

Evaluation of the Agromorphological Determinants of the Spread of the Bacterial Disease in Orchards of the Main Mango-Producing Regions in Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The use of agroecological practices for the management of phytosanitary problems has become a major issue in the context of sustainable development. It is with this in mind that this study was initiated in the regions of Bagoué, Poro and Tchologo. This study consisted of investigating the determinants likely to promote the spread of the bacterial disease in 720 mango trees of the Kent variety distributed in 20 orchards in the regions of Poro, Tchologo and Bagoué. During this study,

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the incidence and severity of bacterial disease on leaves and fruits (IsFe, IsFr, IcFe, IcFr) as well as agromorphological parameters such as East-West and North-South spans, total leaf area, fruit load, trunk circumference, total height and number of main branches (En EO and NS, SFT, ChFr, CirTr, HaTr and RamP) were measured. The performance of the Pearson correlation test revealed that spans (N-S and E-O), HaTr, SFT and ChFr are the 4 agromorphological determinants that promote the spread of bacteriosis in orchards of the three (3) regions. The synthesis of the results of the ACP and the CAH supplemented by a multivariate analysis (MANOVA) made it possible to structure the mango orchards into three (3) homogeneous groups. Group 1 orchards (VB4, VB8, VS1, VF5, VK1, VB7, VF2 and VK2) expressed the lowest severity indices and the incidence of bacteriosis on the leaves (respectively $15.21 \pm 8.87\%$; $12.21 \pm 6.54\%$) and fruits (respectively $13.11 \pm 4.75\%$; $10.40 \pm 2.93\%$). These orchards featured mango trees with medium trunk circumferences (99.14 ± 17.24 cm), medium trunk heights (145.29 ± 7.24 cm) and smallest spans (6.85 ± 1 , 13 m for the NS span and 6.79 ± 1.18 m for the EO span) and total leaf area (15.61 ± 0.06 cm). These results could help develop an agroecological control strategy for the sustainable management of bacterial disease.

Keywords: *Mango tree; determinants; bacterial disease; spatial distribution; agroecological control; Ivory Coast.*

1. INTRODUCTION

In Ivory Coast, the mango sector is experiencing significant growth given the quantities produced. Thus, the country exported in 2016 more than 32,600 tons against 9,800 tons in 2011 [1]. In 2016 and 2017 Côte d'Ivoire experienced record exports, with more than 30,000 tonnes shipped to Europe [2]. Representing 4% of Ivorian GDP, it can be found in several forms in by-products such as dried mangoes, cocktails, juices, jams and nectars [3]. The sector generates more than 10 million euros in income in the northern areas where it is cultivated [2]. Mango production currently holds an important place in the economic development of these regions which previously mainly focused on cotton cultivation. However, the yields of Ivorian orchards still remain low, in the order of 3 to 7 t / ha compared to those of India which are in the order of 10 to 15 t / ha [2]. This low yield could be explained, among other things, by unsuitable farming practices and the environment which is favorable to the proliferation of pests and diseases such as bacteriosis [4,5]. The increase in agricultural productivity of plants over the past five decades has been based on improving the yield potential of cultivated varieties and on the massive use of phytosanitary products [6]. The use of phytosanitary products for the management of crop enemies poses health problems for the population and for the environment; it is noted that there is increasing pathogens resistance [7] and the exceeding of maximum residue limits (MRLs) of pesticides in fruits [8]. It is therefore necessary to find new levers that can be operated to reduce the epidemic development of bacteriosis. For this purpose, a still little exploited

possibility is to modify the environment of the plant to act on the production and the dissemination of the inoculum, through modifications of the microclimate, on the dispersion of the pathogen by affecting the distance between target organs. It is with this in mind that the present study aims to identify the agromorphological determinants favoring the spread of mango bacteriosis disease in the main mango production areas in Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Experimental Sites

The mango orchards of the mango production basin are located in the Poro, Tchologo and Bagoué regions in northern Côte d'Ivoire. Thus, the mango orchards of the departments of Korhogo, Ferkéssédougou, Sinématiali and Boundiali were the sites of the study. The climate of these regions is marked by two seasons consisting of a short rainy season which begins from May to October and a long dry season which extends from November to April with a dry wind from November to March. The average annual rainfall varies between 1000 and 1400 mm in these departments. The vegetation consists of wooded savannah.

