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# Spatial Distribution of Banana Tough Top Disease (BTTD) in Maniema Province, DR Congo

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## ABSTRACT

A study on the spatial distribution of banana bunchy top disease (BBTD) in the banana production areas of Maniema was conducted with the aim of determining the incidence and severity of BBTD, the presence and the importance of the *Pentalonia nigronervosa* vector on the different banana and plantain cultivars grown in this study area of the Province of Maniema. 1890 clumps of banana trees were inspected due to 30 clumps of banana trees per field, 3 fields per village and 3 villages per territory, on seven territories of the Province of Maniema. The selected clumps were analyzed based on key indicators such as: disease incidence, disease severity (BBTD), presence and importance of the vector *P. nigronervosa*, and the state of farmers' knowledge compared to the management of BBTD. From the analysis of the results, it was found that BBTD is present throughout the study area with an incidence ranging from 78.52 to 88.15% where the high rate is on banana trees in Kibombo territory (88.15%) and in Pangi (87.05%). Discoloration of leaves with normal size is the most common symptom and also high on banana trees with an average of 31.90%. The vector *P. nigronervosa* is widespread with an average of 94.85% where a strong presence was found on banana trees in Pangi (97.41%). All the colonies of *P. nigronervosa* are present on the clumps of banana trees. A large colony with winged insects is the most common form with an average of 40.31%. On the other hand, it should be noted that 100% of banana trees are grown in association with rice, cassava, corn or other crops; 95.24% of farmers use shoots from neighboring fields; the age of the banana plantations surveyed varied from less than 3 years to more than 10 years, i.e. 42.86% of the banana plantations are over 10 years old; 38.10% of banana plantations are 5-7 years old and 8.33% of banana plantations are less than 3 years old. From the analysis of different epidemiological parameters, it was found that the growing conditions of banana plants (cropping systems and other practices) favor the incidence and severity of the disease as well as the presence and importance of the vector *P. nigronervosa*.

**Keywords:** distribution, spatial, BBTD, banana trees, Maniema, D.R. Congo

## INTRODUCTION

Heavy parasitic threats currently weigh on the production of bananas and plantains (Ngama, 2014). Among these threats, it is worth noting viral, fungal and bacterial diseases, nematodes and insect pests including the weevil *Cosmopolites sordidus* (Tixier et al., 2010) reported almost everywhere in banana production areas with a very considerable impact on production (Baudouin et al., 2002). Numerous documents and oral traditions testify in different ways to the many sufferings endured by different peoples as a result of plant diseases and which have been at the root of famines and population exoduses (Camara et al., 2010). In recent years, the production of bananas and plantains has globally decreased in several territories in the province of Maniema. This is for several reasons, in particular the incidence of Banana Bunchy Top Disease reported since then in major banana production

hotspots, which has a significant impact on household incomes. This could compromise the sustainability of the agricultural system of this Province, particularly in the territories where plantains are used as staple food (CIRAD, 2011; ISF and CTA, 2011). The general objective is to highlight the spatial distribution of the biological constraints of banana cultivation linked to BBTD in the different banana production areas in the Province of Maniema.

Specifically, this study is undertaken in order to: Determine the incidence and severity of BBTD on the different banana and plantain cultivars grown in this study area; Determine the presence and importance of the vector *Pentalonia nigronervosa*, as well as the cultivation conditions of banana plantations in the Province of Maniema. Indeed, we assumed that there is a variation in the spatial distribution of the biological constraints of the banana crop related to BBTD in the different banana production areas in the Province of Maniema. The incidence and severity of BBTD can be quite variable depending on the different cultivars found in this banana production area of Maniema; the presence and importance of the vector *Pentalonia nigronervosa* can also be variable in these different study areas. The cultivation conditions of banana plantations are also variable.

## MATERIALS AND METHODS

### Study Environment

This study covered the 7 territories of the province of Maniema, in particular: Kailo, Pangi, Kibombo, Punia, Lubutu, Kasongo, and Kabambare. The various territories and villages of the Province of Maniema surveyed are represented by Figure 1.

