Agromorphological Determinants Favoring the Spread of Anthracnose Disease in Cashew Agroforestry Farms in Côte d'Ivoire

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Authors’ contributions

This work was carried out in collaboration among all authors. Author BKG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SS and DD managed the analyses of the study. Author NYCF managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Cashew cultivation faces several health problems. Among these problems, anthracnose causes extensive damage to twigs, leaves and fruits and causes loss of yield. The spread of this disease is thought to be determined by certain agromorphological features of the cashew tree. The objective
of this study was to search for these agro-morphological determinants that influence the spread of anthracnose disease in agroforestry systems in Côte d’Ivoire. To achieve this objective, 30 cashew trees were spread across 26 agroforestry cashew orchards in the Korhogo, Sinématali and Boundiali departments were chosen and geolocated. The factor studied was the clone, consisting of 30 cashew genotypes, with 15 modalities. The collected data was subjected to descriptive analysis, correlation test, PCA and hierarchical ascending classification (CAH). The results showed that the wingspan, leaf area and size of cashew trees are determinants that promote the spread of anthracnose disease. Following this result, the CAH made it possible to screen the genotypes into three groups. These results could contribute to management of anthracnose disease in agroforestry, to enhance and intensify this cropping systems.

Keywords: Disease distribution; cropping system; wingspan; leaf area; size; agroforestry system.

1. INTRODUCTION

The cashew tree is native to northeastern Brazil (Trevian et al., 2005) [1]. It was introduced by the Portuguese in the colonies of Africa and Asia [2,3] (Lautié et al., 2001). Africa alone accounts for 55% of world cashew production [4]. West Africa, led by Côte d’Ivoire, is the newest and most dynamic production area in the world. Indeed, it provides 88% of African production (Koudio, 2018). The cashew tree is traditionally developed in Côte d’Ivoire by farmers following an agroforestry system, as in Tanzania, Mozambique, Nigeria, Guinea Bissau and Benin [5-8]. This crop then experienced a prodigious development for the Ivory Coast [9] thanks to the marketing of cashew nuts [3].

Notwithstanding the nature of a refuge plant for diseases that associated crops can present [10,11] and appear as a potential source of natural inoculation of cashew trees [12,13], the agroforestry system contributes to the reduction of the atmospheric carbon rate, promotes an environment conducive to agricultural and human development [14]. Consequently, this crop has aroused real enthusiasm which is reflected in the increase in the areas sown: 1,350,000 ha in 2018 against 8,200 ha in 1970 [9,15].

The Ivory Coast has managed to occupy the first rank of cashew nut producing and exporting countries since 2015 with 702,510 tonnes of raw nuts [16]. However, the average yield of orchards remains low (350 to 500 kg/ha) [3] due to a growing environment favoring the distribution of diseases on farms, including anthracnose, caused by Colletotrichum gloeosporioides. These orchards are characterized by unimproved planting plant material and in particular vulnerable to pests as the anthracnose, which causes enormous production losses [17-19]. In Tanzania, anthracnose is one of the four diseases responsible for declining cashew yields (NARI, 2009). In 2000, anthracnose caused a drop in production of around 40% in Brazil [20].

The management of these plagues raises several issues. Indeed, chemical control is not only expensive but proves inaccessible for producers, non-resilient and dangerous for the health of populations and for the environment [21-23]. Therefore, the morphology of the host plant can make it more or less vulnerable. According to Calonnec [24] the agromorphological parameters of the tree influence the dynamism of an epidemic within a crop. Thus, knowledge of the determinants of the spread of anthracnose in agroforestry operations and their agroecological management could sustainably curb the damage of anthracnose. In addition, it would contribute to the establishment of a more resilient, less expensive and environmentally friendly agricultural system.

It is in this perspective that the present study, first proposes to identify the agro-morphological determinants favoring the propagation of anthracnose disease in the cashew genotypes developed in an agroforestry system and secondly to structure these genotypes.

2. MATERIAL AND METHODS

2.1 Experimentation Site

The peasant orchards of the departments of Korhogo and Sinématali of the Poro region and those of Boundiali of the Bagoué region were the places that hosted this study. These departments are located in the north of Côte d’Ivoire. In these regions, the climate is Sudanese and is marked by two seasons including a short rainy season which starts from May to October and a long dry season which extends from November to April. The wind is dry there from November to March. The average annual rainfall varies between 1000
and 1400 mm. The vegetation consists of wooded savannah. The soils are ferralitic, moderately to strongly denatured [3].