2.2 Plant Material

The plant material used in this study was made up of 28,800 twigs or individuals, including 40 twigs per mango tree, from 720 mango trees spread over 20 orchards of at least 2 hectares, and made up the observation material. These twigs are made up of the young stem or non-

leafy twig, leaves, flowers and fruits depending on the stage of development of the mango tree. The 720 mango trees spread over the 20 orchards were identified during surveys carried out in the peasant orchards of the departments of Ferkéssédougou, Korhogo, Sinématiali and Boundiali. The mango trees in these peasant orchards have a planting period of 10 years.

2.3 Methods

2.3.1 Prospecting and choice of orchards

The prospecting was carried out in the peasant orchards of the departments of Ferkéssédougou, Boundiali, Korhogo and Sinématiali. During this prospecting, mango orchards with 10 years of planting were sought. These prospected mango orchards mainly consist of the Kent variety. To this end, 20 orchards were selected following the prospecting. In each orchard selected, a block of one-hectare plots comprising 100 mango trees according to a 10 out of 10 system was delimited. At the level of each plot, 1440 branches of 36 mango trees were evaluated according to the diagonal and median method. These tree populations were studied using the traveling inventory method combined with the diagonals and medians method. Each tree or individual was marked / colored, numbered and georeferenced using GPS to conduct eco-geographic surveys [9] and according to the method of Diouf et al. [10], to conduct ethnobotanical surveys.

The incidence and severity of bacteriosis were evaluated on leaves and fruits in order to determine the spatial distribution of bacterial disease in the mango production area and to structure the orchards of the three regions of the mango production area. The fruits studied were all at the harvest or physiological maturity stage.

2.4 Data Collection

For the search for the determinants influencing bacteriosis in the mango tree, agromorphological measurements were carried out on the trees of the orchards studied. The agromorphological parameters measured are as follows

2.4.1 The height of the trunk

Using a decameter, the height of the trunk was measured from the ground to the first level of branching.

2.4.2 The trunk circumference

The trunk circumference was determined with a tape measure at 5 cm from the ground.

2.4.3 Total leaf area

To assess the total leaf area, the length and width of the leaves of 10 branches were assessed. The leaf lengths and widths of leaves on the ten (10) tagged twigs were measured and the average length and width values were then determined. Subsequently, the total leaf area (SFT) was evaluated according to the formula of Cornelissen et al. [11].

$$SFT = 0,86 \times NF \left[0,91 \times 3 \left(0,95 \times L \times l \times \frac{\pi}{4} \right) \right]$$

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

2.4.4 The number of main branches (RamP)

The number of tree branches of each genotype was determined by counting the primary branches.

2.4.5 Scope of the tree structure (Env N-S and Env E-O)

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

2.4.6 Fruit load (ChFr)

The fruit load 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 (10) branches marked on each side of the NS and EO axes to be seen and carried by hand.

2.4.7 Evaluation of the severity index (Is) of the bacterial disease

Ten (10) twigs were marked on each side of the NS and EO axes for sight and hand. The severity was assessed on the leaves and fruits of each tree according to the rating scale of [12,13]. Severity was assessed using a visual rating scale ranging from 0 to 9; Grade 0: no symptoms; grade 1: 1 to 5%; grade 3: 6-10%; grade 5: 11-25%; Grade 7: 26 to 50%; Grade 9: > 50%. The scoring therefore consisted in assigning a percentage to the diseased organs according to the distribution, the intensity of the symptoms and the number of organs affected. The summation of the severity scores at each

marked branch in both directions of the tree was performed in order to obtain an average. The severity index of the observed diseases was determined according to the formula of Kranz [14] cited by Dianda et al., [15] below.

$$I_s = \sum \left(\frac{X_i \times n_i}{N \times Z} \right) \times 100$$

Is: Severity incident; Xi: severity i of the disease on the organ; ni: number of organs of gravity i; N: total number of organs observed; Z: highest severity scale (9).