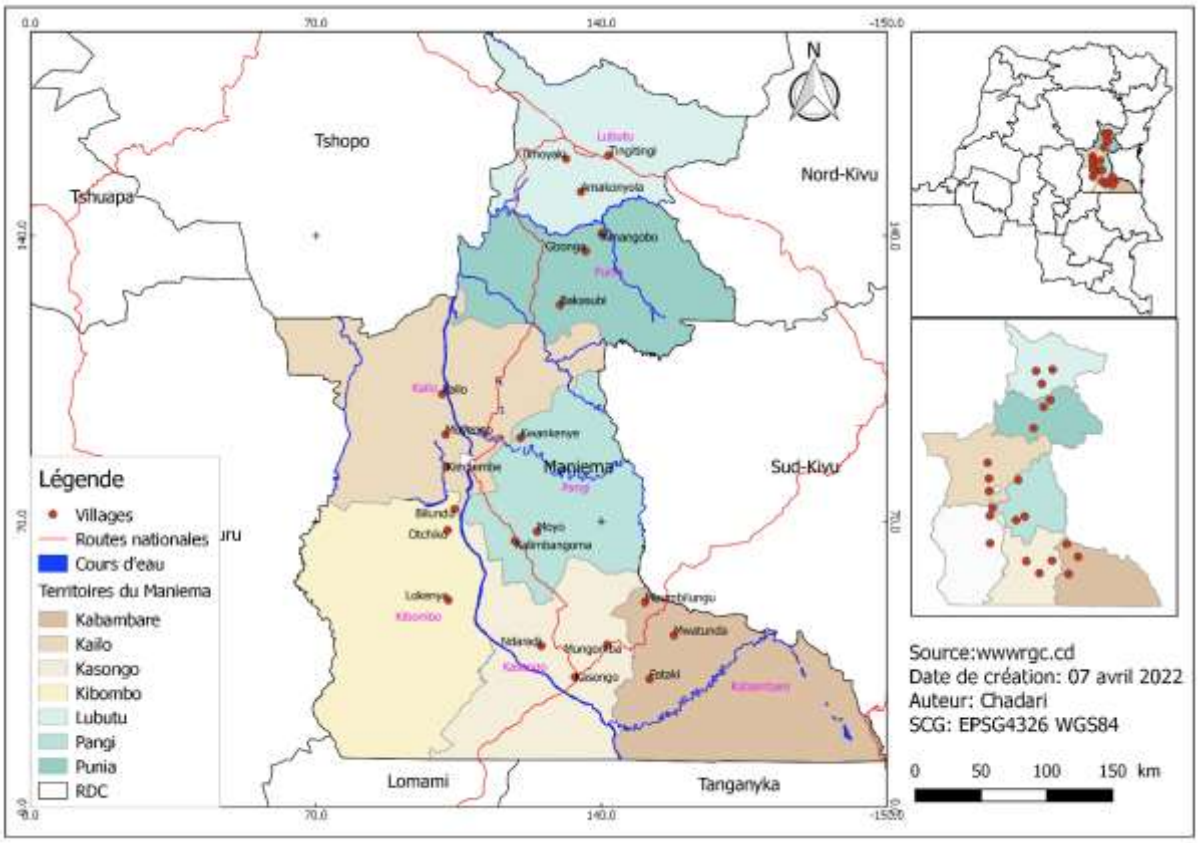


**Figure 1: Administrative map of the study area (Province of Maniema)**

The investigations were carried out in 21 villages for the whole of the Province of Maniema, located in the south-eastern region of the Congolese central basin, during the period from April 2021 until February 25, 2022.

**Location of the Study Area**

The study was conducted in the Province of Maniema, located in the Center-East of the country (D.R. Congo) and extends between 0° and 5° latitude South and 24° 55' and 28 ° 8' East longitude. This Province is bounded to the East by the Provinces of North Kivu and South Kivu, to the North by the Province of Tshopo, to the West by the Province of Sankuru and to the South by the Provinces of Lomami and Tanganyika. Its total area is 132,520 $km^2$ or 5.6% of the total area of the country (Makondambuta, 1997).

**Climate**

The province of Maniema enjoys a hot and humid tropical climate of the AW type according to the Koppen and Martonne classification. The latter evolves towards the equatorial type (AW1) in the North and towards the Sudanese type (AW4) in the South. In these two trends, the length of the dry season is 2-3 months and 3-4 months respectively. It includes two major seasons; the dry season and the rainy season. The average annual temperature is 27°C and the annual precipitation amounts to 1650mm of water (Makondambuta, 1997 Op.cit.).

**The Ground**

As the ground is an extremely complex structure, it sometimes varies quite considerably in the same area. The soils vary from the sandy type (Kibombo) to the compact clay type (Pangi and Kasongo). Depending on the source rock, the soil has three origins:

- Sedimentary with soft, coarse and red sandstone, clay and shales;
- Metamorphic with silicified limestone, quartozitz, gneiss and metamorphic rock;
- Eruptive with eruptive granitic rock (PAPRBIO, 1999). Indeed, the Yangambi-type ferralsol is identified north of Lubutu (Makondambuta, 1997; Ctcpm, 2002).

**Vegetation**

In the Province of Maniema, the equatorial forest describes an are starting from Kindu, passing through Shabunda and Walikale to join the equatorial forest of southern Beni. Starting from the South of Maniema at the South Level of UVIRA to the limit with the Province of Tanganyika, there are mosaics of wooded savannahs and gallery forests reflecting the degradation of the forest by the action of man. The fauna is rich and varied. Two major plant formations cover Maniema: the dense humid forest and the savannah. The dense forest covers the territories of Lubutu, Punia, and Pangi and part of Kailo and Kibombo. This forest is rich in valuable forest species. The gallery forests cover the territories of Kasongo, Kibombo as well as part of the territory of Kabambare where the gallery forest is called Nywema, hence the origin of the name Maniema (Makondambuta, 1997).

**Figure 2: Kailo dense rainforest**

**Figure 3: Kabambare forest galleries**

**Savanna**

The south of Maniema is mainly occupied by shrubby savannah. Within it, some grassy savannahs are present in the South-West, while in the South-East, we find different types of vegetation: shrubby savannah, some small open forests, a small wooded savannah, some wooded savannahs and smaller agricultural areas. These two characteristic ecosystems of dense forest and savannah are relatively well delimited and are explained by the distinct climates experienced by the north and south of the province. Climatic conditions vary from north to south as one moves away from the equator (Makondambuta, 1997).

**Hydrography**

The Congo River crosses the province from South to North. It is navigable from Kindu to Ubundu (Tshopo Province). It is watered by several tributaries, the most important of which are: Lulindi, Musukuyi, Mulongoy, Ulindi, Kasuku, Kunda, Lufubu, Lowa, Lweki and Elila, etc. (Makondambuta, 1997).

**Economy**

The economy of the Province of Maniema is essentially based on agricultural production, which employs the majority of the population. It is largely subsistence agriculture characterized by a low degree of mechanization. Rice, groundnuts, cassava, maize and bananas are grown there as the main food crops (Makondambuta, 1997).


**Figure 4 and 5: Cropping systems in the different study areas in Maniema Province**

As for the industrial crops inherited from colonization and which mainly concerned cotton, coffee and palm oil, they have been at a standstill for several years. Only a few rice mills still remain, the husking of which is now carried out in an artisanal manner, due to the lack of processing factories that have been gradually abandoned by their owners. Traditional livestock farming is practiced there as everywhere, mainly focusing on small livestock and poultry but which is barely enough to meet the needs of the population. Artisanal fishing takes place in the Lualaba River, its tributaries and on Lake Ndjale in the territory of Kibombo (Mrac, 2011).