2.2 Plant Material

The plant material used consists of 30 genotypes of cashew trees from peasant orchards in the locality (Table 1). The cashew trees in these peasant orchards are 10 years old and have been developed in an agroforestry system, in cultural association with the shea tree and the mango tree. In this agroforestry system, the shea trees are arranged randomly, as the farmer found them, when the field is created. The mango trees, unlike the shea trees, represent protective hedges at the border and delimiting portions of the farm. The separation distances in this peasant system are not constant. These distances not only vary from one farm to another and in addition they are variable (2 meters to 10 meters) within the same farm.

2.3 Methods

2.3.1 Orchard prospection and choice of genotypes

The peasant orchards of the departments of Boundiali, Korhogo and Sinématiali were prospected to search for high-producing cashew genotypes (between 20 and 50 kg), 10 years old, developed in an agroforestry system that associates them with the mango tree and the shea tree. These tree populations were surveyed using the traveling inventory method combined with the diagonal and median method. Each tree or individual has been marked/ colored, numbered and geo-referenced using GPS. This approach was inspired by the strategies developed by Maxted et al. [25] to conduct eco-geographic surveys and those of Diouf et al. [26] to carry out ethnobotanical surveys. During surveys, the incidence and severity of bacteriosis on the populations of shea tree, cashew tree and mango tree were realized. Data related to agromorphological parameters were collected.

| Genotypes | Geographic Coordinates | Genotypes | Geographic Coordinates | Genotypes | Geographic Coordinates |
|-----------|------------------------|-----------|------------------------|-----------|------------------------|
| BKYY      | N: 09°33.136'          | KTY1      | N: 09°29.984          | KBSD      | N: 09°35'154'          |
|           | O: 06°26.243'          |           | O: 05°43.309'         |           | O: 005°21'019          |
| BBY       | N: 09°27.798'          | KTY2      | N: 09°30.168'         | KOMC      | N: 09°36.505'          |
|           | O: 06°29.779'          |           | O: 05°34.716'         |           | O: 005°20.710'         |
| BKA       | N: 09°38.382'          | KTYY      | N: 09°31.162'         | KLYN      | N: 09°36.354'          |
|           | O: 06°21.127'          |           | O: 05°38.626'         |           | O: 005°20.627'         |
| SST       | N: 09°37.438'          | KKSN      | N: 09°31.674'         | KT3       | N: 09°33'721'          |
|           | O: 06°20.229'          |           | O: 05°38.783'         |           | O: 005°25'396          |
| SYD       | N: 09°24.467'          | KKSS      | N: 09°17.491'         | BAK       | N: 09°34'751           |
|           | O: 06°21.871'          |           | O: 05°32.697'         |           | O: 005°25'302          |
| SFA       | N: 09°27.935'          | KBT       | N: 09°19.103'         | SSS       | N: 09°34.751'          |
|           | O: 06°25.350'          |           | O: 05°34.223'         |           | O: 005°28'030'         |
| SWSZ      | N: 09°31.733'          | KSCK      | N: 09°23.008'         | STSL      | N: 09°36.669'          |
|           | O: 06°25.921'          |           | O: 05°33.643'         |           | O: 005°22'204'         |
| SLLC      | N: 09°32.295'          | KC3       | N:09°19.033'          | SGYM      | N: 09°29.800'          |
|           | O: 06°30.356'          |           | O: 05°38.441'         |           | O: 005°20.414'         |
| SDYY      | N: 09°28.861'          | KCP2      | N: 09°19.643'         | SYDN      | N: 09°33.345           |
|           | O: 06°32.693'          |           | O: 05°39.207'         |           | O: 005°24.330'         |
| SDYN      | N: 09°39.932'          | KCP1      | N: 09°29.919'         | STSB      | N: 09°32.789'          |
|           | O: 06°29.327'          |           | O: 05°48.486'         |           | O: 005°23.864'         |
2.3.2 Data collection

For the sake of representativeness, data (agromorphological and phtopathological detailed below) were collected on 30 trees in the plots established in each yard.