2.4.8 Evaluation of the incidence (Ic) of the bacterial disease

The incidence was determined as the ratio of the number of sick people to the total number of individuals observed as a percentage. The impacts were determined according to the following formula of Aka et al. [16] et Zahri et al. [17]:

$$I_c = \frac{\text{Nombre d'organe attaqué a la date de l'observation}}{\text{Nombre total d'organe observé}} \times 100$$

This evaluation focused on ten (10) branches marked on either side of the NS and EO axes to be viewed and carried by hand. A scale adapted to that of Bhagwat et al. [18] was used to qualify the level of incidence of bacteriosis on each tree Cardoso et al [12].

2.5 Statistical Analysis of the Data Collected

Data entry and graphing were performed with Excel 2016 software. Statistica 10 software was used to perform descriptive analyzes of the data, tests of homogeneity of the means in the event of a significant difference as well as multivariate tests, such as hierarchical ascending classification (CHA) and principal component analysis (PCA) to structure individuals. Pearson's correlation test was performed with SPSS 16.0 software to establish a relationship between the incidence of anthracnose disease and agromorphological parameters.

3. RESULTS

3.1 Determinants Influencing Anthracnose Disease in Mango Orchards

Relationship between agromorphological and phytopathological parameters by the Pearson correlation test

The Pearson correlation test carried out on agromorphological and phytopathological data showed strong correlations and revealed the existence of determinants of the spread of bacteriosis (Table 1). The correlation matrix made it possible to detect 14 significant correlations between the agromorphological parameters and the manifestation of bacteriosis (Table I). Thus, the north-south extent was positively correlated ($r = 0.74$) with the incidence of bacteriosis on the leaves (IcFe) and the east-west extent was positively correlated ($r = 0.72$) the incidence of bacteriosis on fruits (IcFr). While the north-south and east-west wingspan were positively correlated with the severity index of bacterial blight on the leaves (Env NS ($r = 0.64$); Env EO ($r = 0.71$)) and on fruit (Env NS ($r = 0.69$); Env EO ($r = 0.75$)). The incidence and severity index of bacteriosis on leaves (IcFe; IsFe) and fruits (IcFr; IsFr) were negatively correlated with trunk height with respectively (IcFe (-0.66); IsFe (-0.69); IcFr (-0.71); IsFr (-0.71)). These results made it possible to note that as the height of the trunk increases, the incidence and severity index of bacteriosis on leaves and fruits decreases. The total leaf area (SFT) was positively correlated with the incidence (Ic) ($r = 0.70$) and the severity index (Is) ($r = 0.75$) of bacterial blight on the leaves. This result provides information on the favorable role played by the leaf surface in the manifestation of the disease on the leaves. Fruit load (ChFr) was correlated with both incidence (IcFr) and fruit disease severity index (IsFr), the correlation coefficients were 0.72 and 0.71 respectively. This result attests that a high number of fruits per panicle may be favorable to the manifestation of the disease in the fruits (Table 1).

