameter and plant height ($r = 0.71$) on vigor ($r = 0.51$) and total leaf area ($r = 0.78$) of cashew plants. This means that large size and diameter plants have high vigor with large leaf areas. Pearson's correlation analysis showed that the rate of leaf emergence is strongly and positively correlated with total leaf area ($r = 0.80$). There is also a positive correlation between the total leaf area and the parameters which are correlated with the rate of appearance of the leaves. This means that the total leaf area of the plants evolves in the same direction as these parameters. Finally, the success rate after planting is positively correlated ($r = 0.35$) with the vigor of the plants. From this correlation analyzes, it appears that the T6 and T10 treatments developed more growth parameters that were strongly and positively correlated with each other. This allows them to stand out as the best treatments for obtaining very vigorous cashew seedlings after transplantation.

Discussion

This research revealed that the fertilizer formulas N40P80K72 combined with 2 kg of poultry manure and N40P80 always combined with 2 kg of poultry manure resulted in larger diameters and taller cashew seedlings after transplantation. Plants given the N20P40, N40P80 or unfertilized exhibited smaller diameters and lower heights. The correlation analysis revealed on the one hand the existence of a strong positive correlation between the growth parameters (diameter and height) and on the other hand the existence of a negative correlation between the plant height and vigor. Thus, plants of large size and large diameter will be the most voluminous with a high vigor value (H / DC). However, the T6 treatment, i.e. the N40P80 + F2 fertilizer formula, was an exception to this rule by presenting vigorous plants despite the great heights presented. This peculiarity is explained by the constancy or the decrease in the value of the DC / H ratio. According to Leblanc (2016), a low amount of phosphorus in the soil causes plants to grow much more in diameter than in height. The N40P80 fertilizer formula combining a good proportion of nitrogen and phosphorus favored apical and cambial growth, respectively. This formula combined with poultry manure which is also rich in mineral elements and has an organic amendment property supported the effect of mineral fertilizers. The good vigor ($Vi = 22 < 80$) observed in plants treated with the fertilizer formula N40P80 + F2 can be explained by the fact that these plants have developed a good root system favoring the mobilization of nutrients drawn from the soil. These results further explain the effect of the fertilizers applied. Indeed, these fertilizers made more readily available to the plant's adequate amounts of nutrients. This favored their growth and development, through the formation and installation of a good root system. These results corroborate those of Kambou et al. (2019), who showed that young plants and large diameter plants have a well-developed root system that allows them to mobilize nutrients from the soil. In fact, the quantities of nitrogen and phosphorus supplied have filled the gap in the stock of nutrients previously available in the soil. Thus, the quantities of nutrients that plants need to grow and develop have been achieved. In addition, the association of mineral and organic fertilizers could explain these results obtained because Akanza and Yao (2011) and Akanza (2015), have shown that the combinations of organic manure (poultry manure) and mineral fertilizers (NPK + urea + dolomite) show their effectiveness on the growth, production and yields of the cassava variety. The soils of the town of Save where the experiment was conducted have a severe limitation in nitrogen and phosphorus, especially going from the surface to the underground layers, while these soils are unrestricted with regard to potassium. This was evidenced by the lack of difference between the effects of formulas containing potassium and non-potassium fertilizer formulas. The present study has indeed shown the beneficial effect of organic fertilizer applied in combination with mineral fertilizers such as NP, especially when the quantities of associated elements are in adequate proportions. The best rates of leaf appearance and the largest leaf areas were obtained with the fertilizer formulas N40P80K72 associated with 2 kg of poultry manure and N40P80 associated with 2 kg of poultry manure while the lowest rate and the lowest leaf area were obtained with the N20P40 mineral fertilizer formulas, N40P80 and T0. These results explain once again that the combination of mineral and organic fertilizers allows good exploitation of soil nutrients through their easy accessibility to plants and in a sustained manner. Also, the positive correlation between the rate of appearance of new leaves, the total leaf area and the growth parameters (root collar diameter and height) may explain the results obtained with the formula N40P80 + 2 kg of poultry manure. The cashew is a tree whose root system develops very quickly with a taproot that grows deeply, under favorable conditions. This allows new shoots to benefit from a significant supply of sap for their development as observed by the construction of large leaf areas in large diameter plants. Plants with a large leaf area are said to have a high capacity for receiving sunlight, which is favorable to the strong photosynthetic activity necessary for a good growth (Kambou, 2019). From all of the above, it emerges that the treatments which favored the growth of the plants more in height and/or in diameter presented the most voluminous plants more or less vigorous. The N40P80 organo-mineral fertilizer formula combined with organic fertilizer (poultry manure) produced vigorous plants with better growth parameters. On the other hand, those limiting the growth of the plants in diameter and or in height allowed the plants to have good vigor and therefore robust plants.

The best success and survival rates after planting were obtained with the fertilizer formula N40P80K72 + F2 and N40P80 + F2 while the lowest rates were obtained with the untreated plants. These treatments allowed most of the surviving plants to emit new leaves, unlike the other treatments, particularly those consisting solely of mineral fertilizers. The latter treatments even caused a regression in the survival rate of the plants after emission of new leaves. These results are due to the low quantity of organic matter and generally to the low fertility of the experimental site. Indeed, the soils of the experimental zone (municipality of Save) present a severe limitation in organic matter (organic matter rate < 1 %). Poultry manure, a good quality fertilizer (Hieronymus, 2001) provided organic matter which is rapidly mineralized (Chabalier et al., 2006). This made it possible to make the nutrients of mineral fertilizers easily accessible to the plants, which manage to draw them easily from the soil. This explains why the majority (85 %) of plants treated with this fertilizer formula are kept alive.

CONCLUSION

This ten-month experiment, carried out from 2019 to 2020, revealed a significant difference between the effects of the fertilizer formulas on the parameters studied (survival rate, success rate after planting, root collar diameter, height, rate of leaf appearance, leaf area, vigor and robustness). The organo-mineral fertilizer formulas N40P80 + 2 kg of poultry droppings and N40P80K72 + 2 kg of poultry droppings gave the best results in terms of effect on height, diameter and vigor. These formulas allowed all the plants to survive after emitting new leaves. On the contrary, for the other treatments, a lower survival rate was observed after the emission of new leaves. To greatly reduce the mortality rate of grafted cashew trees, especially in the first years of planting in the field, we suggest that producers use an intensive cultivation system using organo-mineral fertilizer formulas.

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SHELF LIFE STUDIES OF DRY CASHEW APPLE PULP AS A POULTRY FEED INGREDIENT

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Abstract

Contemplating the use of dry cashew apple pulp (DCAP) in the diets of commercial poultry birds motivated the study on the storage conditions and pests. This study evaluated the proximate composition, aflatoxin level and storage pest of DCAP in two different storage containers (the polyethylene sack and plastic bins) over a year. The experimental design was completely randomized design. Data collected were subjected to regression analysis and T-test. Results showed crude protein, fat, crude fibre, total ash and carbohydrate contents (12.60±, 5.14±0.23, 9.17±0.23, 5.88±0.46 and 67.21±2.18 respectively) were not significantly affected at P<0.05. Bulk density, compact bulk density specific gravity, pH and water holding capacity of milled DCAP observed were 0.64±0.01, 0.77±0.01, 0.64, 4.25±0.02 and 0.26±0.01respectively. Aflatoxin level was non-detectable (0ppb). The major storage insect associated with DCAP was Lasioderma serricome (Coleoptera: Anobiidae). Number of insects perkg DCAP were 34.45 and 241.75 for woven polyethylene sack and plastic bin respectively. The study therefore concluded that DCAP can be stored in the woven polyethylene bag for a period of one year without any adverse effect to its quality.

Keywords: Dry cashew apple pulp, shelf-life, proximate composition, Lasioderma serricome (Coleoptera: Anobiidae)

Introduction

By-products of fruits and vegetables have been considered as valuable alternatives to conventional feed ingredients. However, their high moisture content is a barrier to their long term usage. Sun drying and ensiling are methods that have been used for their preservation (Ogunjobi and Ogunwolu, 2010; Dele et al., 2013). Sun drying is not only cheap but has been found to be safe for fruits due to their high sugar and acid contents (Ahmed et al. 2013). The challenges associated with sun drying include labour,contamination, variation in seasons and time.

The use of dry cashew apple pulp (DCAP) in poultry feed industry is novel and yet to attain the status of a feed ingredient internationally. It is still at the experimental level. At this stage, to give itan international recognition as a feed ingredient, it is pertinent to study the shelf life of the product and the nutrient composition overtime. The impact of insect infestation and the identification of such pests with possible means of control need to be studied. There is also the need to confirm how long sun dried cashew apple pulp can be stored and used as animal feed ingredient. Shelf- life parameters could include physical, chemical, biological or microbiological parameters which are necessary for measuring the stability of a feed ingredient in storage (ICCF, 2018). Information of the stored product of DCAP is rare. Thus, this experiment was carried out to assess the proximate composition of dry cashew apple pulp, insect pests associated with stored DCAP, the effect of storage method and its suitability for inclusion in poultry feed during and after the period of one year in storage.

Methodology

This study was done at the Department of Animal Science, University of Ibadan, Ibadan, Oyo State, Nigeria. Ibadan is located on latitude7°22'36.2496°N, longitude 3°56'23.2296°E and altitude 230m.Cashew apples were collected after the removal of the nuts at Aremu Farms, Iwo, Osun State, Nigeria. The cashew apples were pressed to extract juice and the residue was sun- dried until constant moisture content was attained. The dried pulp was mixed thoroughly and randomly divided into five plastic buckets (Plate 1) and five polypropylene sacks (Plate 2) in a completely randomized design and stored for 12 months.

Plate1. Plastic buckets containing dry cashew apple pulp used for the study.

Plate 2. Polypropylene sacks containing dry cashew apple pulp used for the study

Proximate analysis was carried out on quarterly basis and storage pest identified at the Department of Crop Protection of the University of Ibadan. Insect count was carried out at six months intervals. Batches of DCAP were placed on white muslin cloth and individual counts were recorded. The samples were placed in the fridge for 3-5 minutes to prevent the insects from flying. Number of insects was reported as number per kilogram per sample. There were 5 replicates per sample. Data collected were subjected to regression analysis and T-test at $P \leq 0.05$

Results

In this study, the observed dry matter (DM) in DCAP adequately supported the storage of the feed ingredient without significant deterioration to the other proximate components. Though the recommended moisture content is 10-12% for storage of feedstuff to prevent fungal growth, but in this study anaverage of 14.27% adequately supported the storage of dry cashew apple for one year. This is probably due to the high fiber content of dry cashew apple pulp. This is evidence in its aflatoxin content. Reported average dry matter for soyabean, orange pulp, pearl millet, apple pomace and almond hurls are 88, 89, 87, 89 and 87.7% respectively. These are comparable to the DM obtained for DCAP (85 – 86%; Table 1). Aflatoxins were non-detectable (0ppb) in the samples, an indication that the aflatoxins were -within the permissible levels of standard feed ingredients (Becha and Devi). This could be attributed to the effectiveness of sun drying in the preservation of DCAP as a feed ingredient when adequate standards are ,adhered to. The insect infestation was observed after three months of storage (during the second quarter). The main storage insect was Lasioderma serricorne(Plates 3,4 and 5The total insect count for plastic container and polyethylene sack were 242 and 35 insects/kg respectively (Figure 1).

Table 1: Effect of storage container and period of storage on the proximate composition of DCAP

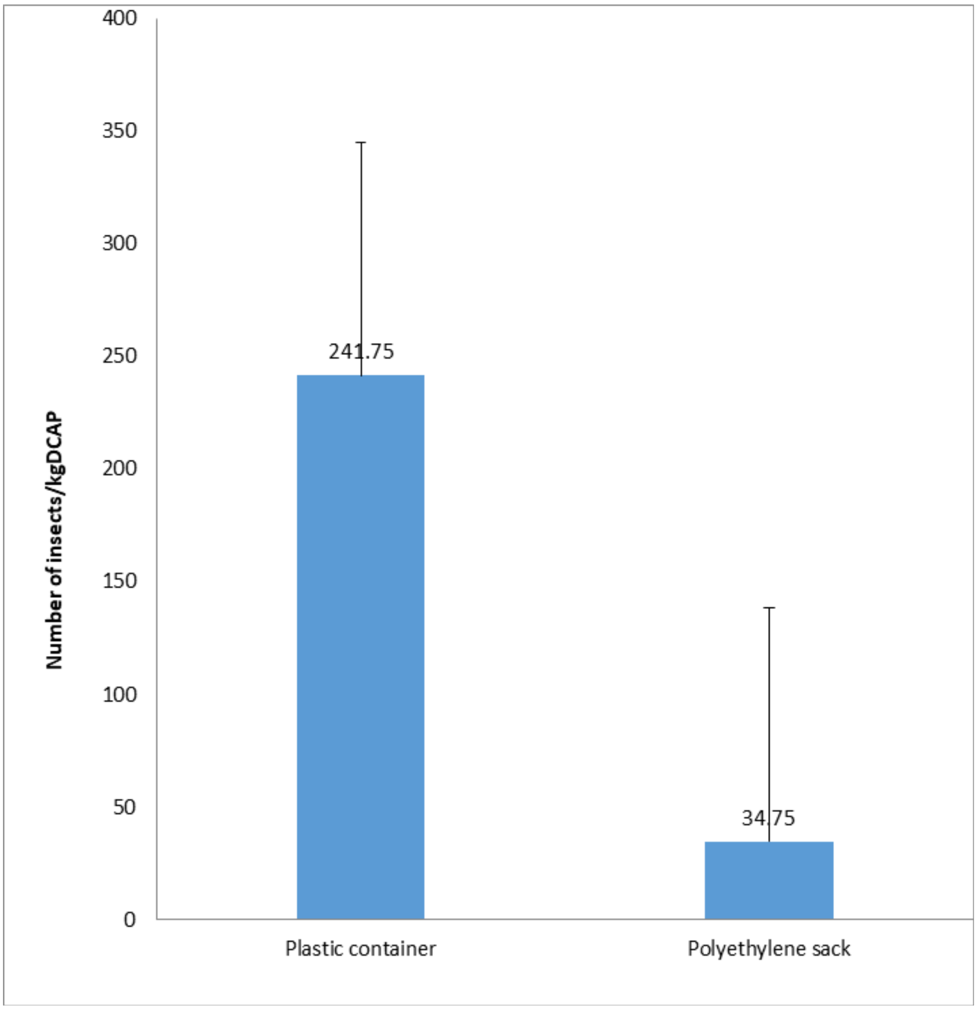
Month/ parameters (%)	Dry Matter		Crude Fat		Crude Fat		Crude Fibre		Ash		NFE	
	PC	WPS	PC	WPS	PC	WPS	PC	WPS	PC	WPS	PC	WPS
June 2017	85.35	85.26	14.91	14.90	4.55	4.55	8.26	8.23	4.45	4.45	53.18	53.13
September 2017	85.49	85.93	14.45	15.01	5.76	3.97	10.54	11.18	5.29	4.67	49.45	51.10
December 2017	85.81	86.32	15.04	14.30	3.33	2.3	10.06	9.82	5.67	5.89	51.71	54.01
March 2018	85.73	85.80	14.77	14.74	4.78	3.59	13.36	10.16	8.89	7.16	43.93	50.15
June 2018	85.77	85.85	14.80	14.71	4.65	3.49	12.59	10.20	8.18	7.93	45.55	49.52
R^2	0.480	0.779	0.083	0.122	0.263	0.836	0.720	0.867	0.433	0.525	0.122	0.001
P- value	0.004	0.015	0.593	0.457	0.160	≤0.01	≤0.001	≤0.001	0.033	0.012	0.203	0.905

PC – Plastic container, WPS – Woven polypropylene sack, R2 – Coefficient of determination

Table 2: Total aflatoxin level in Dry Cashew Apple Pulp stored in plastic containers and woven polypropylene sacks

Storage type	OD(1/10th)	Aflatoxin level	Standard
Plastic container	1.552	0ppb	20ppb
Woven polypropylene sack	1.568	0ppb	20ppb

OD – Optical density



Proximate analysis

The dry matter at the beginning of the experiment was 85.35 (PC) and 85.26 (WPS), at the end of the experiment, dry matter was 85.77(PC) and 85.55(WPS). Crude protein was 14.91(PC) and 14.90(WPS) but reduced to 14.80 and 14.71 respectively. Crude fat was 4.55 for both storage type at the onset of the experiment but 4.65(PC) and 3.49 (WPS) at the end. Crude fibre was 8.26(PC) and 8.23 (WPS), this increased to12.59 and10.28 for PC and WPS respectively. Ash was 4.45 for both storage materials at the beginning but8.18 and 7.93 for PC and WPS respectively. NFE was 53.18 and 53.13 at the beginning and 45,55 and49.52 at the end for PC and WPS respectively

Lasioderma serricorne is commonly known as cigarette beetle or tobacco beetle. It belongs to the family Ptinidae and order Coleoptera. It is one of the commonest insect pests of stored products (REFERENCE). After six months in storage, polypropylene sacks had only about 14% of the insects found in the plastic container. This result corroborates that of Mali and Satyavir (2005) where insect damage on wheat stored in polypropyylene bag was less than in jute bags and tin containers. This could be due to air movement in the sacks than the bin thereby lowering temperature, which could encourage insect proliferation.

Conclusion and Recommendation

Lasioderma serricorne was found as the pest in the storage of dry cashew apple pulp. Dry cashew apple pulp can be stored over a one-year period without deleterious effect if Lasioderma serricorne is controlled. Polypropylene sacks are better than plastic containers in the storage of dry cashew apple pulp. Further studies are also recommended into the collection, processing, storage and preservation of dry cashew apple pulp.

Drying cashew apple during cashew harvest could increase earnings from cashew production and provide more job opportunities thereby enhancing cashew value chain.

Acknowledgement

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EFFECT OF CROWN REDUCTION AND ORDINARY PRUNING ON CASHEW TREE PRODUCTIVITY IN NORTHERN AND CENTRAL BENIN

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Summary

Objectives: The yield gap in cashew cultivation is partly due to pruning practices. This study aims to assess the effect of crown reduction pruning and ordinary management pruning on cashew nut productivity in Benin.

Methodology and results: Eight experimental units were set up in 2019 in Glazoué, Ouèssè, N'Dali and Nikki. The units were sites of three elementary plots. Production and quality data were collected from 2019-2022. One-factor ANOVA analyses of variance (treatment type) were performed to test whether the average yield, seediness and useful kernel yield (KOR) of cashew were significantly different between the two sizes. Two and then three-factor ANOVA analyses were then carried out to assess the combined effects of the different factors on each of the response variables. Ordinary management operations significantly increased yield in the first three years. However, quality was better at the reduction size.

Conclusions and application of results: Seventy-six-point three (76.3) percent of the variation in yield could be attributed to the combined effect of size and zone (the commune) and 43.4% to the combined effect of size and time (the year after operation). Crown reduction pruning improves cashew nut quality and yield. However, the drastic level of pruning does not lead to better yields in the first few years. It is therefore preferable to carry out pruning on very low-yielding trees or those whose lower branches have been drastically removed. Ordinary pruning is no less good, but care should be taken not to destroy low branches and to promote an umbrella-shaped tree architecture.

Key words: Investment; Pruning; Productivity; Comparison

Abstract

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Methodology and results: Eight experimental units were set up in 2019 in Glazoué, Ouèssè, N'Dali and Nikki. The units were sites of three elementary plots. Production and quality data were collected from 2019-2022. One-factor ANOVA analyses of variance (treatment type) were performed to test whether average yield, seediness, and useful kernel yield (KOR) of cashew were significantly different between the two sizes. Next, two- and then three-factor ANOVA analyses were performed to assess the combined effects of the different factors on each of the response variables. Ordinary management operations significantly increased yield in the first three years. However, quality was better in terms of shrinkage size.

Conclusions and application of results: Seventy-six-point three (76.3) percent of the variation in yield could be attributed to the combined effect of size and zone (commune), and 43.4% to the combined effect of size and time (post-operation year). Crown reduction pruning improves cashew nut quality and yield. However, the drastic level of pruning does not lead to higher yields in the first few years. It is therefore preferable to carry out pruning on very low-yielding trees, or those whose lower branches have been drastically removed. Ordinary pruning is no less good, but care must be taken not to destroy low branches and to promote an umbrella-shaped tree architecture.

Key words: Investment; Pruning; Productivity; Comparison.

Introduction

Cashew is a tropical woody species with significant socio-economic potential (Tandjiékpon, 2005). Between 2011 and 2018, raw nut production rose from 1 million tonnes to 1.8 million tonnes in Africa, with annual growth of 5.8%, half of which is produced by Côte d'Ivoire (Hien, 2019). Cashew nuts are an important export crop for the African continent, accounting for more than 55% of global cashew nut production (N'djolosse et al., 2020).. It plays an important role in Benin's economy. It helps solve three major development problems (economic, social and environmental) in the world in general, and in Benin in particular (MAEP, 2003).

Several initiatives are aimed at increasing the area planted with cashew trees. Thus, the areas cultivated are increasing year by year. In 2015, it was estimated at 285,567.7 ha (Adégbola & Crinot, 2016; BéninCajù, 2020), rising to 346,155 ha in 2021 (DSA, 2022). Despite this, orchard productivity is still very low, at around 350-400 kg/ha (Ricau, 2013; BéninCajù, 2020). To improve this yield, old plantations need to be rehabilitated to increase the production of raw cashew nuts.

Different types of tree pruning are used to increase production. These include tip pruning, training pruning, severe pruning, annual renewal pruning and root pruning (Persello, 2018). However, the tree pruning technique depends on the planter's objective. Pruning intensity and time vary according to specific agro-climatic regions (Nayak et al., 2019). The methods used on cashew trees are pruning and thinning

(Ouattara et al., 2012). The current pruning method (ordinary management pruning) in farms is giving very encouraging results (Amanoudo et al., 2019 ; Bhat, et al., 2020). However, the implementation of this practice is drastic. Low branches are systematically cut to a height of three to five metres. Unfortunately, low branches are the ones capable of producing two-thirds of the fruits of trees. It would therefore be advisable to preserve the lower branches to ensure improved production. The aim of this study is therefore to compare the effect of lowering pruning and ordinary management pruning on cashew tree productivity in Benin.

I. Materials and methods

I.1. *Material*

The plant material studied is the cashew tree: Anacardium occidentale.

The study was conducted in four (04) communes in areas of good cashew nut production in Benin. These were the communes of Ouèssè and Glazoué in the hills, and N'Dali and Nikki in Borgou.

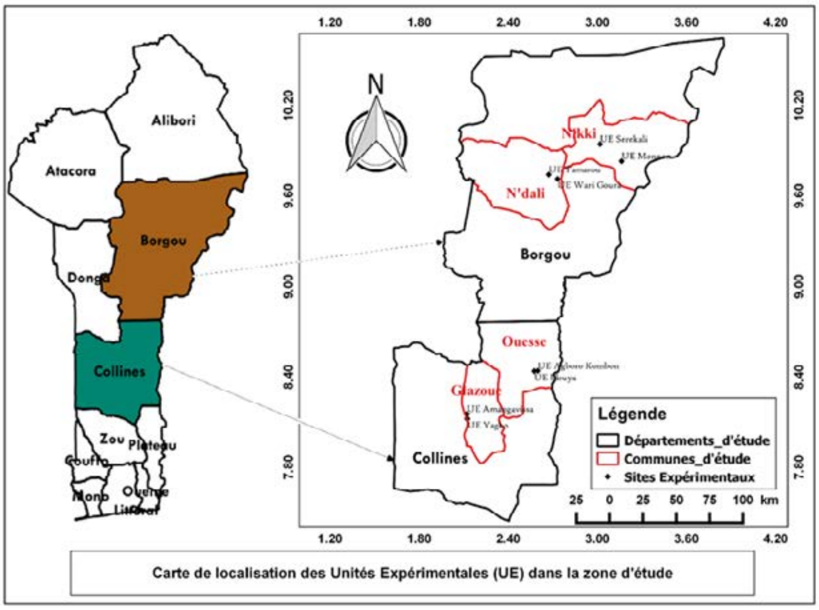


Figure 1 Location of study area and experimental units

I.2. *Method*

I.2.1. *Presentation of the experimental units*

The experimental units were established in plantations belonging to cashew nut growers identified after awareness-raising based on the following criteria:

- Plantation of at least 1 ha in blocks between 11 and 20 years old;
- Low yield plantation, less than 200 kg/ha;
- Plantation whose trees produce small nuts;
- Producers willing to accept innovation and to support data collection;

Table 1 Data on experimental units

Agro-ecological zone	Municipality	Village	EU surface area (ha)	Age of establishment	Pruning		
					PT	TO	TR
III	Nikki	Monnon	0.375	12	No	Yes	Yes
		Sérékali	0.375	13	No	Yes	Yes
	N'Dali	Tamarou	0,375	14	No	Yes	Yes
		Wari-Goura	0,375	13	No	Yes	Yes
V	Ouèssè	Agboro-Kombon	0,375	14	No	Yes	Yes
		Idouya	0,375	15	No	Yes	Yes
	Glazoué	Amangavissa	0,375	12	No	Yes	Yes
		Yagbo	0,375	13	No	Yes	Yes
			0,375	**13,25**	No	Yes	Yes

EU: Experimental Unit; RS: Reduction Size; OS: Ordinary Size; CP: Control Plot

1.2.2. Experimental set-up

The experiment was conducted over three consecutive years. Eight (08) experimental units were established in 2019 in the study area. A Complete Randomized Block (CRB) with four (04) replicates was set up, the municipalities being the replicates. Each replication comprised a site of three elementary plots of 1/8th of a hectare each containing twelve (12) pruned trees (PD & PE). This density was obtained following thinning operations to comply with the recommendations of the Institut National de Recherche Agricole du Bénin.

Figure 2 Reduction pruning (semi-drastic) carried out in a cashew plantation in Sérékali in 2019.

In Benin, according to the extension and advisory support tool (iCA, 2010), maintenance pruning of cashew farms consists of pruning branches that are: (i) dead or dried out; (ii) infested; (iii) too low and in the way of passage or nut collection. Low branches below 1.5 m from the ground are cut and removed from the farm. In this study, this practice constituted ordinary management pruning.

Crown reduction pruning consists of cutting off the vertical branches and the ends of the lateral branches in order to reduce the height of the cashew tree and give it an "umbrella" shape (BAI PRO-Cashew, 2022). There are three types of pruning: light, semi-drastic and drastic. In this study, semi-drastic pruning was used (Figure 2).

After the various operations on the experimental units, the trees were sprayed with Mancozeb and Acetamiprid + Lambda-Cyhalothrin (Figure 3).

Figure 3 Protection of plants against insects and diseases

1.2.3. Agronomic data

Data was collected on both vegetative growth and tree production at the various experimental units from 2019 to 2022. These include the number of primary and secondary branches and the volume of the tree to measure vegetative growth, then the earliness of production, the quality and quantity of nuts per tree for tree development. Data was also collected on the history of the plantations and the practices implemented. Production data were collected from three trees selected on the diagonal (DSA, 2016) in each elementary plot. The fruit production of each tree was measured by weighing the nuts on a weekly basis using an electronic scale, then storing them in jute bags. A quality test was carried out on the stored nuts in February, March and April. A sub-sample of one (01) kg of raw cashew nuts was taken from each elementary plot and the number of nuts per kg was counted (Graining). The useful kernel yield (KOR) was determined from a sample of 1 kg of raw cashew nut using an appropriate kit.

1.2.4. Statistical analysis

The data collected were subjected to one-factor ANOVA (pruning type) to check whether the average yield, graining and KOR of cashew trees were significantly different between the different pruning types applied. Next, two-factor and then three-factor ANOVA analyses were conducted to analyse the combined effects of the different factors (pruning type, department, commune and weather) on each of the response variables (average yield, graining and KOR). The assumption of normality of the data was verified using the Shapiro-Wilk normality test conducted on the residuals of the linear model, and the assumption of homogeneity of variances was verified using the Levene test. Paired comparisons of averages were made using Tukey's post-hoc test.

2. Results

2.1. Effect of different types of pruning on cashew yields

The average cashew yield was significantly different between the different pruning types, $F(2, 66) = 16.60$, $p = 1.45e-6$, with a generalised eta-square equal to 0.335 (Figure 4). This result indicates that 33.50% of the variation in yield between the different plots could be attributed to the type of pruning used. In fact, the average cashew yield increased overall at the ordinary pruning level (6.12 ± 2.44 kg) compared with the control (4.46 ± 1.08 kg) but decreased at the reduction pruning level (2.93 ± 1.89 kg). Paired comparison analysis revealed that the increase in yield of the control at the regular size was statistically significant at the 5% level (1.66; 95% CI = 0.287 to 3.03; $p = 0.0139$), as was the decrease in yield of the control at the reduced size (-1.53; 95% CI = -2.90 to -0.153; $p = 0.0258$). On the other hand, the reduction in yield from regular size to reduced size was highly significant (-3.19; 95% CI = -4.51 to -1.86; $p = 7.13e-7$).

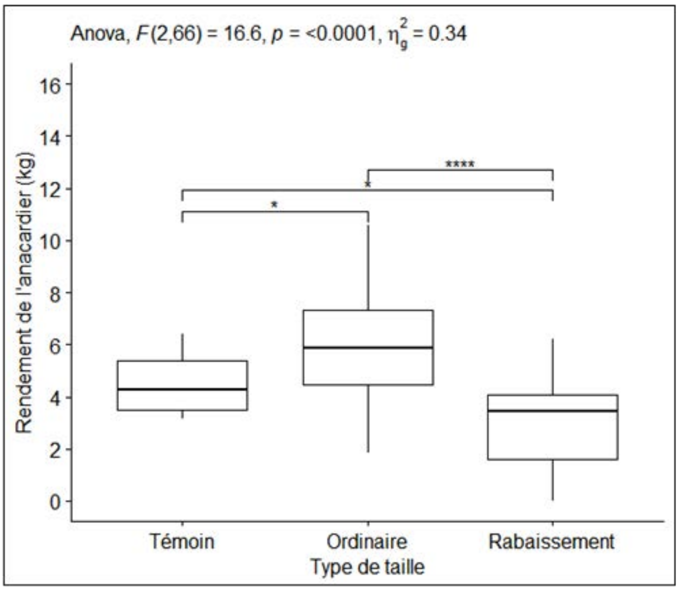


Figure 4 Comparison of overall average cashew yield between pruning types

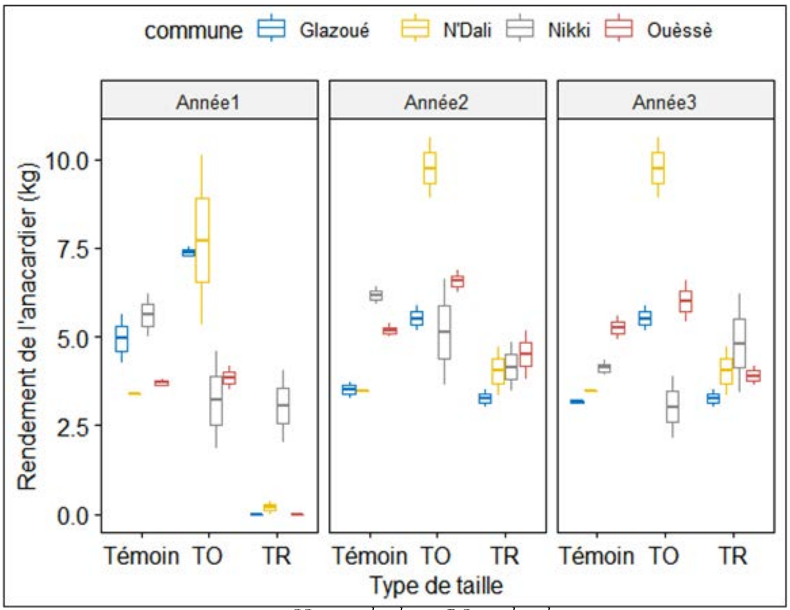
Type III ANOVA revealed no statistically significant three-factor interactions. However, there were statistically significant two-factor interactions between commune and year and the main factor, pruning type, on cashew yield. Thus, the combination of size type and commune showed a highly significant effect on average cashew yield, F (6. 33) = 13.22, p <0.0001 with a generalised eta-square equal to 0.763; indicating that 76.3% of the variation in yield could be attributed to the combined effect of size and commune. There was also a statistically significant interaction between size type and year, F (4. 33) = 6.31, p <0.0001 with a generalised eta-squared equal to 0.434; indicating that 43.4% of the variation in yield could be attributed to the combined effect of size and year.

Pairwise comparison analyses were carried out by commune to check the effect of the type of treatment in each year (Fig. 5, Table 2). The results showed that in the Glazoué commune, ordinary pruning did not significantly increase cashew yield compared with the control plot. On the other hand, switching from the control to low-pruning significantly reduced yield in the first year (p = 0.0001). Furthermore, the practice of pruning down in this Commune very significantly reduced yield compared with ordinary pruning (p < 0.000). In the commune of N'Dali, switching from the control to ordinary pruning very significantly increased cashew yield over the three years of collection (p <0.0001), whereas switching from the control to reduced pruning did not have a statistically significant effect. In the commune of Nikki, pruning practices in the farms had no statistically significant effect on cashew yield compared with the control plot. In the commune of Ouèssè, the switch from the control to pruning reduced yield in the first year (p = 0.0046). This reduction in yield was also statistically significant when switching from ordinary pruning to reduction pruning (p = 0.0033).

Table 2: Pairwise comparison of the effect of pruning on cashew yield by commune and year.

Commune	Year	Group 1	Group 2	p.adj	p.adj.mean
Glazoué	Year1	Indicator	Lowering size	0,0001	**
Glazoué	Year1	Ordinary size	Lowering size	<0,000	****
N'Dali	Year1	Indicator	Ordinary size	0,0067	****
N'Dali	Year1	Ordinary size	Lowering size	<0,000	****
N'Dali	Year2	Indicator	Ordinary size	0,0001	****
N'Dali	Year2	Ordinary size	Lowering size	<0,000	***
N'Dali	Year3	Indicator	Ordinary size	0,0001	****
N'Dali	Year3	Ordinary size	Lowering size	<0,000	***
Ouèssè	Year1	Indicator	Lowering size	0,0046	**
Ouèssè	Year1	Ordinary size	Lowering size	0,0033	***

Only statistically significant variations in yield are shown in the Table.



SS = standard size; RS = reduced size

Figure 5: Average cashew yield per year by size and commune

2.2. Effect of different types of pruning on the quality of raw cashew nuts

- **Effect on graining**

The average number of seeds per kilogram was significantly different between the different types of treatment, F (2. 55) = 15.78, p <0.0001, with a generalised eta-square equal to 0.365 (Figure 6); indicating that 36.5% of the variation in seed set between the different plots could be attributed to the type of pruning practised. The number of seeds per kilogramme decreased overall from the control plot (184 ± 10) to the ordinary pruning (172 ± 10) and to the reduction pruning (166 ± 7), indicating that the seeds produced by the control trees were smaller than those produced by the trees treated with reduction pruning and ordinary pruning. This variation in the average number of seeds per kilogramme was also statistically significant from one year to the next F (2. 55) = 3.72, p = 0.03.

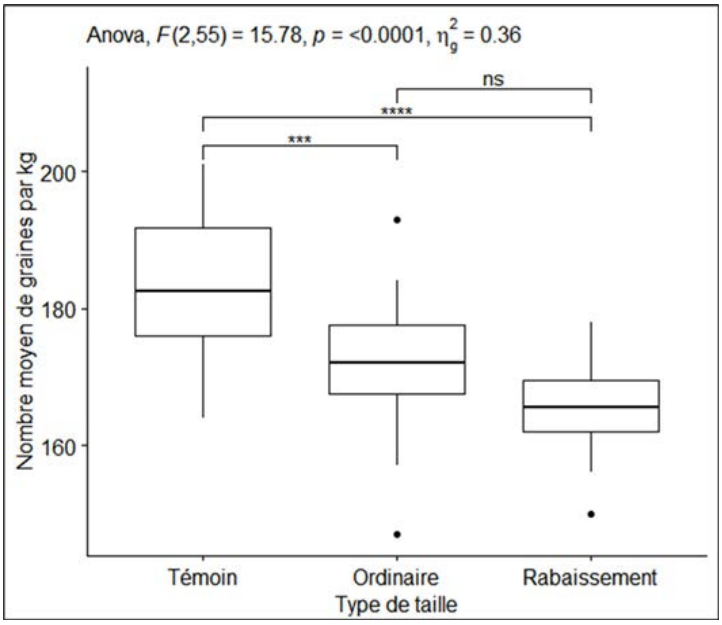


Figure 6Variation in cashew tree graining according to pruning type

- **Kernel Output Ratio (KOR)**

The KOR was significantly different between the different types of treatment, F (2. 55) = 8.09, p = 0.00084, with a generalised eta-square equal to 0.23 (Figure 7); indicating that 23% of the variation in KOR between the different plots could be attributed to the type of pruning practised.

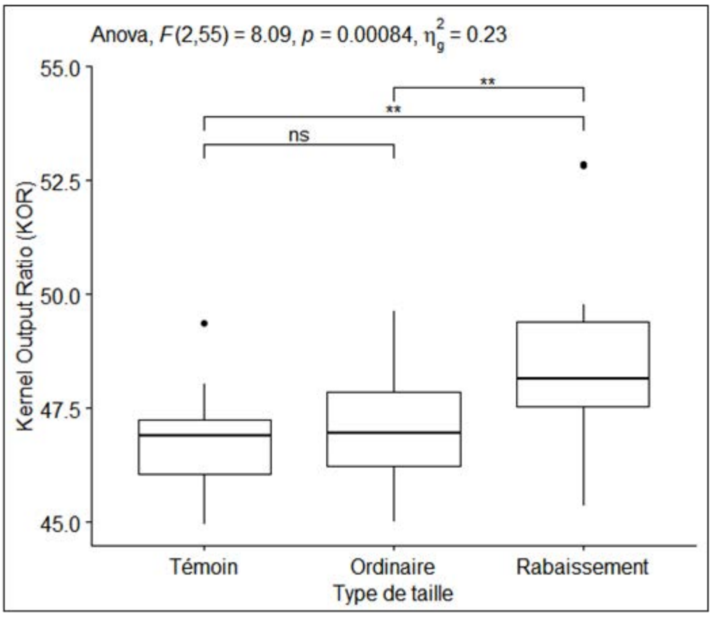


Figure 7: Variation in cashew KOR according to pruning type

The KOR increased overall from the control plot (46.9 ± 1.33) to the ordinary pruning (47.1 ± 1.25) and to the reduction pruning (48.8 ± 2.03), indicating that the seeds produced by the control trees were of lower quality than those produced by the trees treated with reduction pruning and ordinary pruning.

3. Discussion

3.1. Effect of pruning on cashew yield

The cashew trees studied reacted differently to the treatments applied. Overall, the increase in yield from the control plot to ordinary pruning was very significant. On the other hand, it was not significant when the control plot reverted to the reduction pruning. These results can be explained by the fact that in the first year after pruning, the yield was practically zero at the reduction pruning. It was only in the second year that fruit production gradually improved. Pruning intensity has a significant and negative effect on the probability of flowering (Hafle et al., 2009; Bussi et al., 2005; de Souza et al., 2014; Cambreling, 2020, Stahl, 2017). Pruning increases vegetative growth in year n (immediate effect of pruning) to the detriment of flowering. This confirms that the yield obtained with ordinary pruning is higher than that obtained with reduction pruning. With regard to the difference in yield between the control plot and the ordinary pruning, the ordinary pruning made it possible to develop the structure of the tree, improve light penetration, eliminate dead and rotten wood and regulate the harvest (Southwick et al, 1994). Pruning has beneficial effects on cashew yield in the short, medium and long term, given its intensity.