On each of these trees, 10 branches were previously marked in the North-South (N-S) and East-West (E-W) axes. The marked branches are all located at breast height.

The data collected focused on the one hand on the height of the trees, the span, the circumference of the trunk, the leaf area, the number of main branches, the fruit load. In addition, was collected the incidence and severity of anthracnose disease on leaves, twigs and fruit.

2.3.2.1 Tree height

The height of the tree (HAr) was taken from the ground to the last leaf in height using a graduated ruler of length four meters (4 m).

2.3.2.2 Circumference of the trunk

The circumference of the trunk (CirTr) was measured by a tape measure at 5 cm from the ground.

2.3.2.3 Total leaf area

To evaluate the total leaf area (STF), 20 leaves were chosen at random from each plant of the different genotypes. On these leaves, the width and the length were measured then the SFT was determined according to the formula of Cornelissen et al. [27] below.

\[ SFT = 0.86 \times NF \times \left(0.91 \times 3 \times 0.95 \times L \times w \times \pi / 4\right) \]

NF: Number of Leaves per tree (NF = 1); L: Length; w: width

2.3.2.4 Number of main branches

The number of branches (RPr) of trees of each genotype was determined by counting the main branches at the first branch level.

2.3.2.5 Tree spans North-South (Env N-S) and East-West (Env E-W)

The span of each tree was taken using a decametre in the North-South and East-West directions. The North-South wingspan was measured from the last leaf in the south to the last leaf in the north. For the East-West scale, it was taken from the last leaf in the East to the last leaf in the West.

2.3.2.6 Fruit load

The fruit load (ChFr) is the number of fruits present on a panicle. It was evaluated every two weeks by counting the fruits on the panicles of the ten branches.

2.3.2.7 Severity index of anthracnose disease

The severity was assessed on the twigs, leaves and fruits of each tree according to the rating scale of Cardoso et al. [28]. Severity was assessed using a visual rating scale ranging from 0 to 9 [28]; Grade 0: no symptoms; grade 1: 1-5%; grade 3: 6-10%; grade 5: 11-25%; grade 7: 26-50%; grade 9: > 50%. Scoring therefore consisted of assigning a percentage to diseased organs according to the distribution, intensity of symptoms and the number of organs affected. The summation of the severity scores at each branch marked in both directions of the tree was performed in order to obtain an average. The severity index (Is) of the observed diseases was determined according to the formula of Kranz [29] cited by Dianda et al. [30] below.

\[ Is = \sum_{i} \left(\frac{X_i \times n_i}{N \times Z}\right) \times 100 \]

Is: Severity incident; Xi: severity i of the disease on the organ; ni: number of organ of severity i; N: total number of the organ observed; Z: highest severity scale.

2.3.2.8 Incidence of anthracnose disease

Anthracnose disease was diagnosed by the descriptions of symptoms made by Wonni I. et al. [18]; Massawe P. [31]; Afouda et al. [17]; Cardoso et al. [28]. The incidence (Ic) was determined by the ratio of the population of diseased individuals to the total population of individuals observed. The incidence (%) was assessed according to the following formula [32,33]:

\[ Ic = \frac{\text{Number of organs attacked on the date of observation}}{\text{Total number of organs in the plot orbit}} \times 100 \]

Ic: incidence
This assessment focused on forty branches per tree.

2.3.3 Statistical Analysis

Data entry was performed with Excel 2013 software. Statistica 7.1 software was used to perform descriptive analyzes. These analyzes were used to carry out the Pearson correlation test carried out with the SPSS 16.0 software to test the hypothesis according to which agromorphological parameters would be decisive in the propagation of the anthracnose disease in cashew tree culture. However, this hypothesis is verified, the ascending hierarchical classification (CAH), following the orientation of the principal component analysis (PCA) was carried out to structure individuals. Subsequently, the multivariate test completed these analyzes to characterize the homogeneous groups of individuals established by the CAH.