3.1.1 Principal component analysis (ACP) of the studied parameters and of the individuals (mango orchards)

Principal component analysis (ACP) was expressed from three axes which explained 70.38% of the total variability (Fig. 1 and 2). The main contributions to Axis 1 come from four positively correlated variables. This axis, which expressed 31.73% of the total variability and was positively correlated with the incidence and severity index of bacterial disease on leaves and fruits. Thus, axis 1 opposed the trees with the highest incidences and severity indices at the level of leaves and fruits. Axis 2 with four variables which explained 25.97% of the variability was positively correlated and contains

the growth parameters (north-south and east-west span, number of main branches, and trunk circumference). This axis grouped together the trees with the largest spans, a large number of main branches and vigorous trunks. Axis 3 with a variable that returned 12.68% of the variability was negatively correlated with the total leaf area. This axis grouped together trees with a small leaf area (Fig. 1 and 2).

3.1.2 Ascending hierarchical classification (CAH) and multiple analysis of variance (MANOVA)

The results of the Ascending Hierarchical Classification (CAH) are shown in figure 3 and Table II. This classification structured the orchards studied into three groups according to the method of Ward (1963). The dendrogram carried out with the means of the 11 variables studied made it possible to identify the orchards making up the different groups. Thus group 1 is made up of seven orchards including VB4, VB7, VB8, VF2, VF5, VS1 and VK2. Group 2 is also made up of seven orchards including VS3, VS2, VF4, VB6, VF3, VF6, VB5. Group 3 contained six (VK1, VS4, VF1, VB3, VB2, VB1) (Fig. 3). Thus group 1, which expressed 35% of the total population, is characterized by orchards with severity indices on the leaves ($15.21 \pm 8.87\%$) and on the fruits ($13.11 \pm 4.75\%$) light and with weak effects on the leaves ($12.21 \pm 6.54\%$) and on the fruits ($10.40 \pm 2.93\%$). The orchards in this group consisted of trees with the smallest spans (6.85 ± 1.13 m for Env NS and 6.79 ± 1.18 m for Env EO) and small total area (15.61 ± 0.06 cm) Orchards in this group also presented trees with average trunk heights (145.29 ± 7.24 cm) and average trunk circumferences (99.14 ± 17.24 cm). Group 2, which occupied 35% of the total population, stood out from the others as orchards with severe infections on the leaves (47.32 ± 9.54) and fruits (40.08 ± 25). This group also presented orchards with a high incidence on their leaves (40.21 ± 9.07) and fruits (36.20 ± 9.47). Orchards in this group also recorded the greatest trunk heights (185.93 ± 11.72 cm), trunk circumferences (126.28 ± 9.38 cm), spans (12.39 ± 0.95 m for Env NS and 10.40 ± 0.81 m for Env EO) and an average total leaf area (28.62 ± 0.12 cm). Group 3 (30% of the total population) is formed by trees which presented severe infections on the leaves ($40.47 \pm 7.67\%$) and on the fruits ($44.04 \pm 12.66\%$). Strong impact on fruits ($44.78 \pm 13.94\%$) and leaves ($36.85 \pm 15.26\%$). These orchards exhibited the smallest trunk heights (131.64 ± 9.48 cm) and trunk circumferences (84.10 ± 12.49 cm). With large

wingspans (11.35 ± 0.62 m for Env N-S and 13.75 ± 0.20 m for Env E-W) and a large total leaf area (35.70 ± 0.12 cm) (Table 2).