3.2. Effect of size on cashew nut quality

The study shows that the reduction pruning produces better quality nuts (KOR and graining) than the other plots. The difference was statistically significant between the pruned plots and the control plot. This result corroborates that of several authors who maintain that the production of pruned trees, although reduced in the early years, is early and of better quality (Hodgson, 1949; Hafle et al., 2009; de Souza et al., 2014). According to Southwick et al. (1994), regular pruning improves fruit size. The better fruit quality caused by light or semi-drastic pruning could be explained by improved vegetative growth likely to increase the availability of assimilates for fruit growth (Bussi et al, 2005; Asrey et al, 2012). This may also be due to a better microclimate and higher photosynthesis rates (Shaban, 2009). According to Mendonça (2005), plants that underwent more severe pruning produced fruit of greater size and weight.

This study highlights the usefulness of pruning in cashew orchards for improving productivity. However, semi-drastic pruning prevents harvesting in the first year, but picks up again in the second year without achieving the yield of trees pruned normally in the first three years. A light annual pruning generally gives better fruit production than a more severe pruning carried out less regularly (Menzela & Le Lagadec, 2017). Thus, reduction pruning would be indicated in cashew plantations that are not very productive, are ageing or are over-pruned.

Conclusion

Pruning practices in cashew orchards are essential for good tree architecture and improved productivity. To this end, ordinary management pruning of cashew plantations and crown reduction pruning were studied in agro-ecological zones 3 and 5 of Benin. At the end of the study, ordinary management pruning gave better results in terms of average yield for the three years of data collection in 75% of the units. On the other hand, fruit quality was better with crown reduction pruning. Although crown reduction yielded more than the control plot, it did not outperform ordinary management pruning in the first three years.

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ANALYSIS OF FARMERS' PERCEPTIONS OF CLIMATIC PARAMETERS AFFECTING CASHEW NUT PRODUCTIVITY IN BENIN

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SUMMARY

Cashew tree production in Benin is seriously affected by the variability of climatic factors. The aim of this study is to analyse farmers' perceptions of the climatic parameters that affect cashew productivity, with a view to determining the optimum conditions for cashew cultivation in Benin. Eighty farmers aged over 50 with more than 10 years' professional experience were selected from six villages in central and north-western Benin. In each of the selected villages, data were collected using a questionnaire, through individual and group surveys, and field visits. The data collected related to the socio-demographic characteristics of the households surveyed, farmers' perceptions of the effect of climatic events over the past ten years and their impact on cashew productivity. The results of the study indicate that for the majority of farmers (60-100), the various climatic factors have had a negative impact on cashew trees, with the exception of sunshine, which has been good in central Benin. The major climatic variability reported by the farmers surveyed was an increase in temperature and a decrease in rainfall in all the years concerned. Age and gender had a significant influence ($P<0.001$) on farmers' perceptions of the variability of climatic factors. The most significant impacts were: a drop in yield of between 50 and 100%, and the drying out and falling of flowers caused mainly by lack of rain, strong winds and high temperatures. This study shows that farmers are clearly aware of the effects of climate variability on cashew trees. Against this background of uncertainty and change, the contribution of research could be to agronomically test the introduction of improved planting material resistant to different stresses.

Keywords: Cashew farm, climate variability, farmers' perception, Benin.

INTRODUCTION

For many years now, the tropics have been faced with climate change, resulting in a disruption of the dry and rainy season cycles. According to the Institut d'Application et de Vulgarisation en Sciences (IAVS, 2011), this variation is a climate upheaval characterised mainly by a significant increase in the frequency and intensity of climatic shocks (droughts, floods, heat waves, violent winds). The likely impacts of climate change on ecosystem services, agricultural production and living conditions will characterise regions dominated by subsistence food production and highly variable low production potential (Odada et al., 2008; Sivakumar et al., 2005).

Despite the importance of cashew for millions of people and households in Africa, and in Benin in particular, and despite an increase in cashew production, the sector is subject to numerous constraints, including the combined influence of climatic factors (Balogoun et al., 2014). In Benin, two major zones are highly conducive to cashew tree cultivation, namely the Guinean zone and the Sudano-Guinean zone. The work of Gnanglè (2012) shows that in these cashew-growing areas, climatic factors such as the average number of rainy days and rainfall show a regressive trend (from 128 rainy days/year in 1960 to 80 rainy days in 2008). Variations in temperature (mean temperature), on the other hand, show an overall evolutionary trend, with a relatively higher growth rate in the Sudano-Guinean zone of 0.03°C per year from 1960 to 2008 (Gnanglè et al., 2011). According to the author, average relative humidity fell significantly between 1980 and 2008.

According to Balogoun et al (2014), the main constraints on cashew nut production are the vagaries of the weather, characterised by the scarcity and poor distribution of rain, the harmattan through dry and violent winds and low temperatures. According to the authors, this climatic variability has a negative impact on tree yields through drying trends, abortion and the fall of flowers, leaves and even fruits, thus reducing the number of fruits. These climatic variabilities, a major source of concern for farmers in general and cashew nut growers in particular, adversely affect crop yields through their impact on plant growth and development (Adesiji et al., 2012; Luka and Yahaya, 2012). This decline in crop yields due to poor soil and climate conditions is certain to lead to increased food insecurity, vulnerability of farming communities, reduced household incomes and increased poverty (Srivastava et al., 2012). The impacts of climate change on cashew trees have been studied in Côte d'Ivoire and Ghana in order to anticipate the consequences of this disruption on tree productivity (Weidinger and Tandjiékpon, 2014). In Benin, however, no study has yet been carried out on the impact of climate change on cashew trees.

This study was initiated with the aim of improving cashew nut productivity and quality by understanding the influence of climatic factors.

1. MATERIALS AND METHODS

1.1 Study Environment

This study was conducted in two agro-ecological zones favourable to cashew cultivation in Benin according to the division of the Institut National des Recherches Agricoles du Bénin (INRAB, 1995). These are the Central Zone (Zone 1) and the North West Zone (Zone 3) in Benin. In Zone 1, the communes of Glazoué and Savè were identified, while the commune of Djougou in Zone 3 was identified by the study.

The Commune of Savè enjoys a transitional climate between sub-equatorial and Sudanian, with an average rainfall of 1,100 mm. Analysis of the thermal situation shows that the first four and last three months of the year are generally the hottest. Two types of wind blow in the Savè region: monsoon and harmattan (Balogoun et al., 2014). The most dominant wind recorded is generally from the south or south-west, with a maximum average speed of 2m/s (ProDéCom, 2006). The highest wind speeds recorded are 13 to 15 m/s between May and June. The calculated average annual insolation is 1939 hours; the highest averages are recorded during the dry season, and the lowest during the rainy season (Dossouhoui, 2013). The Commune of Glazoué sometimes experiences two rainy seasons and two dry seasons, or one rainy season and one dry season. Average annual rainfall ranges from 959.56 to 1255.5mm (PDC, 2006); the average temperature varies between 24 and 29°C.

The climate in zone 3 is Sudanian (9°45'-12°25'N), with average rainfall of less than 1,000 mm and average relative humidity from 1960 to 2000 of 54.9%; the average temperature is 27.5°C (Gnanglè, 2012). This area essentially benefits from a mountain climate with slight variations (Balogoun et al., 2014). The Commune of Djougou enjoys two seasons, a rainy season from mid-April to mid-October and a dry season from mid-October to mid-April. From December to February, the Commune experiences the harmattan, a dry, cool wind (Balogoun et al., 2014) that blows from the Sahara westwards over West Africa (Orou Wari, 2011).

The targeted villages were generally selected on the basis of a number of criteria, including land availability, the accessibility of the area throughout the season, the openness of farmers to collaborating with the research team and the fact that some were already home to the agronomic trial. Table 1 lists the villages surveyed by zone.

Table 1: List of villages surveyed by zone

Zone	Communes	Village
Centre	Glazoué	Adourékoman
		Kabolé
	Savè	Atchakpa
		Gobé
North West	Djougou	Founga
		Daringa

1.2 Sampling and data collection method

In each village, cashew nut farmers aged 50 or over were identified along the lines of "focus groups". But in the specific case of our study, the people actually surveyed were farmers who still had a memory and above all who continued to maintain their farms themselves. In order to obtain reliable data, 40 farmers were selected from both the central and north-western regions.

Altogether, the individual survey was carried out using the method described by Dansi et al. (2010) and Nyanga et al. (2011) and it involved 80 producers with at least 10 years' experience of cashew nut production. In each of the selected villages, data were collected using questionnaires, individual and group surveys, and field visits (Kombo et al., 2012).

The data collected related to the socio-demographic characteristics of the households surveyed (gender, age, household size, level of education, years of experience in cashew cultivation, labour employed, farm size), the perceptions of producers regarding the effect of climatic events over the last ten years, and their impact on cashew productivity. These events include rainfall, winds, ambient temperature, sunshine duration, etc. Other data were also collected, such as the various adaptations to climatic factors affecting production. The actual areas considered are those corrected by the difference between the values declared and those measured with the Garmin eTrex 20 GPS from a sample of five farmers per village.

1.3 Data Processing and Analysis

The data from the survey were coded in Microsoft Excel and then analysed using SPSS (Statistical Package for the Social Sciences) version 16.0 to determine descriptive statistics in terms of percentages.

In order to subdivide all the different climatic factors into a smaller number of classes or groups made up of fairly homogeneous elements, a numerical classification taking into account the different climatic parameters over 10 years was undertaken using R software. In Africa in general, and in Benin in particular, local perceptions of phenomena and practices are very much influenced by habits and customs, which in turn depend on socio-cultural groups (Gnanglè et al., 2011). For this reason, the subjects surveyed were grouped according to the five main ethnic groups, namely the Idaacha and Mahi, in the Sudano-Guinean zone, and the Cotocoli, Peulh and Yom (in the Sudanian zone). Within each group, subjects were grouped according to two categories of age (adult = 50 to 70 years old; old = over 70 years old) and gender. (Assogbadjo et al., 2008; Gnanglè et al., 2011). Thus, overall, 12 socio-cultural categories (instead of the potential 20) taking into account the combination of the main ethnic groups, age and gender were considered (Table 2). The situation regarding the 12 socio-cultural categories instead of the potential 20 results from the absence in the sample studied of some respondents falling within combinations of age, sex and ethnic group modalities. The climate groups obtained were related to the various socio-cultural groups using principal component analysis (PCA) according to Uguru et al. (2011) in order to facilitate interpretation of the results of this classification.

Table 2 Numbers associated with the 12 main socio-cultural groups studied (N = 80)

Socio-cultural Groups	Codes	Workforce
Adult Women Idaacha	AFI	7
Adult Men Idaacha	AHI	21
Old women Idaacha	PFD	1
Old Men Idaacha	VHI	8
Old Men Mahi	VHM	2
Adult Men Mahi	AHM	1
Adult Men Yom	AHY	20
Old Men Yom	VHY	5
Adult Women Yom	AFY	2
Adult Fulani men	AHP	8
Adult Men Cotocoli	AHC	4
Old Men Fulani	VHP	1

2. RESULTS

2.1 Perception of the quality of climatic factors on cashew trees

Figure 1 shows the results of the descriptive analysis of the effect of climatic factors on cashew trees in 2013. The analysis of these results shows that, generally speaking, for the majority of farmers, the various climatic factors had a negative impact on cashew trees, with the exception of sunshine, which was good in central Benin.

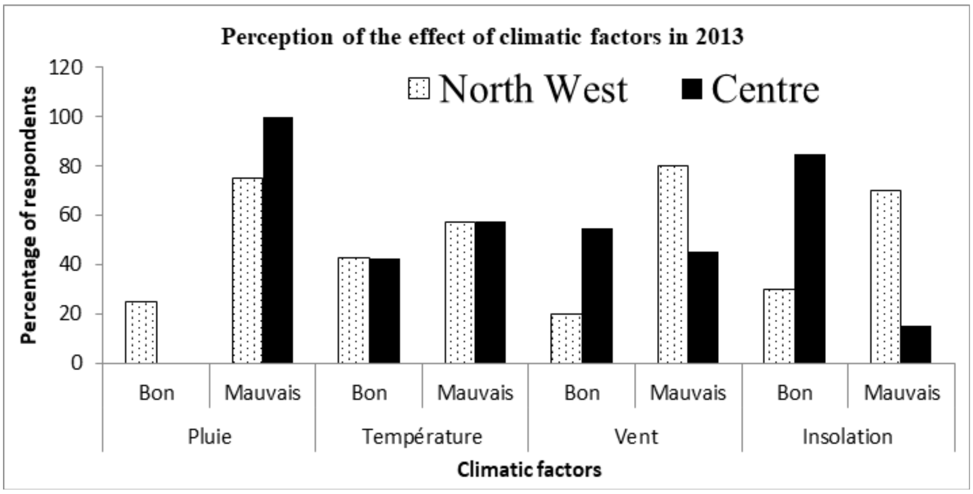

Figure 1: Perception of the effect of climatic factors on cashew trees in 2013

2.2 Perception of major climate variations according to socio-cultural groups

The result of grouping the various climatic parameters, namely quantity of rainfall, rainfall trend, rainfall distribution, number of rainy days, wind speed, ambient temperature, sunshine, number of sunny days and number of cloudy days over the last 10 years prior to 2013, is presented in the form of a dendrogram (Figures 2 and 3). Based on the results of the dendrogram, the initial information allows us to classify these climatic parameters into five groups in the Centre (Figure 2) and three groups in the North West (Figure 3).

In the Centre (Figure 2), the first group comprises:

- ambient temperature (2010 to 2012),
- sunshine (2010 to 2012) and
- number of rainy days (2010 to 2012).

The second group includes:

- rainfall trends (2010 to 2012;
- rainfall distribution (2010 to 2012) and
- wind (2003 to 2009).

The third group comprises:

- rainfall trends (2003 to 2009),
- rainfall distribution from (2003 to 2009) and
- wind (2010 to 2012),

The fourth group includes:

- number of rainy days (2003 to 2009),
- temperature (2003 to 2009) and
- sunshine (2003 to 2009) and

Group 5 covers the number of cloudy and sunny days.

In the north, the first group includes (Figure 3):

- rainfall, rainfall trends and number of rainy days over 10 years.

The second group concerns:

- rainfall distribution, temperature, wind and sunshine over 10 years.

The third group includes:

- the number of cloudy and sunny days over 10 years.

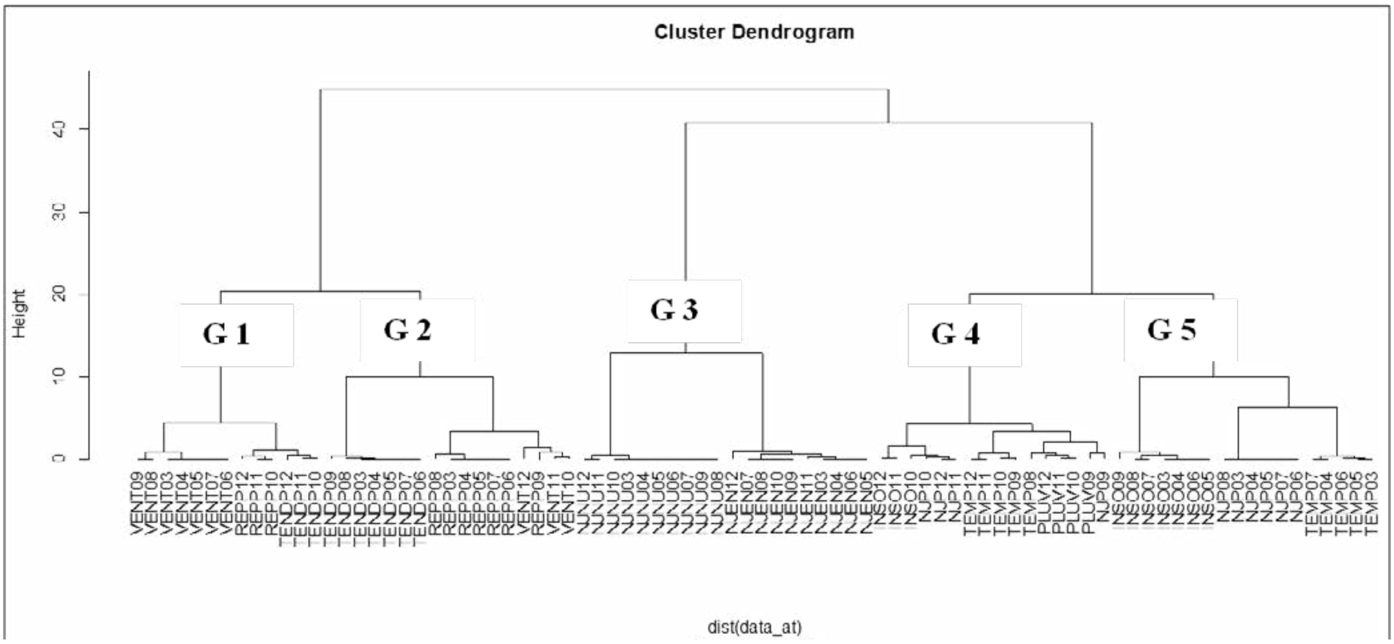

Figure 2: Dendrogram showing the different groups of climatic factors in the Centre (Sudano-Guinean zone).

PLUV=Pluviometry; **TENDP**= Rainfall pattern; **REPP**= Rainfall distribution; NJP= Number of rainy days; TEMP= Ambient temperature; VENT= Wind speed; **NJEN**= Number of sunny days; NJNU= Number of cloudy days. These various parameters are followed by different......

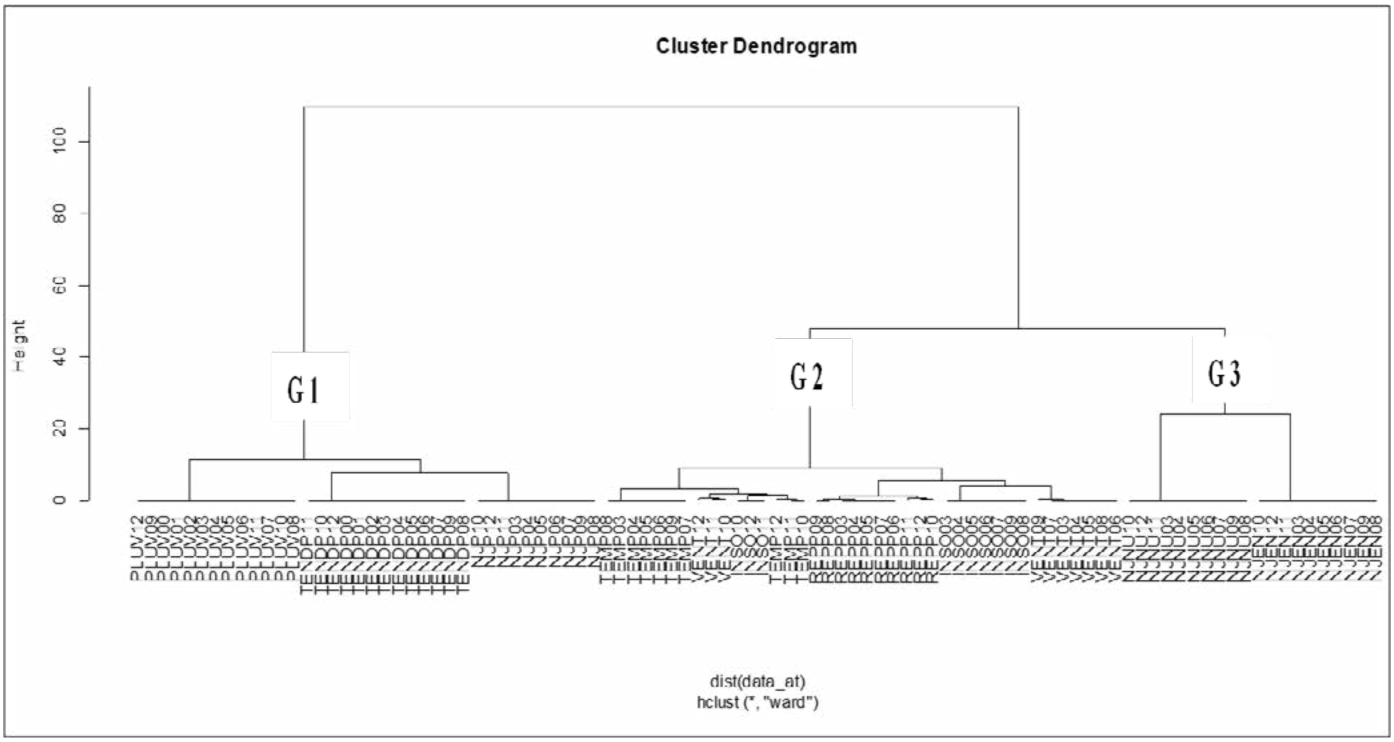

Figure 3: Dendrogram showing the different groups of climatic factors in the North West (Sudanian zone)

PLUV=Pluviometry; **TENDP**= Rainfall pattern; REPP= Rainfall distribution; **NJP**= Number of rainy days; **TEMP**= Ambient temperature; **VENT**= Wind speed; NJEN= Number of sunny days; **NJNU**= Number of cloudy days. These various parameters are followed by different......

At the Centre, the results of the principal component analysis on the various climatic and socio-cultural groups were used to describe the relationships between these perceptions of variations in climatic factors and to refine their analysis. The results show that the first two axes explain 97% of the total information. The first principal component contrasts temperature, sunshine and the number of rainy days from 2010 to 2012 with the number of cloudy days, rainfall and its distribution from 2010 to 2012, and wind from 2003 to 2009 (Figure 4). The result is that from 2010 to 2012, high and well-distributed rainfall is accompanied by low temperature and sunshine. The second component contrasts with the rainfall and its distribution from 2003 to 2009 and the wind from 2010 to 2012 with the number of days of rainfall, temperature and sunshine over the period from 2003 to 2009. Thus, from 2003 to 2009, high and well-distributed rainfall is often associated with low temperature and sunshine. (Figure 4). Projecting the 12 socio-cultural groups (Table 2) onto the system of axes defined by the climatic factors (Figure 4) reveals that Idaacha adults and Idaacha and Mahi old men perceive that during the period from 2003 to 2009, rainfall intensity was high and well distributed, while temperature and sunshine were low. In contrast, Mahi male adults felt that rainfall was high and well distributed. They also perceived a low temperature and low sunshine during the same period. The old Idaacha women, on the other hand, disagreed with the perception of the adult Mahi men (Figure 4).

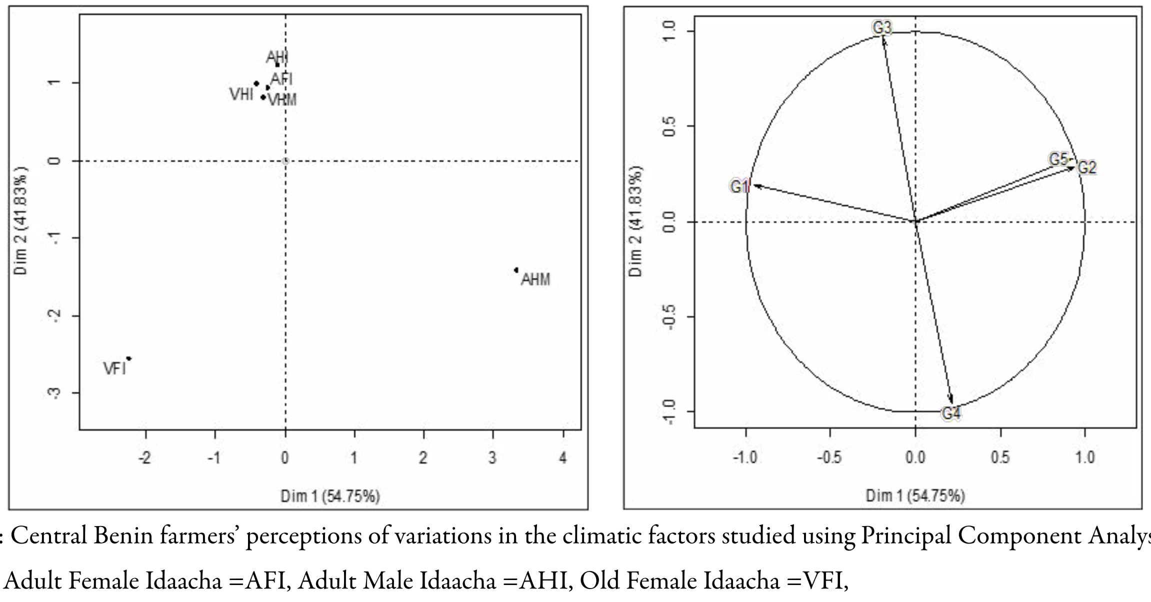

Figure 4: Central Benin farmers' perceptions of variations in the climatic factors studied using Principal Component Analysis (PCA)

Legend: Adult Female Idaacha =AFI, Adult Male Idaacha =AHI, Old Female Idaacha =VFI,

Old Men Idaacha =VHI, Old Men Mahi =VHM; Adult Men Mahi=AHM

In the North, the results of the principal component analysis show that the first two axes explain 93.55% of the total information. The first component involves rainfall, temperature, wind, and cloudy and sunny days (Figure 5). The result is that the good amount of water that fell over the 10 years was well distributed and associated with less wind and better temperature than in 2013. Projecting the 12 socio-cultural group categories (Table 2) onto the system of axes defined by the climatic factors (Figure 5) reveals that Yom adults and old Fulani men perceive that there was a lot of rain and that it was well distributed over the 10 years. Female adults and old Yom men perceived a decrease in wind speed, sunshine and temperature, as well as in the number of rainy days from 2003 to 2012 (Figure 5). These analyses show that adults in the various socio-cultural groups perceived an improvement in the level of all climatic factors over the 10 years prior to 2013, more so than older people.

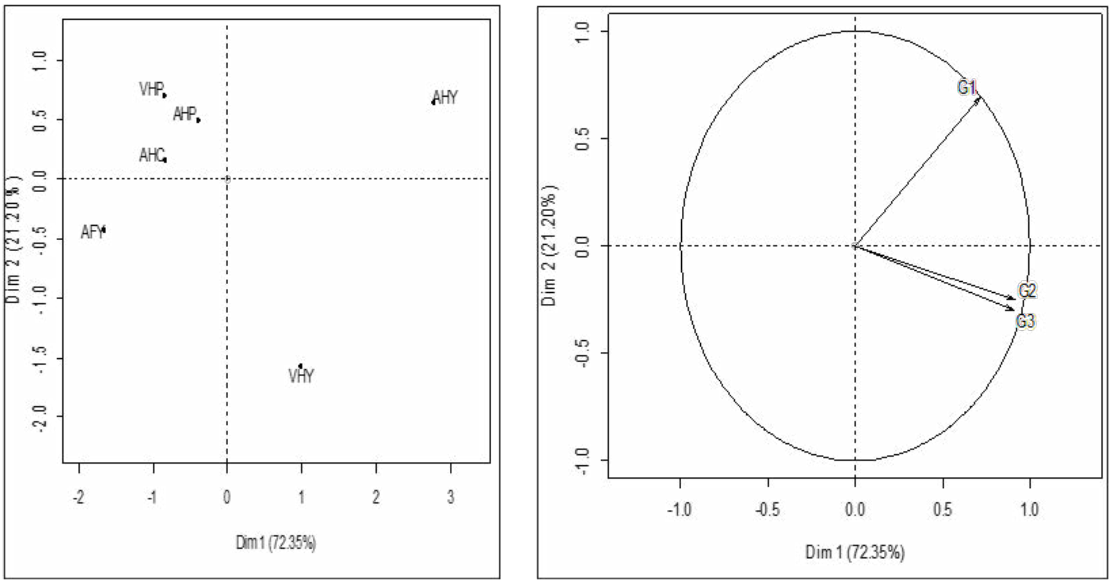

Figure 5: North Benin farmers' perceptions of variations in climatic factors studied using Principal Component Analysis (PCA)

Legend: Adult Men Yom =AHY; Old Men Yom =VHY; Adult Women Yom = AFY;

Adult Men Fulani = AHP; Adult Men Cotocoli = AHC; Old Male Fulani = VHP.

2.3 Farmers' perceptions of climatic factors affecting cashew yield over the last ten years

The descriptive analysis carried out on all farmers reveals that from 2003 to 2012, more than 95% of farmers obtained an increase in cashew nut yield ranging from 50 to more than 100% compared to the production obtained during the 2013 season. These producers claim that this is essentially due to the failure of certain climatic factors. The remaining producers, less than 5% of the total number, obtained a decrease of 5 to 10% compared to 2013. They indicate that the main reason for this was the destruction tof their farms by bush fires and the felling of certain trees to thin the farms.

Tables 3 and 4 present the results of multinomial regression in central and north-western Benin on the effect of climatic factors on cashew production from 2003 to 2012. Analysis of these results shows that for all producers in the two production zones, an increase in the amount of rainfall, an increase in the number of rainy days, less violent winds, a decrease in average temperature and a decrease in sunshine were among the climatic parameters that very significantly ($P < 0.01$) impacted the increase in yield compared with the 2013 season. These different parameters, particularly those that were significant by year, were subjected to multinomial regression in order to identify the most relevant factors that determined the yield increase according to the farmers.

Table 4 presents the results of the multinomial regression analysis in central and north-western Benin. These results, according to the farmers, show that the wind was less violent, average temperature decreased, and especially rain increased in quantity; the number of rainy days increased; these climatic factors have had a very significant impact ($P < 0.001$) on yield increases over the last ten years. As a result, the decrease in the number of rainy days, the stronger winds, the increase in temperature and above all the delay and decrease in the amount of rain observed in 2013 were the climatic factors that caused the drop in production noted by research and farmers in 2013.

Table 3: Results of multinomial regression in Central Benin on the effect of climatic factors on cashew production from 2003 to 2012

Climate parameter	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square
PP	12,25***	10,40***	16,92***	13,01***	7,12**	23,98***	26,13***	26,13***	26,13***	26,13***
MP	5,94**	1.57ns	1.45ns	-	-	-	-	-	-	-
PMF	0.2ns	0.04ns	0.07ns	1.46ns	14,06***	23,98***	17,83***	17,83***	17,83***	17,83***
ANJP	0.34ns	15,14***	0.01ns	18,34***	9,68**	7,62**	24,47***	24,47***	24,47***	24,47***
DNJP	-	-	-	-	-	3.29ns	-	-		-
ATMx	1.32ns	0.88ns	0.82ns	5,49**	-	-	-	-	-	-
DTMx	**2.91ns**	**3.02ns**	0.38ns	-	23,10***	23,98***	26,02***	26,02***	26,02***	26,02***
ATMn	-	-	-	-	3.46ns	-	-	-	-	-
MV	26,91***	**0.28ns**	3.30ns	25,85***	17,37***	23,98***	26,13***	26,13***	26,13***	26,13***
MS	**1.03ns**	-	O,82ns	-	17,37***	12,69**	26,13***	26,13***	26,13***	26,13***
Other	**1.25ns**	**0.75ns**	0.91ns	1.00ns	3.46ns	13,29**	0.02ns	0.02ns	0.02ns	0.02ns

*: significant at the 0.05 threshold; **: very significant at the 0.05 threshold; ***: very highly significant at the 0.05 threshold.

PP: More rain; MP: Less rain; PMF: Less rain; ANJP: Increase in the number of days of rain; DJNP: Decrease in the number of days of rain; ATMx: Increase in the maximum temperature; DTMx: Decrease in the maximum temperature; ATMn: Increase in the minimum temperature; MV: Less wind; MS: Less sunshine; - = effects not reported by farmers.

Table 4: Results of multinomial regression in North-West Benin on the effect of climatic factors on cashew production from 2003 to 2012

Climate parameter	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square
PP	25,78***	18,05***	24,12***	9,29**	35,53***	27,30***	27,30***	27,30***	27,30***	27,30***
MP	0.07ns	-	-	-	-	-	-			
PPF	10,78**	7,76**	7,76**	1.36ns	0.95ns	0.54ns	0.54ns	0.54ns	0.54ns	0.54ns
ANJP	4,76*	7,70**	7,70**	1.96ns	1.28ns	4,92*	4,92*	4,92*	4,92*	4,92*
ATMx	0.05ns	0.002ns	0.002ns	0.25ns	1.47ns	2.43ns	2.43ns	2.43ns	2.43ns	2.43ns
DTMn	-	-	4,82*	0.002ns	0.47ns	0.33ns	0.33ns	0.33ns	0.33ns	0.33ns
PV	**3.20ns**	**3.41ns**	1.39ns	0.62ns	0.43ns	0.000ns	0.000ns	0.000ns	0.000ns	0.000ns
MV	**0.54ns**	**1.39ns**	-	-	-	-	-	-	-	-
PS	**1.79ns**	**0.85ns**	2.42ns	0.76ns	2.67ns	3,85*	3,85*	3,85*	3,85*	3,85*
MS	**1.56ns**	**1.66ns**	1.66ns	0.15ns	1.47ns	2.43ns	2.43ns	2.43ns	2.43ns	2.43ns
Other	23,52***	6,18**	11,96***	7,94**	21,65***	14,81***	14,81***	14,81***	14,81***	14,81***

*: significant at the 0.05 threshold; **: very significant at the 0.05 threshold; ***: very highly significant at the 0.05 threshold.

PP: More rain; MP: Less rain; PPF: More rain; ANJP: Increase in the number of days with rain; ATMx: Increase in the maximum temperature; DTMn: Decrease in the minimum temperature; MV: Less wind; PS: More sunshine; MS: Less sunshine; - = effects not reported by farmers.

Table 5: Result of the multinomial regression showing the most relevant climatic factors influencing cashew production in the Central and North-Western Zones of Benin.

Year	Climatic factors	Centre zone		North West zone	
		Estimated value	KHI-2	Estimated value	KHI-2
2012	More rain	-2,17	5,51**	-3,2	10,41***
	Less Wind	-5,77	15,33***	-	-
2011	More rain	-6,54	14,86***	-3,03	9,63***
	Increase in the number of rainy days	-2,52	11,47***	-	-
2010	**More rain**	-5,45	14,79***	-3,91	8,66***
	Increase in the number of rainy days	-	-	-2,96	7,43*
2009	**More rain**	-	-	-3,01	13,67***
	Increase in the number of rainy days	-3,34	4,27*	-	-
	Less Wind	-3,82	5,19*	-	-
2008	**More rain**	-	-	-3,01	13,67***
	Lower ambient temperature	-3,30	6,72**	-	-
	Less sunshine	-4,13	14,85***	-	-
2007	**More rain**	-5,40	23,98***	-5,14	7,39**
2006	**More rain**	-5,40	23,98***	-5,14	7,39**
2005	**More rain**	-5,40	23,98***	-5,14	7,39**
2004	**More rain**	-5,40	23,98***	-5,14	7,39**
2003	**More rain**	-5,40	23,98***	-5,14	7,39**

*: significant at the 0.05 threshold; **: highly significant at the 0.05 threshold

***: very highly significant at the 0.05 threshold

2.4 Farmers' perceptions of the effect of climatic factors on cashew phenological parameters

Analysis of the results relating to farmers' perceptions of the impact of climatic factors, particularly rain, wind, temperature and sunshine, on cashew phenological parameters in the two cashew-growing areas during the 2013-2014 season (Table 6), shows that, in general, the delay and decrease in the amount of rainfall observed by farmers in 2013 favoured the late appearance of fruit in the Centre and the drying out of flowers (Figure 6) in north-west Benin. The increase in ambient temperature had no positive effect on any of the parameters, but did favour a reduction in the number of flowers in the Centre ($P < 0.01$), whereas it favoured an early appearance and a large number of flowers in the North. As for the winds (strong winds and harmattan), they mainly caused flowers to fall, decrease in number and dry out ($P < 0.001$) in the two production zones visited. On the other hand, sunshine had no effect in the north-west, while in the centre it favoured the early appearance of flowers, an increase in the number of flowers but also their fall. These analyses show that, according to farmers, the climatic factors studied had negative effects on phenological parameters in 2013, which was often not the case in previous seasons. For over 98% of farmers, previous years had better rainfall and less wind than 2013. This has often led to better flowering, with fewer flowers falling off. However, the climatic factor most blamed by farmers remains the variability of rainfall. Mild winds favour an increase in the number of flowers and their viability, while rainfall and its good distribution, combined with average temperatures, mean that the new leaves and flowers come out on time.

Figure 6: Dried cashew flowers

Table 6: Results of multinomial regression analysis on the effect of climatic factors on cashew phenological parameters

	Climate parameters							
	Central zone				North-West zone			
	Rain	Temperature	Wind	Sunshine	Rain	Temperature	Wind	Sunshine
Phenological parameters	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square	Chi-Square
No Positive Effect	-	11,47***	21,40***	-	0.08ns	0.05ns	-	-
Fall of the Flowers	0.44ns	3.68ns	20,33***	39,85***	0.89ns	1.09ns	17,78***	0.03ns
Early flowering	**0.68ns**	**0.78ns**	1.67ns	30,39***	0.08ns	4,29*	-	-
Increase in the number of flowers	**2.39ns**	**0.10ns**	0.01ns	7,62**	-	5,86*	-	-
Reduction in the number of flowers	**0.05ns**	**9,86****	-	-	0.77ns	0.17ns	19,57***	0.005ns
Late flowering	-	-	-	-	0.16ns	-	-	0.002ns
Early appearance of fruit	-	**0.76ns**	-	-	-	1.36ns	-	-
Late appearance of fruit	**9,23****	**1.39ns**	-	-	0.25ns	-	-	-
Flower dryness	**2.39ns**	**0.10ns**	0.51ns	-	5,86*	0.29ns	17,79***	0.07ns
Other	**0.03ns**		-	-	2.56ns	1.40ns	0.07ns	0.05ns

- = effect not reported by farmers

*: significant at the 0.05 threshold; **: very significant at the 0.05 threshold; ***: very highly significant at the 0.05 threshold.

3. DISCUSSION

The adverse effects of the parameters are perceived by cashew farmers, who say that strong winds and pockets of drought, the December and January rains affect cashew productivity through the fall of flowers, their early appearance, and above all, their drying out. This result is in line with that of Ricau (2013), who showed that cashew trees produce during the dry season and are particularly productive when rainfall is regular during the rainy season and temperatures are not too high during the dry season. A very irregular rainy season, even if the volume of rainfall is high, will therefore be unfavourable to tree productivity. Rainfall and its good distribution therefore favour good yields, while mild winds combined with a good average temperature favour an increase in the number of fruits. According to Ricau (2013), the period when climatic conditions are most decisive is flowering and the start of fruiting. During this period, excessively high temperatures, dry or strong winds, thunderstorms and hail can cause enormous damage to the flowers or young, immature fruit and reduce the number of fruits per plant.

Loko et al (2013) also obtained similar information from yam growers in north-west Benin. According to the authors, producers in this region of the country indicated that good rainfall, average temperature, mild wind and average sunshine are ideal conditions for the growth and development of plants in general and yams in particular. The best climatic conditions in the past (good and regular rainfall, average temperature and less violent winds) are those that are responsible for the good yields obtained compared with the low yields currently obtained (Loko et al., 2013).

This study shows that cashew growers in Benin have a good understanding of the variability of climatic factors and its effect on the tree's phenological and yield parameters. According to the growers, the climatic variability experienced in 2013, which was marked by periods of drought and delayed rainfall, had a negative impact on cashew production. These negative effects were to be expected, since according to Ayanlade et al (2010), rainfall is the most important climatic factor influencing agricultural activities in tropical zones. The drop in yields reported by farmers during the 2013-2014 season as the main impact of climate change on cashew cultivation was also noted on other crops such as yam (Loko et al., 2013), cowpea (Ajetomobi and Abiodun, 2010), rice (Nwalieji and Uzuegbunam, 2012) and sorghum (MacCarthy and Vlek, 2012). The same applies to insect proliferation, which has been reported as an impact of climate variability on sesame (Luka and Yahaya, 2012). These climatic factors are contributing to a reduction in the area sown by cashew growers, as is the case with sorghum in Ghana (MacCarthy and Vlek, 2012). There is therefore an urgent need to develop effective adaptation strategies, in particular regular maintenance of the plantation and pruning of old branches, in order to maintain its popularity with growers (MacCarthy and Vlek, 2012), given its importance to the Beninese economy.