3. RESULTS

3.1 Determinants Influencing Anthracnose in Cashew Trees

3.1.1 Relationship between agromorphological and phytopathological parameters

The Pearson correlation test made it possible to detect 5 pairs of variables. These significant and positive correlations were detected between agromorphological parameters and incidence on the one hand, and between agromorphological parameters and severity on the other hand (Table 2). These were the correlations observed between the East-West wingspan and the severity index on the leaves (r = 0.75) and on the fruits (r = 0.67) on the one hand and on the other hand between the East-West wingspan and the incidence of anthracnose on the leaves (r = 0.76) and on the fruits (r = 0.57). The total leaf area (SFT) was correlated on the one hand both with the incidence on the leaves (r = 0.77), on the twigs (r = 0.69) and on the fruits (r = 0.54). On the other hand, the total leaf area (SFT) was correlated with both the severity index on leaves (r = 0.80) and on fruits (r = 0.67). Between the fruit load and the severity index on the fruits (r = 0.76) on the one hand and the incidence of anthracnose on the fruits (r = 0.59) on the other hand. These results showed that the incidence and severity of anthracnose are determined by east-west extent, leaf area, and fruit load.

3.1.2 Structuring of variables and genotypes by principal component analysis (ACP)

The projection of the variables and individuals on the plane (Figs. 1 and 2) made it possible to illustrate the position of the variables and individuals with respect to the axes. Thus, axis 1, expressing 23.79% of the variability, was positively correlated with the severity index of anthracnose on twigs in the KVSS and KTYY genotypes. It was negatively correlated with total leaf area and east-west span with the KTY3 genotype.

Axis 2, which expressed 17.19% of the total variability, was positively correlated with the incidence of anthracnose on fruits with the KTY1 genotype. The incidence on inflorescences was negatively correlated with the genotypes SDYY and SWSZ.

3.1.3 Analysis of genotypes by Ascending Hierarchical Classification (CAH)

The Ascending Hierarchical Classification (CAH) made it possible to structure the genotypes studied into 4 groups (Fig. 3) according to the method of Ward (1963). The dendrogram carried out with the means of the 15 variables studied made it possible to identify 4 groups of genotypes. Group 1 contains 10 genotypes which are KVSS, KTYY, KLYN, KOMC, KBT, KBSD, BAK, SYD, KSCK, BBY. Group 2 is made up of 6 genotypes which are BKKY, STSB, SFA, SGYM, SSS, BKA. Group 3 includes KTY3, SLLC, SDYY (3 genotypes). Finally, group 4 is made up of 11 genotypes which are: KCP1, KCP2, KCP3, KTY1, KTY2, SDYN, STSL, SYDN, KKSN, SWSZ, SST.

Multiple analysis of variance (MANOVA) (Table 3) showed a significant difference between these groups (F> 3 or P <0.005). This significant difference was observed at the level of the East-West extent, of the total leaf area, of the incidence of disease on the inflorescences, the leaves and the twigs as well as at the level of the severity indices on the twigs and inflorescences.

Group 1 was distinguished by severe infections in the twigs (87.75 ± 2.84). Group 2 was characterized by trees with small leaves (157.46 ± 9.27) and low leaf disease incidences (12.57 ± 3.97). Group 3 was distinguished by trees with broad leaves (367.86 ± 10.21) and by strong incidences at the level of leaves (46.25 ± 15.39) and twigs (96.52 ± 0.28). Group 4 was also
characterized by trees with large leaves (280.29 ± 8.51), by a high incidence of the disease in the twigs (91.33 ± 1.83) and inflorescences (69.79 ± 5.48).

Table 2. Correlation matrix between agromorphological and phytopathological parameters

|      | IcINFLO | IcFe | IcRam | IsINFLO | IsFe | IsRam | IsFr |
|------|---------|------|-------|---------|------|-------|------|
| CirTr | -0.10   | 0.04 | -0.03 | 0.15    | -0.11| -0.12 | 0.22 |
| EnvN-S| 0.13    | 0.29 | 0.25  | -0.06   | -0.41| 0.06  | -0.25| -0.03|
| EnvE-O| -0.09   | 0.76 | 0.37  | 0.57    | -0.26| 0.75  | 0.04 | 0.67 |
| HAr   | 0.35    | -0.23| -0.11 | 0.09    | 0.10 | -0.04| -0.02| 0.08 |
| RPr   | -0.16   | 0.25 | 0.02  | 0.22    | -0.07| -0.15| 0.31 | 0.12 |
| SFT   | 0.02    | 0.77 | 0.69  | 0.54    | -0.24| 0.80  | -0.33| 0.67 |
| ChFr  | 0.13    | 0.09 | 0.12  | 0.59    | -0.26| 0.24  | -0.28| 0.76 |