## Materials

The biological materials used in this study are the different cultivars of banana trees and plantains (Musa spp.) inspected in the fields and gardens of the farmers' huts. Table 1 presents the different banana and plantain cultivars, their genotypes and their vernacular names in the study area.

**Table 1: The different banana and plantain cultivars inspected in the study area in the Province of Maniema**

| N° | Vernacular names | Genotypes |
|---|---|---|
| **01** | Mbijaonde ou Mukokoonde | AAB |
| **02** | Mbudi ou Mbuzi | AAB |
| **03** | Muyaudi ou Bisamunyi | AAA |
| **04** | Kibubu ou Kebobo | AAB |
| **05** | Bonjilo ou Bunzilo | AAB |
| **06** | Ibota | AAA |
| **07** | Bambote | AAA |
| **08** | Kamera | AAA |
| **09** | Atili | AAB |
| **10** | Amamundu | AAB |

**Legend:** A: Acuminata; B: Balbussiana

The technical materials used consisted of a survey sheet made up of questions (Bioversity-CIALCA, Ngama 2010), a magnifying glass to visualize aphids, a notebook, a pen, and an AG100 motorbike.

## Methods

### *Cultivation conditions and knowledge of the disease*

To collect information, in relation to the cultivation conditions of banana fields (source of planting materials, age of the banana plantation and the cultivation system) and knowledge of BBTD by farmers (identification of symptoms by farmers, probable origin of BBTD in the study area, dispersion of BBTD in the region and knowledge of the mode of transmission of BBTD) in the banana production areas of Maniema, we surveyed farmers practicing banana cultivation in these different study areas.

### *Disease parameters*

Observations relating to disease parameters (incidence, severity, presence and importance of *P. nigronervosa*) were made on the different banana and plantain cultivars in cultivation in farmers' fields and home gardens.

### *Assessment of the incidence of the disease (BBTD)*

To assess the incidence of the disease, we used the Bioversity-CIALCA questionnaire (in the appendix) to obtain information on the incidence and severity of the disease. The incidence of BBTD was evaluated from symptoms of BBTD disease on at least one plant of the clump inspected per field or home gardens. A total of 30 clumps of banana trees were analyzed per field or garden of huts. Mean BBTD incidence levels were calculated as the proportion of infected plants out of a total number of clumps surveyed. It was obtained from the following mathematical relationship:

Incidence (%) = (Number of infected clumps)/(Total number of clumps) ×100

### *Assessment of disease severity (BBTD)*

Typical symptoms of banana bunchy top disease are very specific, clearly identifiable from those caused by other banana viruses. Different levels of disease severity on infected clumps were determined from visual observations of different aspects (leaf deformations) and leaf colorations. This assessment was made using a standard rating scale ranging from 0 to 5, with higher ratings indicating increasing disease severity. The rating scale (Cialca, 2008; Ngama et al., 2014; Ngama, 2015) used to assess the severity of banana bunchy top disease is as follows:

- Level 0: without symptoms,
- Level 1: streaks on the leaves,
- Level 2: dark streaks up to the pseudo-trunk,
- Level 3: discoloration of the leaves with normal size,
- Level 4: reduced size of discolored leaves,
- Level 5: bushy appearance at the top “Bunchy top”.

### *Evaluation of the presence of the vector Pentalonia nigronervosa*

The black banana aphid *P. nigronervosa* is located between the old leaf sheath and the young leaf sheath. It can even be located on the leaves, cigar and fruit. To observe the presence of aphids, the banana trees of each clump were inspected using a magnifying glass. The observation consisted in unsheathing the false trunk of the banana tree to visualize this aphid. The presence of the aphid *P. nigronervosa* was evaluated from the ratio between the total number of clumps carrying aphids out of all the clumps observed and expressed as a percentage.

### *Evaluation of the importance of the Pentalonia nigronervosa vector*

As the different colonies of *P. nigronervosa* are generally located between the sheath of the most recent leaf and the old leaf sheath, we observed the different colonies of this aphid

on the different banana plant organs. The different forms of aphid (larvae, nymphs, alates or adults) forming the different colonies were observed on the cigar, the unfolded leaves and the leaf sheaths of banana. Vector importance on selected clumps was assessed using the BBTD scale ranging from 0 to 5 with higher scores indicating increased *P. nigronervosa* aphid populations. The rating scale for *P. nigronervosa* aphids is as follows (Cialca, 2008 and Ngama et al., 2014).

- Level 0: no vector on the tuft,
- Level 1: a simple colony without winged insects,
- Level 2: several simple colonies,
- Level 3: a large colony with winged insects,
- Level 4: several large colonies,
- Level 5: generalized colonies on leaves and pseudostem.

***Sampling***

A total of 7 territories were surveyed due to 3 villages per territory. Indeed, 1890 clumps of bananas and plantains were inspected in 63 fields at the rate of 30 clumps per field, 3 fields per village in the whole Province of Maniema. As for the sampling, we used the diagonal method where we established the diagonals in each field to select the clumps of banana trees that could constitute our representative samples on which our observations focused. Villages were selected based on the existence and abundance of banana plantations in the study area. Farmers were also in turn selected based on the size of their banana plantations. For the interview, the head of household alone or accompanied by members of his family answered questions (interview) related to the growing conditions of his banana plantation and on knowledge of banana bushy top disease (BBTD). Figure 6 presents the interview and observation of BBTD disease parameters with farmers.

**Figure 6: Interview with farmers**

***Data analysis***

The data obtained were analyzed by multivariate methods. The factorial method allowed us to make the spatial distribution of the cultivars, while the cluster method was used to classify the cultivars into groups according to their susceptibility to banana bushy top disease using the software STATGRAPHICS_Centurion_XVI version 16.20.04 (32bit).