4. DISCUSSION

Pearson's correlation test revealed that the distribution of bacteriosis in the mango production basin is determined by the organs of the mango trees which are the propagation factors. Thus, the wingspan, the total leaf area, the height of the trunk and the fruit load are determinants of the spread of bacteriosis. In fact, both the size and the total leaf area were positively correlated with the severity index and the incidence of bacteriosis on the leaves and on the fruits. These results could be explained by the fact that trees with large spans and large leaf areas create a microclimate favorable to the development of pests. According to [19] the infection process requires the presence of three factors including the sensitivity of the target organ of the plant, the presence of a minimum amount of virulent inoculum and especially favorable climatic conditions. For [20], better penetration of light into the tree would reduce the period of leaf wetness and limit the development of pathogens. On the other hand, dense plant cover prevents the circulation of air and light by providing a favorable environment (high relative humidity) for the development of pathogens [21]. Also (Richard 2012) has shown in his study of tree architecture in relation to the development of an epidemic that the increase in scale creates closeness between trees and facilitates the spread of spores. The incidence and severity index of bacteriosis on leaves (IcFe; IsFe) and fruits (IcFr; IsFr) were negatively correlated with trunk height with respectively (IcFe (-0.66); IsFe (-0.69); IcFr (-0.71); IsFr (-0.71)). These results from the Pearson correlation test showed that as the height of the trunk increases, the incidence and severity index of bacterial blight on leaves and fruits decreases. In fact, the smaller a tree, the closer the leaves and fruits are to the soil and to the spores. The spores are also spread by wind, rain, insects and dead stems scattered across the field on the soil from season to season [22]. In addition, it is important to underline that the variable "architectural diversity" is one of the main drivers of the dynamics of an epidemic within a culture [6]. These results are also supported by [23] and [24] which show that height (agro-morphological parameter) would also influence the manifestation of the disease. Indeed, according to these authors, the removal of plants from the ground results in a limitation of

the quantity of spores. the dispersion of which is done by splashing and therefore a low level of attack unlike small trees. The positive correlation between the fruit load (ChFr) and the incidence (IcFr) as well as the severity index (IsFr) of bacteriosis. would attest that a high number of fruits per panicle can be favorable to the manifestation of the disease. fruit disease. The

result is therefore a rapprochement between the fruits which would promote better dispersion of the spores and therefore a strong spread of the disease from one fruit to another. Our results are confirmed by those of Agnès et al. [25] who argue that the distances between organs play a major role in the development and distribution of rain disease germs.

Table 1. Correlation matrix between agromorphological and phytopathological parameters

	IcFe	IcFr	IsFe	IsFr
CirTr	0,04	0,15	-0,12	0,18
EnvN-S	0,74**	0,59*	0,64**	0,69**
EnvE-O	0,56*	0,72**	0,71**	0,75**
HaTr	-0,66**	-0,71**	-0,69**	-0,71**
RamP	0,25	0,22	-0,15	0,12
SFT	0,70**	0,59*	0,75**	0,58*
ChFr	0,09	0,72**	0,24	0,71**

*; **: degree of significance at threshold $P < 0.05$ and 0.01 , respectively ; IcRam: Incidence on Rameaux; IcFe: Incidence on Leaves; IsFe: Severity Index on Sheets; IsRam: Severity Index on Twigs; CirTr: Circumference of the Trunk; EnvN-S: North-South scope; EnvE-W: East-West scope; HaTr: Height of the trunk; RamP: Main Branch; SFT: Total Leaf Area; ChFr: Fruit load.