Fig. 1. Projection of the variables in the factorial plane

Fig. 2. Projection of individuals into the factorial plane
Table 3. Characteristics of groups generated by the CAH

| Groups | Statistics |
|--------|------------|
| **GI** | **GII** | **GIII** | **GIV** | **F**  | **p**  |
| CirTr  | 0,42±0,02a | 0,42±0,02a | 0,47±0,02a | 0,41±0,014a | 0,89741 | 0,455762ns |
| EnvN-S | 5,20±0,17a | 5,34±0,40a | 6,13±0,13a | 6,08±0,37a | 2,01568 | 0,136388ns |
| EnvE-O | 5,30±0,08a | 4,37±0,32ab | 3,77±0,62c | 6,16±0,27a | **10,65527** | **0,00095s** |
| HAr    | 4,18±0,19b | 4,37±0,31b | 6,22±0,07a | 3,12±0,16c | 5,23904 | 0,008304ns |
| RPr    | 3,39±0,30a | 3,05±0,25a | 3,17±0,35a | 3,62±0,26a | 0,68429 | 0,569710ns |
| SFT    | 200,33±6,68c | 280,46±9,27b | 157,86±10,21d | 367,29±8,51a | **70,34484** | **0,000000s** |
| ChFr   | 3,96±0,56a | 3,75±0,75a | 4,99±0,69a | 3,97±0,64a | 1,42369 | 0,258414ns |
| IcINFLO| 64,66±4,88c | 81,88±5,43a | 31,47±14,14d | 69,79±5,48b | **11,88806** | **0,000043s** |
| IcFe   | 22,99±5,87b | 25,57±3,97b | 12,25±15,39c | 46,26±4,48a | **3,75718** | **0,062522s** |
| IcRam  | 83,78±1,99b | 86,06±2,51ab | 56,52±0,28c | 91,33±1,83a | **5,08871** | **0,006638s** |
| IcFr   | 22,23±6,67b | 15,49±5,15c | 10,00±15,03d | 29,44±5,95a | **7,34279** | **0,000622ns** |
| IsINFLO| 54,81±4,74b | 68,67±7,18a | 37,85±7,47c | 38,79±5,76c | **4,74867** | **0,009024s** |
| IsFe   | 18,51±4,57b | 41,66±6,77a | 21,82±3,47b | 35,00±4,88b | **3,78737** | **0,00295s** |
| IsRam  | 87,75±2,84a | 59,72±9,36b | 36,95±22,24c | 57,89±5,03b | **7,82056** | **0,0007s** |
| IsFr   | 20,92±8,48b | 14,33±2,97c | 7,19±3,71d | 25,10±7,43a | **6,03655** | **0,002802ns** |

Group size | 10 | 6 | 3 | 11

Numbers assigned the same letters on the lines are not statistically different (Turkey’s HSD test at the 5% threshold). ns: not significant, s: significant, p: probability, F: Fisher
Fig. 3. Dendrogram showing the different groups of individuals by the CAH

4. DISCUSSION

The summary analysis of the results of the Pearson and ACP correlation test demonstrated that the North-South, East-West spans and leaf area are determinants that influence the level of incidence and the severity of the anthracnose disease. Establishing this correlation between these agro-morphological parameters and the severity index and incidence would explain that genotypes of large leaf areas as well as the East-West scope and significant fruit loads would favor an environment of severities and high incidences of anthracnose. Agro-morphological parameters would determine the degree of sunshine inside the canopy. Indeed the surface development of the leaves constitutes a cover for the twigs vis-à-vis the sun, creating a shade which will favor the manifestation of the disease.

This observation is confirmed by Bréda et al. [34]; according to them, all phenomena, such as radiation, precipitation and atmospheric deposition, are closely linked to the degree of closure of the plant cover and its leaf surface. In fact, a fairly pronounced development of the wingspan would reduce the porosity of the canopy to the sun and, under the effect of shade, would create a microclimate which would favor the manifestation of Calonnec [24]. This assertion was evoked by the studies of Zahavi and Reuveni [35] claiming that the light available inside the canopy would depend on the amount of light intercepted by the crown of the trees and therefore on the architecture of the plants used. However, as Poorter [36] argued, UV (Ultraviolet) rays reduce the germination of spores and the growth of mycelium in powdery mildews.