CONCLUSION

This study has shown that cashew growers in central and north-western Benin are well aware of the variability of climatic factors in their respective areas. They also have a good perception of both their effects (increased temperature, reduced rainfall, violent winds, etc.) and their impact on cashew productivity.

Although the study revealed, among other things, that it was mainly men and adults who perceived these effects more strongly, women and the elderly must under no circumstances be excluded from national policies to reduce the impacts of climate change on cashew trees. Government policies and research must therefore take into account farmers' perceptions of climate variability in order to propose adaptation strategies.

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AGRONOMIC AND NUTRITIONAL EFFICIENCIES DUE TO THE APPLICATION OF NUTRIENTS TO CASHEW TREES (*ANACARDIUM OCCIDENTALE* L.) IN BENIN

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SUMMARY

Cashew trees are grown in Benin without fertilisers, with adverse consequences for the sustainability of production systems. The aim of this study is to evaluate the agronomic, recovery and physiological efficiencies resulting from the application of different fertilisers to cashew trees, depending on their age category. To this end, four- and eight-year-old trees were fertilised during two production seasons in farmers' plantations in the village of Adourékoman (Commune of Glazoué) in central Benin. The treatments considered were: absolute control with no fertiliser applied, mineral fertilisation and organo-mineral fertilisation. Nutrient exports and nutrient use efficiency by cashew apples and nuts (almonds and hulls) were the main parameters tested. Nitrogen was the nutrient taken up most by the trees, both in the nuts (an average of 75.71 and 112.43 g N/tree respectively for 4- and 8-year-old trees at the start of the trial) and in the apples (an average of 173.85 and 199.06 g N/tree respectively for 4- and 8-year-old trees at the start of the trial). The application of organo-mineral fertiliser had the greatest influence on the total quantity of nutrients mobilised in both apples and cashew nuts, regardless of tree age. The highest agronomic and recovery efficiencies were obtained in the trees that received organo-mineral fertiliser (21.15 g/g; 22.25 g/g; 1.99 g/g; 2.97 g/g for agronomic efficiency and 32.13%; 28.25%; 12.56%; 17.75% for recovery efficiency). Organo-mineral fertilisation, on the other hand, produced the lowest values for physiological efficiency. Adding value to cashew apples will considerably improve the income of cashew growers.

Key words: Soil fertility, cashew plantation, efficiencies, plant nutrition, integrated soil management.

INTRODUCTION

Cashew (Anacardium occidentale L.) occupied around 5.35 million hectares of plantations in 2011 worldwide (FAO, 2014). In Benin, cashew is currently the second most important export crop after cotton (Yabi et al., 2013; Balogoun et al., 2014). In 2011, the country ranked sixth in the world with around 3.8% of the volume of nuts produced and third among West African countries after Nigeria and Cote d'Ivoire (FAO, 2014). Despite the favourable situation for the development of the crop in Benin, a large number of constraints are still holding back the upstream development of the sector. The study by Balogoun et al (2014) shows that current plantation management practices, i.e., irregular plantation maintenance and a very low level of fertiliser use, do not allow for a significant increase in cashew apple and nut productivity in Benin. Current production yields are less than 300 kg/ha (Balogoun et al., 2014). Production is therefore strictly mining, with virtually no use of inputs such as fertilisers to improve soil fertility. Faced with this situation, several solutions have been proposed, including fertilising cashew trees. These will not only improve soil productivity, but above all improve nut and apple yields (Biaou, 2014). Improving nut productivity and exporting nutrients requires integrated soil fertility management to make production competitive.

Fernandopulle (2000) has shown that regular application of major nutrients (nitrogen, phosphorus and potassium) is beneficial for tree health and increasing cashew yields. However, in the context of sustainable agriculture, we should not limit ourselves to simply recommending fertilisers to crops, but rather to optimising the use of mineral elements by crops (Malcolm, 2011). The unbalanced, inadequate or excessive use of fertilisers is one of the major causes of low yields in most African countries (Doberman, 2007).

Inefficient use of nutrients in fertilisers contributes to depletion of financial resources, increased production costs and potential environmental risks (Tarekegne and Tanner, 2001). This implies improving absorption efficiency and determining the efficiency with which nutrients are used by crops, hence the need to determine efficiencies (Janssen, 1998). Nutrient use efficiency is an important concept for evaluating production systems in general and can be significantly affected by applied fertiliser management practices (Fixen et al., 2014).

The efficiency with which nutrients are used by a plant can be defined as the yield per unit of fertiliser applied or in terms of the recovery of the fertiliser applied (Malcolm, 2011). In fact, not all the nutrients contained in fertilisers applied to crops are taken up by the crops. The difference between nutrient uptake efficiency and nutrient use efficiency may be associated with better root geometry, the plant's ability to take nutrients from low concentrations in the soil, the plant's ability to solubilise nutrients in the rhizosphere, better transport and distribution of nutrients within the plant (Baligar et al., 2001; Fageria and Barbosa Filho, 2001; Fageria and Baligar, 2003). Thus, in order to measure the effectiveness of fertilisation, it makes sense to determine the quantity of nutrients actually absorbed and the quantity contributing to the formation of the various cashew products. To this end, determining agronomic effectiveness and efficiencies linked to the uptake of the various nutrients contained in the fertilisers applied will make it possible to analyse the profitability of fertiliser inputs, the reduction of potential risks of losses (sources of pollution) and the sustained increase in yields.

Furthermore, the use of fertilisers on cashew plantations, while respecting the doses and application techniques, will enable Benin to rank among the top five nut exporting countries in the world, and to top the list of West African countries in terms of quality production.

Additionally, the evaluation of the different efficiencies will make it possible to analyse the profitability of the different fertilisation practices that will be proposed to producers and the internal nutritional balance of the plant. However, it has to be said that very few, if any, studies have been carried out to assess the efficiencies of fertilisers applied to cashew trees in Benin. The rare studies measuring efficiency have only been carried out on annual crops, particularly cereals. This study will help to fill this gap.

I. MATERIALS AND METHODS

1.1 Description of the study environment

This study was carried out in central Benin in the village of Adourekoman (Commune of Glazoué) located at latitude 7°91'58''N and longitude 2°27'30''E at an altitude of 152 m. The commune of Glazoué was chosen because of the size of the area planted with cashew trees and nut production in Benin. The study area is under the influence of a transitional climate between sub-equatorial in the south and Sudanian in the north. Average annual rainfall ranges from 960 to 1256 mm and average annual temperature varies between 24 and 29°C (Balogoun et al., 2016). The soils are predominantly leached tropical ferruginous types formed on Precambrian crystalline rocks (granite and gneiss) classified as Ferric Lixisol (FAO, 1990). The chemical characteristics of the soil before the trial are provided in Table 1.

Table 1 Chemical characteristics (mean ± standard errors) of the soil at the experimental site was set up before the trial

Soil depth (cm)	pH(water)	pH(KCl)	C-Organic (g/kg)	N Total **(g/kg)**	P Bray1 (mg/kg)	K sample (cmol/kg)
0-20	6,31±0,04	5,39±0,05	11,09±0,47	1,25±0,08	39,14±5,58	0,86±0,05
20-40	6,35±0,04	5,44±0,05	8,27±0,33	0,93±0,08	39,24±5,50	0,82±0,04
40-60	6,37±0,05	5,33±0,05	6,68±0,33	0,97±0,08	42,77±6,07	0,85±0,04

I.2 Materials used

Simple mineral fertilisers: KCl (60% K2 O), super triple phosphate (46% P O25) and urea (46% N), were used to fertilise cashew trees. Cattle dung manure was used as organic fertiliser because of its availability in the study area. An electronic scale (Tefa brand, 3 kg capacity) was used to weigh mineral fertilisers. A Weiheng brand scale with a 40 kg capacity was used to weigh nuts and apples, and a spring-loaded pocket scale with a 50 kg capacity was used to weigh manure.

I.3 Choosing plantations and setting up trials

The trees studied were identified following a forest inventory of cashew plantations carried out from June to July 2013 (Chabi Sika et al., 2015). They were chosen taking into account the uniformity of tree age due to the fact that recommended fertiliser doses are a function of tree age. For example, trees aged 4 and 8 years were selected during the first season (2013-2014). This would mean that these trees are 5 and 9 years old respectively in the second season (2014-2015). Information on the age of cashew plantations was provided by the farmer based on the transplanting date of seedlings purchased from nurserymen in the region. Twelve trees per age category were selected as replicates for data collection. Three treatments were considered:

T0: Control plants without fertiliser;

T1: Plants fertilised with mineral fertiliser;

T2: Plants fertilised with mineral and organic fertiliser (organo-mineral fertilisation).

Table 2 shows the quantities of fertiliser applied per tree according to age.

Table 2 Fertiliser doses and quantities of mineral fertiliser applied per cashew tree according to plantation age for treatment T1

Production season	Age of plantations (years)	Nutrient doses (g/tree)*			Quantities (g) of simple mineral fertiliser applied per tree		
		N	P	K	Urea	TSP	KCl
2013-2014	4	289	217	144	628	1081	290
	8	364	273	364	791	1360	731
2014-2015	5	356	267	178	774	1330	357
	9	364	273	364	791	1360	731

* Source: Tandjiékpon et al (2005)

The experimental unit consisted of 2 age categories x 3 treatments x 12 replications, that is, a total of 72 trees. The nutrient doses applied were those recommended by the extension services for cashew trees in Benin (Tandjiépkon et al., 2005). The amount of manure applied was calculated on the basis of its chemical composition. The nutrient content of the manure used was as follows: N-total (3.29 g/kg), C-organic

(255.41 g/kg), K (48.24 g/kg) and P (1.22 g/kg). The dose of organic fertiliser applied to treatment T2 was calculated on the assumption of an equitable supply of the major nutrients in mineral and organic form. The calculations were based on the nutrient composition of the manure, the quantity of nutrients supplied in the form of mineral fertiliser in treatment T1 and the average annual mineralisation rate of 2% in tropical zones (Pieri, 1989). Major nutrients (N, P and K) were supplemented in the form of mineral fertiliser in comparison with the equivalent T1 treatment. To achieve this, straight fertilisers (urea 46% N; TSP 46% P O25 and KCl 60% K2 O) were used. Table 3 shows the quantities of cattle manure applied per tree and per age category for treatment T2.

Table 3: Quantities of cattle manure applied and fertiliser content per tree according to plantation age for treatment T2

Production season	Age of plantations (years)	Quantity of manure applied (kg/tree)	Mineral fertiliser supplement (g/tree)			Amount of fertiliser (g) applied per tree		
			N	P	K	Urea	TSP	KCl
2013-2014	4	355,5	205,1	194,04	35,93	445	965	71
	8	589,5	222,75	234,92	184,8	484	1170	372
2014-2015	5	355,5	272,1	244,04	69,93	592	1215	140
	9	589,5	222,75	234,92	184,8	484	1170	372

1.4 Conducting the tests

Before fertilisers were applied, a root profile was made of some of the trees to assess root distribution. Most of the roots were located within 1.5 m of the trunk and distributed at a depth of 35-40 cm. The fertiliser was therefore applied in the form of a ring around the trees over a diameter of 3 m and a depth of 40 cm, based on the results of the observation of the root profile. The application holes were then closed to limit losses through volatilisation and leaching.

1.5 Data collection methods

The yield parameters measured were the weights of cashew nuts and apples per tree. Estimates of nut and apple yields per tree were made throughout the fruit production period, during the 2013-2014 and 2014-2015 production seasons. The nuts were collected daily and weighed separately to determine the yield per tree. The ratio of apple weight to nut weight was calculated from the 10 randomly selected fruits in order to determine the weight of the apples from the total weight of the nuts.

1.6 Chemical analysis of cashew products

Samples of apples and walnuts were collected, pre-sun-dried in the field and then oven-dried at 65°C in the soil science laboratory of the Faculty of Agricultural Sciences at the University of Abomey-Calavi. Given their perishable nature, the apples were first cut into strips before being pre-dried in the sun to reduce their water content. They were then oven-dried to constant weight (96 hours). The nut samples were shelled to recover the kernels and shells. The kernels and shells were placed separately in paper envelopes and weighed. Each part of the fruit was ground using an iron mortar for laboratory analysis. A total of 72 samples were taken for each type of product (apples, almonds and hulls). The analyses were carried out at the ISO 17025-accredited Soil, Water and Environment Laboratory of the National Agricultural Research Institute of Benin (LSSEE/INRAB) and focused on determining:

Total nitrogen by the Kjeldahl method, consisting of wet digestion in the presence of H2SO4 and selenium. After digestion, the substrate was distilled by steam distillation in the presence of 1N NaOH, followed by titration with 0.1N sulphuric acid (H2 SO4);

Total phosphorus using the Duval method, which involves calcinating the sample at 550°C overnight. The ash was collected in a solution of HNO3 1N, heated slightly and then filtered into a flask. The filtrate was stained with ammonium molybdate in the presence of ascorbic acid, and the intensity of the staining was determined by colorimetry at a wavelength of 660 nm;

Total potassium, calcium and magnesium by Atomic Absorption Spectrophotometry. The rest of the extracts obtained from the ash collected in the HNO3 1N solution were used for these determinations.

1.7 Determination of nutrient exports by different cashew tree products

The total quantities of nutrients exported in apples and nuts (kernels and shells) considering the age of the trees and the different treatments were determined by multiplying the nutrient contents (of apples and nuts) by the apple and nut yield of each tree (Abegaz, 2008). For apples, nutrient exports in g/kg of fresh matter were estimated from the average water content of apples, which is 87.5% (Lautié et al. 2001; Soro, 2012). Nutrient exports were calculated as follows:

$U_x = Y_y * T_x$

with U_x , the export of nutrient x in product y (g of nutrient x exported per tree).

Y_y, the yield of product y (kg/tree);

T_x, the nutrient x content of product y (g of nutrient x per kg of product y).

1.8 Calculation of nutrient efficiencies of different cashew products

The efficiencies determined in this study are: agronomic efficiency (AE), recovery efficiency (RE) and nutrient use efficiency (NUE).

The agronomic efficiency (AE) of the nutrients N, P and K was calculated for each product (apple and walnut) considering the different treatments and the age categories of the trees according to the formula of Doberman (2007):

$EAx=(YT-Y0)/Fx$

with:

EAx: Agronomic efficiency of nutrient x for product y (g of product y per g of nutrient x per tree)

YT : Yield of product y obtained from fertilised trees (g/tree)

Y0: Yield of product y obtained from unfertilised control trees (g/tree)

Fx: Total quantity of nutrient x supplied (kg/tree).

The recovery efficiency (RE) of the nutrients N, P and K was calculated for each product (apple and walnut) considering the different treatments and the age categories of the trees according to the formula developed by Doberman (2007). This is a partial efficiency calculation, as it does not take into account nutrients found in the biomass. As cashew is a perennial species, the nutrients contained in the leaves are recycled in the form of litter to the benefit of the tree. The recovery efficiency (RE) was determined by the formula:

$ERx=(Ux-U0)/Fx$

with:

ERx: Recovery efficiency of nutrient x for product y (g of nutrient x exported per g of nutrient x applied)

Ux: the total quantity of nutrient x removed by the product y from the fertilised trees (g nutrient x exported per tree)

U0: the total quantity of nutrient x removed by the product y from unfertilised trees (g nutrient x exported per tree)

Fx: Total quantity of nutrient x applied (g/tree).

N, P and K nutrient use efficiency was calculated for each product (apple and walnut) considering the different treatments and tree age categories using the formula developed by Janssen (1998).

$EUx=EAx/ERx$

with:

EUx: Efficiency of use of nutrient x (kg of product y per g of nutrient x exported)

EAx: Agronomic efficiency of nutrient x (kg of product y per g of nutrient x applied)

ERx: Recovery efficiency of nutrient x (g of nutrient x exported per g of nutrient x applied).

1.9 Statistical analysis of data

Microsoft Excel (version 10) was used to enter and process the data. Analyses of variance were performed using the general linear model of the Statistical Analysis System software (SAS version 9.2). For walnut and apple yields, the analysis of variance model used was a mixed model with two factors (production season and fertiliser type) per tree age category at the start of the trial. In relation to nutrient concentration in apples, almonds and shells in the 2014-2015 season, the ANOVA model used is the two-factor fixed model (tree age and fertiliser type). The Student Newman-Keuls test at the 5% threshold was used to compare means.

As the overall averages of nut yields and nutrient concentrations in the nuts for the different types of fertiliser were used for the export and efficiency estimates, no statistical analysis was carried out for these exports and efficiencies.

2. RESULTS

2.1 Effect of different types of fertiliser on nutrient exports from nuts and apples according to tree age categories

Table 4 shows the total quantities of N, P and K exported in apples and cashew nuts according to age and types of fertiliser applied. In general, the total quantities of nutrients exported in apples and cashew nuts vary from one nutrient to another depending on the type of fertiliser applied and the age of the trees. The quantities of nutrients mobilised in fresh apples are much higher than those determined in walnuts. Nitrogen is the nutrient taken up most by the trees in both walnuts (an average of 75.71 and 112.43 g N/tree respectively for 4- and 8-year-old trees at the start of the trial) and apples (an average of 173.85 and 199.06 g N/tree respectively for 4- and 8-year-old trees at the start of the trial). On the other hand, phosphorus mobilisation was low in both walnuts (an average of 0.44 and 1.40 g P/tree for 5- and 9-year-old trees respectively) and cashew apples (an average of 0.55 and 2.50 g P/tree for 4- and 8-year-old trees respectively at the start of the trial).

Whatever the age of the trees, organo-mineral fertilisation had the greatest influence on the total quantity of nutrients mobilised in both apples and cashews. Thus, for 4-year-old trees, organo-mineral fertilisation induced the greatest quantities of N and P mobilised in apples and cashew nuts (234.13 and 97.12 g of N/tree respectively for apples and nuts compared with 0.59 and 0.83 g of P/tree respectively for apples and nuts). On the other hand, mineral fertilisation induced high K exports in apples (0.85 g K/tree).

For 8-year-old trees (2014-2015 production season), the highest N exports were obtained with organo-mineral fertiliser (260.36 and 143.94 g N/tree for apples and walnuts respectively). On the other hand, the highest P exports were induced by mineral fertiliser (3.40 and 1.84 g

P/tree for apples and walnuts respectively). The greatest quantities of K mobilised in apples were induced by organo-mineral fertiliser (37.25 g K/tree), while mineral fertiliser induced the greatest mobilisation of K in walnuts (9.24 g K/tree).

Table 4: Total quantities of N, P and K mobilised (g/tree) in apples and walnuts according to the age of the trees at the start of the trial and the types of fertiliser applied.

Ages	Treatments	Apples			Nuts		
		N	P	K	N	P	K
4 years	Indicator	119,76	0,53	6,95	52,40	0,23	3,27
	Mineral manure	167,65	0,52	8,85	77,60	0,25	2,35
	Organo-mineral fertiliser	234,13	0,59	8,32	97,12	0,83	4,52
8 years old	Indicator	157,53	0,98	13,78	79,34	0,66	4,38
	Mineral manure	179,29	3,40	34,96	114,01	1,84	9,24
	Organo-mineral fertiliser	260,36	3,12	37,25	143,94	1,69	8,35

2.2 Agronomic efficiencies, recovery and nutrient use due to the application of different manures on cashew trees according to tree age categories

Table 5 shows the results for agronomic efficiency, recovery efficiency and use efficiency for each nutrient (N, P and K) for apples and nuts harvested from the trees, according to tree age and fertiliser applied.

Analysis of the results in the table shows that the agronomic efficiency of apples is clearly higher than that of walnuts, regardless of the type of nutrient, the age of the trees and the type of fertiliser applied. Considering the age of the trees and the different nutrients, the agronomic efficiency of K is higher in 4-year-old trees (1 g of K applied induces an increase in yield varying between 29.38 g and 42.30 g in apples and 2.58 to 3.99 g in walnuts) compared with N and P. On the other hand, in 8-year-old trees, the agronomic efficiency of P is higher than that of N and K (1 g of P applied induces an increase in yield varying between 15 g and 29 g in apples and 1.72 to 3.96 g in walnuts). Taking into account the type of product, the type of fertiliser and the type of nutrient, organo-mineral fertilisation provides higher agronomic efficiencies than the application of mineral fertiliser, whatever the nutrient and the type of product (walnuts and apples).

The results in the table also show that apples have a higher recovery efficiency than walnuts, whatever the age of the trees and the type of fertiliser applied. Additionally, the recovery efficiency of N is much higher than that of P and K (0.06 to 0.32 g of N exported for 1 g of N applied compared with 10-4 to 8.8.10-3 g of P exported for 1 g of P applied and 5.10-4 to 6.45.10-2 g of K exported for 1 g of K applied).

In apples, the highest value of N recovery efficiency was obtained in 4-year-old trees receiving organo-mineral fertiliser (0.32 g of N exported for 1 g of N applied). On the other hand, the highest value of P recovery efficiency was obtained in the 8-year-old trees that received mineral fertiliser (8.8.10-3 g of P exported for 1 g of P applied). The highest K recovery efficiency value was obtained in the 8-year-old trees that received organo-mineral fertiliser (6.45.10-2 g of K exported for 1 g of K applied).

Regarding nuts, the highest N recovery efficiency value was obtained in the 8-year-old trees that received organo-mineral fertiliser (0.18 g of N exported per g of N applied). On the other hand, the highest value of P recovery efficiency was obtained in the 8-year-old trees that received mineral fertiliser (4.3.10-3 g of P exported per 1 g of P applied). The highest K recovery efficiency value was obtained in the 8-year-old trees that received mineral fertiliser (1.34.10-2 g of K exported for 1 g of K applied).

Apples generally have a higher nutrient use efficiency than walnuts. Additionally, P use efficiency was significantly higher than that of N and K (1 g of phosphorus removed and found in apples/nuts led to an increase in yield ranging from 1.78 to 117.08 kg of apples/tree and 0.66 to 23.23 kg of nuts/tree). In apples, the highest value of N use efficiency was obtained in the 8-year-old trees that received mineral fertiliser (0.20 kg of apples per g of N applied). On the other hand, the highest P and K nutrient use efficiency values were obtained in the 4-year-old trees that received organo-mineral fertiliser (117.08 kg of apples per g of P exported and 5.49 kg of apples per g of K exported). For walnuts, the highest P and K nutrient use efficiency values were obtained in the 4-year-old trees that received organo-mineral fertiliser (23.23 kg of walnuts per g of P exported and 5.04 kg of walnuts per g of K exported).

Table 5: Effect of different manures on the agronomic, recovery and physiological efficiencies of apples and walnuts according to tree age

Type of products	Age	Type of fertiliser	Agronomic efficiency (g/g)			Recovery efficiency (%)			Physiological efficiency/use (kg/g)		
			N	P	K	N	P	K	N	P	K
Apple	4 years	Mineral manure	14,69	19,59	29,38	13,45	0,03	1,07	0,11	67,49	2,75
		Organo-mineral fertiliser	21,15	28,20	42,30	32,13	0,02	0,77	0,07	117,08	5,49
	8 years old	Mineral manure	11,81	15,75	11,81	5,98	0,88	5,82	0,20	1,78	0,20
		Organo-mineral fertiliser	22,25	29,67	22,25	28,25	0,78	6,45	0,08	3,80	0,35
Nuts	4 years	Mineral manure	1,29	1,72	2,58	7,08	0,01	0,05	0,02	23,23	5,04
		Organo-mineral fertiliser	1,99	2,66	3,99	12,56	0,22	0,70	0,02	1,18	0,57
	8 years old	Mineral manure	2,14	2,86	2,14	9,52	0,43	1,34	0,02	0,66	0,16
		Organo-mineral fertiliser	2,97	3,96	2,97	17,75	0,38	1,09	0,02	1,05	0,27

3. DISCUSSION

3.1 Fertilisation and improving nutrient exports from cashew products

The results of this study showed, on the one hand, that the total amounts of nutrients exported by apples are higher than that of walnuts and, on the other hand, that nitrogen is the nutrient most taken up by the trees. These results can be explained by the fact that apple yields are higher than walnut yields, with export being the product of yield times nutrient content of produce (Samaneh et al., 2014). The fact that nitrogen is the nutrient taken up most by the trees is explained by the high demand expressed by the trees in relation to this nutrient and the availability of the said nutrient in the soil (Mossedaqq, 1999). Phosphorus is still the nutrient found least frequently in apples and walnuts, despite the fact that organo-mineral fertilisation has considerably improved the chemical properties of the soil, particularly in terms of carbon, nitrogen, potassium and phosphorus, regardless of the age of the trees (Balogoun, 2016). However, it cannot be said directly from these results that almost none of the phosphorus applied to the soil is taken up by the trees, since apples and cashew nuts account for less than 10% of total dry matter production (Richards, 1993).

Organo-mineral fertilisation improved the total quantities of nutrients exported, especially for 8-year-old trees. This can be explained by the greater availability of these elements to the trees through these types of fertilisers, thereby facilitating their uptake, since nutrient uptake is a function of nutrient availability. Apples, compared with walnuts, export most of the nutrients contained in the fertilisers applied. These apples need to be put to better use in order to make the fertilisers applied and the cash income of growers as profitable as possible.

In general, the results of this study show that cashew growers engage in mining agriculture. However, given the nature of the soil in cashew-growing areas, an application of organo-mineral fertiliser can sustainably compensate for nutrient exports from cashew nuts and apples.

3.2 Fertilisation and nutrient use efficiency

The results of this study show that the best agronomic efficiencies were obtained in trees that received organo-mineral fertiliser. This could be explained by the ability of this type of fertiliser to ensure that nutrients are available to the trees over time, thereby facilitating maximum mineral nutrition and reducing the risk of nutrient loss through leaching.

The N recovery efficiency obtained is significantly higher than that of P and K. These results can be explained by the rapid uptake of N by trees compared with P and K. N is one of the elements most used by plants. In fact, N is one of the elements most used by plants (Bado, 2002). However, these N use efficiency results are still low compared with the values of 51%, 50% and 30 to 35% found respectively by Doberman (2007), Cantarella (2007) and Fan et al. (2004) for cereals. On the other hand, the values obtained are close to those found by Quaggio et al. (2005) and Chien et al. (2009) for perennial species such as lemons (25 to 50%). The physiological efficiency results show that it is higher for P than for N and K. This can be explained by the fact that the recovery efficiency of P is the lowest compared with the other nutrients. At the same time, despite the fact that a higher recovery efficiency for N compared with P and K was observed, the lowest nutrient use efficiency values were observed. This can be explained by the high N content of apples and walnuts. The best agronomic, recovery and physiological/utilisation efficiencies were obtained in trees that had been fertilised with organo-mineral fertiliser, demonstrating the capacity of this type of fertiliser to ensure better mineral nutrition of the trees. This is justified by the availability of nutrients over time following mineralisation of the organic fraction.

Apples are generally more efficient than walnuts in terms of agronomy, nutrient recovery and nutrient use. In fact, from an agronomic point of view, 1 g of N, P or K applied to cashew trees results in an increase of 21 to 42 g of apples per tree, that is, 2.1 to 4.2 kg/ha (with a density of 100 trees/ha). From the point of view of nutrient use, 1 g of N, P or K exported by cashew trees leads to an increase of around 120 kg of apples per tree, that is, an increase of 12 tonnes/ha (with a density of 100 trees/ha). Adding value to cashew apples will considerably improve the income of cashew growers.

Conclusion

Nutrient exports followed the same trend, although nitrogen exports were higher than those of other nutrients, regardless of the product or the age of the trees. Agronomic efficiency, recovery and use of N, P and K nutrients are better in trees that have received organo-mineral fertiliser. An application of organo-mineral fertiliser provides long-term compensation for nutrient exports from cashew nuts and apples.

Apples are generally more efficient in terms of agronomy, recovery and use of nutrients than nuts. Adding value to cashew apples will considerably improve the income of cashew growers.

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EVALUATION OF THE GERMINATION AND NURSERY DEVELOPMENT POTENTIAL OF CASHEW SEEDS IN BENIN

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SUMMARY

Cashew is an important crop worldwide, and its production contributes to the economic development of producing countries. In order to assess the germination and nursery development potential of cashew seeds, an experiment was set up in the commune of Kétou (Plateau department). The aim was to improve the agronomic performance of cashew trees by improving the germination rate of cashew seeds. To do this, two factors were studied: the type of seed (dried collected seed; non-dried collected seed; picked dried seed; picked non-dried seed) and the type of phytosanitary treatment applied to the seeds (untreated control, treatment with aqueous neem leaf extract and treatment with Momtaz fungicide), the combination of which gave twelve treatments repeated three times in a complete randomised block design. Data collected during the experiment included germination rate, plant height and plant mortality rate. These data were subjected to a two-factor analysis of variance and the Student Newman-Keul test using R software version 3.4.3. The results showed that the highest germination rates (73.33% and 83.33) were obtained with dried and undried collected seeds respectively. The lowest mortality rate (13.33%) was obtained with the Momtaz fungicide treatment of collected and dried seeds. This study recommends that farmers use collected seeds that have been dried and then treated with Momtaz fungicide to produce cashew seedlings. This will produce good quality seedlings with high germination and low mortality rates, guaranteeing good productivity. This study will thus contribute to knowledge of phytosanitary treatments for cashew seedlings in nurseries and the type of plant material to be used in nurseries to improve cashew production in Benin.

Key words: Nursery, germination, treatment, fungicide, cashew seedlings.

INTRODUCTION

The cashew tree, whose scientific name is Anacardium occidentale L., contributes to the socio-economic development of several countries around the world (FAO, 2014). It is one of the world's leading export crops (FAO, 2014). In Benin, cashew is the second most profitable crop in the country after cotton, and is also a source of income in other countries in the sub-region (Koffi and Oura, 2019). After cotton, cashew is the second most important export crop in Benin (Yabi et al., 2013; Balogoun et al., 2014). According to Tokore et al (2021), cashew is used for reforestation in Benin and in countries such as Tanzania, Côte d'Ivoire and Nigeria. In Benin, this crop has been a foreign exchange earner for the economy since the 1930s. Cashew production is profitable, simple and easy to manage (Balogoun et al., 2014). The Beninese government therefore took to heart the redevelopment of certain sectors such as cashew. To this end, producers have become aware of the advantages of cashew nuts, which had previously been neglected in favour of cotton (Tokore et al., 2021). Furthermore, Benin is one of the countries in the sub-region with a high added value to be harnessed through cashew nuts as part of the Government's Action Programme (Balogoun et al., 2014; Yelouassi et al., 2021).

Despite the advantages and benefits of cashew nut production in Benin, nut yields in production fields remain low (Adégbola et al., 2005). The aim of this study was to help increase cashew nut production in the Kétou Commune.

MATERIALS AND METHODS

Study area

This study was carried out in the Commune of Kétou (Figure 1). The Commune of Kétou is located at the northern end of the Plateau department between latitudes 7°10' and 7°41'17'' North and longitudes 2°24'24'' and 2°47'40'' East (IGN, 1963; INSAE, 2008). It covers an area of 2,183 km2 according to the RGPH4 (DGCS-ODD, 2019). It is bordered to the north by the Commune of Savè, to the south by the other two Communes of the Plateau, namely Adja-Ouèrè and Pobè, to the west by the Communes of Dassa and Zagnannado, and to the east by the giant Nigeria (INSAE, 2008).

Kétou's climate is Sudano-Guinean, with a bimodal rainfall pattern of two shades (middle Zou and southern plateaux) and two rainy seasons accompanied by two dry seasons. The rainy season starts from March to July and the short dry season in August (INSAE, 2008; DGCS-ODD, 2019). The short rainy season runs from September to October and the long dry season from November to February.

The vegetation is characterised by wooded savannahs of Daniella oliveri, Lophira lanceolata, Parkia biglobosa and forests (Kétou Dogo) covering around forty-seven thousand hectares (Bani, 2006). The soils are impoverished, weakly desaturated and hardened, and associated with vast sheets of ferruginous cuirass with sparse vegetation (DGCS-ODD, 2019).

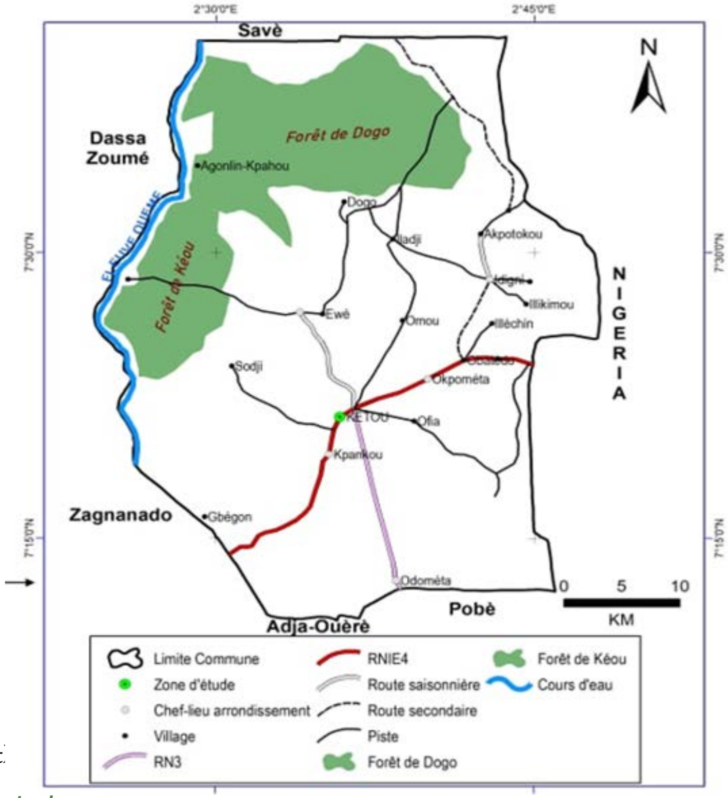


Figure 1: Map of t dy area

Experimental set-up

The experiment highlighted two factors: the type of seed (dried collected seed (RS); non-dried collected seed (RNS); dried collected seed (CS); non-dried collected seed (CNS)) and the type of treatment given to the seeds (untreated control, treatment with aqueous neem leaf extract and treatment with Momtaz fungicide), the combination of which gave 12 treatments spread over three (3) replications in a complete randomised block design.

Test installation

The plant material used is cashew seeds (collected and picked). The seeds are collected and partly dried. On the day the seeds are dried in the shade, a solution of aqueous neem leaf extract is also prepared. The aim of starting production of the neem leaf aqueous extract on the same day as the seeds are dried is to enable a solution to be obtained on the sixth day, which will coincide with the third day of soaking of the seeds when the aqueous extract is to be used.

For the aqueous extract manufacturing procedure, 1.8 kg of neem leaves were chopped, ground and then soaked in 10 litres of water at ordinary temperature, that is, after 1 litre of aqueous neem leaf extract to treat each quantity of seed (Mondedji et al., 2014; Baoua et al., 2013). The neem leaves were soaked in plain water for four days (4 days) before the addition of palm soap cut into pieces on the sixth day of soaking to allow the solution to become viscous and cling to the seeds during soaking (Mondedji et al., 2014).

A fungicide solution was also prepared on the same day as the seeds were soaked. To do this, a beer cap filled to the brim with Momtaz was poured into a container containing the quantity of seed to be treated. This is sprinkled with a few drops of water and stirred to evenly distribute the product over the surface of the seeds (Mondedji et al., 2014). One litre of water at normal temperature is poured over the seeds homogenised with the product for soaking.

For the installation, polyethylene bags previously potted with undergrowth compost (Acacia auriculiformis) are placed on the plot units. Each plot unit comprises ten (10) pots. Each pot receives one seed for sowing. The soaked seeds are sown in potted polyethylene bags and laid out. The seeds are not pushed too far into the bags. Sowing is done in such a way that the hilum of the seed is slightly inclined downwards and a little shallow to prevent the seeds from rotting. Labels were made from the pieces of can and placed at the head of each experimental unit to serve as a reminder of what was being planted in that unit.

Data collection.

To assess the effectiveness of each treatment on the germination, growth and development of cashew seedlings, the following parameters were taken into account during data collection:

- ***Germination rate***

Collection of germination rate data began ten (10) days after sowing. Germinated seeds were counted every day for a fortnight. This rate (T) was determined according to the formula:

T= (Total of germinated seeds)/(Total number of seeds sowed x 100)

- ***Height of Seedlings***

Seedlings height data was measured with a centimetre pruner. This collection began twenty (20) days after sowing. Seedlings heights were taken every 15 days for two (2) months. The measuring tape was placed at the neck of the seedling and stretched to the youngest leaf.

- ***Mortality rate***

For the mortality rate, the data was collected every 15 days by counting the dead seedlings or dead seeds and lasted two (2) months. It was also done by subtracting the number of seeds sown from the number of seeds germinated and checking to see if other germinated seedlings had died. It began on the twentieth day after sowing.

Each item of data collected was recorded on a collection sheet using a pen. Five (5) of the ten (10) seedlings planted were selected for data collection.

Data analysis

The data collected during the experiment were recorded in Excel version 16 and then analysed using R software version 3.4.3. The three-factor analysis of variance, considering time as a random factor, was performed at the 5% error threshold for each repeated-measure growth parameter. The two-factor analysis of variance was performed at the 5% error threshold for each point parameter (mortality rate and germination rate). The Student Newman-Keuls test at the 5% threshold was used to compare means.

RESULTS

Effect of seed type and treatments on cashew seed germination

Table 1 presents the analysis of variance of the effect of seed type and seed treatment on cashew seed germination. From this table, it can be seen that the two factors studied (seed type and seed treatment) had no significant influence on seed germination rate (P > 0.05).

Table 1: Analysis of variance results for the effect of seed type and treatment on cashew seed germination.

Source of variation	**ddl**	**Sum of mean squares**	**Medium square**	**Value of F**	**Probability**
Types of seeds	3	856	285,2	1,267	0.308 ns
Seed treatment	2	117	58,3	0,259	0.774 ns
Types of seed* Seed treatment	6	2528	421,3	1,872	0.127 ns

ddl = degree of freedom; ns = not significant at the 5% threshold

Figure 2 shows the evolution of cashew seed germination rate according to seed type and treatment. Considering seeds collected under the trees and dried (RS) and seeds collected under the trees but not dried (RNS), there is no significant difference between the different treatments applied. For both types of seeds, the controls (untreated seeds) had the highest germination rates (RST0 with 73.33 and RNST0 with 83.33). As for the seeds collected from the trees, whether dried or not (CS and CNS), the untreated seeds had the lowest germination rates. Those treated with the fungicide Momtaz had the highest germination rates (CST2 with 86.66 and CNST2 with 83.33).