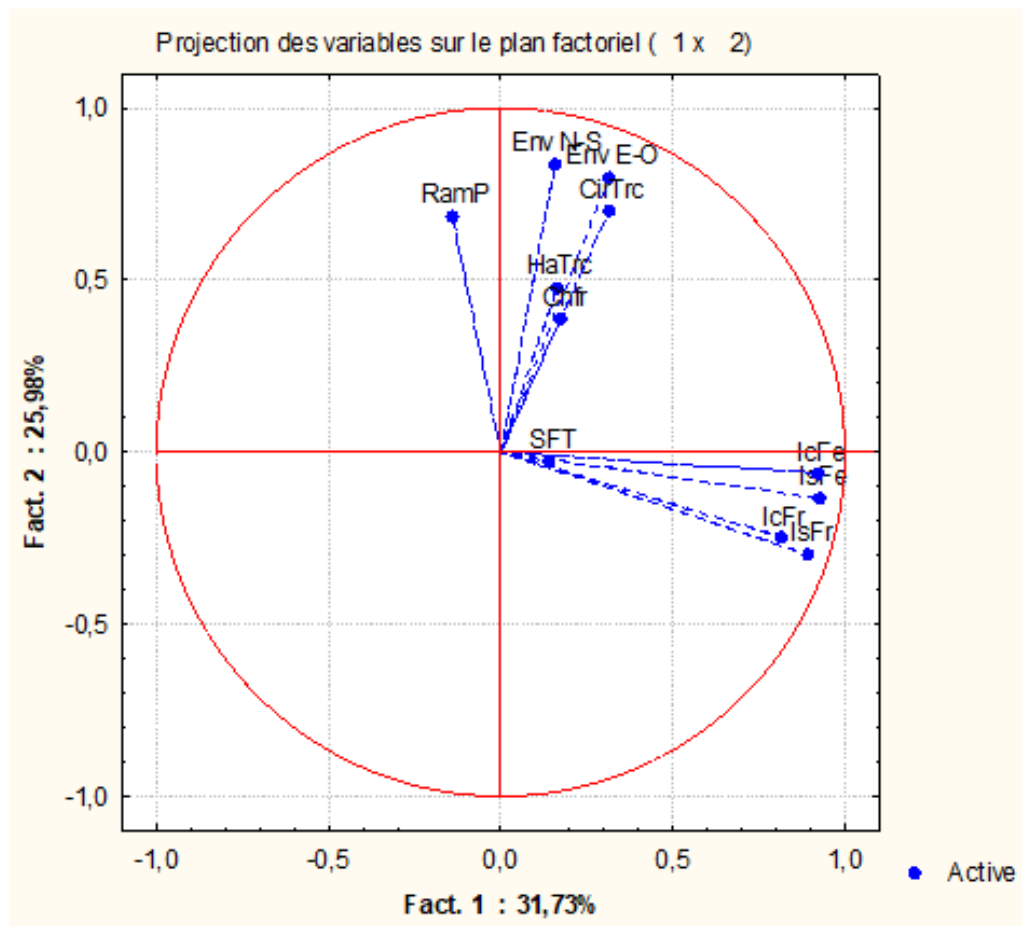


Fig. 1. Representation of variables in the plane of axes 1 and 2 of the ACP

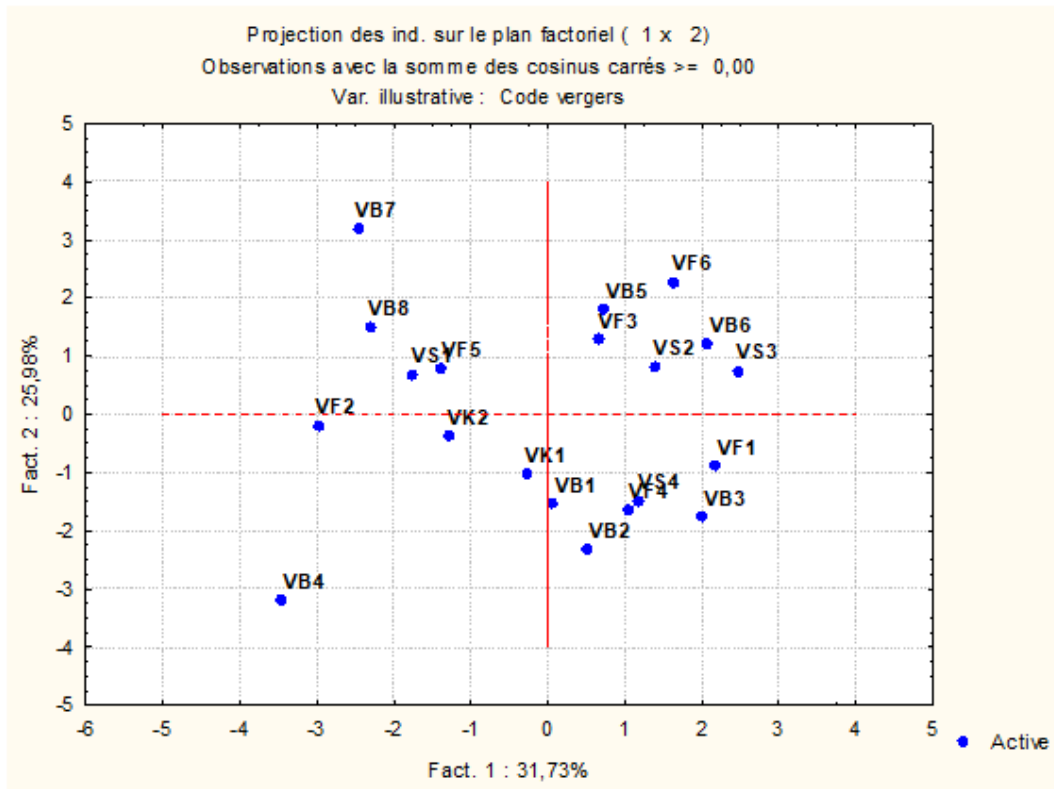