In addition, the positive correlation observed between the total leaf area and the incidence of anthracnose on leaves and fruits. This would attest to the close relationship between the leaves and the fruit. Indeed, the fruits are covered by the leaves; the closeness of these two organs can be detrimental for two-tier leaves. First, at the level of the interception of solar rays; This observation is also supported by studies by Calonnec [24] showing that solar radiation affects the survival of the spores of many fungi. Then, in terms of the dispersion of the spores, it should be noted that bringing the organs together would facilitate the dispersion of the spores between the organs. This result can be confirmed by
Calonnec [24] who specifies that in the environment, the main effect of tree architecture on the process of spore dispersal is the distance between the organs.

The structuring by CAH of the 30 genotypes studied and their characterization by multiple analysis of variances suggested that the group 3 genotypes, in this case KTY3, SDYY and SLLC representing 10% of the total number, presented trees of a significantly low East-West span, a significantly high tree height with a significantly low leaf area. These agromorphological characters could explain the low severity indices and the low incidence of anthracnose on the fruits. Indeed, according to Arraiano et al. [37] plant morphology influences the manifestation of an epidemic by making the host plant more or less vulnerable. The great heights of the trees would not favor the transport of spores or germs taking place by splashing. Indeed, the work of Simón et al. [38] corroborated by those of Arraiano et al. [37], high plant heights may reduce the incidence and severity of disease. These authors state that taller plants are characterized by increased distances between the upper leaves and the lower leaves which are most often the main source of inoculum. Also, the increased distance of plants from the ground would result in a limitation of the amount of spores occurring by splashing.

Moreover, this distribution could explain the fact that each cashew tree genotype has its own specific characters that would allow it to react specifically to the aggression of the pathogen. Thus, each individual would have a specific resistance mechanism enabling him to react to an aggression against his aggressor [39,40]. In this context, the structuring of the cashew tree diversity into 3 groups would indicate that the genotypes of group 3 having recorded low severities and incidence on nuts would be more tolerant to attacks by the causative agent of anthracnose.

5. CONCLUSION AND PERSPECTIVES

The present study finds that the total leaf area, the east-west wingspan and the height of the tree are determinants of the spread of anthracnose.

The Ascending Hierarchical classification coupled with multivariate analysis made it possible to screen the genotypes into four groups. Group 3, consisting of genotypes KTY3, SDYY and SLLC, was distinguished by low severity and incidence of anthracnose on nuts. These genotypes of cashew trees exhibit better resilience for agroecological crop protection. In a context of reducing greenhouse gas emissions to fight climate disturbances, these cashew trees could help to enhance and intensify agroforestry cropping systems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Zoumarou N, Bagnan M, Akossou A, Kanlindogbe C. Morphological characterization of a collection of cashew fruits from the municipality of Parakou. (Bénin). International Journal of Biological and Chemical Science. 2016;10(6):2413-2422.
2. Martin PJ, Topper CP, Bashiru RA, Boma F, Dewaal D, Harries HC, Kasuga LJ, Katanila N, Kikoka LP, Lamboll R, Maddison AC, Majule AE, Masawe PA, Millanzi KJ, Nathaniels NQ, Shomari SA, Sijaona ME, Stathers T. Cashew nut production in Tanzania: Constraints and progress through integrated crop management. Crop Protection. 1997;16(1):5-14.
3. Djaha A, J-B, Annicet HN, Edmond KK, Achille N, Sévérin A. Morphological diversity of cashew accessions (Anacardium owest). Introduit in Ivory Coast. Rev. Ivory. Sci. Technol. 2014;23.
4. N’Djolossé K, Adou A, Bello S, Maliki R, Kpéra G. Nathalie, Oukoun G, Azontondé A. N.P.K. for better cashew nut yields according to the age of the plantations in Center-Benin and North-Benin. INRAB Technical Sheet. 2018;12.
5. Tandjikpon A, Lagbadohossou A, Hinvi J, Afonnon E. Cashew cultivation in Benin: Technical Reference. EditionINRAB, Bénin. 2003;86.
6. Dwomoh EA, Ackonor JB, Afun JVK. Survey of insect species associated with...
cashew (Anacardium occidentale Linn.) and their distribution in Ghana. African Journal of Agricultural Research. 2008;3(3):205-21.