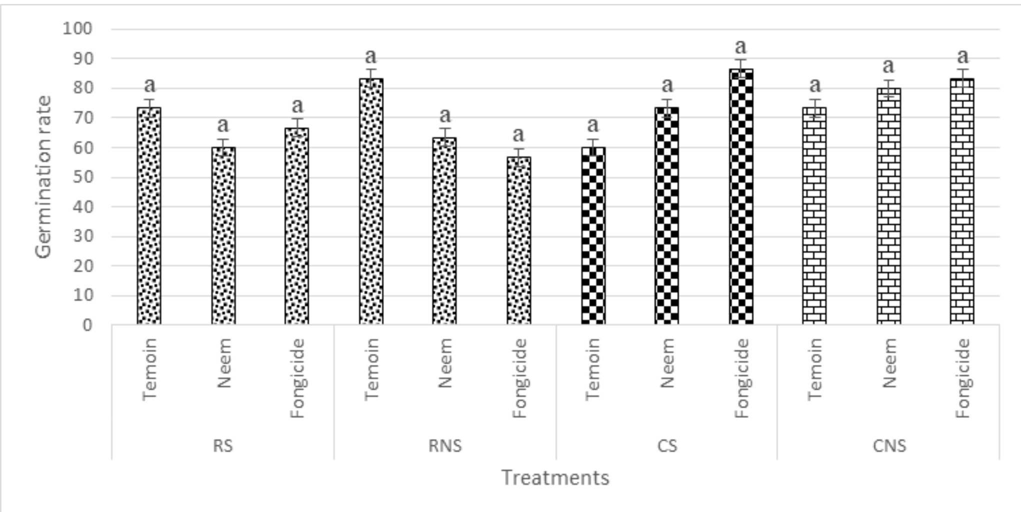


Figure 2: Evolution of cashew seed germination rate according to type and different treatments

Legend: RS: Dried collected seed; RNS: Non-dried collected seed; CS: picked dried seed; CNS: picked non-dried seed.

Means followed by the same alphabetical letter are not significantly different (P > 0.05) according to the Student Newman-Keuls test.

Effect of seed type and treatments on cashew seedling height

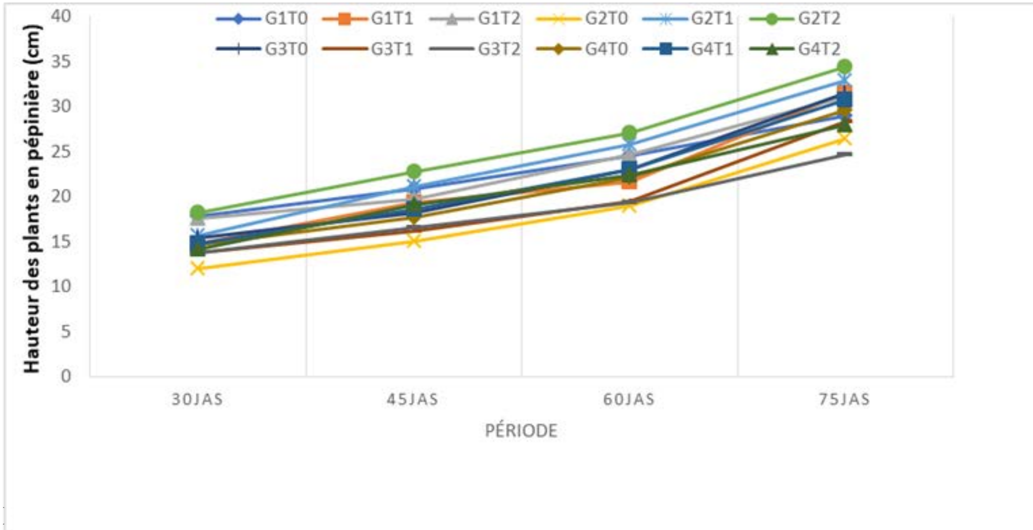
Table 2 presents the analysis of variance of the effect of seed type and treatments on the height growth of cashew seedlings. The table shows that seed type had a strong influence on height growth (P < 0.001). Height growth did not depend on seed treatment (P > 0.05). However, the combination of the two factors (seed type and seed treatment) had a strong influence (P < 0.001) on the height growth of cashew seedlings. The height of cashew seedlings also varied with time.

Table 2: Results of analysis of variance of the effect of seed type and treatment on height growth of cashew seedlings

Sources of variation	ddl	Sum of squares	Medium square	Value of F	Probability
Types of seeds	3	448	149	6,058	0.004 ***
Seed treatment	2	138	69	2,805	0.061 ns
Time	3	21132	7044	285,498	P<0.001***
Type of seed* Seed treatment	6	1998	400	16,196	P<0.001***
Type of seed* Time	9	76	8	0,343	0.960 ns
Seed treatment*Time	6	108	18	0,727	0.628 ns
Type of seed* Seed treatment* Time	18	290	19	0,783	0.697 ns

ddl = degree of freedom; ns = not significant at the 5% level; ***: highly significant at the 5% threshold.

Figure 3 shows the growth in height of cashew nursery seedlings as a function of time. From this analysis, it can be seen that the seeds harvested, dried and treated are those with the best performance in height growth. CST2 had a height of 34.32 cm compared with 32.80 cm for CST1. There was no significant difference between these two treatment combinations (CST2 and CST1).



Legend: DAS: Days After Sowing; G1 = RS: Dried Picked Seed; G2 = RNS: Undried Picked Seed; G3 = CS: Dried Picked Seed; G4 = CNS: Undried Picked Seed.

Effect of seed type and treatments on cashew seedling mortality rate

Table 3 presents the analysis of variance of the effect of seed type and seed treatment on cashew seedling mortality rate. The analysis of this table shows that the two factors studied (seed type and seed treatment) have no influence (P > 0.05) on the mortality rate of cashew seedlings in the nursery.

Table 3: Analysis of variance results for the effect of seed type and treatment on cashew seedling mortality rate.

Source of variation	ddl	Sum of squares	Medium square	Value of F	Probability
Types of seeds	3	1586	528,7	2,409	0.091 ns
Seed treatment	2	406	202,8	0,924	0.410 ns
Type of seed* Seed treatment	6	772	128,7	0,586	0.737 ns

ddl = degree of freedom; ns = not significant at the 5% threshold

Figure 4 shows the mortality rate of cashew seedlings in the nursery as a function of seed type and treatment. Analyses of this parameter show that seeds collected from under the trees and dried have the lowest mortality rates, despite the absence of any significant difference between treatments. It should be noted that the Momtaz fungicide treatment for seeds collected and dried produced the lowest mortality rate (13.33%).

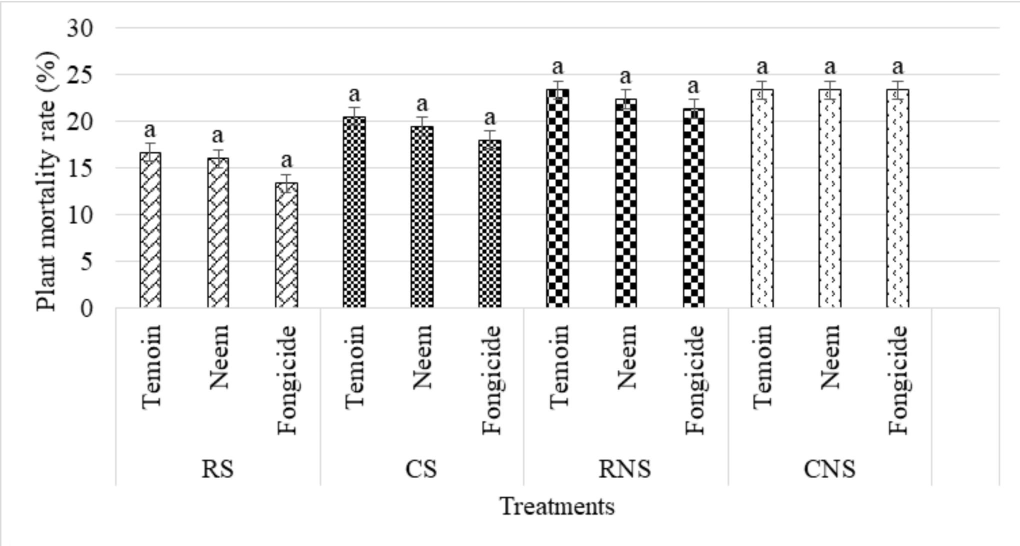


Figure 4: Mortality

Legend: RS: Dried picked seed; RNS: Non-dried picked seed; CS: Dried picked seed; CNS: Undried picked seed.

Means followed by the same alphabetical letter are not significantly different (P > 0.05) according to the Student Newman-Keuls test.

DISCUSSION

The results of this study show an improvement in the germination rate of the seeds, but also good growth and a reduction in the mortality rate with the different treatments. Of these results, the use of seeds picked from the trees, dried and then treated with the fungicide Momtaz (RST2) gave the best results in terms of germination rate (73.33%) and low mortality rate (13.33%). On the other hand, seeds picked from trees, whether dried or not (CS and CNS) and untreated, had the lowest germination rates. Furthermore, the fact that seeds picked from trees, treated with the fungicide Momtaz had the highest germination rates compared with untreated seeds suggests that treating cashew seeds with the fungicide Momtaz has a positive effect on the germination of these seeds. It is in this context that Ndour et al (2021) asserted that seed treatment plays an important role in the long-term survival of the species. The fungicide Momtaz therefore has the ability to promote germination, stimulate emergence and combat pest and disease attacks. These results are in line with those of Silue et al (2018), who showed that the use of the fungicide has advantages over the germination and use of carbendazim. The same authors claim that the biological fungicide NECO inhibits the in vitro mycelial growth of the pathogen, maintains the serenity of anthracnose and has antifungal activity.

Apart from the treatment of the seeds, this difference in performance between collected and harvested seeds is linked to their degree of ripeness. According to Djaha et al (2008), seeds are collected when the fruit falls from the tree by itself when fully ripe. Ndour et al (2021) have shown that chemical substances produced by the plant and accumulated in the fruit or seed may be plant hormones that inhibit germination, as in the case of abscisic acid, where germination may be faster after elimination.

Considering seeds collected under trees and dried (RS) and seeds collected under trees but not dried (RNS), the absence of any significant difference observed suggests that they have very similar intrinsic characteristics.

Regarding the use of the aqueous extract of neem leaves, the results of the experiments showed that this treatment did not give better performance on the various growth parameters. However, some authors, including Tokore et al (2021), have shown that the use of aqueous extracts, as in the case of false Ashoha (Polyalthia longifolia) applied directly for grafting, leads to better performance in terms of plant height growth and leaf area. In the same vein, Yao et al (2022) showed that the aqueous extract of neem seeds was effective against most pests and these aqueous extracts can be used in an integrated pest management programme against major crop pests such as cabbage pests.

CONCLUSION

The present study evaluated the effect of collected and dried seeds, collected and dried seeds, collected undried seeds and collected undried seeds and the types of seed treatments (Momtaz fungicide and neem leaf solution and aqueous solution) on the agronomic performance of cashew seedlings in the nursery. The use of seeds collected then dried and treated with the Momtaz fungicide resulted in good performance in terms of germination rate and seedling mortality rate. For this reason, farmers are advised to use cashew seeds collected and then dried and treated with the fungicide Momtaz in the production of young seedlings in the nursery. With this in mind, farmers need to be sure of the origin of the seeds. The germinative capacity of seeds collected from under the trees should also be studied over time.

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MORPHOLOGICAL EVALUATION OF THREE CASHEW GENOTYPES UNDER DEFICIT WATER SUPPLY CONDITIONS

DOBO Bi Zan Alexis· KOUAKOU Charles Konan· N'Da Hugues Annicet· KOUADIO Konan Doubin· KOUAME Koffi Kévin

SUMMARY

Used in the 1960s to combat erosion and land degradation in Côte d'Ivoire, the cashew tree has now become a perennial income-generating crop for many producers. The country remains the world's leading producer and exporter of cashew nuts, with 1,028,172 tonnes in 2022. However, with the effects of climate change, water is becoming increasingly scarce. Côte d'Ivoire is experiencing an increase in climatic variability, with recurrent and unpredictable pockets of drought. In Côte d'Ivoire, grafted seedlings are made available to farmers as selected planting material without any real knowledge of their behaviour in the face of water shortages. The aim of this study is to characterise three cashew genotypes at the nursery seedling stage in terms of their adaptation to low rainfall environments through their drought tolerance levels. The experimental design used was a randomised complete block with three replications. The results showed that in cashew seedlings of all three genotypes, stem height, circumference and number of leaves gradually decreased under low rainfall conditions. However, the KADM-87 genotype did not reduce the length (reduction rate: -2.77%) or width (-3.11%) of its leaves, whereas the other two genotypes reduced the length and width of their leaves: KADM-40 (6.06 and 7.04%) and KADM-98 (5.94 and 10.93%). This genotype also maintained its root volume under water deficit conditions, compared with the other two genotypes. KADM-87 is thought to be predisposed to water deficit tolerance. The rate of transpiration in all three genotypes decreased as soil humidity fell. It would be interesting to continue this study on a larger number of genotypes, including the three genotypes and other physiological parameters determined using equipment such as the CI340 and the Scholander pressure chamber, in order to gain a better understanding of their behaviour in the face of water deficit.

Key words: Cashew, climate change, water deficit, morphological parameters

INTRODUCTION

Africa is a continent with low greenhouse gas (GHG) emissions, yet it will undoubtedly be the most affected by the effects of climate change (Tinlot, et al., 2010). These climate changes have naturally led to a change in the variability of climatic parameters such as temperature, relative humidity, vapour pressure (Mamoudou, 2012) and changes in rainfall patterns. Changes in rainfall patterns increase the risk of water deficit for rainfed crops (Métangbo, 2007).

The cashew tree was introduced into Côte d'Ivoire in 1951 (Goujon et al., 1973), with the main aim of reforestation and soil protection. Rooting depth, size and extent of foliage were the criteria used to select varieties. The plant became a cash crop from the 1990s onwards, due to the growing demand for cashew nuts on the international market. The cashew industry has undergone spectacular development, with national production of raw cashew nuts rising from 19,000 tonnes in 1990 (Kéhé et al., 1997) to 700,000 tonnes in 2015 (Rabany et al., 2015).

Ivorian cashew nut production reached 1,028,172 tonnes in 2022, up 6% on the 968,676 tonnes recorded in 2021. The cashew nut sector generates a turnover of more than 600 billion CFA francs per year and an annual income of more than 300 billion CFA francs for the 400,000 Ivorian producers (Anonymous, 2023). The nut, which is the most widely used part of the fruit in Côte d'Ivoire, generates significant turnover for cashew industry players through its marketing (Doukouré & Kodjo, 2018). However, with the effects of climate change, water will become increasingly scarce in most regions of the world (Morrison et al., 2009). Since the end of the 1960s, Côte d'Ivoire has experienced an increase in climatic variability, reflected in a change in rainfall patterns and a decrease in annual rainfall (Brou et al., 2005). Furthermore, temperature rises and strong winds are causing flowers to fall (Bello et al., 2017).

In Côte d'Ivoire, grafted seedlings are made available to growers as selected planting material without any real knowledge of their behaviour in the face of water deficit. It therefore seems important to determine the behaviour of these genotypes in relation to rainfall variations, both at the seedling stage in nurseries and on the farms.

The aim of this study is therefore to characterise three cashew genotypes for their adaptation to low rainfall environments through their drought tolerance levels.

Specifically, this will involve:

- Evaluating water management by the different genotypes under water deficit during the vegetative phase;
- Structuring cashew genotypes according to their ability to adapt to water deficit

MATERIALS AND METHOD

Plant material

Th ... ge ... 'Ivoire)

Figure 1: Genotypes used in the experiment (a: A42, b: A2SINE, c: PK18)

Conduct of the trial

The experiment was conducted under a shelter covered 100% with translucent metal sheets, with the following dimensions: length 14 m, width 7 m and height 3 m. The cashew nuts for the rootstocks were sown on 25 February 2022. The seedlings were sown in 11-litre buckets. It should be noted that these nuts came from the mother trees of the three genotypes used in the trial. Grafting was carried out on 4 May 2022. The grafts were taken from the mother trees of the three genotypes in order to minimise the interaction between rootstocks and grafts. Dry-down began on 8 September 2022 with 4-month-old grafted plants. On the eve of the start of the dry-down, all the pots were watered to saturation and left to drain overnight in order to evacuate the excess water. Ten (10) kg of potting soil was placed in each pot for sowing. The field capacity of the 10 kg of potting soil was determined beforehand using the gravimetric method. This method involved placing several samples of potting soil in an oven for 12 hours at 70°C. After this, 10 batches of 10 kg of potting soil were made up. These samples were then saturated with water and left to drain for 24 hours. They were then weighed to determine their fresh weight. The difference between the fresh weight of the pots and the dry weight is the field capacity. In this study, the field capacity was 2700 millilitres. The pots of the control plants (Irrigated) were watered so that they were above 80% of field capacity without causing drainage. To avoid a rapid imposition of water stress and to homogenise its installation, the stressed plants (STR) were allowed to lose 100 ml of water/day. Any water lost through transpiration in excess of this amount was returned to the pots on a daily basis (Liu & Stutzel, 2002). Dry-down ended when the weight of the stressed plant pots became constant.

The experimental system used to set up the trial was a randomised complete block design (Fisher) with three replicates (Figure 4). Each block consisted of three elementary plots, with 30 plants per block. The system designed for STR plants was repeated for ETM plants.

NB: ETM (Irrigated in a standard way), STR (Stressed)

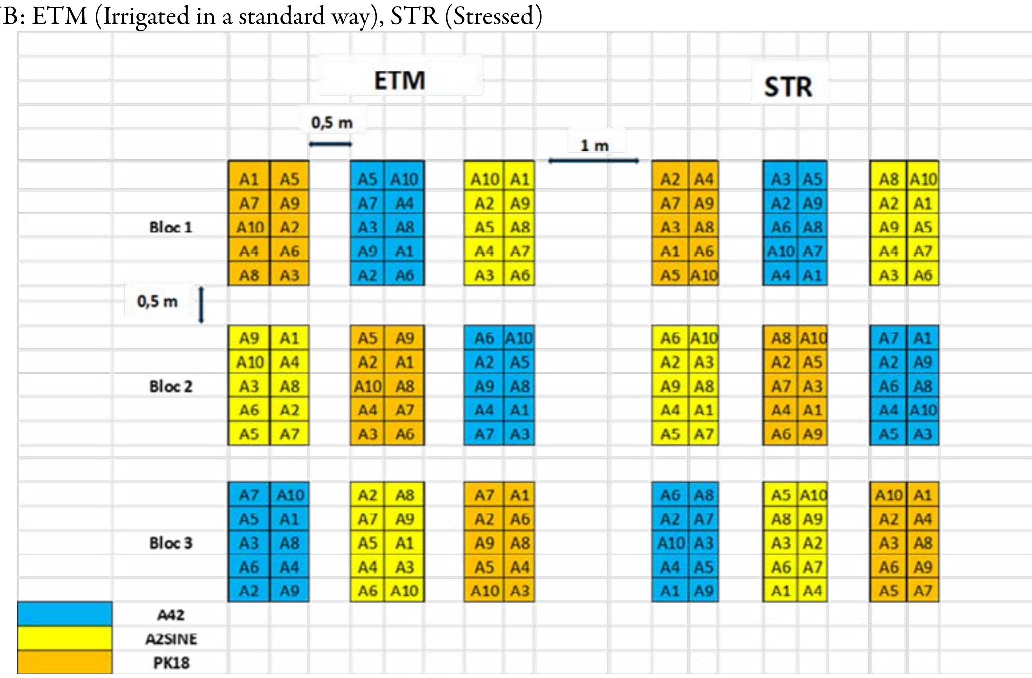


Figure 2. System for evaluating three cashew genotypes under progressive water stress (Dry-down).

Parameters assessed

Three types of parameters were assessed: climatic, agro-morphological and physiological parameters (Table 1).

Table 1. Parameters assessed during the test

Parameters assessed	Measurement periods	Measurement method
Temperature	Daily at 8 a.m. and 12 p.m.	Recorded using a sensor
Relative humidity	Daily at 8 a.m. and 12 p.m.	Recorded using a sensor
Number of leaves	At the start and end of the test	Number of leaves on the seedlings was determined by manual counting.
Length of the leaves	At the beginning and end of the test	Length of the leaves was determined using a tape measure on four randomly selected leaves.
Width of the leaves	At the beginning and end of the test	Width of the leaves was determined using a tape measure on four randomly selected leaves.
Circumference of the stem	At the beginning and end of the test	Circumference below the grafting point using an electronic calliper
Stem height	At the beginning and end of the test	Measure the height of the stem using a ruler and tape measure, from the crown to the terminal bud.
Dry biomass of leaves	At the end of the test	Dry biomass of the leaves was determined by oven drying at 70°C for 48 hours.
Dry biomass of stems	At the end of the test	Dry biomass of the stems was determined by oven drying at 70°C for 48 hours.
Ratio of root biomass to stem biomass	At the end of the test	Ratio between the dry mass of the root and the dry mass of the stem
Fraction of water in transpirable soil	At the end of the test	By dividing the difference between the weight on day x and the final weight by the difference between the initial weight and the final weight
Rate of transpiration	At the end of the test	By making the ratio equal to the average transpiration of all the stressed plants over the transpiration
Dry root biomass	At the end of the test	Dry biomass of the roots was determined by oven drying at 70°C for 48 hours.
Ratio of root biomass to stem biomass	At the end of the test	Ratio between the dry mass of the root and the dry mass of the stem
Fraction of water in transpirable soil	At the end of the test	By dividing the difference between the weight on day x and the final weight by the difference between the initial weight and the final weight
Rate of transpiration	At the end of the test	By making the ratio equal to the average transpiration of all the stressed plants over the transpiration

Data analysis

Multiple analysis of variance (MANOVA) was used to study the effect of water regimes on agronomic parameters of cashew plants. In the case of the present study, once the MANOVA revealed a significant difference, an analysis of variance (ANOVA) was carried out for each parameter in order to identify the one or ones that contribute to the effect of the factor considered. For each discriminant variable identified, multiple comparisons were made using the least significant difference (LSD) test. This test was used to identify the treatment(s) that differed significantly from one another (Dagnelie, 1998). The significance of the difference in means was determined by comparing the probability P associated with the Fischer-Snedecor test statistic with the theoretical threshold of $\alpha = 0.05$. Thus, when $P \geq 0.05$, there is no significant difference, but when $P \leq 0.05$, there is a significant difference between the different means. All tests were performed using STATISTICA version 7.1 software. The curves were drawn using Excel 2016.

Results

Maximum and minimum relative temperatures and humidity under shelter

The daily temperature (°C) and relative humidity (RH) recorded at 8 and 12 o'clock during the experimental period are shown in Figures 3 and 4. It can be seen that these two variables move in opposite directions, i.e., a fall in humidity corresponds to an increase in temperature and vice versa. The average temperature recorded at 8 a.m. was 28.35°C, with a minimum of 22.7°C and a maximum of 32.2°C. At 12 noon, the average temperature recorded was 36.3°C, with a minimum of 27.2°C and a maximum of 42.1°C. The average relative humidity at 8 am was 74.19%, with a minimum of 54% and a maximum of 99%. Similarly, at 12 noon, relative humidity averaged 45.70%, with a minimum of 30% and a maximum of 84%.

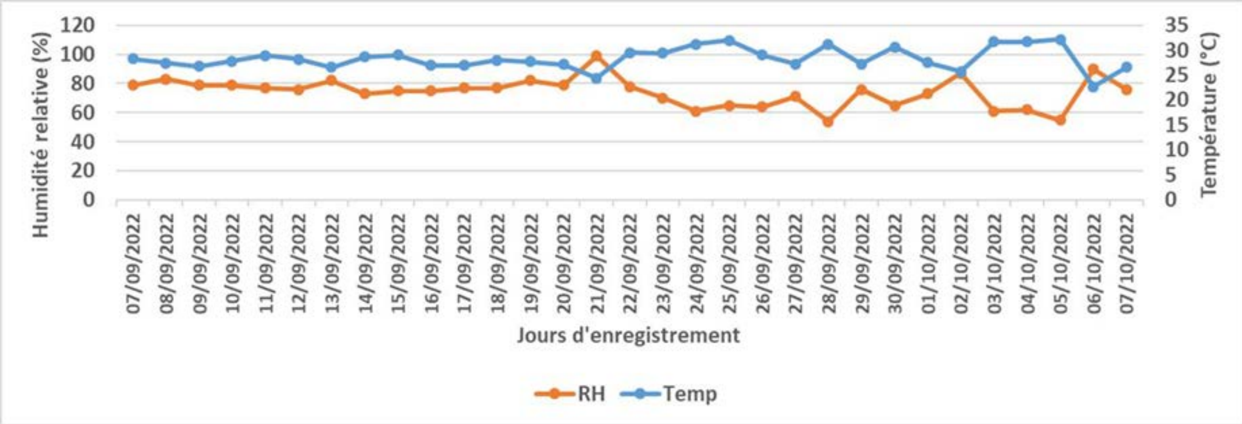


Figure 3. Daily variation at 8 a.m. in relative humidity (RH) and temperature under cover during the test

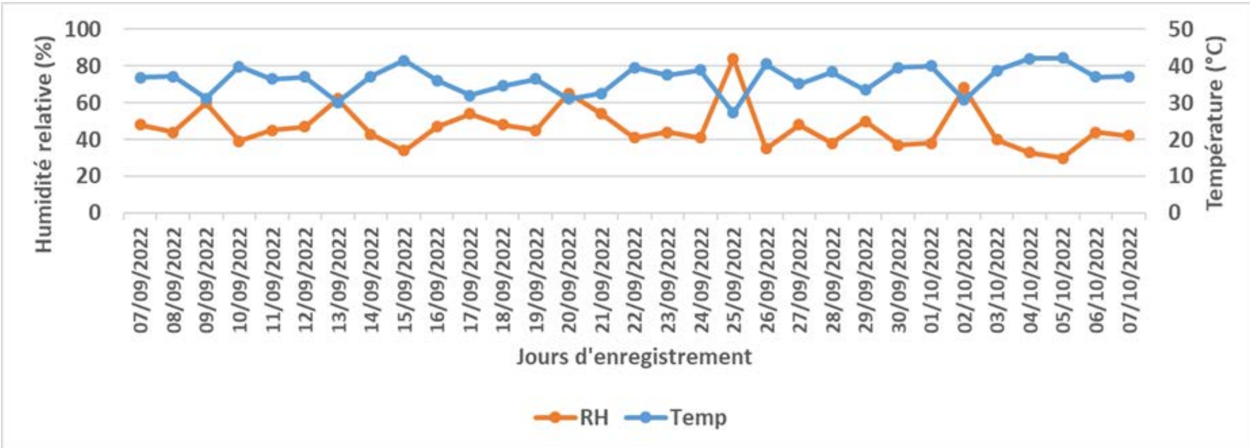


Figure 4. Daily variation at 12 p.m. in relative humidity (RH) and temperature under cover during the test.

Effect of irrigation regime on the general appearance of cashew trees under cover

The application of the water regime altered the visual appearance of the cashew trees. Under stress, the three cashew genotypes A42, A2SINE and PK18 showed wilting followed by leaf drop (Figure 5, 6 and 7). At the same time, patches of yellowing appeared from the apical end of the leaves and spread inwards. Progressive drying was also observed from the terminal bud of the stems.

Under normal water supply conditions (irrigated), the cashew trees showed spreading, turgid leaves and vigorous stems (Figure 8). Under this irrigation regime, branching was also observed in all three cashew genotypes.

Figure 5: (a) A42 leaf wilt, (b) A42 leaf drop

Figure 6: (a) A2 SINE leaf wilt, (b) A2SINE leaf drop

Figure 7: (a) leaf wilting in KP18, (b) leaf dropping in KP18

Figure 8. Morphological appearance of cashew trees under normal water treatment (irrigated), a: A42, b: A2SINE, c: PK18

General effect of the water regime on the agro-morphological characteristics of cashew trees.

Stem circumference and stem height

The results of the statistical analysis revealed a significant effect of the water regime (irrigated and stressed) on the circumference ($P < 0.05$) and stem height ($P < 0.05$) of cashew trees. The mean values in the absence of water stress (irrigated), which were 9.77 mm and 55.15 cm respectively for circumference and stem height, fell to 8.23 mm and 44.61 cm under water stress (Table 2).

Number and width of leaves emitted

The results of the statistical analysis revealed a significant effect of the water regime (irrigated and stressed) on the number of leaves emitted

(P < 0.05) and the width of the leaves (P < 0.05) of cashew trees. The mean values in the absence of water stress (irrigated), which were 36.40 and 8.94 cm respectively for the number of leaves emitted and leaf width, fell to 21.26 and 8.22 cm under the stressed irrigation regime (Table 2).

Dry weight of stems and dry weight of leaves

The results of the statistical analysis revealed a significant effect of water regime (irrigated and stressed) on stem dry weight (P < 0.05) and leaf dry weight (P < 0.05) of cashew trees. The mean values in the absence of water stress (irrigated), which were 19.85 g and 14.79 g respectively for stem dry weight and leaf dry weight, fell to 14.91 g and 10.13 g under the stressed irrigation regime (Table 2).

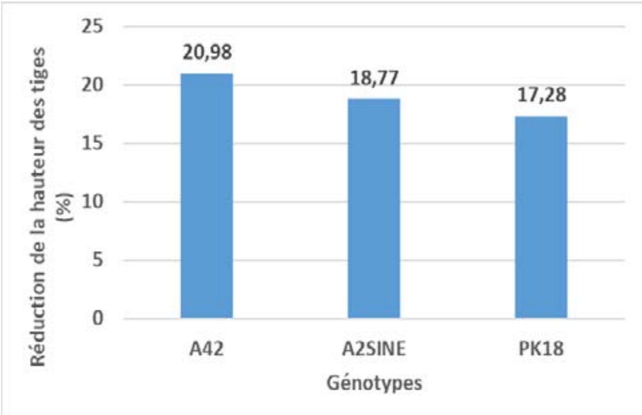
Total dry weight and ratio of root dry weight to stem dry weight

The results of the statistical analysis showed a significant effect of the water regime (irrigated and stressed) on the total dry weight and the root dry weight/stem dry weight ratio (P < 0.05) of cashew trees. The mean value for total dry weight in the absence of water stress (Irrigated) was 34.44 g, dropping to 25.04 g under stressed irrigation. The mean value for the root weight/dry stem weight ratio in the absence of water stress (Irrigated) was 31.39%, increasing to 38.18% under stressed irrigation (Table 2).

Table 2. Effect of water regime on agro-morphological parameters of cashew trees

Irrigation regimes	CiTi (mm)	HaTi (cm)	NbFe	LoFe (cm)	LaFe (cm)	PsTi (g)	PsFe (g)	PsRa (g)	PsTo (g)	Ra/Ti (%)
Irrigated	9.77±0,19^{a}	55.15±1.45^{a}	36.40±2,47^{a}	18,18±0.34^{a}	8,94±0.25^{a}	19.85±1,31^{a}	14.79±0.64^{a}	5,97±0,30^{a}	34,44±1,59^{a}	31,39±1,16^{b}
Stressed	8,23±0.13^{b}	44.61±1,16^{b}	21.26±0,84^{b}	17,57±0.24^{a}	8.22±0,14^{b}	14.91±0,68^{b}	10.13±0,44^{b}	5,41±0,22^{a}	25,04±0,80^{b}	38,18±2,10^{a}
LSD (p ≤ 0.05)	0,0001	0,0001	0,0001	0,058	0,0001	0,0001	0.0001	0,151	0,0001	0,0025

CiTi: stem circumference, HaTi: stem height, NbFe: number of leaves produced, LoFe: leaf length, LaFe: leaf width, PsTi: stem dry weight, PsFe: root dry weight, PsTo: total dry weight, Ra/Ti: root dry weight/stem dry weight ratio



Rate of reduction of parameters under water deficit conditions Stem height

Under a deficient water regime, the stem height of plants of the three genotypes decreased gradually, from genotype A42 (20.98%) to A2Sine (18.77%) to PK18 (17.28%).

Figure 9. Stem height reduction rate

Stem circumference

Stem circumference was reduced by 23% in the PK18 genotype and by 13.47 and 10.11% in the A2Sine and A42 genotypes, respectively, under poor water conditions (Figure 10).

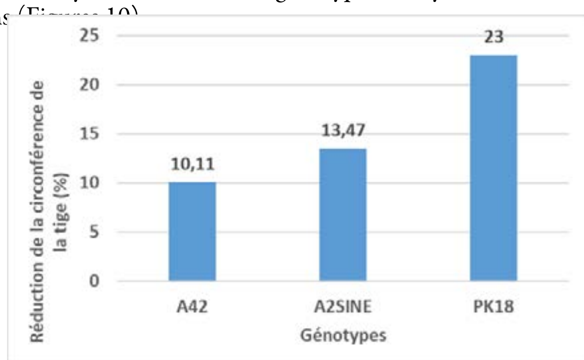


Figure 10. Stem circumference reduction rate

Number of leaves

All three genotypes dropped their leaves under water deficit, reducing from 43.63% (A2Sine) to 40.4% (PK18) and 39.93% (A42).

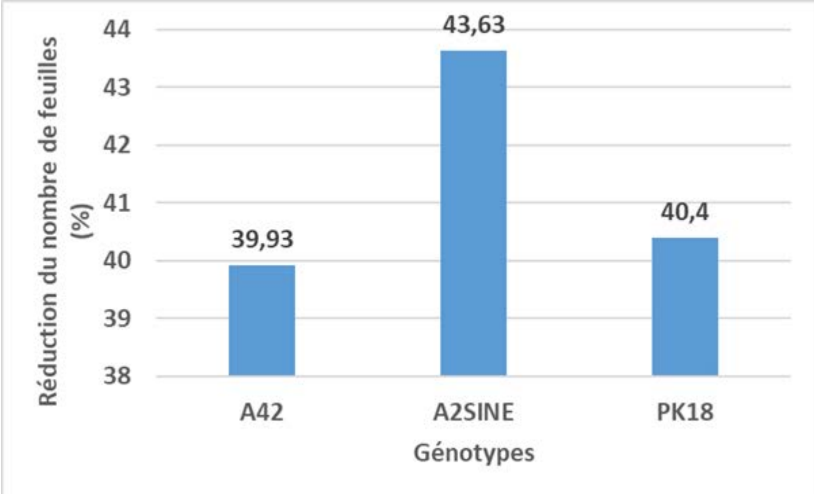


Figure 11. Rate of reduction in the number of leaves

Dry weight of leaves

Under poor water conditions, leaf dry weight (Figure 13) was reduced less in A2Sine (23.32%) and PK18 (27.72%) than in A42 (40.98%).

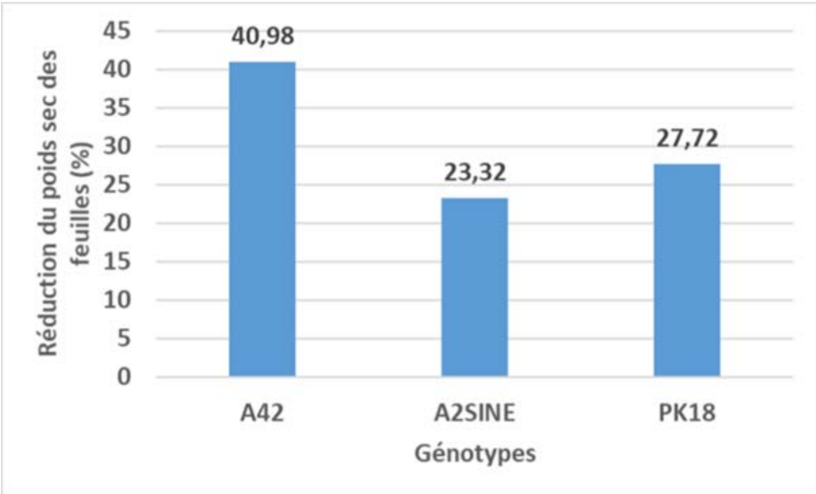


Figure 12. Rate of reduction in leaf dry weight

Length and width of leaves

Under water deficit conditions (Figures 14 and 15), the A2Sine genotype did not reduce the length (reduction rate: -2.77%) or width (-3.11%) of its leaves, whereas the other two genotypes reduced the length and width of their leaves: A42 (6.06 and 7.04%) and PK18 (5.94 and 10.93%).

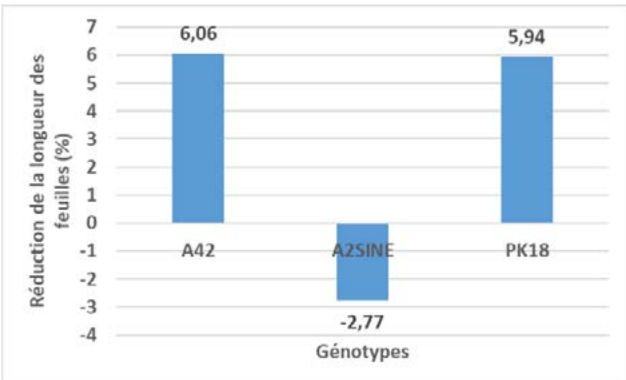


Figure 13. Rate of reduction in leaf length

Figure 14. Rate of reduction in the width of leaves

Evolution of the transpiration rate (NTR) as a function of the fraction of soil transpiration water (FTSW)

Figures 15 to 17 show the evolution of the transpiration rate as a function of the fraction of transpirable soil water for the three genotypes studied during the experiment. Very strong correlations were observed between NTR and FTSW for the three genotypes studied. For the A2SINE genotype this coefficient was 0.96, for the PK18 genotype it was 0.88 and for the A42 genotype, the coefficient of correlation was 0.93. For these three genotypes used in the experiment, the NTR and FTSW moved in the same direction.