## RESULTS AND DISCUSSION

### Knowledge about BBTD by the Farmer

***Identification of BBTD symptoms by farmers***

The values relating to the identification of BBTD symptoms by farmers in the study area are presented in Figure 7.

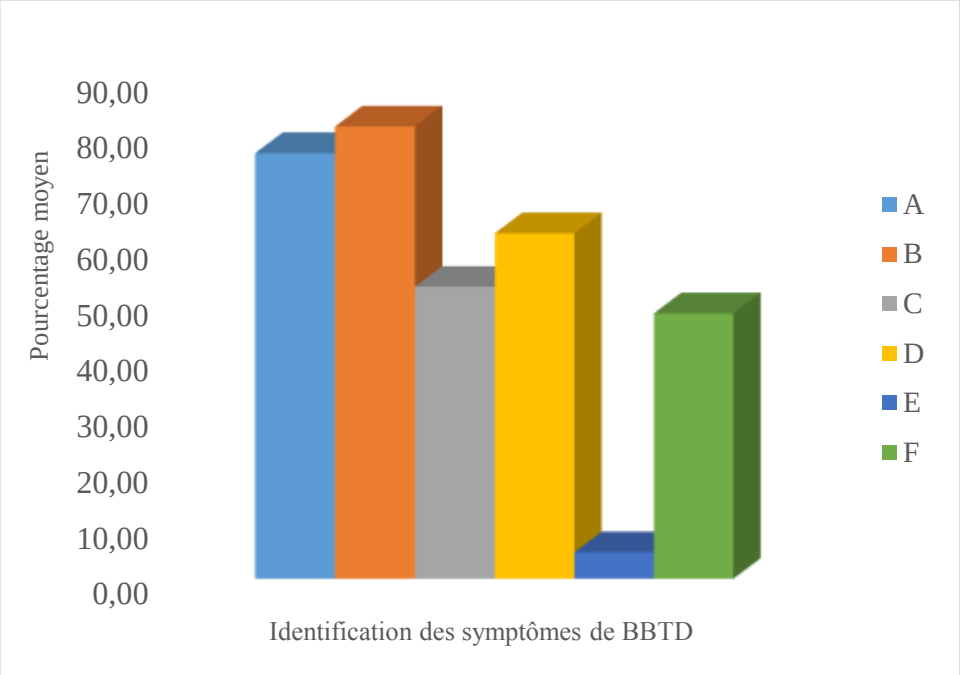


**Figure 7: Identification of BBTD symptoms by farmers in the study area**

**Legend:** A: Knowledge of BBTD; B: Observation of symptoms on the leaves; C: Observation of symptoms on the pseudostem; D: Bushy appearance of infected plants; E: Non-functional rooting system; F: Other details.

Analysis of the results in Figure 7 indicates that 76.19% of the farmers in the study area are aware of banana bushy top disease, on the other hand 80.95% identify the disease by observing the symptoms on the leaves; followed by 61.90% who identify the symptoms by the bushy appearance at the top; of 52.38% who identify the disease by the symptoms at the pseudostem. While, 47.62% suggest the identification otherwise, compared to 4.76% who identify the disease from the non-functional rooting system. The typical symptom of banana Bunchy Top disease is very specific, clearly identifiable from those caused by other banana viruses (Ngama et al., 2014; Magee, 1927; Kavino et al., 2007). Despite this clarity in disease expression, symptoms in farmers' fields are not well enough defined by farmers for visual diagnosis. This complicates the management of this disease (BBTD) in the field, increasing the risk of spreading the pathogen (BBTV) (Ngama, 2015; Allen, 1927).

***Probable origin of the disease (BBTD) in the study area***

The values relating to the probable origin of BBTD in the study area are presented in Figure 8.