7. Hammed S, Arshad M, Ashraf M, Avaish M, Shahid MA. Prevalence of common mastigotogens and their antibiotic susceptibility in Tehsil Burewala, Pakstans. Pak. J. Agri. Sci. 2008;45(2).

8. Yabi I, Yabi Blaou F, et S. Dadegnon. Diversity of plant species within cashew-based agro-forests in the town of Savalou in Benin. Int. J. Biol. Chem. Sci. 2013;7(2):696-706. DOI: http://dx.doi.org/10.4314/ijbcs.v7i2.24

9. Lebaillly P, Steev L, Hubert S. Study for the preparation of a strategy for the development of the cashew sector in Ivory Coast: Proposal of a strategy for the development of the cashew sector, Final report Ivory Coast. 2012:145.

10. Hamza AA. Taxonomy and diagnosis of Xanthomonas species associated with bacterial scab of tomato and Capsicum spp.: situation in the South West Indian Ocean islands. Agricultural Science. University of Réunion. NNT: 2010LARE0022. Phone. 008191814. Thesis Dissertation. 2010:40-47 :245. Available: http://www.afriquescience.info

11. Pruvost O, Lionel G. Epidemiology and control of mango Bacteriol Black spot. The American Phytopathological Society. Plant Diseases. Flight. 2001;85(9):928-935. DOI: 10.1094/PDIS.2001.85.9.928

12. Ricau P. Know and understand the international cashew market. 2013:49

13. Le Quy Kha. Importance et facteurs clés du succès du secteur de l’anacarde au Vietnam. African Cashew Alliance (ACA). 2017:43.

14. Balogoun I, Saïdou A, Ahoton EL, Amadji IG, Ahoahuendo CB, Adebo IB, Babatounde S, Chougourou D, Adoukonou-Sagbadja H. Ahanchede A. Characterization of cashew-based production systems in the main growing areas in Beni. African Agronomy. 2014;26(1):9–22.

15. FIRCA. The cashew sector, final report of activity. 2018:56

16. Doukouré CF, Kodjo AA. Impact of agricultural advice on the performance of cashew producers in Côte d’Ivoire. European Scientific Journal. 2018;14:292-310. DOI: 10.19044/esj.2018.v14n30p292

17. Afouda LCA, Zinsou V, Balogoun RK, Onzo A. Ahoahuendo BC. Inventory of pathogens in cashew trees (Anacardium occidentale L) in Benin. Bulletin de la Recherche Agronomique du Bénin. 2013;73:13-19.

18. Wonni I, Sereme D, Ouedraogo I, Kassankagno AI, Dao I, Ouedraogo L, Nacro S. Diseases of Cashew Nut Plants (Anacardium Occidentale L) in Burkina Faso. Adv Plants Agric Res. 2017;6(3):9.

19. Dénis ETH, Afio Z, Rachidatou S, Adomou AC, Zinsou V, Sharif B, Kouami N. The economic losses due to anthracnose of the cashew tree in Benin. European Scientific Journal. 2018;14(15). ISSN: 1857 – 7881. DOI: 10.19044/esj.2018.v14n15p127

20. Topper CP. Issues and constraints related to the development of cashew nuts from five selected african countries (Côte d’Ivoire, Ghana, Guinea, Guinea Bissau and Nigeria). Rapport Réunion régionale sur le développement des exportations de noix de cajou d’Afrique. CCI/CNUCED/OMC/ CFC/CNEX. Project No. INT/W3/69” Développement des exportations des noix de cajou d’Afrique” 23-26 juillet 2002, Hôtel du Port « La Marina », Cotonou, Bénin; 2002:24.

21. Paré S. Burundi Agricultural Market Development and Productivity Project (Pdrama-Bu). Integrated Pest and Pesticide Management Plan (PGPP). Study Report. 2011:88.

22. MINADER. Support Project for the Competitiveness of the Cashew Value Chain in Ivory Coast: Pest Management Plan (PGP). 2017:10-13:168.