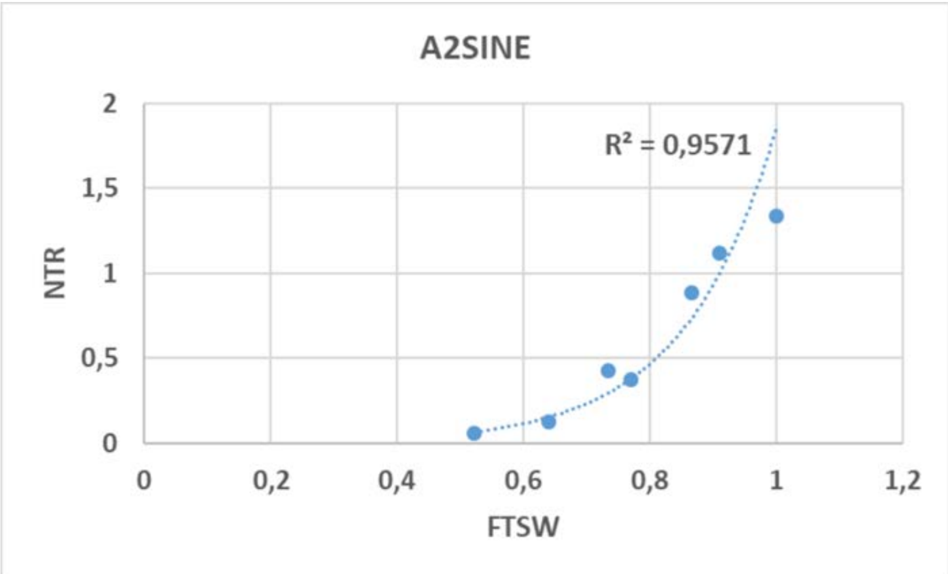


Figure 15. Evolution of NTR as a function of FTSW in A2Sine

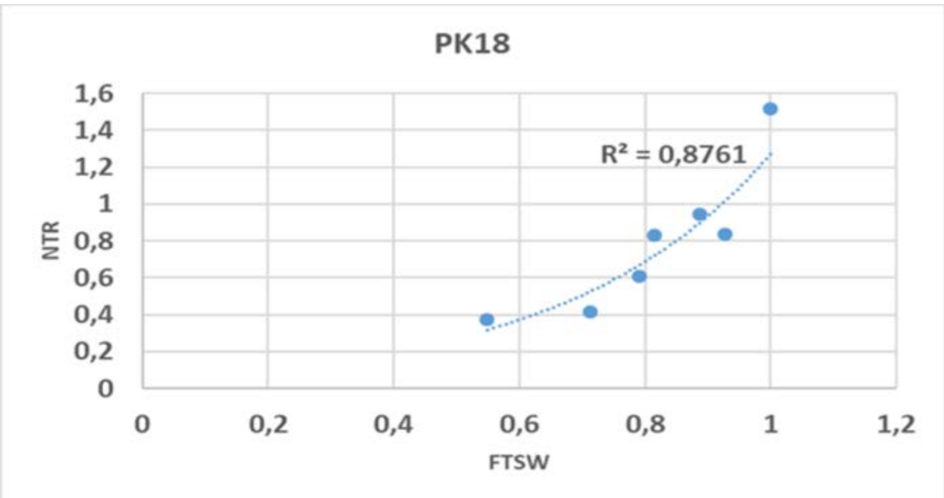


Figure 16. Evolution of NTR as a function of FTSW in PK18

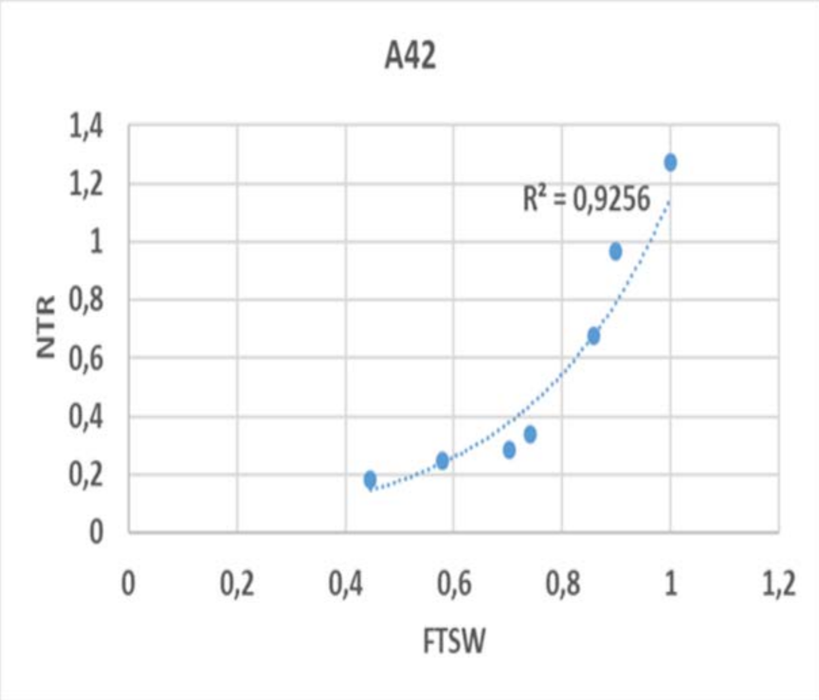


Figure 17. Evolution of NTR as a function of FTSW in A42

Discussion

According to Domínguez-Caraveo et al (2010), experiments carried out under shelter are essential because they allow early conclusions to be drawn before evaluation in the field or on the farm, and also allow environmental conditions to be controlled. This discussion focuses on the results relating to the phenotypic, morphological and physiological characteristics of cashew genotypes subjected to progressive water stress under shelter. At the phenotypic level, wilting followed by leaf drop was observed in cashew plants under a deficient regime (Stressed). This phenomenon was observed in all three genotypes. This is probably due to the fact that under a deficient water regime (Stressed), the plants were unable to maintain the integrity of the cell membranes in the leaves. On the other hand, in the absence of stress (Irrigated), the leaves of cashew plants of all three genotypes remained very green. Branching was even observed in all three genotypes. Water is a major constituent of all living organisms and is involved in important biochemical processes, including photosynthesis. Its availability in adequate quantities can affect the behaviour of a plant species. Following the various experiments carried out on young cashew trees under shelter, the results obtained suggest a depressive effect of the induced water stress deficit on the morphological characteristics of the plants. The results of the statistical analysis revealed a significant effect of the water regime (irrigated and stressed) on the stem height ($F = 42.94$; $P < 0.05$) of cashew trees. Dam et al (2020) found similar effects in sorghum plants. Moreover, in citrus fruit, stem length growth also decreases under water stress conditions (Bniken et al., 2010). Physiologically, the more water a plant receives, the more it grows, and the less water it receives, the less it grows. Thus, water is very important for plant growth. This idea was confirmed by Diallo in 2009, who showed that water deficit is the circumstance in which plants show a reduction in growth and production as a result of insufficient water supply). In all three genotypes, low rates of reduction in leaf length were observed under water deficit conditions. This was 6.06% for the A42 genotype, 5.94% for the PK18 genotype and -2.77% for the A2SINE genotype. This genotype was therefore the least affected for this parameter. For leaf width, the reduction rates were 7.04%, 10.93% and -3.11% for genotypes A42, PK18 and A2SINE. The A2SINE genotype was the least affected for this parameter. Similar effects were noted on biomass production of young cocoa plants in greenhouses by M'BO (2016). Similar effects were also observed on

the vegetative vigour of cocoa trees in the field by Elain et al. (2013), who deduced that these genotypes were well adapted to the field. The experiments also showed that the transpiration rate of cashew trees under a deficient water regime decreased as the fraction of transpirable water in the soil decreased. Our results are in line with those of Bniken et al. 2010. Indeed, these authors demonstrated that the rate of leaf transpiration of most citrus rootstocks placed under water stress decreased as the severity of the stress applied increased. According to Tezara et al (2002), the reduction in transpiration is due to a decrease in stomatal conductance and, consequently, a reduction in photosynthesis.

Conclusion

Dry-down (progressive water stress) is an effective approach for assessing plant behaviour in the face of water deficit at a young age. The results showed that the application of the water regime modified the visual appearance of young cashew seedlings. The transpiration rate in all three genotypes decreased as soil moisture decreased. This can be explained by the closure of the stomata under water-starved conditions to prevent the plant from transpiring too much. This reduces biomass production. Such a phenomenon in adulthood can reduce yield. These results show that, on the basis of changes in transpiration rate as a function of the fraction of water in the transpirable soil, these three genotypes appear to be sensitive to water shortage at a young age. It would be interesting to continue this study on a larger number of genotypes, including the three that have already been studied, in order to gain a better understanding of their behaviour in the face of water deficit. Other physiological parameters determined using the CI340 and the Scholander pressure chamber would be used.

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QUALITY AND STABILITY OF CASHEW APPLE (*ANACARDIUM OCCIDENTALE L.*) JUICE CLARIFIED WITH CASSAVA AND RICE STARCH

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SUMMARY

Used in the 1960s to combat erosion and land degradation in Côte d'Ivoire, the cashew tree has now become a perennial income-generating crop for many producers. The country remains the world's leading producer and exporter of cashew nuts, with 1,028,172 tonnes in 2022. However, with the effects of climate change, water is becoming increasingly scarce. Côte d'Ivoire is experiencing an increase in climatic variability, with recurrent and unpredictable pockets of drought. In Côte d'Ivoire, grafted seedlings are made available to farmers as selected planting material without any real knowledge of their behaviour in the face of water shortages. The aim of this study is to characterise three cashew genotypes at the nursery seedling stage in terms of their adaptation to low rainfall environments through their drought tolerance levels. The experimental design used was a randomised complete block with three replications. The results showed that in cashew seedlings of all three genotypes, stem height, circumference and number of leaves gradually decreased under low rainfall conditions. However, the KADM-87 genotype did not reduce the length (reduction rate: -2.77%) or width (-3.11%) of its leaves, whereas the other two genotypes reduced the length and width of their leaves: KADM-40 (6.06 and 7.04%) and KADM-98 (5.94 and 10.93%). This genotype also maintained its root volume under water deficit conditions, compared with the other two genotypes. KADM-87 is thought to be predisposed to water deficit tolerance. The rate of transpiration in all three genotypes decreased as soil humidity fell. It would be interesting to continue this study on a larger number of genotypes, including the three genotypes and other physiological parameters determined using equipment such as the CI340 and the Scholander pressure chamber, in order to gain a better understanding of their behaviour in the face of water deficit.

Key words: Cashew, climate change, water deficit, morphological parameters

INTRODUCTION

The objective of this study was to evaluate the impact of clarification with starch (cassava and rice) on the quality and stability of cashew apple juice (JPC) in comparison with clarification with gelatin. The juice samples: unclarified raw juice (JB), juice clarified with rice starch (JR), juice clarified with cassava starch (JM) and juice clarified with gelatin (JG) were stored at room temperature (30°C±2) in cardboard boxes protected from light. The physico-chemical and microbiological parameters of the juices were assessed on day T0 and every 45 days over a period of 135 days, while the sensory characteristics were assessed at the beginning and end of the storage period. The results showed that there was no significant difference ($p<0.05$) between the pH, titratable acidity, colour, browning index and mineral content of the juices regardless of the clarifying agent used. On the other hand, the tannin and total phenol content of the clarified juices was significantly ($p<0.05$) reduced. The reduction was about 12% in JR and JM juices, 19% in JG for phenols and about 53% in JR and JM juices, 72% in JG for tannins. The fructose, glucose and sucrose contents of the juices varied respectively from 38.85 to 48.34 (mg/mL); 20.89 to 26.23 (mg/mL) and 1.72 to 2.57 (mg/mL). JM had significantly ($p<0.05$) higher sugar, acetic (1.12 mg/mL), propionic (0.48 mg/mL) and citric (0.33 mg/mL) acid contents than RS and JG. From a sensory point of view, the Penalty Analysis of the juices (JM, JR, JG) indicated that none of the attributes (colour, odour, acid taste, astringent taste, sweet taste) of cashew apple juice penalised its overall acceptability rating by the consumer.

During storage, the physico-chemical parameters of the juices changed in the same direction independently of the clarifying agents used. There was a significant reduction ($P<0.05$) in pH, ESR, phenol, tannin and vitamin C content. The absorbances of the juices at 440 nm and 420 nm increased significantly ($P<0.05$) from T0 day to T135 days.

Key words: Cashew apple juice, clarification, starch, stability.

Introduction

Cashew apples are a good source of vitamins, carbohydrates, minerals, amino acids, carotenoids, phenolic compounds, organic acids and antioxidants (Irevisan et al., 2006; De-carvallio et al., 2007). Due to its high nutritional value, it is processed into various by-products, including juice. As with fruit juices in general, browning, loss of nutrients, particle formation and sedimentation can be observed during storage of cashew apple juice (Bracco, 1986). According to Dèdéhou et al. (2015a), although starch removes the majority of tannins from cashew juice, depositing of particles and colour change are observed during storage of clarified juice. Studies have shown that storage conditions have a significant effect on the physico-chemical, microbiological and organoleptic stability of juices (Garrido et al., 1993; Galeb et al., 2002; Lavinas et al., 2006; Siebert, 2006; Queiroz et al., 2008; Vijayanand et al., 2010). Several studies have shown that thermal and aseptic methods can maintain the physico-chemical characteristics of cashew apple juice for up to twelve months (Costa et al., 2003). Juice treated with tannase and stored at 4°C was stable for two months (Campos et al., 2002). Treating cashew apple juice at a high hydrostatic pressure of 400 MPa for 3 minutes at 25°C, followed by storage under refrigeration, maintains its stable quality for 8 weeks (Lavinas et al., 2008). The optimum conditions for removing tannins from cassava and rice starch were determined by Dèdéhou et al. (2015b).

In addition to this work, this study aims to assess the impact of using cassava and rice starch on the quality and stability of cashew apple juice.

Materials and methods

Plant Material

The plant materials used consist of:

- ripe cashew apples harvested at Bantè (8 25 ‘0’’N and 1 52 ‘60’’E) in the department of Collines in Benin and transported to the Physico-chemistry and Sensory Evaluation Laboratory for Foodstuffs at the University of Abomey-Calavi with ice for preservation;

- starches originating from the Nerica 1 rice variety and cassava variety RB89509, used as clarifying agents under the conditions described by Dèdéhou et al. (2015b);

- commercial gelatin used as a reference clarifying agent. For this purpose, a 10% (w/v) gelatin solution was prepared by dissolving gelatin in water at 60°C. The gelatin solution thus obtained was used after cooling at a dose of 2 g per litre of raw juice for clarification for 60 minutes, according to the method described by Talasila et al. (2012).

Method of cashew apple juice

Cashew apple juice was produced using the traditional process as described by Dèdéhou et al. (2015b) and shown in Figure 1. The tannin removal step using rice and cassava starch was carried out under optimal conditions. Indeed, for cassava starch 6.2 mL/L of juice for 300 minutes and for rice starch 10 mL/L of juice for 193 minutes are required for optimal tannin removal in the case of the traditional process (Dèdéhou et al., 2015b).

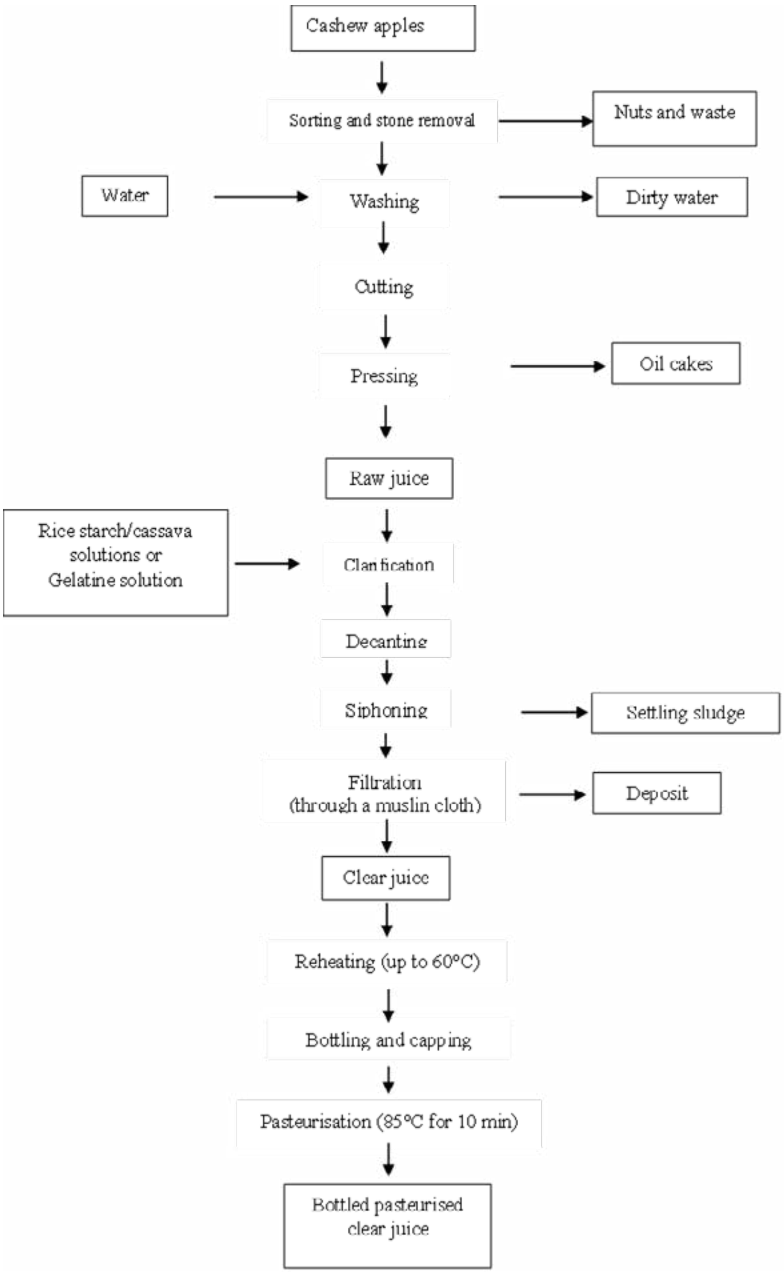

Figure 1: Cashew apple juice production diagram

Assessment of juice stability during storage

The juice samples produced were stored at room temperature (30°C ± 2°C) in cardboard boxes protected from light. The physico-chemical and microbiological parameters of the juices were assessed every 45 days over a period of 135 days. Sensory characteristics were assessed at the beginning and end of the storage period.

Physical and chemical analyses

In order to assess the physico-chemical quality of the juices, the following parameters were analysed using the methods described by Dèdéhou et al (2015a,b). These were pH, titratable acidity, refractometric dry extract (°Brix), colour, browning index, total phenol, condensed tannin, vitamin C and mineral content.

Microbiological analyses

The microbiological quality of the juices was assessed by determining the aerobic mesophilic flora, yeasts and moulds. To do this, 1 mL of the sample to be analysed was taken aseptically and 9 mL of sterile saline peptone water (5 g peptone, 8.5 g NaCl, pH = 7.2±0.2) was added; this mixture, homogenised by vortexing for 2 minutes, was used as the stock solution; successive decimal dilutions were then made and used to plate Petri dishes.

The aerobic mesophilic flora was determined on Plate Count Agar (PCA, oxoid, CM 325, Hampshire, England) using the method specified in standard ISO 4833: 2003.

Yeasts and moulds were counted following incubation of 1 mL of each dilution on Malt Extract Agar (MEA, oxoid, CM 325, Hampshire, England) at 25°C for 72 hours using the method specified in ISO 21527-1: 2008.

Coliforms (total and faecal) were counted using VRBG medium. 1 ml of each dilution was inoculated into a double layer of 10 to 15 ml of VRBG agar, then incubated after solidification of the medium at 37°C for 72 hours in accordance with ISO 21528-2: 2008.

Sensory analysis

The sensory analysis of the juices was carried out using an overall assessment test coupled with penalty analysis. Penalty analysis is a method used in sensory analysis to identify possible areas of improvement for products (Plaehn, 2009). A total of 105 consumers took part in the test. Two types of data were sought:

- Overall assessment data corresponding to overall satisfaction indices for clarified cashew apple juice.

An overall rating on a 9-point hedonic scale ranging from 9 = "extremely pleasant" to 1 = "extremely unpleasant".

- Data on a JAR (Just About Right) scale corresponding to scores from 1 to 5 for the following characteristics of the juices studied: colour, odour, acid taste, astringent taste and sweet taste. 1 corresponds to "Not at all enough", 2 to "Not enough", 3 to "JAR" (Just About Right), an ideal for the consumer, 4 to "Too much" and 5 to "Much too much".

These two types of data are combined and analysed numerically to determine the product attributes that penalise the consumer's overall appreciation. These are the attributes which, if adjusted, would have the greatest impact on improving the quality of the product, thereby increasing the consumer's overall appreciation score (Rothman, 2007). The penalty is the difference between the average of the preference data for the JAR category and the average of the data for the other two categories (Anon, 2003 and Rothman, 2007). An attribute will penalise the consumer's overall acceptability rating of the product if its effect on the average is significant and revealed by more than 20% of consumers (Xiong et al., 2007).

Statistical analysis

SAS v 9.2 software was used for statistical analysis of the data. Analysis of variance (ANOVA) was performed and the differences between the data were determined by the Student-Newman-Keuls test at the 5% threshold. Penalty analysis was performed using XLSTAT software.

Results and discussion

Physico-chemical quality of cashew apple juice clarified with starch (cassava and rice)

Table 1 shows the titratable acidity, pH, soluble solids, vitamin C, tannin and total phenol contents of raw unclarified juice (JB), rice starch clarified juice (JR), cassava starch clarified juice (JM) and gelatin clarified juice (JG). The analysis of variance showed that there was no significant difference ($p<0.05$) between the pH, titratable acidity, colour and browning index of the juices regardless of the clarifying agent used, compared with the raw juice. While the pH of raw juice is 4.9, Akinwalé (2000), Damasceno et al (2008) and Adou et al (2012) obtained a pH of 4.1, 4.4, 4.3 and 4.5 respectively for raw cashew apple juice. Furthermore, Akinwalé (2001) and Adou et al. (2012) obtained a soluble dry extract content of 11 and 10.2 to 10.9 °Brix respectively for raw cashew apple juice, as in this study (10.8 °Brix).

The reduction in the tannin and total phenol content of the clarified juices was more pronounced in the JG juice than in the JR and JM juices. It was around 12% in JR and JM juices, 19% in JG for phenols and around 53% in JR and JM juices, 72% in JG for tannins. Several studies have shown that clarification reduces the phenolic compound content of juices.

Vitamin C in cashew apple juice was significantly ($p<0.05$) reduced during the clarification process. The greatest loss of vitamin C was observed in the GJ juice and the least in the RJ juice. This loss could be explained by the rapid oxidation of the vitamin during pasteurisation of the juice after clarification (Vivekanand et al., 2012). Indeed, the use of cassava and rice starch for tannin removal followed by filtration through Whatman No. 1 paper did not induce any significant loss of ascorbic acid (Dèdéhou et al., 2015b).

The vitamin C content of the juices obtained in this study is higher than those obtained by Akinwalé et al. (2001) in Nigeria after 10 to 30 minutes of heating cashew apples, which is 120.60 to 152.40 mg/100 mL compared with 195.80 mg/100 mL for raw juice from unheated cashew apples, while Talasila et al. (2012b) obtained 123.9 to 184.46 mg/100 mL for cashew apple juice.

Table 1: Chemical characteristics of the different juices

Parameters	JB	AM	AR	JG*
pH	4,9±0,0a	4,9±0,0a	4,9±0,0a	4,9±0,0a
Titratable acidity	0,4±0,0a	0,4±0,0a	0,4±0,0a	0,4±0,0a
ESR (°Brix)	10,8±0,0a	10.4±0.0ab	10,2±0,0b	10,2±0,0b
Colour (Abs)440nm	0,2±0,0a	0,1±0,0a	0,2±0,0a	0,1±0,0a
Browning index (Abs)420nm	0,2±0,0a	0,2±0,0a	0,2±0,0a	0,1±0,0a
Vitamin C (mg/100 mL)	418,1±2,3a	359,2±1,2c	382,8±1,9b	331,3±0,9d
Tannin (mgEqCatechin/100 mL)	162,1±0,4a	74,7±1,3b	79,1±1,9b	44,5±1,0c
Phenol (mg Ac gali/L)	2081,0±15,6a	1831,0±9,9b	1834,0±11,3b	1681,0±7,1c

Values with different letters on the same line are significantly different at 5% according to the SNK test.

*JB: unclarified raw juice, JM clarified cassava starch, JR: clarified rice starch, JG: clarified gelatin juice.

Table 2 shows the sugar and organic acid content of the raw and clarified juices. The fructose, glucose and sucrose contents of the juices vary respectively from 38.85 to 48.34 (mg/mL); 20.89 to 26.23 (mg/mL) and 1.72 to 2.57 (mg/mL). Fructose is the most abundant sugar in cashew apple juice, while sucrose content is very low. The sugar contents of the three types of juice were significantly ($p<0.05$) different. JM has the highest fructose, glucose and sucrose content.

Glucose, fructose and sucrose are the main sugars in cashew apple juice as shown by many authors (Sivagurunathan et al., 2010; Adou et al., 2012). The sucrose, glucose and fructose contents of the raw juice in the present study are similar to those (0.0 to 1.6 mg/mL; 17.3 to 34.6 mg/mL, 31.6 to 65.5 mg/mL for sucrose, glucose and fructose respectively) obtained by Dèdéhou-Attemba et al. (2023) for cashew apple juice from some cashew cultivars in Benin.

The sugar content of juice clarified with starch is higher than that of JB and JG; this is due to the presence of starch residues in the juice after filtration. In fact, starch, which consists mainly of a carbohydrate fraction (98 to 99%) and a minor non-carbohydrate fraction (1 to 2%), can undergo saccharification during juice storage, a process that could result in an increase in sugar levels. In addition, according to Mahajan (1994), sucrose is inverted into fructose and glucose due to acidity and high temperature. In the production technology used in this study, the juices were pasteurised at 80°C for 15 minutes. Sucrose inversion, also favoured by the low pH of the juices, would have occurred at this stage of the technological process. Carvalho et al (2008) reported an increase in glucose and fructose content in pineapple juice hydrolysed with commercial pectinase.

Of the five organic acids, oxalic acid, citric acid, propionic acid, acetic acid and malic acid, only citric acid (5.62 mg/mL) and malic acid (3.1 mg/mL) were identified in raw cashew apple juice. The cashew apple juice clarified with cassava starch (JM) had significantly ($p<0.05$) higher acetic (1.12 mg/mL), propionic (0.48 mg/mL) and citric (0.33 mg/mL) acid contents than JR and JG.

Table 2: Sugar and organic acid content of cashew apple juice in mg/mL

	JB	JM	JR	JG
Glucose	20,9 ± 0,0c	26,2 ± 0,22a	23,5 ± 0,4 b	20,6 ± 0,0c
Fructose	38,8 ± 0,0c	48,3 ± 0,05a	44,5 ± 0,7b	38,1 ± 0,0c
Sucrose	2,1 ± 0,0b	2,6 ± 0a	1,7 ± 0c	2 ± 0,0b
Oxalic acid	0±0b	0 ±0b	0,06 ± 0,0a	0±0b
Citric acid	5,6 ± 0a	0,3±0c	1,0±0b	5,3 ± 0a
Propionic acid	0 ± 0c	0,5 ± 0,0a	0,2 ± 0,0b	0 ± 0c
Acetic acid	0±0c	1,1 ± 0a	0,6 ±0,0b	0±0c
Malic acid	3,1 ±0a	0,9 ± 0,08b	0 ± 0c	2,8 ±0a

Values with different letters on the same line are significantly different at 5% according to SNK

The contents (mg/kg) of potassium, phosphorus, magnesium, sodium, calcium, iron and zinc in cashew apple juice are presented in Table 3. Potassium levels varied from 1178.1 to 1253.9, followed by phosphorus 141.6 to 175.8, magnesium 126.3 to 143.1, sodium 39.1 to 57.9, calcium 14.0 to 17.6, iron 1.6 to 1.8 and zinc 0.7 to 0.9. Clarification, regardless of the clarifying agent used, had no significant impact ($P>0.05$) on the mineral content of the juices.

Table 3: Mineral content of cashew apple juice expressed as (mg/kg)

Minerals	JB	JM	JR	JG
Magnesium	143,1±14,4a	139,3±5,2a	126,3±3,8a	138,7±0,6a
Potassium	1253,9±12,9a	1237,4±8,0a	1178,1±77,4a	1247,5±45,7a
Sodium	46,5±9,0a	51,6±10,4a	39,1±9,8a	57,9±4,1a
Calcium	14,5±0,0a	17,1±1,1a	14,0±0,7a	17,6±1,5a
Iron	1,7±0,1a	1,8±0,4a	1,6±0,4a	1,6±0,1a
Zinc	0,8±0,2a	0,7±0,0a	0,7±0,3a	0,9±0,2a
Phosphorus	166,5±13,4a	167,9±1,7a	141,6±1,5a	175,8±35,8a

Values with different letters on the same line are significantly different at 5% according to the SNK test.

Overall acceptability and juice penalty test

The histograms in Figure 2 show the distribution of consumers according to the scores given to the various juice criteria on the JAR (Just About Right) scale. For the characteristics of the juices (JM, JR, JG) tested, that is, colour, odour, acid taste, astringent taste and sweet taste, the score 1 corresponds to "Not at all enough", 2 to "Not enough", 3 to "JAR" (Just About Right), an ideal for the consumer, 4 to "Too much" and 5 to "Much too much". The results expressed by histograms a, b, c, d and e show that the five indexed juice characteristics were found to be ideal (JAR) for the consumer.

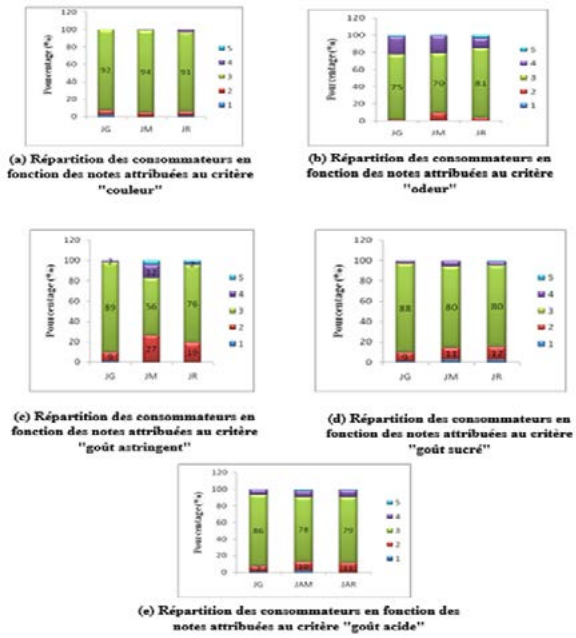

Figure 2: Distribution of consumers according to the scores attributed to the different criteria for cashew apple juice

Table 4 presents the penalty analysis on the mean for cashew apple juice (JM, JR, JG). The variables of colour, odour, astringent taste, acid taste at the "too weak" level and sweet taste at the "too strong" level significantly ($p<0.05$) reduced the overall acceptability of cashew apple juice by consumers. The overall acceptability score was reduced by 0.82; 0.86; 0.68; 0.93; 0.65 points by colour-, odour-, astringent-, acid- and sweet+ respectively.

Table 4: Penalty analysis and effects on average JAR for cashew apple juice

* Significance at the 5% level.

Variables	Level	%	Average (overall ac.)	Effects on the average	p-value	Penalties
Colour	Too weak	6	6,16	0,82	<0,001	0,05*
	JAR	93	6,98			
	Too strong	1	6,75	0,23	0,402	0,00
Odour	Too weak	5	6,25	0,86	<0,001	0,04*
	JAR	75	7,11			
	Too strong	20	6,39	0,72	0,664	0,14
Astringent taste	Too weak	18	6,43	0,68	<0,001	0,13*
	JAR	74	7,11			
	Too strong	8	6,36	0,75	0,774	0,06
Sweet taste	Too weak	13	6,78	0,22	0,123	0,03
	JAR	83	7			
	Too strong	4	6,07	0,93	0,01	0,04*
Acid taste	Too weak	10	6,39	0,65	<0,001	0,07*
	JAR	81	7,04			
	Too strong	9	6,48	0,56	0,75	0,05

All the attributes of cashew apple juice that have significant effects on the average were revealed by less than 20% of consumers. This result indicates that none of the attributes (colour, odour, acid taste, astringent taste, sweet taste) of cashew apple juice penalises its overall acceptability rating by the consumer. In fact, according to Xiong et al (2007) an attribute penalises the overall acceptability rating of a product by the consumer if its effect on the average is significant and revealed by more than 20% of consumers.

Assessment of the physico-chemical stability of the juice

The physico-chemical parameters of the juice during storage are summarised in Table 5. The physico-chemical parameters of the juices evolved in the same direction independently of the clarifying agents used. During storage, there was a significant reduction ($P<0.05$) in pH, ESR, phenol, tannin and vitamin C content. The absorbances of the juice at 440 nm and 420 nm, which indicate colour and browning index respectively, increased significantly ($P<0.05$) from T0 to T135 days.

Table 5: Physico-chemical characteristics of juice during storage

Parameters	Samples	T0 Day	T45 days	T90 days	T135 days
pH	JG	4,9±0,0a	4,5±0,0b	4,2±0,0c	4,0±0,0d
	JR	4,9±0,0a	4,6±0,0b	4,3±0,0c	4,1±0,0d
	JM	4,9±0,0a	4,6±0,0b	4,3±0,0c	4,1±0,0d
Titratable acidity	JG	0,4±0,0a	0,4±0,0a	0,4±0,0a	0,4±0,0a
	JR	0,4±0,0a	0,4±0,0a	0,4±0,0a	0,4±0,0a
	JM	0,4±0,0a	0,4±0,0a	0,4±0,0a	0,4±0,0a
ESR (°Brix)	JG	10,2±0,0a	10,1±0,0a	10,0±0,0a	10,0±0,0a
	JR	10,2±0,0a	10.1±0.0ab	10,0±0,0b	9,0±0,0c
	JM	10,4±0,0a	10,1±0,0b	10,1±0,0b	10,0±0,0b
Colour (Abs)440nm	JG	0,1±0,0c	0,3±0,0b	0,3±0,0b	0,4±0,0a
	JR	0,2±0,0d	0,3±0,0c	0,4±0,0b	0,5±0,0a
	JM	0,1±0,0d	0,3±0,0c	0,4±0,0b	0,5±0,0a
Browning index (Abs)420nm	JG	0,1±0,0d	0,3±0,0c	0,4±0,0b	0,5±0,0a
	JR	0,2±0,0d	0,4±0,0c	0,5±0,0b	0,7±0,0a
	JM	0,2±0,0d	0,4±0,0c	0,5±0,0b	0,7±0,0a
Vitamin C (mg/100 mL)	JG	331,3±0,9a	325,0±0,2b	318,1±0,3c	312,2±0,5d
	JR	382,8±1,9a	362,7±0,0b	342,7±1,3c	322,5±1,6d
	JM	359,2±1,2a	349,1±0,0b	339,0±0,2c	328,3±0,5d
Tannin (mgEqCatechin/100 mL)	JG	44,5±1,0a	34,2±0,4b	24,5±0,1c	14,6±0,1d
	JR	79,1±1,9a	64,7±0,0b	50,7±0,5c	36,0±0,0d
	JM	74,2±5,0a	65,2±0,0b	56,2±0,0c	47,2±0,0d
Phenol (mg Ac gali/L)	JG	1681,0±7,1a	1648,3±0,5b	1616,1±0,4c	1584,0±0,1d
	JR	1834,0±11,3a	1823,4±0,0a	1756,7±0,0b	1690,3±1,1c
	JM	1830,0±22,6a	1794.3±0.5ab	1759.7±0.5bc	1725,0±0,1c

Values with different letters on the same line are significantly different at 5% according to the SNK test.

Several studies have shown that storage conditions have a significant effect on the stability of cashew apple juice. Indeed, storing cashew apple juice for 48 hours at 4°C resulted in a loss of ascorbic acid of up to 8.8% for concentrated juice and 6.4% for non-concentrated juice. The other parameters remained stable during storage (Queiroz et al., 2008). Evaluation of the physico-chemical stability of cashew apple juice stored at room temperature for 24 h, refrigerated for seven days or frozen for 120 days showed that the ascorbic acid content of fresh cashew juice, which was 147.29 ± 0.41 mg/100 mL, was reduced by 6.57% when stored at room temperature. In juice stored in the refrigerator and frozen, the rate of ascorbic acid reduction was 1.16%/day and 0.05%/day respectively. The other physico-chemical parameters remained stable (Lavinas et al., 2006). According to Vijayanand et al. (2010) on Litchi chinensis L juice, no significant change ($p\geq0.05$) was observed in ESR, pH, ascorbic acid during storage, but non-enzymatic browning and tannin content increased ($p<0.05$) after 6 months of storage. Galeb et al (2002) also observed an increase in non-enzymatic browning in concentrated cantaloup juice stored at 25°C for 4 months. For these authors, this result could be explained by the high pH of cantaloup and the high storage temperature. The same trend was observed by Sandhu et al. (1985) during the storage of pineapple juice. Alper et al (2005) reported a 22.7% reduction in the initial phenol content of pomegranate juice after fining and pasteurisation. For Siebert (2006), enzymatic browning of the juice is one of the defects of this type of beverage. Co-oxidation and polymerisation reactions lead to changes in colour and aroma, and the presence of polyphenols in the juice increases its susceptibility to enzymatic browning.

On the other hand, testing the efficacy of chemical preservatives in combination (sodium benzoate and sodium metabisulphite at 0.1 g/L each, sodium benzoate and citric acid at 0.1 g/L each and sodium metabisulphite and potassium metabisulphite at 0.05 g/L each) extended the shelf life of cashew apple juice to 20 days, and vitamin C and total sugars in the samples were found to be almost stable (Talasila et al., 2012). The shelf life of juice treated with citric acid and benzoic acid at 0.1 g/L each and stored at 4°C was extended to 90 days (Talasila et al., 2011). Cashew apple juice, microfiltered through a tubular membrane with 0.3µm pore diameter after hydrolysis and stored at low temperatures, was stable for consumption after a shelf life of two months, as a source of vitamin C and without any turbidity (Campos et al., 2002).

Sediment formation and deposition have been observed in all bottles, regardless of the clarifying agent used. Some studies have shown that even juices that have undergone ultrafiltration are subject to sediment formation after bottling (Nagel and Schobinger, 1985). Floribeth and

Lastreto (1981) reported that up to a residual content of 1%, starch can be responsible for the formation of particles in the juice and hinder its filtration. According to Carrin et al (2004), the presence of starch in juice can cause particle formation. Phenolic compounds have also been shown to be responsible for the formation of insoluble sediments in juices (Musingo et al., 2001). According to Garrido et al (1993), sediment formation induced by phenolic compounds is accelerated by high storage temperatures and pasteurisation heat treatments. For Yamaski et al (1964) this defect is known as late sedimentation and could develop if the juice, during the production process, was subjected to temperatures higher than the storage temperature, as was the case in this study.

Microbiological stability of different clarified juices during storage

Evaluation of the microbiological characteristics of the juices during storage revealed that no microorganisms were identified in the juices after 135 days of storage.

This could be explained by the fact that the pasteurisation heat treatment was effective in eliminating all micro-organisms at T0 day. The microbiological stability of the juices indicates that there was no development of spores during storage at room temperature (30°C±2). The relatively low pH of the juices does not favour the development of most bacteria (Ranganna, 1986). The same trend was observed by Talasila et al (2011) on cashew apple juices with added chemical preservatives (citric acid and benzoic acid) for up to 90 days. After three months, bacteria (< 5 CFU/mL), yeasts and moulds (1 CFU/mL) developed in the juices due to the germination of spores following the gradual reduction in the effectiveness of the chemical preservatives used. Evaluation of the microbiological stability of cashew apple juice stored at room temperature for 24 hours, refrigerated for seven days and frozen for 120 days showed an increase in the number of mesophilic bacteria, yeasts and moulds in the juice stored at room temperature. In the juice stored in the refrigerator for seven days, the number of mesophilic bacteria decreased and that of yeasts and moulds increased. On the other hand, in the frozen juice, yeast and mould numbers were reduced compared to the initial numbers, while mesophilic bacteria showed variation up to the 30th day and remained stable up to the 120th day (Lavinas et al., 2006).

Overall acceptability of juice after storage

Table 6 shows consumers' overall appreciation of the juices at 0 days and 135 days of storage. Analysis of variance showed that all the juices were still found to be pleasant by consumers after storage for 135 days. According to the work of Talasila et al (2012), the sensory attributes of cashew apple juice with added chemical preservatives also indicated good overall acceptability after 20 days of storage. Vijayanand et al. (2010) observed that in sensory terms, Litchi chinensis L juice remained stable in terms of colour, taste and odour after 6 months.

Table 6: Overall assessment of juice at 0 days and 135 days of storage

Products	Time	GJ	CJ	RJ
Overall acceptability	T0 day	7.1±0.8ab	6.7±1.0ab	7.0±0.8ab
	T135 days	7,3±0,5a	5,8±1,5c	6,6±0,8b

Values with different letters on the same line are significantly different at 5% according to the SNK test

Conclusion

Clarification of cashew apple juice did not affect the pH, titratable acidity, colour, browning index or mineral content of the juice. Gelatin was more effective at eliminating tannins and polyphenols than the two types of starch. A loss of 9 to 21% of vitamin C in the juices was noted, which would be induced by the juice pasteurisation operation and not by the nature of the clarifying agents used. The greatest loss of vitamin C was observed in the juice clarified with gelatin and the least in the juice clarified with rice starch. From a sensory point of view, on the JAR scale, the five characteristics (colour, odour, acid taste, astringent taste, sweet taste) of both the gelatin clarified juice and the cassava and rice starch clarified juices were found to be ideal for the consumer, with the same overall rating. Although the three types of juice were still pleasant to consume after 135 days of storage at room temperature (30°C±2), there was a significant reduction ($P<0.05$) in pH, ESR, phenol, tannin and vitamin C content and an increase in the browning index.