Fig. 2. Projection of individuals in the factorial plane

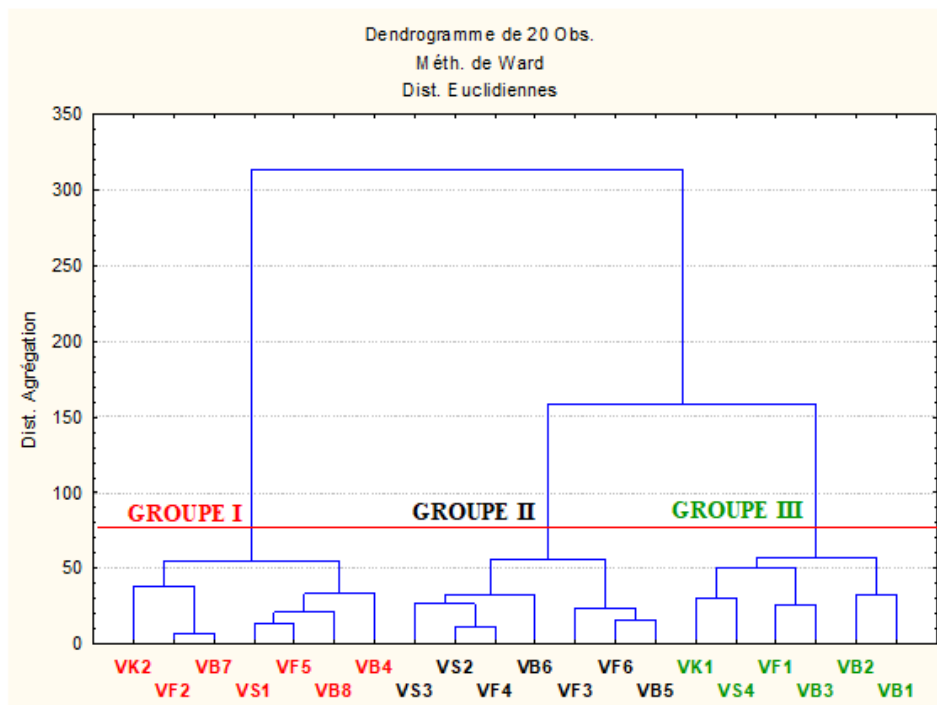


Fig. 3. Structuring of groups of mango orchards by the Ascending Hierarchical Classification (CAH)