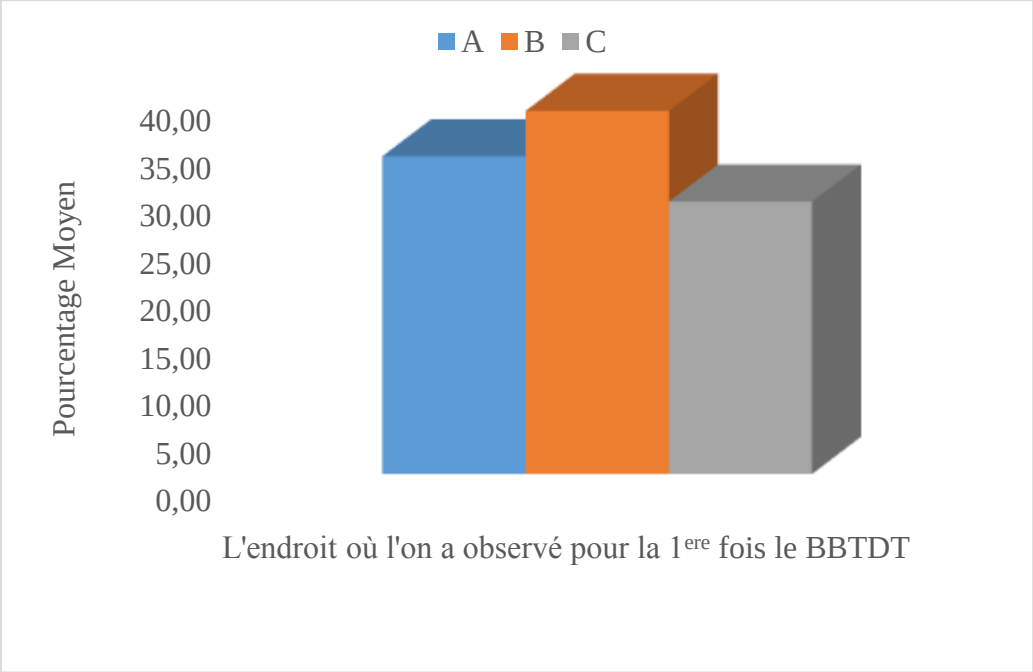


**Figure 8: Probable origin of the disease in the study area**

**Legend:** A: In his own plantation; B: At the neighbors (less than 10 km); C: Not known by the farmer.

It emerges from the analysis of Figure 8 that in the study area, the probable origin of BBTD is not clearly known precisely by the farmers (28.57%). On the other hand, a good average of farmers attribute it to neighbors less than 10 km from their villages (38.10%) against only 33.33% who attribute it to their own fields. BBTD disease was first recorded in mainland Africa, specifically in Egypt around 1901 (Fahmy, 1927), where economic damage occurred in 1953 (Dale, 1927). In Central Africa, in the region of Kisangani (D.R. Congo), it was observed in the 1950s (Ngama, 2014; Wardlaw, 1961). On the other hand, in DR Congo, this disease is already reported, especially in the Provinces of Bas Congo, South and North Kivu as well as in the dismembered former Eastern Province and its surroundings (Province of Maniema) (Ngama et al., 2014; Ngama, 2015; FAO, 2010). The late entry into Africa around 1958, more precisely in Yangambi, in the Province of Tshopo would be introduced by contaminated rejects offered as gifts to King Albert I. Therefore, it is quite possible that the same planting materials that circulate between farmers in the area and its surroundings are the basis of the spread of the disease (BBTD), since contamination over long distances is due to the movement of materials by humans and at short distances by the aphid *Pentalonia nigronervosa*.

***Dispersion of BBTD in the study area***

The values relating to the dispersion of BBTD in the region (duration of production of the strain after observation of symptoms) are presented in Figure 9.

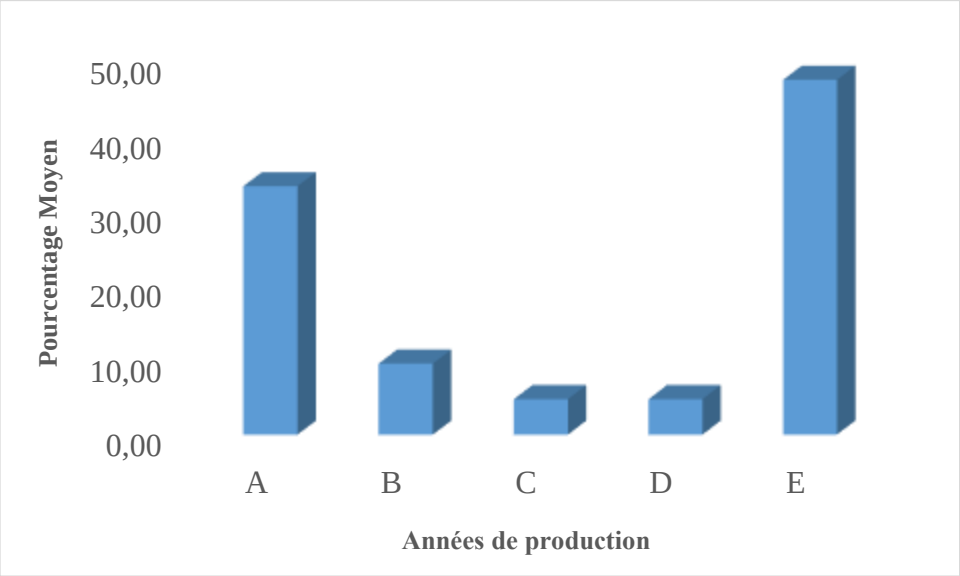


**Figure 9: Duration of production of the strain after observation of the symptoms**
**Legend:** A: 2 years of production; B: 3 years of production; C: 5 years of production; D: More than 5 years; E: Less than one year.

The results in Figure 9 indicate that, in the study area, 47.62% of banana trees infected with BBTD remain productive for less than a year; 33.33% of banana trees remain productive for up to 2 years, 9.52% go up to 3 years and 4.76% of banana trees can still produce for up to 5 years and more. These results are confirmed by Faure G., et al., (2018) who states that the disease essentially affects growth and renders affected subjects unproductive during their vegetation. Since suckers from banana clumps are almost always infected, Magee (1927) thinks that the disease is supposed to be systemic. However, Caruana (2003) reports that BBTD is transmitted through all vegetative forms of the material used for planting including suckers and plants from in vitro cultures. However, studies by Lokana et al., (2016) on the systemicity of BBTD in Kisangani established that when one strain is infected, all suckers and mother plants will be infected even if the infection is not initially present in all parts of the stump. In addition, suckers from virus-infected strains are inevitably carriers of the BBTV virus and thus the spread of the disease is generally due to the use of contaminated plant material, points out the same author. And yet, in the different banana production regions, humans apparently play an important role as a dispersal agent for the *Pentalonia nigronervosa* vector and indirectly for the BBTV virus, reports Thomas et al. (2003).

***Knowledge of the mode of transmission of BBTD by the farmer***

The values relating to the knowledge of the mode of transmission of BBTD by the farmers in the study area are presented in Figure 10.