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EFFECTS OF DRIED CASHEW (ANACARDIUM OCCIDENTALE L.) PULP-BASED FEED ON THE PERFORMANCE OF BROILERS DURING THE GROWTH PHASE IN CASAMANCE/SENEGAL

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SUMMARY

In Casamance, using cashew nut pulp for poultry feed could help reduce the cost of poultry feed. This study consisted of testing the effect of dried cashew nut pulp during the growth phase, using four collection and processing approaches for the manufacture of poultry feed during the growth period. The experiment lasted 40 days with 190 chicks of the Cobb500 strain randomly divided into 5 groups, including a control group (Gt). The chicks in each group were fed the same diet with the industrial feed 'AVISEN' during the start-up period. During the growth period, 18% of the maize was replaced by dried cashew pulp. The parameters measured were average daily gain (ADG) and feed intake (feed conversion ratio). The control group received the industrial feed 'AVISEN' throughout the experiment, while the other four groups received four types of feed containing dried cashew nut pulp. The results of the experiment showed that the chickens fed a feed containing cashew pulp from itineraries B and D recorded a performance quite close to the control group, with average weights of 1.390 kg each compared with 1.612 kg for the control group (Gt) on the 40th day. Consumption indices were higher in Group 4 (2.8), followed by Group 1 (2.7), Group 2 (2.6) and Group 3 (2.4) compared with the control (1.8). Itinerary B and D are recommended for the collection and processing of cashew pulp for the manufacture of poultry feed.

Keywords: cashew nut pulp, broiler chicken, consumption index.

INTRODUCTION

Originating from the Caribbean and north-east Brazil, the cashew tree (Anacardium occidentale L.) is now widely cultivated in all tropical areas, including Africa, the West Indies, north-east Brazil, south-east Asia and India (Lautié et al., 2001; Trekpo, 2003). It was cultivated for a long time by indigenous peoples before being discovered by the Portuguese, who later introduced it to the African colonies (Abdou et al., 2012). In Senegal, Anacardium occidentale L. was introduced in 1914 to reforest degraded areas (Totjssaint-Norlet and Giffart, 1961). Interest subsequently grew with the increase in demand for raw nuts from the Indian and Vietnamese industries (PADEC, 2012).

Global cashew nut production has grown exponentially from 288,000 tonnes in 1961 to 4,087,563 in 2016 (FAOSTAT, 2019). Senegal exports around 50,000 tonnes per year (ACA, 2020). Cashew nut production is an important part of the country's economy, making Senegal the 15th raw nut producer in the world and the 9th producer in Africa (ACA, 2014). A well-maintained and fertilised cashew orchard produces between 1.5 and 2 tonnes of nuts per hectare and around 20 tonnes of apples at peak production (Modeste and Louppe, 2003). Thus, the tonnage harvested per hectare for cashew apples is 5 to 9 times greater than for walnuts (Lautié et al., 2001). Cashew apples are discarded after the juice has been extracted, or even without extraction, in the fields after the nuts have been harvested. At the same time, Senegal's poultry industry, which is constantly expanding and has a turnover of 68 billion CFA francs (Diaw et al., 2010), is suffering from a demand for chicken feed that is outstripping supply. This false fruit, considered to be a by-product of walnut production, represents a considerable economic challenge. The rapid fermentation of cashew apples is one of the difficulties associated with their use in animal feed (Aboh et al., 2011). However, its use has been reported in rabbit feed (Fanimo et al., 2003) and for Barbary ducklings (Aboh et al., 2012). In Senegal, apple processing is still fairly experimental and the fruit is still very little used (PADEC, 2016). Using apples in chicken feed could reduce the cost of poultry feed. The aim of this study is therefore to contribute to adding value to cashew by-products by processing dried cashew pulp for broiler feed.

2. MATERIALS AND METHODS

2.1. Pulp collection and treatment methods

Four itineraries (A, B, C and D) were used to collect and process cashew pulp. Each itinerary constituted a cashew pulp by-product. The reduction of anti-nutritional factors in cashew nuts was a motivation for the choice of these different itineraries below.

2.1.1. Pulp taken from a dump and dried (Photo A)

The pulp was collected from a two-month-old cashew pulp dump. This is a dump of cashew pulp discarded after extraction of the juice with a jack press. It is under shade and has a cross-sectional diameter of 6.45 m, a thickness of 0.70 m and an average temperature of 43.3°C at the surface, 47.8°C at 35 cm and 48.3°C at 70 cm depth. A sample of cashew pulp was taken vertically from the centre so as to touch all the layers of the dump. The pulp was then dried in the sun on cloths for 5 days. A 15 m metric tape and a shovel were used to measure the diameter and thickness of the pulp.

2.1.2. Dried pulp after juice extraction with the addition of 1% salt (Photo B)

Fresh cashew apple pulp, that is, collected and pressed on the same day, was recovered after extraction of the juice using a jack press. This pulp was mixed with 1% iodised salt (100kg pulp to 1kg salt) and then dried in the sun on cloths for 6 days. Salt helps to preserve the organoleptic qualities of food by acting as a dehydrating agent and reducing water activity. It also inhibits the development of micro-organisms and stops enzymatic reactions (Mishra and Gupta, 2006).

2.1.3. Dried pulp after juice extraction, washing and pre-cooking (Photo C)

The fresh pulp was recovered directly after extraction of the juice by a jack press, washed, pre-cooked and dried in the sun. Washing reduces glucose (to limit fermentation) and tannin (Zimmer and Cordesse 1996), both of which are soluble in water. Pre-cooking preserves the organoleptic qualities of the pulp and improves its digestibility. Pre-cooking was carried out as follows:

First of all, the pot is put on the fire with water and starch in proportions of 16% and 1% respectively, and boiled to make a porridge. The starch captures the tannin;

Then weigh the pulp, put it in the pot and leave it to boil for 30 minutes;

Finally, remove the pot from the heat, drain off the water and dry in the sun on cloths for 5 days.

2.1.4. Pulp buried in a pit after extraction of the juice with the addition of 2% salt (Photo D)

The fresh pulp was recovered after extraction of the juice by the jack press, salted with a 2% iodised salt (100kg of pulp for 2kg of salt) and buried in a pit. The proportion of salt added to I4 was assessed to ensure that its concentration in the finished product did not constitute a nutritional limit when formulating the compound feed. In fact, the salt content of the feed indicated for broiler nutrition is 0.15 to 0.23% (Cobb500, 2012). The pit product was stored for 4 weeks.

Figure 1: Different methods of collecting and treating pulp

2.3 Manufacture of different types of feed for growth

This involves the formulation and preparation of the feed.

2.3.1. Feed formulation

A compound growth feed was formulated using different ingredients. The ingredients were selected according to their nutrient composition and then formulated using linear programming with Feedwin formulation software. The formulation, using linear programming, enabled the nutritional and economic objectives to be achieved.

The Feedwin algebraic solution searches for levels of incorporation xi of Nj ingredients, characterised by:

- a technical vector (a) ij
- and a cost cj, within a mixture Mi which must comply with constraints Bi

$\sum a_{ij} X_j \leq B\, i$

And which must have a minimum cost

$\sum c_j\ X_j$

Bearing in mind that linear programming can only be applied because the chicken's feed units or nutrient requirements are additive, feed formulas are composed for the four groups of chicken. The differentiation between the four types of feed is expressed by the method used to collect and process the cashew. The feed units remained identical for all four groups. Maize was substituted for cashew pulp at a rate of 18% in the growth feed produced. Given the quality of its digestive energy (DE) contribution, maize remains the basic cereal in the formulations, with incorporation rates of around 60% for chicken. For the experimental feed, maize accounts for 45.4%. Peanut meal and fish meal account for 15% and 18.7% respectively (Table 1). The chemical composition was estimated using Feedwin software (Table 2).

Table 1: Nutrient composition of growth feed

INGREDIENTS	PERCENTAGE (%)
Maize	45.4
Groundnut cake	15
Fish meal	18.7
Cashew	18
Vegetable oil	2.5
Lysine	0.2
Methionine	0.1
Salt	0.3
CMV	0.125
Afimould	0.150

Table 2: Estimated physico-chemical composition during growth

ESTIMATED COMPOSITION*(1)	PERCENTAGE (%)
ME (kcal/kg)	3155
Lysine	1.09
Methionine	0.51
CF	6.05
CP	20.39
Ca	1.17
P	0.70

*(1) Value indicated by the feedwin formulation software

2.4. Experimental protocol

2.4.1. Experimental set-up

At the end of the start-up phase, of the 200 chicks in the flock, 190 chicks remained. These 190 chicks were divided into 5 groups of 38 chicks each. These groups were divided into 5 partitions of 4m each2 which were made in the rearing building (Figure 6). Each partition contained wood shavings, a 5-litre drinking trough and two 1 m linear feeders. These groups of chicks were fed different feeds during the growth phase, which lasted 23 days (from 17th day to 40th day).

2.4.2. Conduct of the Test

2.4.2.1. Consumption Control

At each feed distribution, the quantity of feed distributed to each group was weighed. The quantity of feed remaining in the troughs was also checked before renewal. This procedure was used for all the groups and enabled us to determine:

- CAM: The average quantity of food ingested per subject/group

  With CAM = Q = (Qd-Qr)/ number of subjects per group

  Q: quantity of feed ingested from day (Di) to day (D i+n)

  Qd: quantity of feed distributed

  Qr: quantity of feed refused

- CI: Consumption index by group/period

Based on the quantities ingested and the GMQ, consumption indices (CI) can be calculated: CI = CI (Di, Di+n) = Qi (Di, Di+n) /GMQ

2.4.2.2 Weight Control

A needle pointer scale was used to check the weight of the subjects. Subjects were weighed at regular 3-day intervals to determine the average weight per group and the associated CI. All subjects in each group were weighed over a 3-day interval (tridian). This made it possible to calculate the consumption index (CI) or average food conversion ratio per group. The feed conversion ratio is the ratio that measures the conversion of the quantity of feed consumed into live body weight. The aim of this test was to determine the following parameters:

P: average weight/individual/group at each weighing session (g);

P = (sum of the weights of individuals weighed in the group)/(total number of individuals in the group)

2.5 Data processing

The various results collected throughout the experiment were subjected to an analysis of variance using XLSTAT software. The Student Newman Keuls test at the 5% threshold was used to compare the effect of the different collection and processing itineraries for dried cashew pulp on broiler growth. Graphs were produced using Excel version 2010.

3. Results

3.1. Physico-chemical characteristics of pulp from the different itineraries

Analysis of the pulp from the different itineraries revealed an acid pH for all four itineraries (Table 4). Itinerary B had the most acidic pH (pH=3.72), followed by Itinerary A (pH=4), C (pH=4.05) and D, which had the least acidic pH (pH=4.36). Moisture analysis shows that moisture content is lower for A and C. However, itineraries B (moisture content = 38.3%) and D have moisture values 3 times higher than the first two (A and C).

Table 4: Humidity and pH of the different itineraries

Itineraries	pH	Moisture content (%)
A	4.00	12.20
B	3.72	38.30
C	4.05	12.70
D	4.36	41.40

3.2 Feed Consumption

A progressive increase in the quantity of feed ingested was noted from the first to the eighth tridian for Gt, G2, G3 and G4. For G1, an increase was noted from the first to the second tridian and a decrease from the second to the third tridian, followed by an increase up to the eighth tridian (Figure 7). ANOVA revealed that feed consumption was not significantly different between groups Gt, G1, G2, G3 and G4 ($p \geq 0.48$).

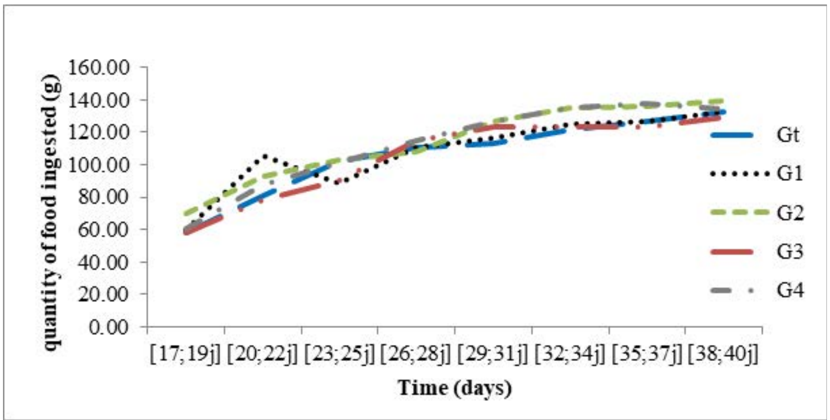

Figure 7: Change in feed consumption by day (tridian)

3.3 Weight trends

Figure 8 shows how the average weight of the different groups changed over the 23 days of the experiment. There was a gradual increase in the average weight of each group. On the 40th day of the experiment, group Gt recorded the highest average weight with a value of 1612.16g, followed by G4 (1390.27g), G2 (1360.53g), G3 (1288.16g) and G1 (1243.24g).

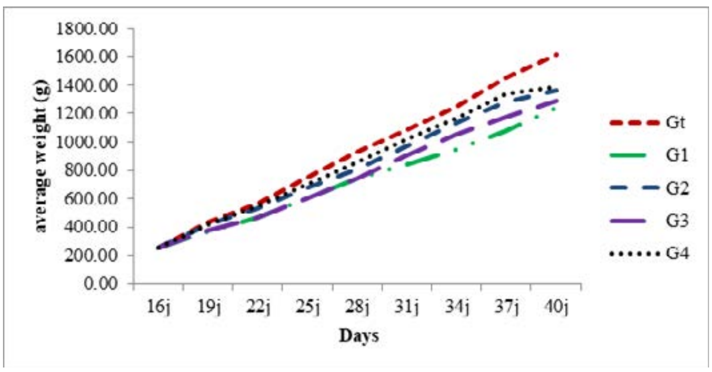

Figure 8: Change in average weight by day.

Statistical analysis revealed that there was no significant difference ($p \geq 0.287$) between the different groups using Fisher's Multiple Comparison Test (Table 5). In other words, the rations derived from the pulp-rich itineraries produced the same weight in chickens, and this weight was more or less equal to that of chickens fed industrial feed.

Table 5 : Classification of chicken groups

Groups of chickens	Weight (in g)	Groupings
G1	726,382	A
G3	763,273	A
G2	826,431	A
G4	855,119	A
Gt	926,917	A

3.2.4 Consumption Index (CI)

Figure 9 shows the average consumption index for the different groups throughout the experiment. G4 had a higher CI, followed by G1, G2, G3 and Gt, with values of 2.82, 2.71, 2.65, 2.47 and 1.89 respectively. Statistical analysis shows that the difference is not significant ($p \geq 0.113$) between the group of chickens fed industrial feed (Gt) and the groups of G1, G2, G3 and G4 chickens fed cashew-containing feed. However, the relationships between G1 and Gt, G2 and Gt, G3 and Gt and G4 and Gt show that the CIs of G1, G2, G3 and G4 are respectively 1.3, 1.4, 1.3 and 1.5 times greater than the CI of Gt.

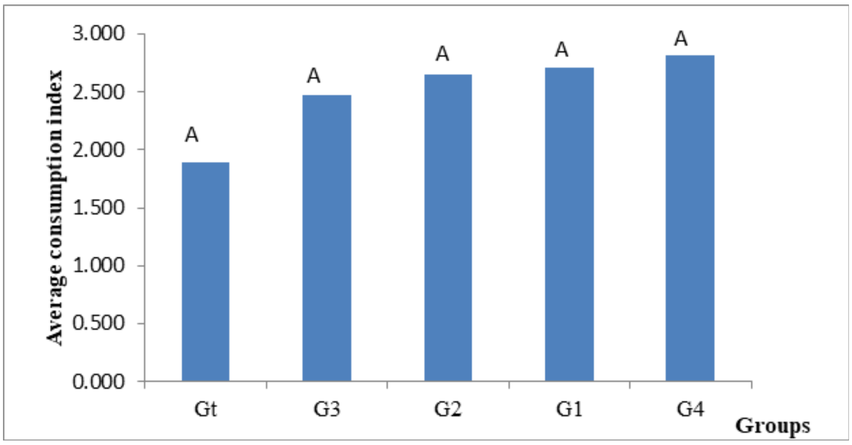

Figure 9: Average consumption index by group

4. Discussion

The factors that influence the drying time of products are temperature and ambient humidity. These two parameters, combined with atmospheric pressure, speed up or slow down the drying process, which is initially rapid and gradually slows down. In practice, the maximum humidity for preserving agricultural products is 11% (Pangui et al., 2011).

The nutritional value of ingredients is expressed as a percentage of dry matter. A feed containing a high proportion of water, compared with its drier counterpart, appears to be less concentrated in nutrients. On the other hand, it was found that the raw materials obtained with the addition of salt (B and D) to accelerate drying produced the best growth performance in broilers despite being wetter. It is assumed that the processing itineraries for raw materials A and C resulted in a deterioration in the nutritional quality of the cells. The rapid fermentation of cashew apples has been reported by some authors, due to the transformation of glucose into ethanol (Aboh et al., 2011).

Dry ingredients rich in fibre are thermolabile, so when they come into contact with air, they gradually lose their energy quality (Sauvant et al., 2004). The destruction of nutrients in less moist cashew products by heating could be the second reason for the poor performance of A and C.. Indeed, the moisture values of B and D are assumed to be high, compared with A and C, which nevertheless recorded the lowest weight gains.

The lowest performance of the four batches expressed by this itinerary is supposed to be induced by the initial quality of the cashew pulp, which was taken from a heap composed of apples several days old. This indicates the importance of the freshness of the raw material. However, its CI of 2.82, which is close to that of the Gt control group, could be due to the combined effects of the evacuation of tannin through the draining of the apple and the dissipation of ethanol in an anaerobic environment.

The group of chickens fed with the product from A showed the best homogeneity. Its CI of 2.7 at the end of the cycle was relatively high compared with the average of around 1.6 indicated in the information review published by Isolysine, the owner of the Cobb strain. This can be explained by a poor estimate of the energy that can be metabolised during formulation. This resulted in a shortage of the fuel needed to metabolise and transport the nutrients ingested. The palatability of the food appears obvious. This is expressed by a cumulative feed intake of 911.40 g/subject, even though feed efficiency appears low. However, increasing the energy content of the ration could correct this imbalance. The group's water consumption appeared normal.

The processing of C's finished product takes into account the usual practices used to reduce or eliminate tannin and glucose from agricultural products. Despite the biochemical nature of tannin and glucose being taken into account during processing, the nutritional balance recorded by C seems to be poor. In fact, the process of reducing the concentration of tannin by incorporating the rice porridge was not complete. The tannin supposedly sequestered by the rice starch had to be eliminated before the pulp was cooked.

Salt appears to be the major determinant in maintaining the nutrients in the pulp and improving its digestibility by growing chickens. This situation is thought to be induced by salt's potential to preserve the organoleptic qualities of agricultural products, in particular the glucose (energy source) and amino acids contained in the pulp. The food units in rations are interchangeable: proteins can be catabolised by the body into energy or amino acids, and vice versa. The sensation of fullness occurs in chickens when energy requirements are covered (Sauvant et al., 2004). In the absence of an assay of the finished product resulting from the processing of the pulp, it is assumed that the ration containing D cashew contains more protein than the others if we consider the response in animal product of the order of 1390g in 40 days. Among the factors limiting the digestion of cashew, it is worth highlighting the important role played by the tannin and plant wall content of the compound feed. The tannin contained in the cashew apple gives the product a black colour and leaves an indelible stain on fabrics. Tannin reduces the availability of proteins in the feed by forming complex atomic bonds. It has been reported that the fibre constituents of dried cashew represent 20.07%.

Conclusion:

Parameters were monitored throughout the experimental phase, during which chickens receiving feed containing cashew pulp from itineraries I4 and I2 performed better than chickens receiving feed containing cashew pulp from itineraries I1 and I3, apart from chickens receiving industrial feed. Itineraries D and B performed better than itineraries A and C, and it is therefore suggested that collection and processing itineraries D and B be used. As the pH values recorded for the processed pulp from the four itineraries were all acidic, experiments aimed at reducing the acidity of the pulp are desirable.

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DYNAMICS OF THE INFESTATION OF CASHEW ORCHARDS (ANACARDIUM OCCIDENTALE L) IN THE DEPARTMENT OF GOUDOMP (SÉDHIOU REGION, SENEGAL) BY THE WOOD BORER: APATE TEREBRANS PALLAS

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SUMMARY

The cashew tree (Anacardium occidentale L) is an important species, particularly in rural areas where it can significantly increase household income. However, orchard yields remain low, at between 250 and 300 kg per hectare. This can be attributed to the low adoption of good agricultural practices and the use of unimproved planting material, and above all to the persistence of phytosanitary problems, including attacks by insect pests such as Apate terebrans Pallas, which is a stem borer that undermines productivity. The aim of this study was to assess the presence of the pest Apate terebrans Pallas, its impact on cashew trees and local perceptions of the dynamics of infestation in orchards in the Goudomp department. Five (5) orchards were selected to adequately cover the study area based on one (1) elementary plot of one (1) hectare per orchard. Pest presence and damage were determined by inspecting elementary plots diagonally with 10 m spacing between two observed plants. The local perception of the dynamics of infestation in the orchards was determined by surveys of a random sample of 100 farmers based on a database. The results showed that infestation rates differ significantly from one locality to another. It was 28% in Terembasse, 33% in Djibanar, 40% in Goudomp, 66% in Sindima and 80% in Mangacounda, the average number of holes per tree was 9.71 holes/tree and the number of damaged branches varied between 2 and 7 branches per orchard. The surveys revealed that 80% of farmers attested to the presence of the pest in their orchards, and 48.5% considered that the damage had an average impact on production. On the other hand, 25.8% of respondents viewed the impact of the attacks to be severe and 25.7% considered the impact of the attacks to have a low impact on production. The Pearson correlation test indicates positive effects between local perception of the presence of the species, the number of holes, the number of damaged branches and the infestation rate. It is essential to extend this study to other cashew pests in Senegal in order to provide an adequate response to damage and production losses, and to propose sustainable and effective means of control to improve the productivity of cashew plantations.

Key words: Production, Pests, Infestation, Damage, Farmers' perception, Goudomp

ABSTRACT

Dynamics of infestation of cashew orchards (Anacardium occidentale L) of the Goudomp zone in Senegal by the wood borer: Apate terebrans Pallas

The cashew tree (Anacardium occidentale L) is an important species especially in rural areas where it can significantly increase household income. However, the yield of orchards between 250 and 300 kg per hectare is still low. This may be attributed to low adoption of good agricultural practices and the use of unimproved plant material, and especially the persistence of phytosanitary problems, including insect pest attacks including Apate terebrans Pallas which is a stem borer compromising productivity. This study aimed to assess the presence of the pest Apate terebrans Pallas, its impact on cashew trees and the local perception of orchard infestation dynamics in the department of Goudomp. Five (5) orchards were selected to adequately cover the study area based on one (1) elementary plot of one (1)

hectare per orchard. The presence of the pest and the damage were determined by inspecting the elementary plots on the diagonal with spacings of 10 m between two observed plants. Local perception of orchard infestation dynamics was determined through surveys of a random sample of 100 farmers from a database. The results obtained showed that infestation rates differ significantly from one locality to another. Indeed, it is 28% in Terembasse, 33% in Djibanar 40% in Goudomp, 66% in Sindima and 80% in Mangacounda, the average number of holes per tree is 9.71 holes / tree and the number of damaged branches varies between 2 and 7 branches per orchard. Surveys revealed that 80% of farmers testify to the presence of the pest in orchards, and that 48.5% of people consider that the damage has an average impact on production. On the other hand, 25.8% of respondents consider that the impact of attacks is severe and 25.7% consider that the impact of attacks has a low impact on production. The Pearson correlation test indicates positive effects between local perception of the presence of the species, the number of holes, the number of damaged branches and the infestation rate. It is essential to expand this study to cover other cashew pests in Senegal in order to provide an adequate response to damage and production losses, and to propose sustainable and effective means of control to improve the productivity of cashew plantations.

Keywords: Cashew tree, Apate terebrans, Infestation, Damage, Goudomp, Farmer perception

I. INTRODUCTION

Originating from South America (Boris, 1949), more specifically from the Ceara region to the north-east of the Brazilian coast (Trévian et al., 2005; Ohler, 1979), the cashew tree (Anacardium occidentale L) was already very important at the time for the indigenous peoples, who used both the kernel and the tree's false fruit. Portuguese navigators later introduced it to all their tropical colonies to benefit from the aromatic flavours of its false fruit (Boris, 1949). It was with this in mind that the cashew tree was introduced to West Africa in the 15th century by Portuguese navigators (Martin et al., 1997; Azam et al., 2001).

Nowadays, the importance of this specie lies in its nut, which is the subject of major transactions around the world (Lefèbvre, 1966; Dendena and Corsi, 2014). Of the estimated global production of more than 8 million tonnes in 2020, Africa is said to account for 58.4% (FAOSTAT, 2020), including 1.9 million tonnes in West Africa, making this region the world's leading producer of raw nuts (Pierre Ricau, 2020).

In Senegal, particularly in the regions of Ziguinchor, Kolda, Sédhiou and Fatick, cashew nut production plays a key role, involving 25,337 producers in 22,551 households and generating 25,593 jobs with a turnover of over 5 billion in 2016 (PADEC, 2016). Cashew nut production has thus become the most profitable agricultural activity in certain areas of Senegal, such as the department of Goudomp in the Sédhiou region (Ndiaye, 2019).

Given the socio-economic importance of this crop, the sector has benefited from numerous projects and programmes (PFRK, PADEC, LIFFT-Cajou, etc.) aimed at boosting production and developing the value chain, which makes a significant contribution to food security, increasing people's incomes and creating new jobs.

Despite the importance of cashew in Senegal, orchard yields are still low, at between 250 and 400 kg/ha (Charahabil et al., 2017). The reasons for this low yield are linked to the use of unimproved planting material, and above all the persistence of phytosanitary problems, particularly insect pest attacks, which undermine cashew nut yield in terms of quantity and quality. Among the most damaging pests infesting cashew trees is the wood borer Apate terebrans Pallas, which is causing serious production losses in many countries, including Guinea Bissau (Vasconcelos et al., 2009), Côte d'Ivoire (Mallet, 1993; Diabate et al., 2020), Nigeria (Adedeji et al., 2021) and Burkina Faso (Nébibé, 2021).

Unfortunately, to the best of our knowledge, there are no data on the damage caused by this pest to cashew trees at national level, which jeopardises any attempt to manage, control or eradicate it. It is against this background that the current study is being carried out, with the aim of contributing to improving the productivity of cashew orchards through good control of one of their main pests: the wood borer (Apate terebrans Pallas).

Specifically, this will involve:

- Assessing the presence of the pest in the Goudomp area;
- Determining attack rates in cashew orchards in the field;
- Determining the damage caused by the pest on cashew trees;
- Evaluating local perceptions of the dynamics of infestation in orchards.

1-1 STUDY ENVIRONMENT

The study took place from June to August in the localities of Mangacounda, Goudomp, Djibanar, Terembasse and Sindima in the department of Goudomp in the Sédhiou region, which is one of the cashew nuts producing areas in Senegal.

The department of Goudomp is located between longitude 16°68' and 16°08' West and latitude 12°61' and 12°26' North. It covers an area of 1,756 km^2 (ANSD, 2016), or 24.2% of the total area of the Sédhiou region (ANSD, 2019).

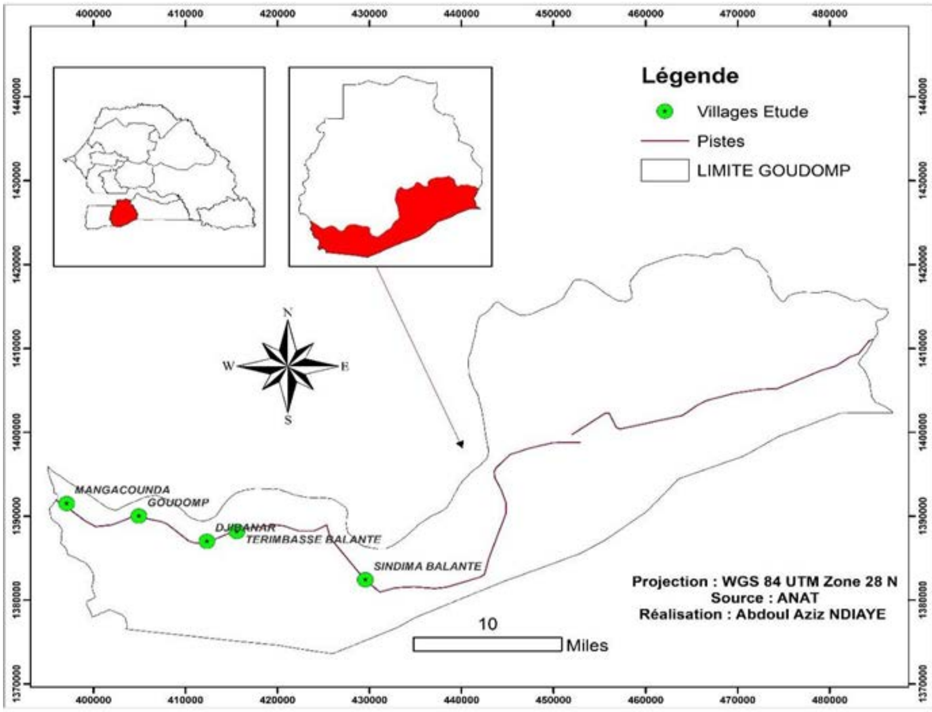

Figure 1: Location of villages sampled

2. MATERIALS AND METHODS

Initially, a questionnaire was used to gather the local perceptions of 100 cashew growers selected at random from the database provided by the NGO Shelter For Life, which includes 232 farmers in the study area. The main topics covered were: phytosanitary problems encountered in the orchards, in particular the presence of the pest in cashew plantations, damage and the impact of the pest on production. Secondly, an orchard was selected in each locality, for a total of five orchards. Then, within each orchard, an elementary plot of 100 m * 100 m (that is, 1 ha) was demarcated and the method applied by SIBIRINA et al., 2020 consisting of following the diagonal by meticulously observing the cashew trees with a spacing of 10 m between two plants observed was used. Observations are made twice a month (every 15 days) according to the method used by KONE et al. 2019 over a three-month period from June to August, in all orchards. During each observation, the stems and branches of cashew trees are observed to check for the presence or absence of damage (holes/grooves on the trunks and branches of cashew trees, sawdust). The organ attacked, the type of damage and an assessment of the rate of attack are recorded on a collection sheet and the geographical coordinates of the subjects recorded using a GPS.

2.1 Monthly assessment of attack rate

The attack rate on cashew seedlings was calculated using the following formula.

$Ta = (Npa \times 100)/(Ntp)$

Ta: attack rate per orchard; Npa: number of plants attacked; Ntp: number of plants observed per orchard.

2.2 Statistical analysis

Two types of software were used to process the data obtained. These were Rsudio v 4.1 and Excel 2016. After testing for normality, the number of holes was subjected to analysis of variance. The rate of infestation of trees by Apate terebrans and the number of damaged branches were subjected to the Kruskal Wallis test and then a multiple comparison test was carried out to see the difference between orchards. Pearson correlation, which describes the strength and direction of a linear relationship between two or more measured parameters, was used to measure the degree of linear associations between the parameters studied.

3 RESULTS AND DISCUSSION

3.1. Local perception of the dynamics of infestation of orchards by Apate terebrans

3.1.1. Presence of the species in the study area

Farmers' perceptions of the pest's presence in orchards vary from one village to another. In Sindima, Terembasse and Mangacounda, the presence of Apate terebrans is widely noticed by orchard owners, with 100%, 85% and 80% of farmers respectively attesting to the presence of the species in their orchards, compared with 60% in Djibanar and Goudomp. However, the pest was well known to 80% farmers in the zone, compared with 20% who said they did not recognise the species in their orchards (Figure 7).

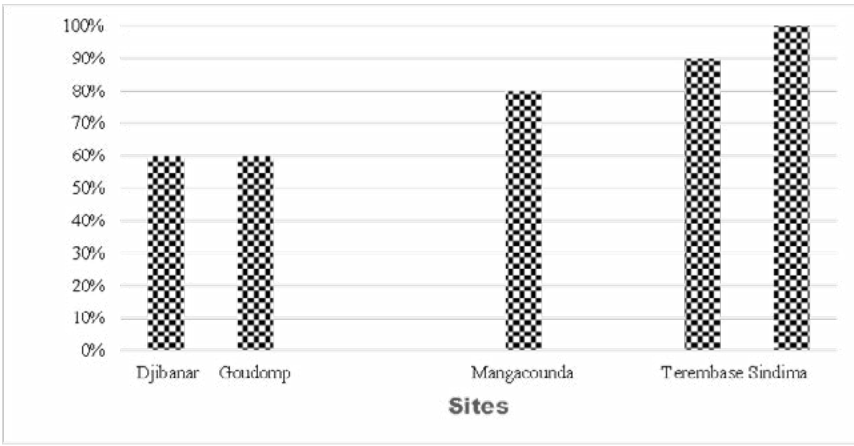

Figure 1: Presence of Apate terebrans in the study area, by site

3.1.2. Parts of the tree attacked by Apate terebrans in each locality

The results of the survey show that the pest specifically attacks two parts of the tree: the trunk and the branches. With the exception of Goudomp and Sindima, where only the trunk was damaged, the pest attacked the branches as well as the trunk in Djibanar, Mangacounda and Terembasse in similar proportions, with the exception of Terembasse where the species attacked the trunk more (63%) than the branches (27%) (Figure 8).

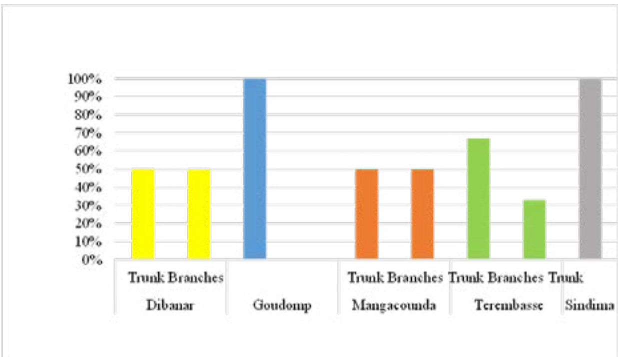

Figure 2: Parts of the tree attacked by Apate terebrans, by site

3.1.3. *Period of occurrence of the pest in the zone*

According to the farmers, the species appears in the orchards in two periods: before the harvest and after the harvest. In the villages of Goudomp, Mangacounda and Terembasse, the pest appeared before and during the harvest, unlike in the villages of Sindima and Djibanar, where it only appeared before the harvest (Figure 9).

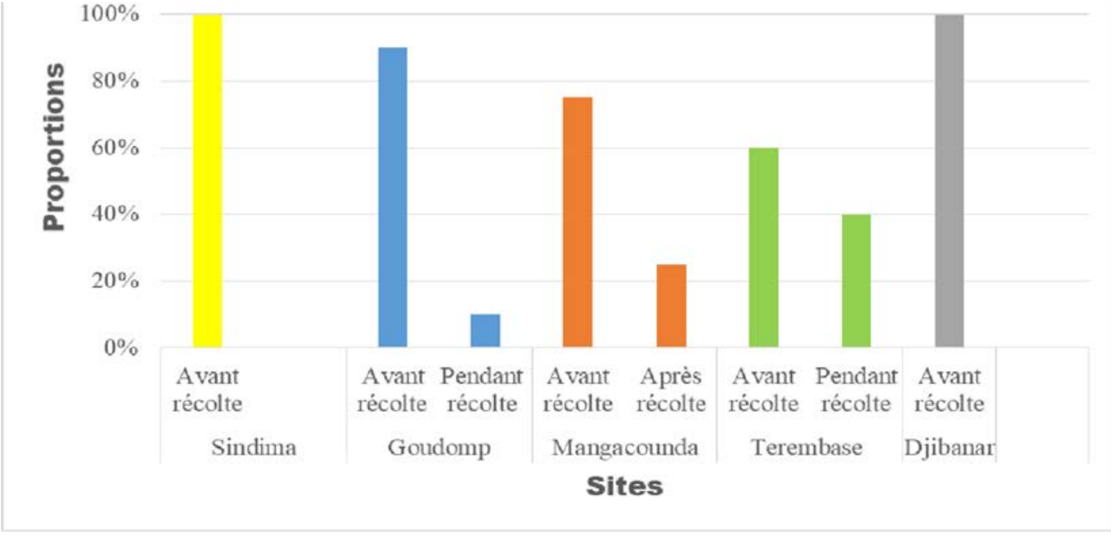

Figure 3: Occurrence of Apate terebrans in orchards by site

3.1.4. *Impact of the pest on production*

Farmers' perceptions of the pest's impact on yield are very mixed. The impact was described as "severe", "medium" or "low". Most farmers described the impact as "medium", as in Sindima, Goudomp, Mangacounda, Terembasse and Djibanar, where 70%, 70%, 75%, 60% and 68% of farmers respectively were of this opinion. This impact is also judged to be

"Severe" in Sindima, Terembasse and Djibanar by 30%, 40% and 31% of farmers respectively, and "weak" by 30% and 25% of farmers in Goudomp and Mangacounda (Figure 10).

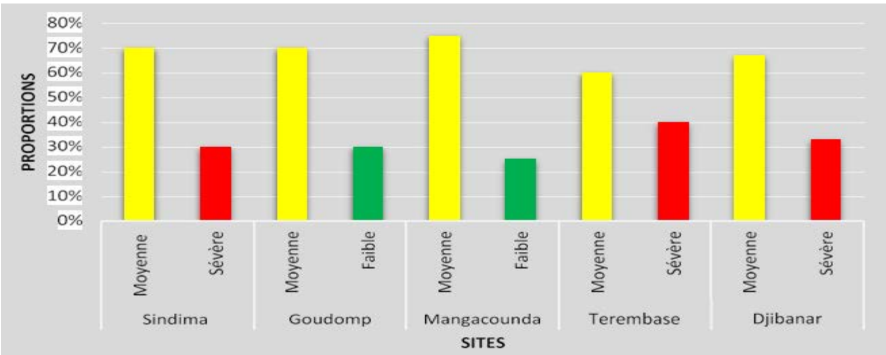

Figure 4: Impact of Apate terebrans on orchard yields by site

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

Djibanar Goudomp Mangacounda Sindima Terembasse
33 40 80 66 28
kruskal.test (Infestation.rate ~ Group, data=Dataset)
Kruskal-Wallis rank sum test
Data: Infestation.rate by Group
Kruskal-Wallis chi-squared = 13.923, df = 4, p-value = 0.007546

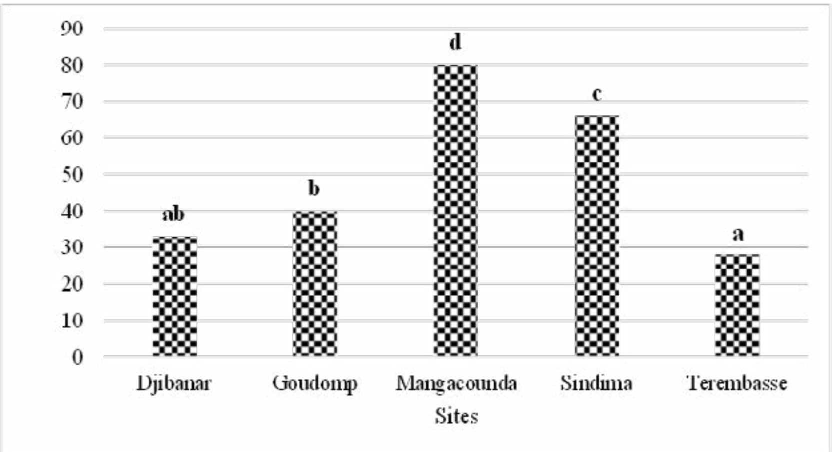

Figure 5:Comparison of attack rates between orchards

3.2.2 Number of holes

Analysis of variance revealed a highly significant difference for all orchards in the number of holes opened by the pest (Pr (>F) = 1.26e-14). A total of 136 holes with an average of 9.71 holes/tree were found. The highest number of holes was observed in Sindima (49) and the lowest in Goudomp (13) (Table 3). A comparison of the number of holes between orchards shows a total difference between them (Figure 12).