Table 2. Descriptive analysis of the different groups formed with the CAH

Variable	Group I	Group II	Group III	F	p
IsFe	15.21±8.87 ^b	47.32 ± 9.54 ^a	40.47±7.67 ^a	25.62968	0.000007 ^s
IsFr	13.11±4.75 ^b	40.08±8.25 ^a	44.04±12.66 ^a	24.13672	0.000011 ^s
IcFe	12.21±6.54 ^b	40.21±9.07 ^a	36.85±15.26 ^a	14.28678	0.000229 ^s
IcFr	10.40±2.93 ^b	36.20±9.47 ^a	44.78±13.94 ^a	23.20505	0.000014 ^s
Env N-S	6.85±1.13 ^b	12.39±0.95 ^a	11.35±0.62 ^a	7.96524	0.000084 ^s
Env E-O	6.79±1.18 ^c	10.40±0.81 ^b	13.75±0.20 ^a	11.21351	0.000034 ^s
SFT	15.61±0.06 ^c	28.62±0.12 ^b	35.70±0.12 ^a	13.38585	0.000975 ^s
RamP	3.98±1.66 ^a	3.75±0.87 ^a	2.82±0.44 ^a	1.98755	0.167622 ^{ns}
CirTrc	99.14±17.24 ^a	126.28±9.38 ^b	84.10±12.49 ^a	16.53543	0.000103 ^s
HaTrc	145.29±7.24 ^b	185.93±11.72 ^a	131.64±9.48 ^c	0.56756	0.007287 ^s
ChFr	5.73±1.00 ^a	6.03±0.80 ^a	5.62±0.72 ^a	0.40185	0.675273 ^{ns}
Size	7	7	6		
Contribution	35%	35%	30%		

s: significant; ns: not significant. P: probability. F: Fisher ; The numbers assigned the same letters in the rows are not statistically different according to Fisher's LSD test at the 5% level.

The structuring of the orchards studied made it possible to divide the mango trees into three homogeneous groups according to the distribution of bacteriosis in the study regions. Thus, the mango trees of group 1 (VB4, VB7, VB8, VF2, VF5, VS1 and VK2) representing 35% of the total number, presented slight signs of severity of bacteriosis on the leaves and fruits as well as low incidences on these organs unlike the other two groups (group 2 and 3) of mango trees. These groups (2 and 3) presented signs of severity and severe type effects on leaves and fruits. This significant difference in the distribution of bacteriosis in mango trees in the mango production area is thought to be the result of the architecture of these mango trees. Which architecture would be imposed by the producers. In fact, unlike the mango trees in groups 2 and 3 orchards, the mango trees in group 1 orchards are characterized by an average trunk height and trunk circumference, small wingspan and low leaf surfaces. These agromorphological characters could explain the low indices of severity and incidence of bacteriosis on leaves and fruits. Indeed, according to [23] the architecture of the plant influences the manifestation of an epidemic by making the host plant more or less vulnerable. The low tree heights as well as large spans and total leaf area would be favorable conditions for the development of the pathogen. Indeed, according to the work of [24] a high plant height can reduce the incidence and severity of the disease. In addition, keeping plants away from the ground would limit the amount of spores produced by splashing. Moreover, this similar distribution of the bacterial disease in the three (3) regions of the mango production basin suggests the use of common orchard management practices. Which practices would

be, among others, the failure to collect leaves, dead branches, infected fruits which remain scattered on the ground in the field and would be incubators of inoculum for bacterial disease.

5. CONCLUSION

Pearson's correlation test revealed that total leaf area, wingspan (east-west and north-south), fruit load and tree trunk height are determinants of bacterial blight distribution in plants, mango trees. The synthesis of the results of the PCA and the CAH supplemented by a multivariate analysis (MANOVA) made it possible to structure the mango orchards into three (3) homogeneous groups. Group 1, consisting of orchards VB4, VB7, VB8, VF2, VF5, VS1 and VK2, is distinguished by low severity and low incidence of bacterial blight on leaves and fruits. Group 2 was distinguished by orchards VS3, VS2, VF4, VB6, VF3, VF6, VB5, with severe infections and high incidence of bacteriosis on leaves and fruits. Group 3 contained six orchards (VK1, VS4, VF1, VB3, VB2, VB1), which presented severe infections with a high incidence on the leaves and fruits. The architecture of the mango trees in group 1 orchards shows better resilience and could contribute to an agroecological crop protection program against bacteriosis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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