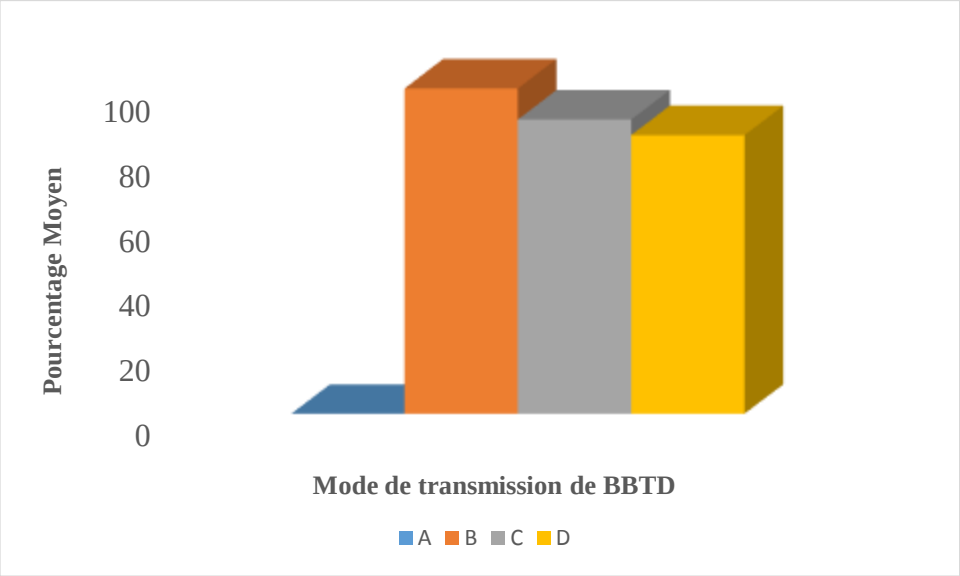


**Figure 10: Knowledge of the mode of transmission of BBTD by the Maniema farmer**
**Legend:** A: Transmission by the soil; B: Transmission by rejects; C: Transmission by a vector; D: Transmission by tools (hoes, machetes, etc.).

Reading the results in Figure 10 reveals that 100% of the farmers in this area confirm transmission of the disease by suckers; on the other hand 90.48% say that BBTD is transmitted by a vector; 85.71% believe that the disease is carried by work tools (hoes, machetes, etc.) and so a probable transmission of BBTD by the soil is not recognized by farmers. BBTD is caused by the BBTV virus which is mainly transmitted by infected planting material and, secondly, by an aphid vector *P. nigronervosa*. The movement of infected planting material is the main mechanism for the spread of the disease over long distances through the different banana production areas, according to Thomas and Caruana (2000) and Ngama et al. (2014). However, the results of Ngama's study (2015) on the epidemiology of BBTD in the field and fallow without aphids, indicate that the spread of the disease over long distances is made by humans who use suckers from infected plantations. The virus is spread from one plant to another by infected aphids and from one plantation to another by people transporting infected materials, infected aphids on clothes and even the transport of infected aphids by ants reports the same author. However, the BBTV virus is not transmitted mechanically.

**Banana Bushy Top Disease (BBTD) Parameters**

***Incidence of BBTD in the study area***

The results of the observations of the incidence of BBTD obtained on at least one plant of the clump of banana trees are illustrated in Figure 11.

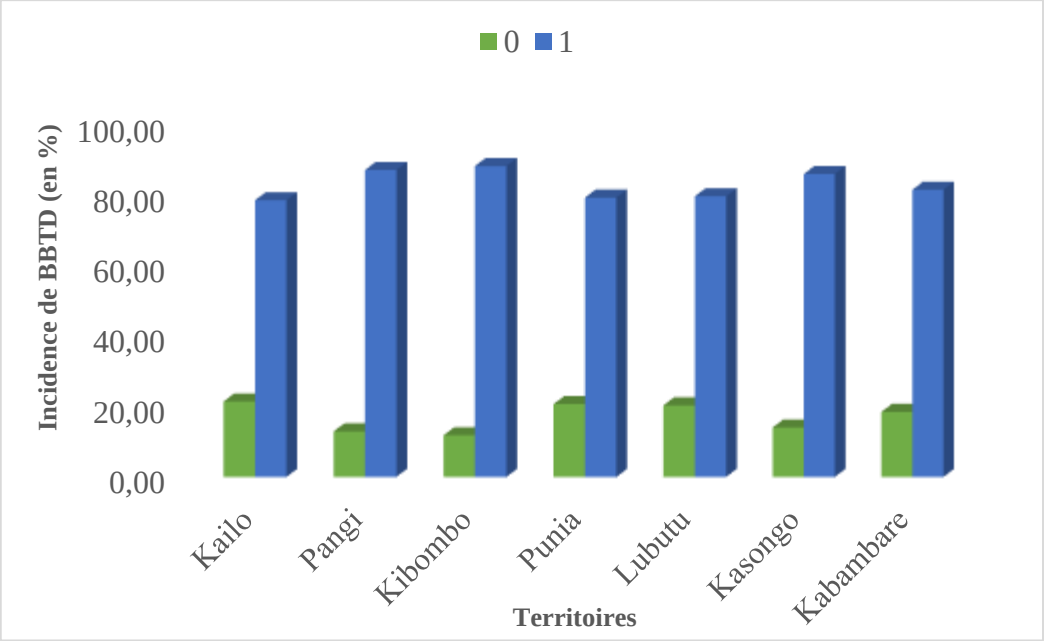


**Figure 11: Incidence of BBTD on at least one banana clump plant**
**Legend:** 0: Absence; 1: Presence.

Figure 11 shows that the incidence of BBTD varied from 78.52% to 88.15% in the banana production areas of Maniema. On average 82.85% of the tufts investigated carried the symptoms of BBTD. However, the highest rate is recorded in the territory of Kibombo (88.15%) followed by Pangi (87.05%), Kasongo (85.93%), Kabambare (81.48%), Lubutu (79. 63%), Punia (79.26%) and Kailo (78.52%). Numerically, these values are high in the different banana production areas of Maniema and remain comparable to those found by Ngama (2014) in the North-East region of the Congo Basin where the incidence of BBTD ranging from 70.2% to 96 5% was observed in the different localities surveyed. Similarly, these values are in fact much higher than those found in home gardens and in plantations (5 to 30%) by Magee (1927) during his first survey of BBTD disease. The relatively low values observed in the territory of Kailo, Punia, Lubutu and Kabambare could also be justified by high altitude values since this disease is typical of low and medium altitude conditions (FAO, 2010). This is also demonstrated by Thomas and Dietzgen (1991) who state that the incidence of BBTD fluctuates with altitude. The different high levels of altitude can therefore be an element that can partly explain the lower incidence of the disease in certain territories of the Province of Maniema. However, this parameter is not the only one to have an influence on the development of BBTD disease underlines Caruana (2007). In addition, these results also showed that the BBTD disease is widely spread throughout the banana production area of Maniema and varied according to territory. Based on these observations as documented in the 1950s for the D.R. Congo (Wardlaw, 1961; Ngama et al., 2014), it is quite possible that the critical factors for the first spread of BBTD in news regions were farmers' traditional practices, preferences for certain types of banana cultivars, demand for planting material and direction of movement of this material from disease-affected areas (BBTD).