Table 2: Analysis of variance for number of holes

> kruskal.test (Average.number.of. holes ~ Group, data=holes)
Kruskal-Wallis rank sum test
Data: Average number of holes by Group
Kruskal-Wallis chi-squared = 13.923, df = 4, p-value = 0.007546
Tapply (Average.number.of.holes ~ Group, mean, na.action=na.omit, data=holes) # mean by groupst
Djibanar Goudomp Mangacounda Sindima Terembasse
24.00000 13.00000 38.00000 49.33333 11.00000

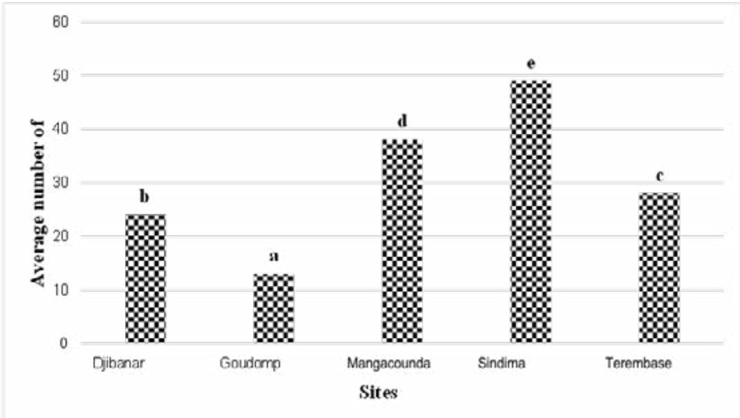

Figure 6: Comparison of the average number of holes between orchards

3.2.3 Number of damaged branches

The Kruskal-Wallis test (Table 5) revealed a significant difference in the number of damaged branches between orchards (Kruskal-Wallis chi-squared = 14, df = 4, p-value = 0.007295), with a maximum value of seven (7) damaged branches in Djibanar and a minimum of two (2) damaged branches in Terembasse. Comparison of the averages (Table 6) highlighted this difference within the groups, showing significant variation between the number of damaged branches in the villages of Djibanar, Mangacounda and Sindima, and perfect similarity between the villages of Goudomp and Terembasse. These variations are illustrated in Figure 13.

Table 3: Shapiro and Kruskal-Wallis test of the average number of damaged branches per orchard

normalityTest (~Number.of.damaged.branches, test="shapiro.test", data=Dataset 3)
Shapiro-Wilk normality test
data: Number.of.damaged.branches
W = 0.76819, p-value = 0.001477
> Tapply(Number.of.damaged.branches ~ Group, median, na.action=na. omit, data=Dataset3) # medians by group
Djibanar Goudomp Mangacounda Sindima Terembasse
7 2 36 2
> kruskal.test (Number.of.damaged.branches ~ Group, data=Dataset3)
Kruskal-Wallis rank sum test
data: Number.of.branches.damaged.by Group
Kruskal-Wallis chi-squared = 14, df = 4, p-value = 0.007295

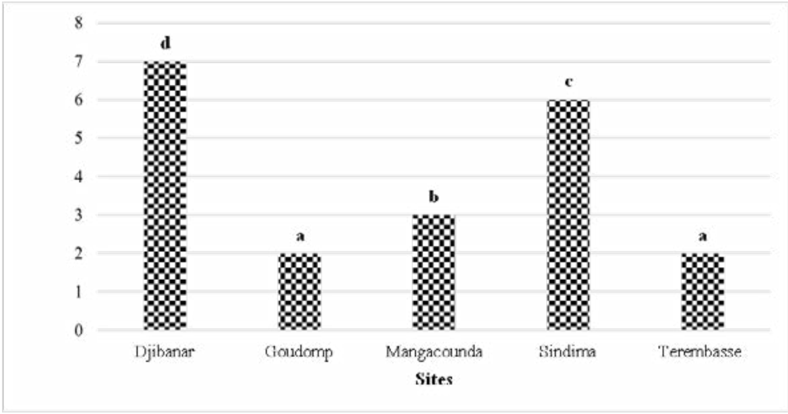

Figure 7: Comparison of the number of damaged branches between orchards


3.2.4 *Correlation between measured parameters and local perception of the presence of the species*

Analysis of the correlation matrix shows, on the one hand, a strong positive correlation between local perception of the presence of the species and the number of holes (r=88%) and on the other hand, a positive but moderate relationship between local perception of the presence of the species and the rate of infestation (r=42%), which means that the local perception of the presence of the species is conditioned by the damage caused by the pest to cashew trees, particularly holes, and that it does not necessarily imply a high infestation in the orchards. This analysis of the matrix also shows that the infestation rate is very weakly correlated with the number of damaged branches (r=2%), which shows that an increase in the infestation rate does not always mean an increase in the number of damaged branches. This analysis also shows that the correlation between the number of damaged branches and the number of holes is weak, but positive, indicating a certain relationship between the two (Table 7).

Table 4: Correlation matrix of measured parameters

Parameters	Average number of holes	Number of damaged branches	Local perception of presence of the species	Infestation rate
Average number of holes	1			
Number of damaged branches	0.3884217	1		
Local perception of the presence of the species	0.8867682	0.06206513	1	
Infestation rate	0,6453594	0,02457770	0,42016110	1

4. DISCUSSION

Damage caused by the Apate terebrans Pallas beetle was observed in all plantations with infestation rates ranging from 28% to 80%. These results, which are very different from the 8% and 3% infestation rates observed in Bondoukou and Bouna in Côte d'Ivoire (Yeo et al, 2018), are similar to the 60% infestation rate recorded on cashew trees in Benin (Onzo et al., 2018) and are consistent with farmers' statements that 80% of the area is infested with the pest. The parts of the tree indicated by the farmers as being attacked by the pest, that is the trunk and branches, are consistent with the data collected in the field, reflecting the farmers' good knowledge of the pest's characteristics and damage, as mentioned by Balogoun et al. (2015). The average number of holes per tree (9.71 holes/tree) recorded in this study is in line with the 10.73 holes/tree found by Onzo et al. (2018) in cashew orchards in Benin. This high number of holes per tree indicates that the pest is attacking cashew trees in large numbers, which confirms the statement by Vorster et al. (2017) that beetles are known for their massive attacks through hormone secretion. These attacks sometimes lead to branch breakage, as revealed in this study, where the average number of damaged branches varies from 2 to 7 per orchard. This result corroborates that of Gabriel et al. (2021), who found branch tears on 10.7% of cashew trees in Niger. Branch tears can be caused by the harmful effects of wind, which cause branches to break after being weakened by the grooves dug by Apate terebrans, as demonstrated by studies on wind, which show its impact on wood, particularly its capacity to cause breakage. The period indicated by producers as being the period of occurrence of Apate terebrans in the orchards (before and during harvest), corresponding to the months of January to July, falls within the range reported by Agboton et al. (2017), who maintain that in Benin the pest appears in cashew orchards in September, reaches its peak in January-February and then decreases to zero in July-August. This mixed assessment of the impact of the pest on production was observed by Tchetangni et al. (2019) and corroborates Velay et al.'s (2001) view that endogenous knowledge is directly connected to the environment that produces it, in direct and instantaneous phase with its changes.

CONCLUSION AND RECOMMENDATIONS

This study, carried out in the department of Goudomp, assessed the dynamics of infestation of orchards by Apate terebrans. Infestation rates were found to be as high as 80% in Mangacounda, the most densely populated area of the department.

The average number of holes per tree recorded was 9.71 holes and the number of damaged branches varied from 2 to 7 branches per orchard. Positive correlations were found between local perception of the presence of the species, the number of holes, the infestation rate and the number of damaged branches. Analysis of farmers' perceptions of the presence and damage caused by Apate terebrans showed that 80% of the growers surveyed recognised the species, identified the trunk and branches as the parts attacked and indicated the period before and during harvest as the period when the pest appeared in the orchards. The majority of farmers considered the pest's impact on the harvest to be moderate or low.

Given the importance of cashew cultivation in Senegal, particularly in rural areas, it is necessary to provide a complete bibliography on the pests of this crop. Thus, an exhaustive inventory of cashew pests, their modes of infestation and periods of occurrence is required in order to provide an adequate response to the damage and production losses they cause, and ultimately to improve orchard yields and boost the cashew industry.

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PEST AND DISEASE SURVEILLANCE AND REPORTING SYSTEM (PDSRS) APPROACH FOR THE MANAGEMENT OF PESTS AND DISEASES ON CASHEW

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SUMMARY

Executive Summary

In most cashew growing countries in Africa, pesticide (mainly insecticides and fungicides) application on cashew for the management of pests and diseases is by blanket approach and the use of calendar-based systems. Lack of monitoring, threshold levels and forecasting systems for pests and diseases make the continuous use of pesticides on a calendar-based system inevitable. Introduction of novel pesticides with different modes of action, different planting materials and changes in climate over the years, have resulted in changes in the temporal and spatial distribution of pests and diseases on the crop. We therefore suggest the need to develop monitoring systems to provide information on the incidence, severity and distribution of pests and diseases on cashews during the cropping season for timely and effective management. This would provide the basis for a shift from blanket calendar-based recommendations to need-based systems for pest and disease management. This write-up therefore advocates for the establishment of a Pest and Disease Surveillance and Reporting System (PDSRS) as a decision support tool for the management of pests and diseases in cashew growing countries in Africa.

Keywords: Pest Surveillance and Reporting System (PDSRS), forecasting, fungicides, insecticides, monitoring, threshold levels

Background

The African cashew industry has grown rapidly over the last decade. This growth is driven by factors such as increasing demand for cashew nuts and the use of the tree for afforestation and export diversification. The increased demand is also fuelled by reported nutritional and health benefits of the nuts (Egbe and Sobamiwa, 1989). Revenue generation along the cashew value chain is expected to grow from USD 793.37 million in 2023 to USD 950.04 million by 2028, at a Compound Annual Growth Rate (CAGR) of 3.67% during the forecast period (2023-2028) (Orduz-Rodríguez and Rodríguez-Polanco, 2022). Despite the gains in cashew production in Africa, yields are below optimum levels partly due to pest and disease problems (Muntala et al., 2021). Cashew cultivation requires pesticides use due to the myriad of pests and diseases associated with the crop (Amoako-Attah et al., 2020, Muntala et al., 2021).

Pesticides are important in agriculture because they reduce pest and disease damage on crops considerably. Unfortunately, in most developing nations, lack of education on proper handling and use of these pesticides has resulted in their misuse, endangering the lives of farmers, consumers and the environment (Awudzi et al., 2022, Braak et al., 2018). The impacts of pesticide contamination on human health range from short-term effects such as headaches and nausea to chronic conditions such as cancer, reproductive harm, and endocrine disruption (Misebo et al., 2023). Pesticide residue in fruits and vegetables continue to raise global concerns (Misebo et al., 2023). High residue levels of dithiocarbonate, flusilazole and triazole based fungicides have been reported in some crops including cashew (Cui et al., 2021, Jardim et al., 2018). Recently, pesticide residues have been detected in cashew apples and nuts exceeding the maximum residue limits (MRLs) in Brazil and Côte d'Ivoire (Stephane et al., 2021, Authority et al., 2020). There is therefore the need to investigate pesticide use patterns and residue levels of commonly used pesticides in cashew nuts and apples. The residue levels and the range of pesticide molecules used for pest and disease control on cashew in most cashew growing countries in Africa is not comprehensively known. Meanwhile, indiscriminate use of pesticides can also lead to the development of resistance by pests and disease pathogens, increasing the need to apply more synthetic chemicals with the concomitant risk to the environment and human health.

With all these negative effects of pesticides on human health and the environment, there are no pest and disease surveillance and reporting systems on cashews in most cashew growing countries in Africa. Basically, an effective monitoring program to quickly determine the incidence, severity, distribution, population dynamics and detect changes in status of major pests and diseases on cashew in most cashew growing countries is absent. Pest and disease management recommendations are therefore not directly linked to distribution, current pest dynamics, status and damage trends. Pesticides are applied on a blanket or calendar-based system. Because of the unavailability of a monitoring program, exogenous pests and diseases may not be promptly detected. Monitoring the status of known pests and identifying new ones are always difficult and near impossible without a proper surveillance system. National research institutions therefore rely on reports from farmers and extension agents for "unusual or hitherto unknown" outbreak of pests and diseases. This could result in late detection and an eventual outbreak of endogenous and exogenous pests and diseases.

With the phenomenon of climate change affecting pest populations and disease distribution (Porter et al., 1991, Shrestha, 2019), there is the need to routinely gather information on insect pest distribution and disease incidence with a view to developing forecasting systems to provide early warning for efficient pest and disease management. A monitoring system of this sort will provide the needed information for the development of pest and disease modeling approaches which would feed into an integrated pest and disease management control strategy for the crop. We are of the opinion that pest and disease surveillance and reporting systems will ensure judicious use of pesticides to minimize risk to human health and the environment as well as avoid resistance development. This write-up therefore proposes the establishment of a multifaceted Pest and Disease Surveillance and Reporting System (PDSRS) for the management of pests and diseases on cashews.

Proposed components of the Pest and Disease Surveillance and Reporting System (PDSRS) for the management of pests and diseases on cashew

Components that could potentially form the PDSRS on cashew include a Programme Implementation Body (PIB), Research, Data Collection/Analysis and Communication/Information Transfer.

Programme Implementation Body (PIB)

This component would provide the administrative needs of the system and can be led by the ministry of Agriculture or a body mandated to manage cashew production in the participating country.

Research, Data Collection and Analysis

This component would be responsible for the day-to-day surveillance and data collection from the field. This component could be hosted in a national research institution working on cashews. Data collection in the field would include pests and diseases damage levels/severity, vegetative and reproductive growth parameters of the crop such as leaf flush intensities and fruit sets as well as weather parameters (e.g. rainfall, temperature and relative humidity). These are biotic and abiotic factors known to influence pest and disease dynamics.

Communication and Information Transfer

This is responsible for all the communication needs of the PDSRS. It will link all the components together into one system. Thus, it will handle components such as data transfer from the field to the data analysis, interpretation of results and transfer of relevant information to end-users. It will also ensure effective feedback between the various components. National telephony platforms, radio and television networks, web portals, extension agents and local public address systems can be used to provide the needed platforms to disseminate information to end users.

End Users

These are users of the information generated after the interpretation of results and conclusions drawn from the field data. They can be smallholder cashew farmers, large plantation managers, research scientists, as well as governmental and non-governmental agencies for various purposes. Information generated from field data will be fed into the national cashew pests and diseases control programmes for effective pest and disease management. Differences in pest and disease load amongst regions/zones would be picked up by the monitoring system and treated appropriately. A flow chart showing how the components are linked to each other is presented in Figure 1.

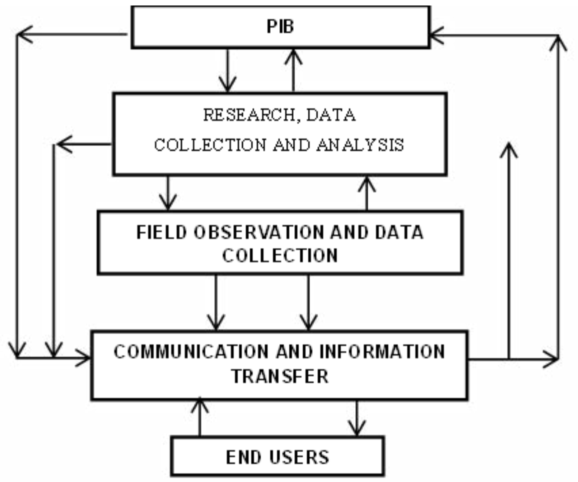

Figure 1: Components of PDSRS for the management of pests and diseases on cashew

Conclusion

The proposed PDSRS would ultimately result in a need-based system for pest and disease control on cashews. Health risks to farmers, sprayers and the environment from the abuse of pesticides could also be minimized. To achieve this, a well-coordinated national PDSRS framework for collecting data on the dominant factors influesncing pest and disease incidence, severity and population dynamics can be established to develop forecasting models.

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FUNGAL FLORA ON WEEDS IN THE CASHEW (*ANACARDIUM OCCIDENTALE L.*) ORCHARD IN CÔTE D'IVOIRE

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Abstract

Since 2015, Côte d'Ivoire has been the world's largest cashew producer. However, cashew orchards in Côte d'Ivoire are infected by fungal diseases that weaken production. And the contribution of weeds to the spread of these diseases is not yet understood. This study was initiated with the aim of establishing the role of weeds in the proliferation of pathogenic fungi in orchards. It consisted of a survey of weeds showing disease symptoms in cashew orchards in Côte d'Ivoire from February 2021 to July 2022. The itinerant method was used for the weed inventory. Symptomatic leaves were collected and sent to the laboratory for diagnosis on PDA (Potatoes Dextrose Agar) medium. In total, 50 species in 46 genera and 23 families were recorded. Laboratory diagnosis of the samples showed that 80% of the weeds identified harboured pathogenic fungi. The highest infection rates were obtained on Danielia oliveri R. (99.33%to 100%), Vitellaria paradoxa G. (100%), Pterocarpus erinaceus P. (83.91% to 99.33%), Micuna pruriens L. (98.33% to 100%) and Isoberlinia doka C. et S. (56.33% to 100%). The diagnosis revealed the presence of Lasiodiplodia sp, Colletotrichum sp, Pestalotia sp, Alternaria sp and Curvularia sp on weeds in the cashew orchard in Côte d'Ivoire.

Keywords: Weed, Infection Rate, Symptoms, Cashew, Côte d'Ivoire

1. Introduction

Cashew (Anacardium occidentale L.) is an Angiosperm in the class Dicotyledonous in the order Sapindaceae, which contains 73 genera and about 600 species [1]. Native to Brazil, the cashew is currently cultivated in more than 32 countries around the world. However, the vast majority of marketed production is concentrated in four major areas, namely Southeast Asia, West Africa, East Africa and Brazil [2]. Africa produces about 40% of the total raw nuts in the world and 80% of the production is obtained in West Africa with over 2,901,825 ha of plantations [3] [4]. Côte d'Ivoire has been the world's leading producer and exporter of raw cashew nuts since 2015. Indeed, Ivorian cashew nut production has undergone a spectacular evolution. Production has risen from 235,000 tonnes in 2006 to 968,676 tonnes of raw cashew nuts in 2021, an increase of 14% compared to 2020 [5].

Cashew tree cultivation and exploitation contribute to the socio-economic development of several countries in the world [6] [7]. In rural areas, the cashew sector is a powerful lever in the fight against poverty and unemployment. This crop has become the main source of income for the population and facilitates the schooling of children in rural areas. In addition, cashew products are full of nutritional and therapeutic benefits. Cashew kernel consumption is an excellent way to reduce the risk of cardiovascular disease [8]. Cashew apples are very rich in vitamin C polyphenolic compounds [9] [10] [11] [12] and have a very diverse carotenoid profile [13]. It is also used for wine and vinegar production [14].

Unfortunately, the productivity of cashew orchards is compromised by numerous phytosanitary problems. In addition to pests, more than a dozen diseases have been described on cashew [15]. Among these diseases, anthracnose (Colletotrichum gloeosporioïdes), pestalotiose (Pestalotia heterocornis) and bud rot (Lasiodiplodia theobromae) are responsible for significant damage in the cashew orchard in Côte d'Ivoire [16]. He found that symptoms of these diseases are also present on weeds in the orchard. These weeds could be alternative hosts of fungal pathologies in the orchard. Despite the importance of cashew in the Ivorian economy, there is very little data on the presence of alternative weed hosts of cashew fungal diseases in the orchard. However, knowledge of these alternative host weeds can help to implement a sustainable control strategy against cashew fungal diseases. This study was initiated to establish the role of weeds in the spread of pathogenic fungi in cashew orchards. The aim was to characterize symptomatic weeds and then to identify the pathogenic fungi they harbour.

2. Material and Method

2.1. Study Areas

Figure 1 illustrates the different study zones, namely the Northern agro-ecological zone, the Central agro-ecological zone, the Eastern agro-ecological zone and the Central-Western agro-ecological zone.

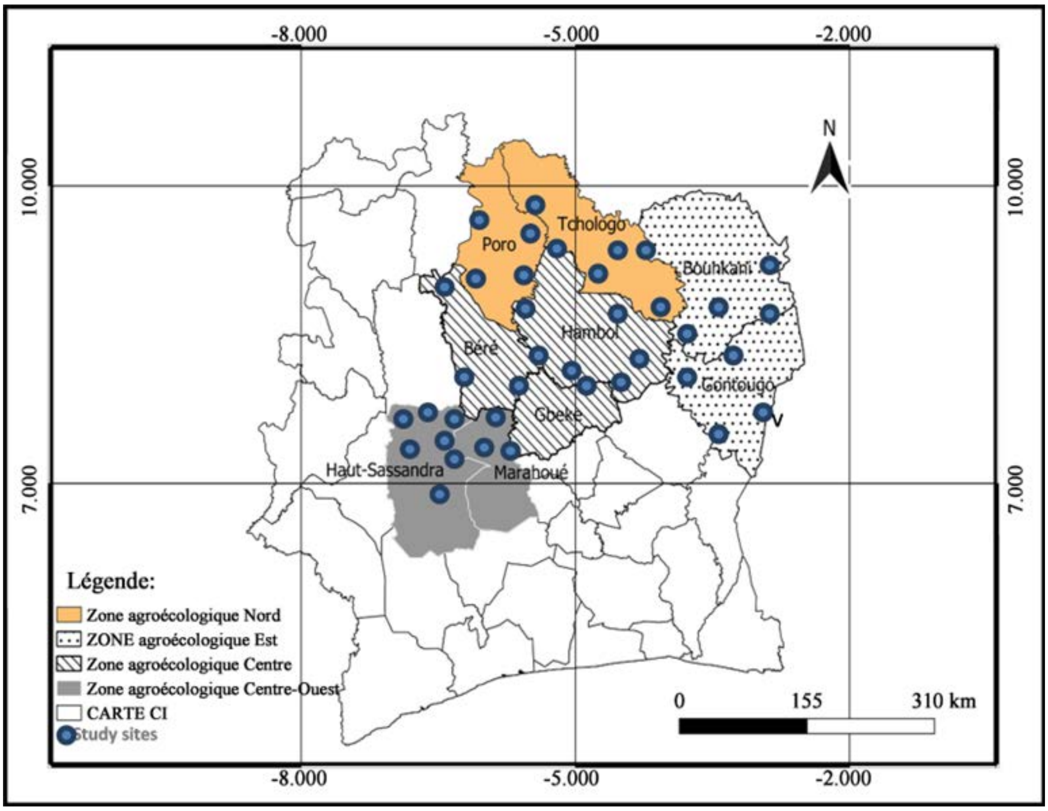


Figure 1. Study areas.

The Northern agro-ecological zone is characterized by a Sudanese climate with two seasons. The dry season runs from November to April and the rainy season from May to October. Average temperatures vary between 24˚C and 33˚C. The average annual rainfall is between 1100 and 1600 mm. The vegetation in this zone is savannah.

The eastern agro-ecological zone is characterised by a tropical climate with a very hot and dry period from November to February and a rainy period from March to October. The average annual temperature in this zone is 26.4˚C and rainfall averages 850.8 mm. The vegetation is essentially tree and shrub savannah with gallery forests.

The climate of the Central agro-ecological zone is of the Baulean type, characterised by a very hot and dry period from November to February and a rainy period from March to October. The average annual temperature varies between 26˚C and 34˚C. The average annual rainfall varies between 745.4 mm and 1580 mm. The vegetation is dominated by savannah trees.

The Centre-West agro-ecological zone is characterised by a mountain climate with four seasons. The long rainy season starts in April and ends in mid-July, while the short dry season lasts from mid-July to mid-September. The short rainy season runs from mid-September to mid-November and the long dry season from December to March. The dry and wet seasons alternate with temperatures ranging from 24.65˚C to 27.75˚C on average. Almost the entire basin is in the tropical rainforest zone with dense forest vegetation.

2.2. Material

The plant material used in this study consisted of leaves of weeds showing disease symptoms in the cashew orchard. The technical equipment consisted of a GPS, a camera, pruning shears and sterile bags. In the laboratory, PDA medium, an autoclave, a laminar flow hood and an electronic balance were used.

2.3. Methods

2.3.1. Collection of Samples

Surveys were conducted in orchards in four agro-ecological zones of the Ivorian cashew basin from February 2021 to July 2022. In each agro-ecological zone, ten orchards of one hectare in size were randomly selected. The itinerant method was used for the inventory of weeds showing disease symptoms in the orchard. The method consisted of walking the orchard in a diagonal direction. Weeds with disease symptoms found elsewhere in the orchard were added to the list.

During this survey, the name and morphological type of weeds showing disease symptoms were determined. Attacked organs were collected with pruning shears which were immediately cleaned with 70% alcohol after sampling. The samples collected consisted mainly of leaves. These samples were stored in envelopes and coded and sent to the laboratory for diagnosis on PDA (Potatoes Dextrose Agar) medium.

2.3.2. Isolation and Purification of Fungi

In the laboratory, samples showing the characteristic symptoms of anthracnose, desiccation and pestalotiose were selected for diagnosis. Riviera's method has been modified and used [17]. Each sample was thoroughly washed with tap water and dried on blotting paper. After drying, the samples were cleaned with 70% alcohol. Then, 3 - 4 millimetre explants were taken from the growth front of the symptoms using a sterile scalpel. The sampling equipment was automatically cleaned with 70% alcohol after each sample. Explants from the same sample were then soaked in 5% sodium hypochlorite for 3 minutes before being rinsed three times in succession with sterile distilled water and dried on blotting paper in an aseptic environment. Seeding of the explants was done under a laminar flow hood near the flame of the benzene burner. It consisted of placing four explants of the same sample equidistantly in a Petri dish containing frozen PDA medium. The Petri dishes were sealed with para film, coded (reference and date) and then incubated at a temperature of 27°C ± 2°C until proliferation of the fungal colonies.

The purification of the fungal colonies was done under the same aseptic conditions as the inoculation. A fragment of the mycelium was removed from the outgrowth zone of the fungal colony and transplanted into the centre of a new Petri dish containing frozen PDA medium. Pure fungal isolates were obtained from successive purifications [18]. The fungal isolates obtained from the diagnosis were identified according to their macroscopic characteristics on PDA medium and microscopic characteristics according to the identification key of [19].

2.3.3. Weeds Infection Rate

A weed is said to be infected if the diagnosis reveals the presence of at least one fungus on a sample from one of its organs showing disease symptoms. The infection rate was calculated according to the following formula:

$$Ti\ (\%) = (NEp/NtE)*100 \quad (1)$$

With:

Ti: Infection rate of a weed,

NEp: Number of samples testing positive and

NtE: Total number of weed samples showing disease symptoms.

2.3.4. Frequency of Fungi

Walder's formula was used to calculate the isolation frequency of fungi [20]:

$$Fi\ (\%) = (Ni/Nti)*100 \quad (2)$$

With:

Fi: Frequency of isolation in percentage.

Ni: Number of isolations of one fungal genus in all samples.

Nti: Total number of isolations of all fungal genera.

2.3.5. Data Processing

Microsoft Excel 2013 spreadsheet software was used for data entry and graph construction. Statistica version 7.1 was used for statistical analysis of the data. Normality was checked before the data were subjected to analysis of variance (ANOVA). When differences were significant at the 5% level, comparison of means by the Newman-Keuls test was performed.

QGIS software version 3.28.0 was used to produce the Study Area Map.

3. Results and Discussion

3.1. Results

3.1.1. Observed Symptoms

The study conducted on weed symptomatology in the cashew orchard in Côte d'Ivoire identified 50 species divided into 46 genera and 23 families. The most represented family was the Fabaceae. Weeds showing disease symptoms in the cashew orchard belonged to two classes, namely Dicotyledons (76%) and Monocotyledons (24%). The main symptoms identified were of four types. These included necrosis on the leaves, beach-like spots in the form of burning, desiccation and deposits of red or whitish powder on the leaves (Figure 2). Laboratory diagnosis of the samples showed that 80% of the weeds identified harboured cashew pathogenic fungi in the orchard in Côte d'Ivoire. The infected weeds were distributed among three morphological types, namely shrubs (65%), lianas (25%) and herbaceous plants (10%).

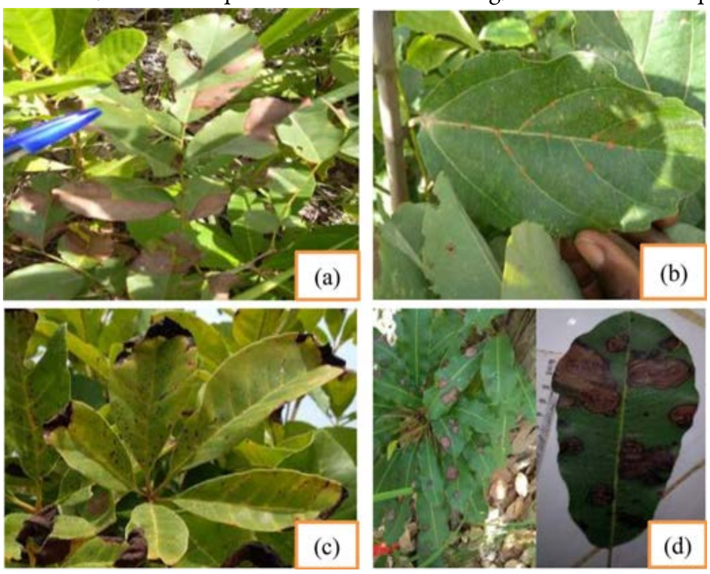


Figure 2. Symptoms observed on weeds in the cashew orchard. (a) Necrosis patch (Anthracnose) on Pterocarpus erinaceus Poir. (b) Rust on Ficus sur leaf on F. (c) Withering on leaves of Vitex doniana S. (d) Necrosis spots evolving in concentric circles on leaves of Vitellaria paradoxa G.

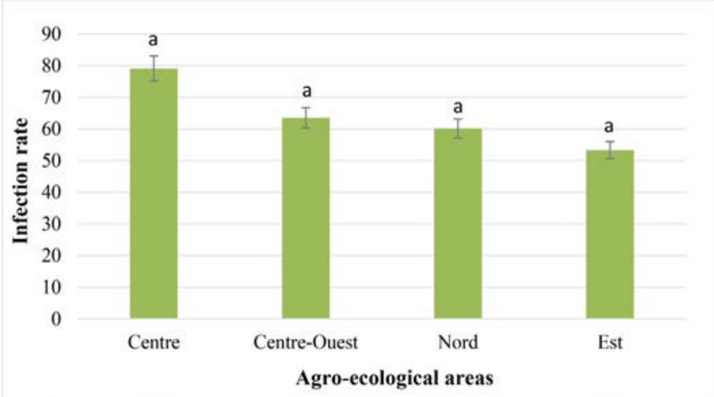
3.1.2. Weed Infection Rate in Cashew Orchard According to Agro-Ecological Zones

Figure 3 shows the infection rate of weeds showing disease symptoms in the cashew orchard in Côte d'Ivoire. The weed infection rate varies according to the agro-ecological zones. ANOVA tests showed that there was no significant difference (F = 1.96 and P = 0.12) between weed infection rates in the different agroecological zones surveyed. However, the highest infection rate (79.12%) was obtained in the Central agroecological zone. In contrast, the lowest weed infection rate was obtained in the Eastern agro-ecological zone. Intermediate infection rates of 63.51% and 60.15% were obtained in the North and Centre-West agroecological zones respectively.

3.1.3. Weed Infection Rate in the Agro-Ecological Zones According to Species

The infection rate within the agro-ecological zones varies according to the weeds identified. The ANOVA test performed at the 5% level showed that there was a highly significant difference (F = 14.35 and P = 0.000) between the weed infection rates within each agroecological zone.

The highest weed infection rates in the eastern agro-ecological zone were obtained on Daniellia oliveri R. (100%), Micuna pruriens L.



(100%), Vitellaria paradoxa G. (100%) and Albizia zygia M. (99%). Intermediate infection rates were obtained on Bridelia ferruginea B. (87.13%), Terminalia schimperiana H. (75.25%), Diospiros mespiliformis H. (45.33%) and Calepogonium mucunoides Desv. In contrast, Centroseuma pubescens B. and Ficus sur F. had the lowest infection rate (25.75%) in the eastern agro-ecological zone. The infection rate was zero for the weeds Anchomanes diformis Bl., Stylochiton hypogaeus Lepr. and Synedrella nodiflora L. (Figure 4).

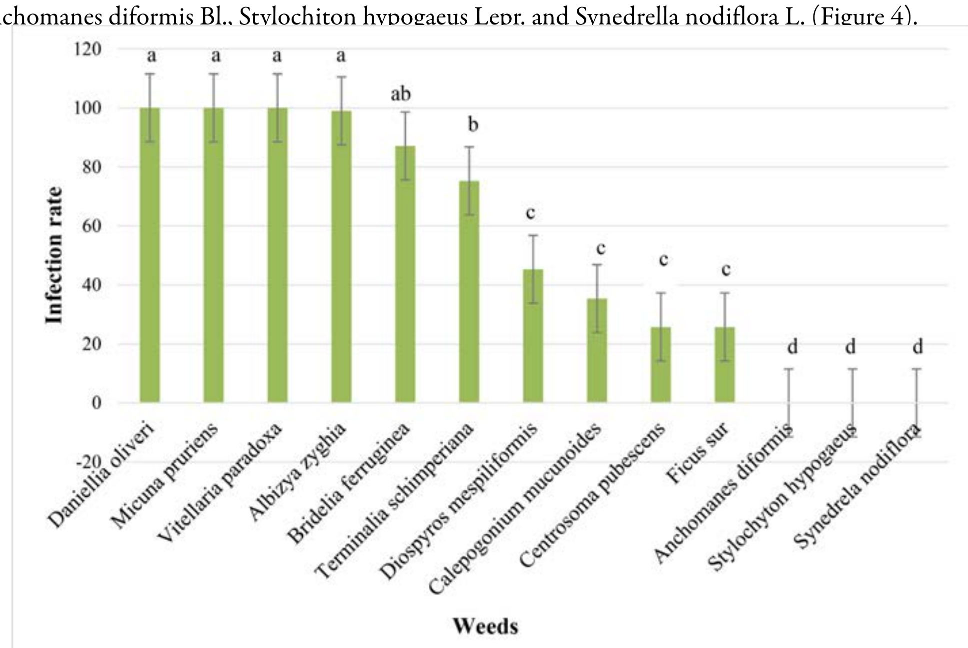
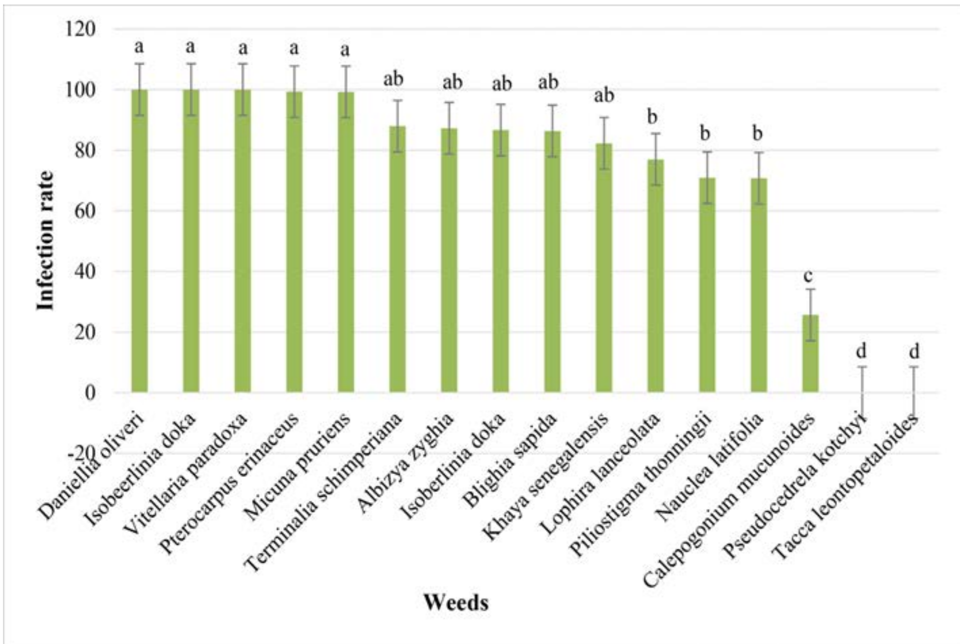


Figure 3. Weed infection rates according to agro-ecological zones. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

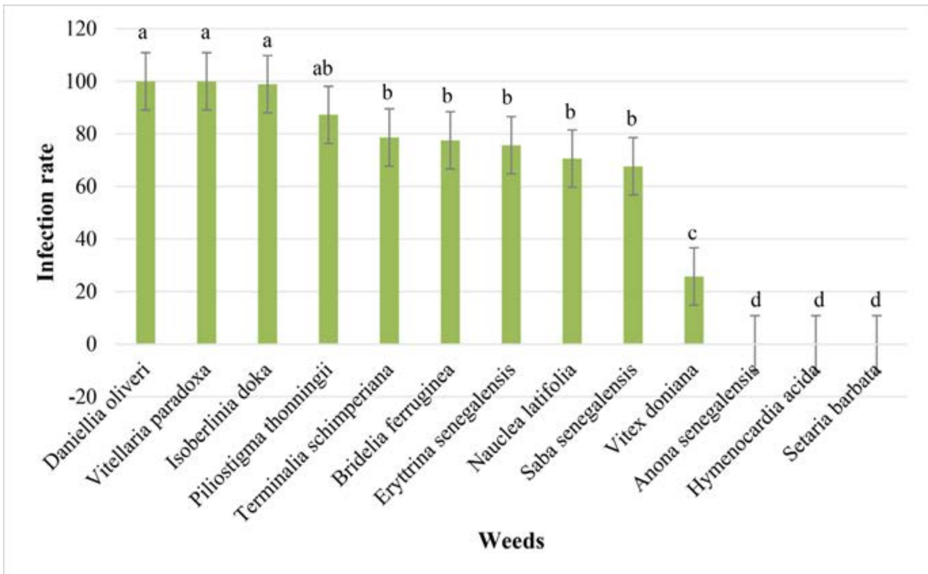
Figure 4. Weed infection rate according to species in the agro-ecological zone East. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold

Weed infection rates in the Central agro-ecological zone varied from 25.66% to 100%. The highest infection rates were obtained on Daniellia oliveri (100%), Isoberlinia doka C. et S. (100%), Vitellaria paradoxa G. (100%), Pterocarpus erinaceus P. (99.33%) and Micuna pruriens L. (99.26%). While Calepogonium mucunoides Desv. had the lowest infection rate (25.66%) in the Central agroecological zone. In this zone, no fungi were isolated from the weeds Pseudocedrela kotchyi Sch. and Tacca leontopetaloides L. (Figure 5).

The infection rate of the weeds in the northern agro-ecological zone varied from 25.75% to 100%. The highest infection rates were obtained on Daniellia oliveri R. (100%), Vitellaria paradoxa Gaertn. (100%), Isoberlinia doka Craib. et Stapf. (98.86%) and Piliostigma thonningii Schumach (87.22%). The species Vitex doniana S. had the lowest infection rate (25.75%) in the Northern agro-ecological zone. In this zone, intermediate infection rates were recorded for the species Terminalia schimperiana H. (78.66%), Bridelia ferruginea B. (77.54%), Erythrina senegalensis DC. (75.66%), Nauclea latifolia Smith. (70.60%) and Saba senegalensis A. DC. (67.66%). The infection rate was zero for the weeds Anona senegalensis Pers., Hymenocardia acida Tul. and Setaria barbata Lam (Figure 6).