23. Ducroquet H, Tillie P, Louhichi K, Gomez-Y-paloma S. Agriculture in Côte d’Ivoire under a magnifying glass: Inventory of plant and animal production sectors and review of agricultural policies. In Science for Policy Report. 2017:85-87:244.

24. Calonnec A. Shaping plant architecture to control plant diseases. Biofutur. 2013;343:6.

25. Maxted N, Ford-Lloyd BV, Hawkes JG. Plantgenetic conservation. The in situ approach, 1st edn. Chap-man and Hall, London; 1997.

26. Diouf M, Diop M, Lô C, Drame KA, Sene E, Ba CO, Gueye M, Faye B. Prospecting for traditional African-type leafy vegetables in Senegal. J.A.C. herbal medicine, hweya, P.B. Eyzaguirre (Eds.), The Biodiversity of
Traditional Leafy Vegetables, IPGRI. 1999; 111-154.

27. Cornelissen R, Deswarte JC, Azamali SN. A preliminary strategy for model development in Bambara groundnut. In: Sesay A., Edje O.T., Cornelissen R. (eds): increasing the productivity of Bambara groundnut (Vigna subterranea) for sustainable food production in semi-arid Africa. Proceeding of Bambara groundnut. 2002;167-17.

28. Cardoso JE, Santos AA, Rossetti AG, Vidal JC. Relationship between incidence and severity of cashew gummosis in semi-arid north-eastern Brazil. Plant Pathology. 2004;53:3. Available:https://doi.org/10.1111/j.0032-0862.2004.01007.x

29. Kranz J. Measuring plant disease: In: Kranz, J., Rotem, J. (eds), Experimental techniques in plant disease epidemiology. Springer, Berlin. 1988;35-50.

30. Dianda ZO, Woni I, Zombré C, Traoré O, Séré B, Ouedraogo SL, Sankara P. Prevalence of desiccation of the mango tree and evaluation of the frequency of fungi associated with the disease in Burkina Faso. Journal of Applied Bioscience. 2018;126:12686-12699. DOI: 10.4314/jab.v126i1.6

31. Massawe PAL. Innovations in cashew research. World Cashew Festival and Expo organized by Africa Cashew Alliance (ACA), 19-22 septembre, Bissau, Guinée-Bissau. 2016;44.

32. Aka RA, Kouassi KN, Agneroh TA, Awancho NA, Sangare A. Distribution of and incidence of cucumber mosaic disease (CMV) in industrial banana plantations in the South-East of Côte d’Ivoire. Science and Nature. Flight. 2009;6(2):171-183.

33. Zahri S, Farih A, Badoc A, Douira A. Statut des principales maladies, cryptogamiques foliaires du blé au Maroc en 2013. Journal of Applied Biosciences. 2014;77:6543–6549. ISSN 1997–5902. Available:http://dx.doi.org/10.4314/jab.v77i1.5

34. Bréda N, Soudani K, Bergonzini J-C. Measurement of leaf area index in the forest. ECOFOR, eds. 2002;157.

35. Zahavi T, Reuveni M. Biological Management of Diseases of Crops: Plant Pathology. European Journal. 2012;133:511-5.

36. Poorter L. Resource capture and use by tropical forest tree seedlings and their consequences for competition. In Burslem DFRP, Pinard MA, et Hartley SE, eds. Biotic interactions in the tropics. Cambridge University Press. 2005;35-64.

37. Arraiano LS, Balaam N, Fenwick PM, Chapman C, Feuerhelm D, Howell P, Smith S, Widdowson JP, Brown JKM. Contributions of disease resistance and escape to the control of septoria tritici blotch of wheat. Plant Pathology. 2009;58(5):910–922.

38. Simón MR, Perelló AE, Cordo CA, Larrán S, van der Putten PEL, Struik PC. Association between Septoria tritici blotch, plant height, and heading date in wheat. Agronomy Journal. 2005;97(4):10–72.

39. Freeman CB, Beattie GA. An Overview of Plant Defenses against Pathogens and Herbivores. The Plant Health Instructor. 2008;12.

40. Desanlis M. Analysis and modeling of the effects of cultivation on two major fungal diseases of sunflower: Phoma macdolnaldii and Phomospsi helianthi. Doctoral School in Ecological, Veterinary, Agronomic and Bioengineering Sciences. UMR INRA-ENSAT, France, 1248 AGIR. 2013;198.