***Severity of the disease (BBTD) in the study area***

Values relating to the severity of bushy top disease (BBTD) in the different territories of Maniema are presented in Figure 12.

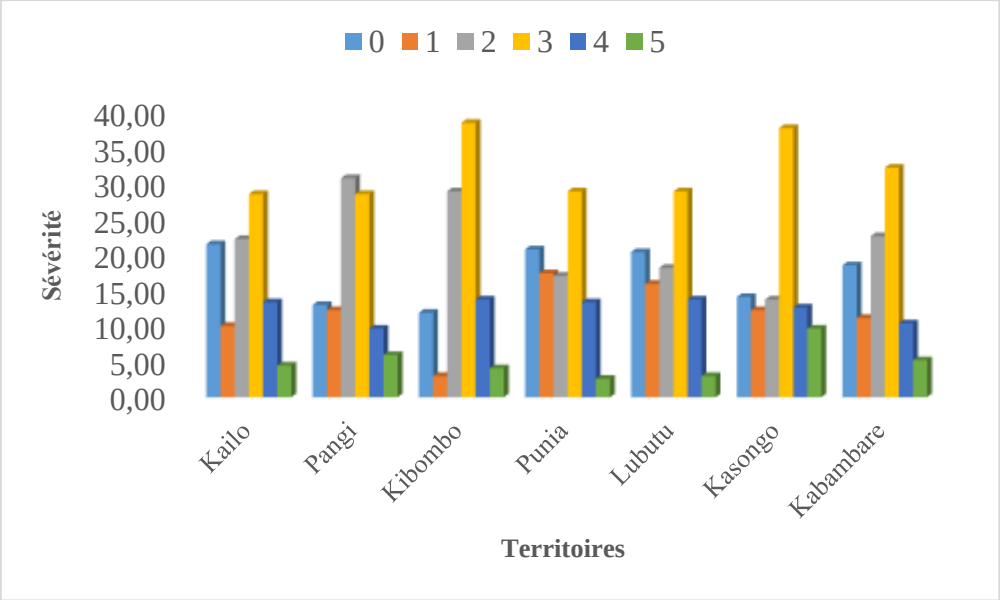


**Figure 12: Severity of BBTD on banana cultivars by territory**

**Legend:** 0: without symptoms; 1: streaks on the leaves; 2: dark streaks up to the pseudo-stem; 3: discoloration of the leaves with normal size; 4: size reduced with discolored leaves; 5: bushy appearance at the top "Bunchy top."

Analysis of the results presented in Figure 6 in relation to the severity of BBTD starting from the rating scale ranging from 0 to 5 indicates that the different levels of BBTD symptoms are present on the majority of banana trees in this zone of banana production. However, discoloration of leaves with normal size (level 3) is frequent and higher on all bananas and plantains in the different territories. On average, 31.90% of the banana trees bore discolored leaves with normal size (level 3). The dark streaks up to the pseudostem (level 2) are also relatively high with an average of 21.90% compared to levels 1, 4 and 5 respectively stripes on the leaves, reduced size of discolored leaves and bushy appearance at the top which remain lower. In general, symptoms were apparent on clumps of banana trees observed in the study area. At least the plants showing the typical symptoms of the disease (reduced size of the discolored leaves and a bushy appearance at the top) were observed across the different territories of Maniema. However, for the whole Province, it is in the territory of Punia and Lubutu that we find the fewest banana trees having reached levels 4 and 5 of the said disease. These values obtained on the severity of BBTD disease in this study area are generally lower but remain comparable to those found by Ngama et al. (2014) in his study on the distribution of BBTD in the Congo Basin, in the North-East region, where on average 37% of the banana tufts surveyed showed streaks on the leaves (stage 1), followed by discolored leaves with normal size (20.5%) and streaks up to the pseudostem (19.7%). The reduced size of discolored leaves (stage 4) and the bushy appearance at the top (stage 5) being weakly represented. The different altitude levels (400 to 800m) and the environmental conditions (temperature, rainfall, etc.) can also partly explain the lesser severity of BBTD in the banana production areas of Maniema. Indeed, there is a great variation in the symptoms of BBTD in the different banana and plantain cultivars, this can also be attributable to genetic differences in bananas underlines Magee (1953). The same author suggests that, banana plants in their initial stages of recovery, show the symptoms of streaking (level 1) on only a few leaves and always in a large part of the reduced leaf form (levels 4 and 5). The area of first symptom development on the leaf is variable. In some cases, the first symptoms are mild and consist only of slight marginal chlorosis. According to Magee (1948), there is no single symptom, or group of symptoms, on which a definitive diagnosis could be based.

***Presence of the Pentalonia nigronervosa vector on banana clumps***

The presence of the *P. nigronervosa* vector on each banana clump in the study area is shown in Figure 13.