In the Centre-Ouest agro-ecological zone, infection rates of weeds showing disease symptoms in orchards varied from 20.56% to 99.33%. The highest infection rates were obtained on Daniellia oliveri R. (99.33%), Micuna pruriens L. (95.33%) and Vitex doniana S. (95%). On the other hand, the species Millettia zechiana Harms. had the lowest infection rate (20.56%) in the Centre-Ouest agro-ecological zone. The



infection rate was zero for the weeds Calepogonium

Figure 5. Weed infection rate according to species in the Centre agro-ecological zone. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

Figure 6. Weed infection rate according to species in the Northern agro-ecological zone. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

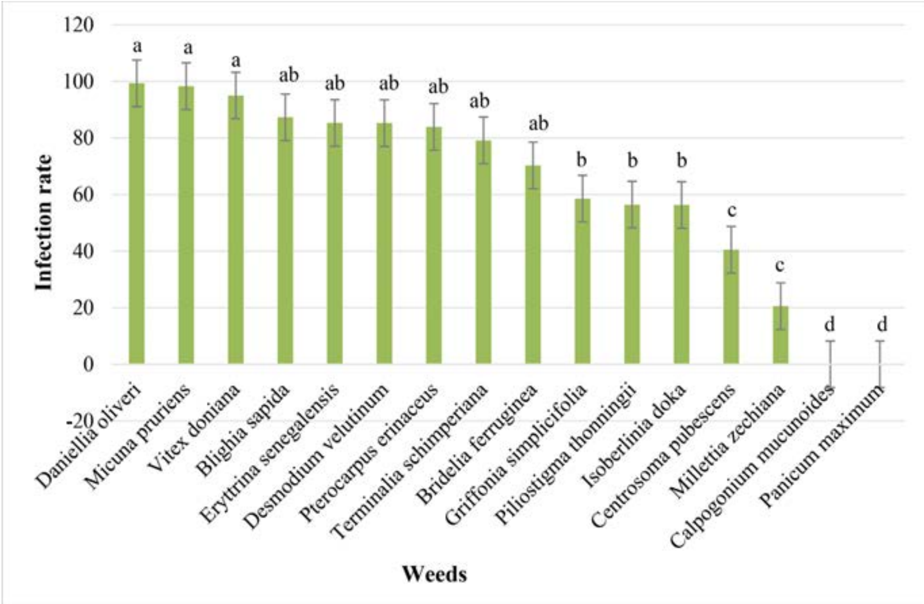


Figure 7. Weed infection rate according to species in the Centre-Ouest agro-ecological zone. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold. mucunoides Desv. and Panicum maximum Jacq. (Figure 7).

3.1.4. Fungal Flora on Weeds

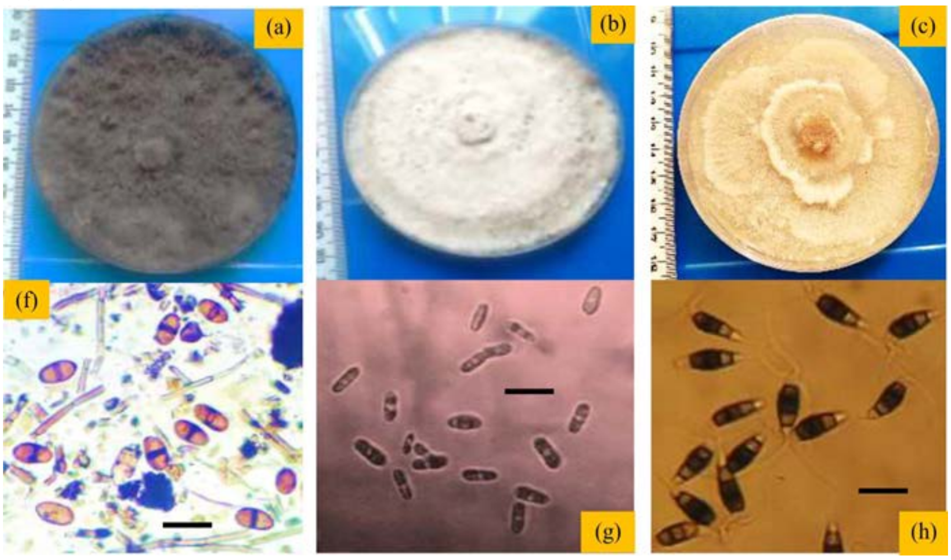
Samples taken from weeds showing disease symptoms in the cashew orchard were subjected to laboratory diagnosis. This diagnosis revealed that five species of fungi, namely Lasiodiplodia sp, Colletotrichum sp, Pestalotia sp, Alternaria sp and Curvularia sp are present on weeds in the cashew orchard in Côte d'Ivoire.

These mycopathogens were identified on the basis of morphological characters on the PDA culture medium and under the microscope. Three of the species identified were common on shrubs and vines in the four agroecological zones surveyed (Figure 8).

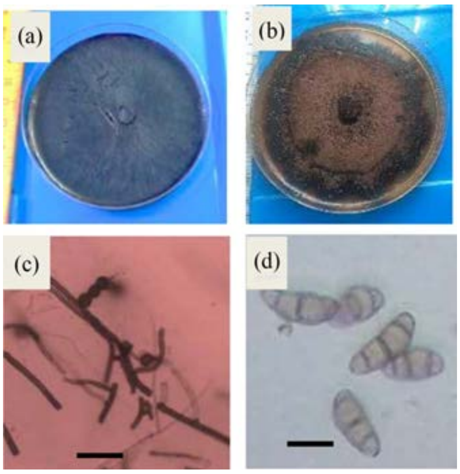
The other two, Alternaria sp and Curvularia sp, were occasionally found on shrubs and grasses in the Central-Western and Northern agro-ecological zones of Côte d'Ivoire (Figure 9).

3.1.5. Frequency of Fungi

Figure 10 shows the frequency of isolation of the three most frequent fungi on weeds in the cashew orchard in Côte d'Ivoire. The graph shows that the species Colletotrichum sp was the most frequent in all agro-ecological zones. Furthermore, the frequencies of Colletotrichum sp (47.5% to 55.25%), were statistically identical for all agro-ecological zones. In contrast, the isolation frequencies of Pestalotia sp (10.5% to 22.5%) were the lowest in all agro-ecological zones. The isolation frequencies of Lasiodiplodia sp (30% to 40.33%) were intermediate in all agro-ecological zones.



The analysis within each agro-ecological zone shows that there is a significant difference between the isolation frequencies of the different fungus species. In fact, in the Northern agro-ecological zone, the highest frequency (47.5%) was obtained by Colletotrichum sp. and the



lowest frequency (22.25%) was obtained by Pestalotia sp.

Figure 8. Main fungi identified on weeds in cashew orchard. (a) and (f): Lasiodiplodia sp; (b) and (g): Colletotrichum sp; (c) and (h): Pestalotia sp. (Observation au microscope optique, grossissement 40)

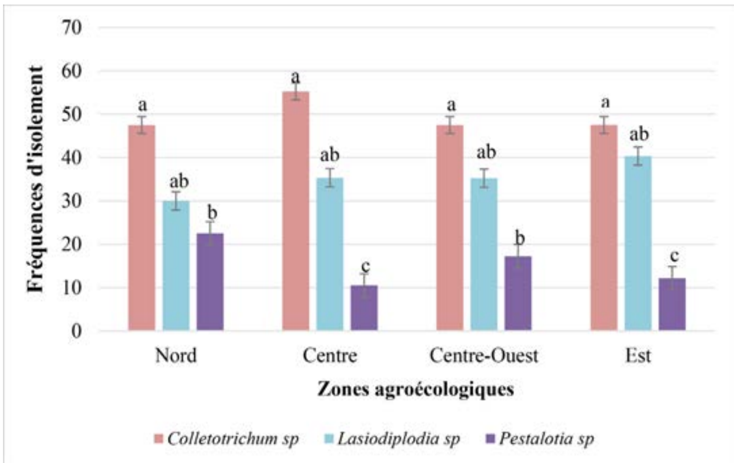


Figure 9. Fungi occasionally found on weeds. (a) and (c): Alternaria sp. (b) and (d): Curvularia sp. (Observation au microscope optique, grossissement 40

Figure 10. Frequency of species according to agro-ecological zones. Bands with the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

In the Central agro-ecological zone, the highest frequency (55.25%) was obtained by Colletotrichum sp. While Pestalotia sp. had the lowest frequency of isolation (10.5%). The highest frequency of isolation (47.5%) in the agroecological zone Centre-West was obtained by Colletotrichum sp. While, the lowest frequency (17.25%) was obtained by Pestalotia sp. In the agroecological zone East, the highest frequency of isolation (47.51%) was obtained by Colletotrichum sp. And Pestalotia sp had the lowest frequency of isolation (12.16%).

3.2. Discussion

The results showed that fungi are present on weeds in the cashew orchard in Côte d'Ivoire. The infection rate of the weeds surveyed was 80%. This high in fection rate indicates that the majority of the symptoms observed on weeds in the cashew orchard are due to fungal attacks. The main symptoms identified were necrosis spots on the leaves, beach spots in the form of burning, desiccation and red or white powdery deposits on the leaves. The high presence of these symptoms on weeds in the cashew orchard is thought to be related to the presence of Colletotrichum gloeosporioides, Lasiodiplodia theobromae, Pestalotia heterocornis, Cephaleuros virescens or Oïdium anacardii. These symptoms are identical to those described on cashew by several authors in previous studies. The necrosis spots evolving into a beach-like burn on cashew leaves are caused by Colletotrichum gloeosporioides. And the red powdery deposits on cashew leaves were described as a symptom of red rust caused by Cephaleuros virescens on cashew [21]. Similarly in Cameroon, cashew powdery mildew is manifested by the appearance of whitish colonies on the upper leaves [22]. In Burkina Faso, Lasiodiplodia theobromae is responsible for mango tree desiccation [23]. Pestalotia heterocornis causes leaf necrosis spots in cashew in Côte d'Ivoire [24].

At the level of morphological type, results showed that shrubs with an infection rate of (65%) were the most infected in the cashew orchard. This could be explained by the fact that the shrubs have a tissue structure similar to that of cashew. These plants, which are essentially made of lignin, would be compatible to the same fungal pathogens. This high rate for shrubs would also be due to the fact that the latter benefit from a relatively longer presence time than the other morphological types in the orchard. This time would be sufficient for the pathogenic fungi to establish a compatibility relationship with the shrubs. Some shrubs in the cashew orchard have food or medicinal functions [25].

Diagnosis of symptomatic samples identified five species of fungi, namely Colletotrichum sp, Lasiodiplodia sp, Pestalotia sp, Curvularia sp and Alternaria sp. According to several authors the fungal genera identified are responsible for cashew tree diseases in different producing countries [26] [27] [28]. They are said to be capable of attacking all cashew organs. In Côte d'Ivoire, C. gloeosporioides has been identified as responsible for anthracnose on all cashew organs [26]. The species L. theobromae, is involved in the drying of cashew buds bitten

by helopeltis sp in Côte d'Ivoire [27]. In Burkina Faso, C. gloeosporioides, P. heterocornis and Alternaria sp have been identified on cashew leaves [28]. Furthermore, these authors reported that Curvularia sp is associated with disease symptoms on cashew nut and cashew apple.

C. gloeosporioides and L. theobromae were the most frequent species in all agroecological zones. This could be explained by the diversity of host plants of these two species in the cashew orchard. This frequency would also reflect the ability of these fungi to adapt to different agroclimatic conditions. C. gloeosporioides and L. theobromae are associated with mango desiccation in four provinces belonging to different agroclimatic zones in Burkina Faso [29].

The presence of alternative weed hosts of anthracnose and desiccation in the orchard is a threat to cashew production in Côte d'Ivoire. Indeed, in Mozambique, the yield losses due to cashew anthracnose are between 50% and 70% [30]

The bud desiccation alone can cause cashew yield losses of 70% and the death of more than 50% of vegetative shoots [31]. Furthermore, the results highlight the indirect harmfulness of weeds in the cashew orchard in Côte d'Ivoire. A similar study showed that weeds maintain phytoviruses in Solanaceae crops in Côte d'Ivoire [32].

4. Conclusion

At the end of this study, it was found that the cashew orchard harbours a diversity of weeds hosts of cashew pathogenic fungi in Côte d'Ivoire. The symptoms observed were anthracnose, desiccation, mildew/oidium rust and pestalotiosis.

The overall infection rate of weeds showing these symptoms in the orchard was 80%. And the most infected weeds in the cashew orchard were Daniellia oliveri, Vitellaria oliveri, Pterocarpus erinaceus, Micuna pruriens, Albizia zygia and Bridelia ferruginea. Furthermore, the study revealed the presence of Colletotrichum sp, Lasiodiplodia sp, Pestalotia sp, Curvularia sp and Alternaria sp on weeds. The results of this study are interesting and deserve to be deepened by a molecular characterization of the fungi obtained and the realization of transmission tests of the fungi between the infected weeds and the cashew trees.

5. Significance Statement

This is the first study carried out on alternative weed hosts of cashew pathogenic fungi in the cashew orchard in Côte d'Ivoire. The results of this study show that the cashew orchard in Côte d'Ivoire harbours alternative weed hosts of pathogenic fungi.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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ESTIMATION OF THE QUANTITY OF CARBON SEQUESTERED BY CASHEW TREES

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Summary

Global warming is a problem whose main cause is the increasing concentration of greenhouse gases in the atmosphere. Thanks to their capacity to absorb carbon, trees, including cashew trees, store CO2 through photosynthesis. The aim of this project, which is being undertaken in Benin from 2020 to 2022, is to estimate the amount of CO2 stored in cashew trees. The sample involved 73,721 trees from 652 ha of plantations belonging to 385 producers in two cashew-producing departments in Benin. Ten to twenty trees were sampled per hectare on average along the diagonals of the plantation to collect height and diameter at breast height parameters. FarmerLink software was used to collect the data. The allometric equation dependent on diameter at breast height (DBH) was used to assess biomass. Biomass is used to reveal the carbon stock in cashew trees. The ANOVA test was carried out using R software and Tukey's post test was used to compare the means. The results showed that cashew trees aged 15 years and over had a high biomass (193.82± 9.73 Kg/tree/year) with a high carbon sequestration capacity (17.03± 0.98 kgCO2/tree/year), unlike younger trees. However, on average, a cashew tree sequesters around 16 kgCO2/year with an average biomass of 109.78 ± 8.08 kg/tree/year. It should be noted that age, biomass and the quantity of CO2 sequestered by cashew trees are strongly and positively correlated. In other words, an increase in one of these factors leads to an increase in the others. Under normal planting conditions and with proper maintenance, cashew fields with an average density of 105 to 113 trees per hectare can sequester between 1.7 and 1.9 tonnes of carbon per hectare per year. This appears to be an opportunity that could provide cashew producers with up to 19% additional income over and above the sale of raw cashew nuts.

Keywords: Carbon sequestration, Global warming, Biomass, Cashew tree, Benin.

Introduction

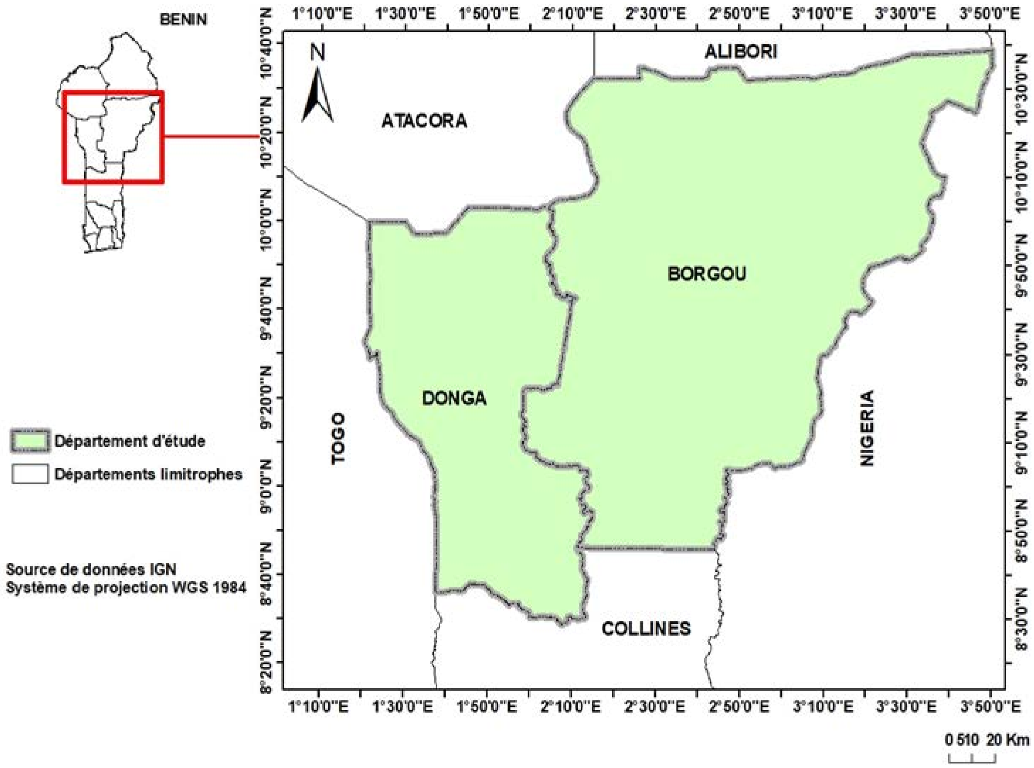
Research into climate change confirms that greenhouse gas (GHG) emissions are driven by human activities such as industrialisation, land-use change and excessive exploitation of natural resources. These emissions are responsible for the global warming currently observed on Earth (Tinlot, 2010; Thiombiano et al., 2011; Aliou et al., 2012; Zapfack et al., 2013; Tayo, 2014; Noiha et al., 2015). Several studies indicate that these GHGs, notably carbon dioxide (CO2), methane (CH4) and nitrous oxide (N 2O), released by these anthropogenic activities are leading to an increase in the Earth's temperature, an accumulated frequency of extreme weather events and a rise in sea levels (Razafimbelo, 2011; Muoghalu, 2014). CO2 is a gas that allows the Earth to benefit from a natural greenhouse effect that is essential for life, maintaining the Earth's average temperature at 15°C rather than -18°C. However, increasing its concentration has a direct influence on the effectiveness of this greenhouse gas effect, leading to global warming and climate change (Dorvil, 2010; Muoghalu, 2014). This climate disruption is responsible for numerous disasters that increase the number of victims of humanitarian emergencies every year. Our planet is currently undergoing change on a considerable scale. Global warming, which is currently underway, is the greatest threat ever posed by mankind, due to the activities that generate greenhouse gases. Since the industrial revolution, the global average concentration of CO2 in the atmosphere has risen from around 277 ppm in 1750 to 399 ppm in 2015, an increase of 44%. This alarming trend is continuing upwards, with the current concentration having exceeded 400 ppm (Le Quéré et al., 2016). As a result, the absorption of infrared rays emitted by the Earth's surface is increasing, leading to global warming of the troposphere (Hansen et al., 1998). In 2015, our anthropogenic activities emitted 41.9 ± 2.8 Gt of CO2 into the atmosphere, that is, 49% more than in 1990, and 91% of these emissions were caused by the combustion of fossil fuels, while changes in land use (deforestation, etc.) are responsible for the remaining 9% (Le Quéré et al., 2016).

However, thanks to their capacity to absorb carbon, trees such as cashew trees store CO2 through photosynthesis. This quantity of carbon sequestered by cashew trees can be estimated and put on the market as compensation. This contributes to the reduction of greenhouse gases and, by extension, to mitigating their effect on global warming, while paying additional income to the partner processing plants. Given the opportunities offered by international structures to offset excess carbon emissions, it is becoming increasingly important to factor carbon sequestration into the carbon balance. This represents an opportunity for cashew nut producers. With this in mind, this study aims to estimate the sequestration potential in producers' cashew nut orchards.

I- Materials and methods

1.1 Materials

The work was carried out in the departments of Borgou and Donga in Benin (Figure 1). The Department of Borgou is located in the north-east of Benin. It borders the Republic of Burkina Faso to the north-east, the Republic of Niger to the north and the Federal Republic of Nigeria to the east. The department of Donga is bordered to the north by the department of Atacora, to the south by the department of Collines, to the east by the department of Borgou and to the west by the Republic of Togo. Located between 8.5° and 12.5° latitude and between 2.15° and 3.45° longitude, the department of Borgou covers an area of 52,098 km2 or 45.3% of the total land surface area of Benin (MDGLAAT, 2017), while Donga covers an area of 11,126 km. Borgou has a Sahelo-Sudanian and Sudano-Guinean climate, with two successive seasons: a dry season from November to April and a rainy season from May to October. Average annual rainfall varies between 1,200 mm in southern Borgou and 900 mm in northern Borgou. In the department of Donga, the climate is of the Sudano-Guinean type, characterised by a dry season that covers the period from mid-October to mid-April and a rainy season between mid-April and mid-October with normal rainfall of between 1,200 mm and 1,300 mm, with August being the wettest month (INSAE. 2016). Borgou's soil consists of Precambrian bedrock of the Dahomean type, with a broad alluvial sedimentary fringe along the Niger and Cretaceous sandstones in the north-east. There are two main categories of soil: The thick, clayey hydromorphic soils of the Niger valley and the granito-gneissic soils representing the largest extension. The flora is highly diversified, depending on the climatic spread and the extension of the soil. Vegetation cover is made up of classified forests, gallery forests, wooded savannah and shrub forest, which serve as reserves for animal species

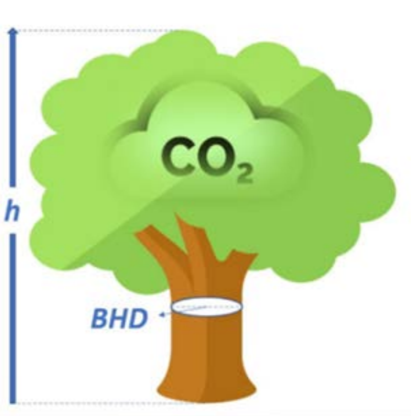


(MDGLAAT, 2017). The soils of Donga are of the crude mineral, indurated tropical ferruginous and hydromorphic type. These soils require significant inputs of organic matter to rebuild the humus layer on plots under cultivation. Vegetation is dense along watercourses, forming gallery forests. These two departments are in pole 4, whose priority industry is cashew nuts (INSAE. 2016).

Figure 1: Map of the study area

1.2 Methods

The study was conducted over a three-year period from 2020 to 2022. To collect the data, 385 producers from the national cashew nut producers' federation in Benin were selected. These are producers who maintain their plantations to prevent them from being consumed by wildland fires. To collect data after monitoring the plantations, an average of ten to twenty trees per hectare were sampled and marked with paint along the diagonals of the plantation. The data required relates to the number of trees in the plantation, and the height and diameter at breast height of the sample trees. These data were transferred directly into the FarmerLink application (the data collection tool used). Altogether, 73,721 trees from 652 ha were sampled and measured



1.3. Data analysis

Excel spreadsheet (2016) was used for data processing and R software version 4.3.1 a for statistical analysis. Analysis of variance (ANOVA) and Tukey's post test were used to calculate the means and compare at a 5% significance threshold. Furthermore, the allometric equation linking the diameter to the height of a tree at breast height (DBH), i.e., the diameter of the trunk measured at 1.3 m above the ground, was used to calculate the above-ground biomass. The allometric equation is typically expressed as follows: $B=a\times DBH^{b}$; where B is the above-ground biomass of the tree (in kilograms), DBH is the diameter at breast height (in centimetres) and a and b are species-specific parameters that are estimated using regression analysis. Using the biomass and age of the tree, the amount of carbon sequestered was estimated.

II- Results

2.1. Cashew nut plantation densities

Table 1 below shows the average density of the plantations studied. This table shows that the plantations in the departments of Borgou and Donga in Benin had an average density of between 105 and 113 trees per hectare.

Table 1: Cashew nut plantation density

mean_density	variation	IC_inf	IC_sup	minimum	maximum
109.54	2.37	100.67	105.41	10,00	215,00

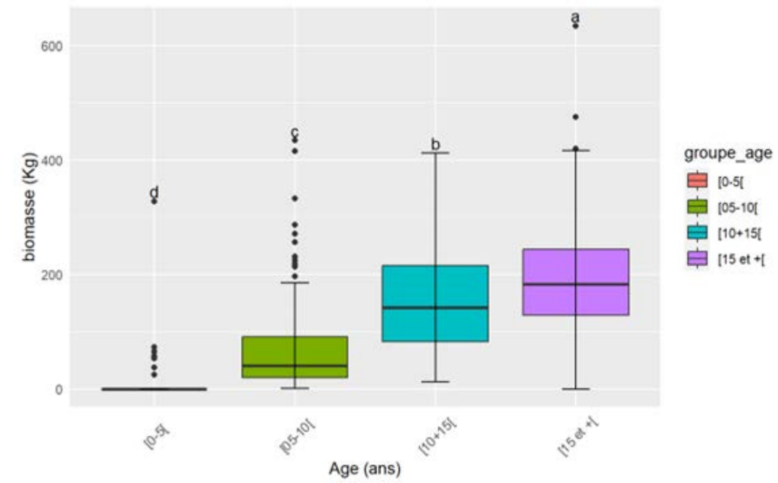
2.2. Cashew tree biomass

The results of the ANOVA test of biomass according to cashew age group are presented in Table 1. The analysis reveals that, at a threshold of 5%, there is a significant difference between the biomass produced by cashew trees according to their age group (P-value < 0.05).

Table 2: Cashew tree biomass by age group.

	Df	Square sum	Medium square	F value	P value
Age_group	3	1426235	475412	62,99	<2e-16
Residues	385	2883222	7548		

Figure 1, showing the results of the comparison of average biomass according to cashew tree age group, using the Tukey test, indicates a gradual change in the biomass produced with the age of the trees. In fact, the age group 15 years and older has the highest average biomass, with a value of 193.82± 9.73 Kg/tree/year. This was followed by cashew trees in the 10-15, 05-10 and 0-5 age groups, with mean biomass



values of 154.61 ± 8.61 kg/tree/year, 70.07 ± 8.10 kg/tree/year and 20.65 ± 5.88 kg/tree/year respectively.

Figure 2: Comparison of cashew tree biomass by age group

2.3 Quantity of carbon sequestered by cashew trees

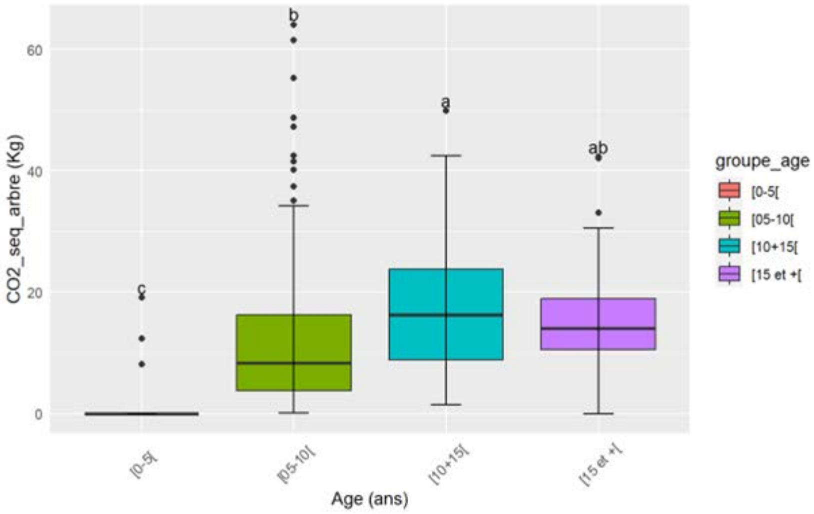
The analysis of variance (ANOVA) of the quantity of carbon sequestered by the tree as a function of cashew age is presented in Table 2. This table shows that, at a threshold of 5%, there is a highly significant difference between the quantity of carbon sequestered by cashew trees according to their age group (P-value =1.08e-13< 0.05).

Table2: Quantity of carbon sequestered as a function of cashew age group

	Df	Square sum	Medium square	F value	P value
Age_group	3	6768	2255,9	22,98	1,08e-13
Residues	385	37509	98,2		

Figure 2 shows the results of a comparison of the average quantities of carbon sequestered as a function of the age of the cashew trees. Analysis of this figure shows that the amount of carbon sequestered increases progressively with the age of the cashew trees, reaching a peak between

10 and 15 years. The age group 10-15 years and older has the highest average amount of carbon sequestered, with a value of 17.03± 0.98 Kg/tree. This was followed by cashew trees in the 05–10-year age group, with an average carbon sequestration of 12.81±1.33 Kg/tree. The



quantity of carbon sequestered by cashew trees less than 5 years old is very low

Figure 3: Comparison of the quantity of carbon sequestered by cashew trees according to age group

2.4. Relationship between area, total biomass, carbon content and age of cashew trees

The results of training the multiple linear regression model (Table 3) revealed that the explanatory variables accounted for 88% of the variability in biomass produced. At a threshold of 5%, there was a positive relationship between the quantity of biomass produced and the plantation area, circumference, size and age of the cashew trees. An increase of one hectare in the plantation area leads to an increase in biomass. Similarly, an increase of one centimetre in the circumference and/or height of the trees leads to an increase in biomass. Finally, an increase of one year in the age of the trees leads to an increase in the biomass produced of 714.09 Kg/ha.

Table 3 Results of multiple linear regression of total biomass produced on explanatory variables

	Estimate	Std. Error	P value	Actual estimate
Intercept	0,015	0,021	0,461	11144,76
nb_trees	0,027	0,060	0,641	2,761
_plantation zone	0,388	0,020	2,00E-16*	6132,666
circumscribed	0,539	0,037	2,00E-16*	288,172
height	0,287	0,035	1.50E-14*	2306,53
age	0,076	0,029	0,0106*	714,098

R Square = 88.03 R square adj = 87.81

** Equivalence of the effect of the variation of one unit of the independent variables on the standardised biomass with respect to the unit of the non-standardised biomass.

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2.5. Sequestration potential and economic value

The results of work carried out in the producers' network of the National Federation of Cashew Producers of Benin show that, on average, additional income of around 22,385 CFA francs/ha, i.e., 19% of plantation income, is generated by beneficiaries of carbon credits (Table 5). Analysis of the same table shows that producers involved in FENAPAB's Cashew Capture Carbon (CCC) project have an average of 1.4 ha of plantation, enabling them to generate average additional income of around 31,339 CFA francs on their farms.

Table 4: Cashew tree systems in carbon sequestration

Heading	Unit	2020	2021	2022	Average
Number of farmers	The farmers	121	363	355	-
Digital plots	Plots	142	456	443	-
Zone	Ha	225	620	590,26	-
#trees	Trees	22 454	73 466	70333	-
Biomass weight trees	Mount	3 702	9 841	9610	-
# tCO2 sequestered	tCO2	430	1 034	1012	-
Region/farmer	Ha/Farmer	1,9	1,7	1,7	1,8

Surface area	Ha/plot	1,6	1,4	1,3	1,4
Density	Trees/ha	101	118	119	113
Sequestration/tree	kg CO2/year/tree	19	14	14	16
Sequestration/ha	tCO2-eq/year/ha	1,9	1,7	1,7	1,8
Additional CO2 income	CFA francs per ha	22 473	22 341	22 341	22 385
Yield of Plantations	Kg/ha	392	398,45	431,24	407,23
Producers' NBC income	CFA francs per ha	123 694	119 535	118 591	124 200
Additional income - % (in euros)	%	17%	19%	19%	19%

III- Discussion

The farmers whose plantations are taken into account during this work are those who maintain them. This explains the average tree density of 113 trees per hectare, close to the recommended standard (100 plants per hectare). In the departments of Borgou and Donga, cashew plantations are young and established more or less in accordance with orchard creation standards. However, it should be noted that according to the report of the cashew nut yield estimation survey commissioned by PRO-Cashew in 2022, cashew nut plantations throughout Benin are very dense, with an average of 165 trees per hectare (Enq report, 2022). This could also explain the presence of plantations with densities close to the norm. Woody species, including cashew trees, store a considerable quantity of this element in their biomass via photosynthesis (Montagnini 1 Nair, 2004). The results showed that cashew trees over 15 years old have a very high biomass (193.82±9.73 kg/tree/year) with a high carbon sequestration capacity (18.15±9.03 kg CO2/tree/year), unlike younger trees. Similar results were found with Ouédraogo et al (2020) on their work on Tectona plantations. According to them, the abundance of large-diameter trees in Tectona plantations explains the large total quantity of biomass (122.96 tMS/ha) and carbon (61.47 tC/ha) obtained. The results obtained can be explained by the well-developed plant cover and the diameter of the cashew trees, which are around 15 years old. Cashew agrosystems have a strong capacity to store more carbon compared with disturbed natural savannas (Awe Djongmo et al., 2016). The results show that biomass and the quantity of CO2 sequestered by cashew trees are strongly and positively correlated, and a one-year increase in the age of the trees leads to an increase in the biomass produced of 714.09 kg/ha. This result confirms those of Ouédraogo et al (2020)who concluded that biomass production and carbon storage capacity vary according to vegetation type. Furthermore, Saïdou et al (2012) confirm that above-ground biomass accounted for around 62% of the total carbon stock assessed. All of this could explain the fact that as the age of the tree increases, the above-ground biomass develops, thus increasing the quantity of carbon sequestered. Seghiéri, (2019) shows that throughout the growth of cocoa trees and associated trees, carbon storage increases, sometimes reaching a level close to that of a forest system (Saj et al., 2017). However, it appears that carbon storage is mainly due to large trees with a diameter greater than 30 cm, which are favoured throughout the life of the cocoa plantation (Saj et al., 2019). These results are confirmed by the low quantities of carbon sequestered in very young and smaller trees. In fact, the highest average quantities of sequestered carbon are observed in old trees with a large diameter. On average, 1.8 tCO2-eq/year/ha were sequestered in the cashew nut plantations monitored. This amount is lower than that obtained by Awe Djongmo et al, 2016 (28.29 t/ha) in Cameroon for trees aged 10 to 20 years and Thiombiano (2010) in Burkina Faso for cashew trees aged 16 years (7.17 t/ha). This difference could be linked to the counting methodology used, but mainly to the variability of the density of the undergrowth, and even to the level of maturity of the cashew trees. In fact, the counting method used in this work is very much focused on data collection and estimation on individual cashew trees. The quantity sequestered on the plantation is estimated by extrapolation, which shows a correlation between density and the quantity of carbon sequestered. For higher densities, this quantity could be high, a choice that could also explain the differences in results obtained with Awe Djongmo et al. 2016 and Thiombiano (2010). Indeed, the density of cashew plantations monitored is the lowest (105-113 trees per hectare) in Cameroon and Burkina Faso, where plantations can sometimes reach densities of 198 trees per hectare. The greatest increases in uptake also occur when moving from a low biomass system (annual crops, grassland, fallow land) to a tree-based system (Palm et al., 2000). Cashew trees therefore have a very high potential in a context where sequestered carbon offers farmers additional income (Dixon, 1995). Indeed, the producers involved in this work can earn an additional income of around 19% from cashew nut sales, which can contribute to the maintenance and management of their plantations.

Conclusion

Estimating the biomass and carbon content of cashew trees is becoming increasingly important around the world, not only enabling producers to generate additional income but also allowing industrial companies to offset their gas emissions. In the current context of difficult market conditions for cashew nuts and consumers' desire to eat healthily and without carbon emissions, carbon-neutral cashew nuts constitute a niche market just like organic, fair trade and even Rainforest Alliance certificates. This could help to improve producers' incomes, as the methods used to calculate carbon have an impact on the final payment. In addition, there is a need for a harmonised approach in West African countries, to help set up an exchange for the sale and purchase of sequestered carbon units. Furthermore, carbon calculation methods have a high degree of uncertainty, and estimating this uncertainty is also important to ensure that carbon payments do not exceed the actual amount of carbon sequestered.

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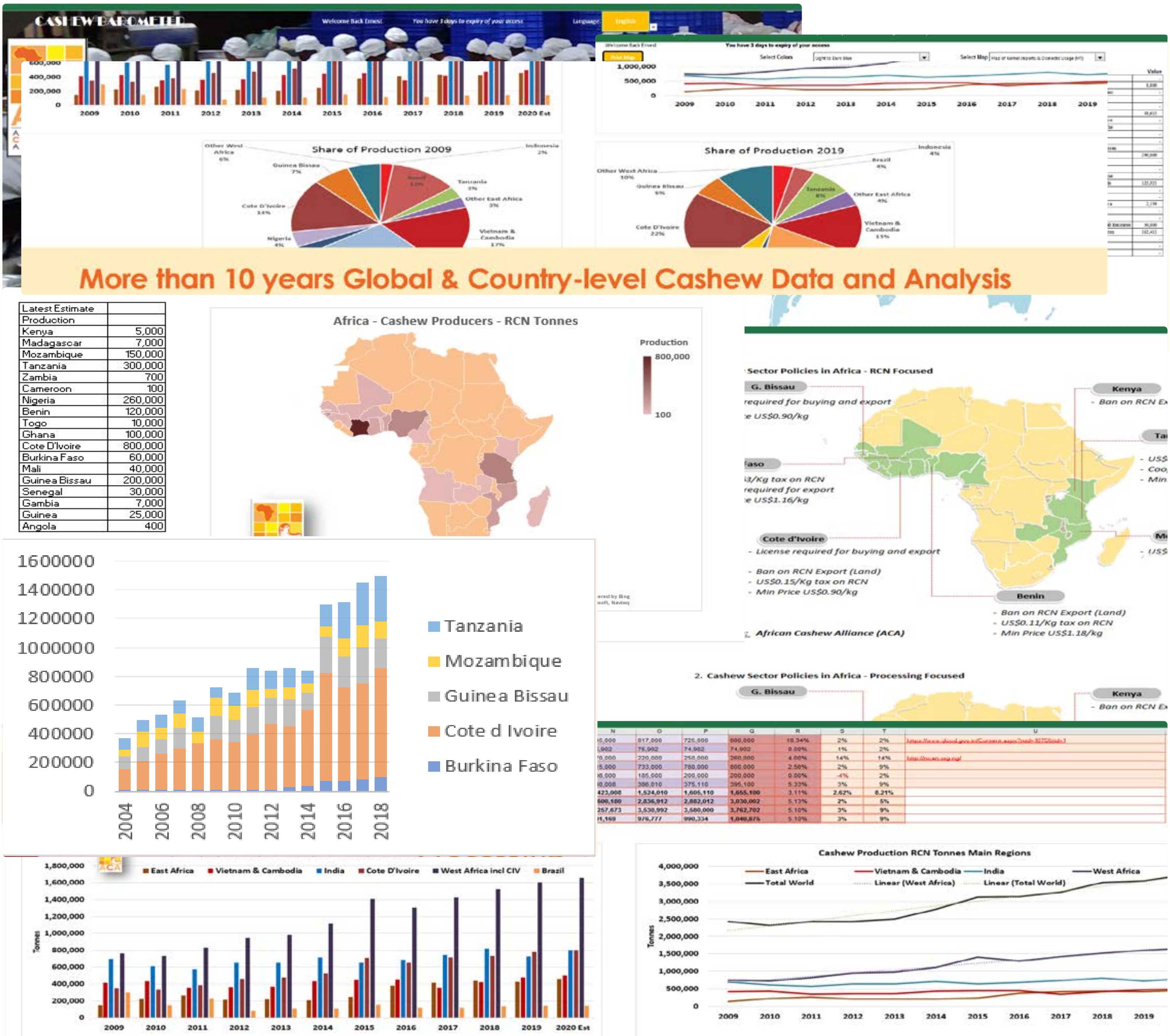
Cashew Barometer



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