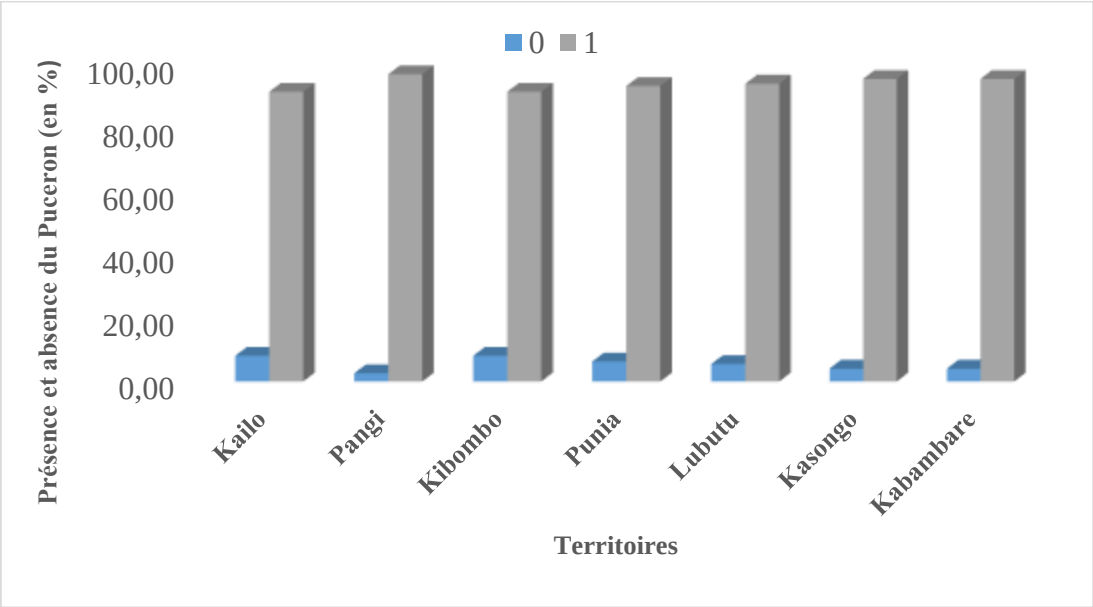


**Figure 13: Presence or absence of the vector on each clump of banana trees surveyed**
**Legend:** 0: Absence; 1: Presence.

In view of the values shown above, it appears that the vector *P. nigronervosa* is widespread in the different territories of Maniema; which corresponds to fairly high values, testifying to the presence of aphids with an average of 94.44%. These values fluctuated differently in the Province of Maniema in the range of 91.85% to 97.41% with the highest rate in the territory of Pangi (97.41%). These values obtained in the medium and high altitude conditions of the banana production zone of Maniema on the presence of the vector *P. nigronervosa* are generally very high and remain comparable to those found by Ngama et al. (2014) in the regions of low and middle altitudes of the Congo Basin. The high rate of *P. nigronervosa* aphid could certainly be due to the presence of certain host plants of this aphid, the altitude and the importance of the plantation of banana trees which can give rise to a high rate of this vector. However, this aphid, probably native to Southeast Asia, is present in most regions of the world where banana cultivation is practiced. Indeed, this crop is the main host for this aphid which is pantropical today, since it is practically present in all the tropics (Mau et al., 1994; Waterhouse, 1987).

***Importance of the vector Pentalonia nigronervosa on the clumps of banana trees (in %)***

Figure 14 indicates the importance of the vector *Pentalonia nigronervosa* on the clumps of banana trees chosen according to the BBTD scale (0-5).

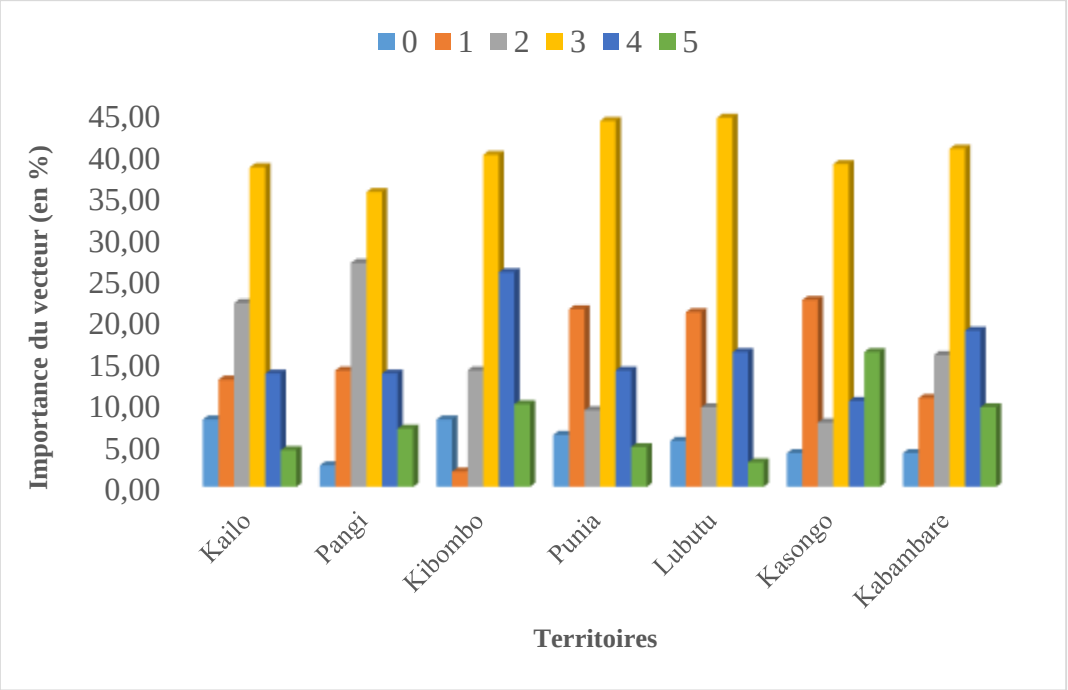


**Figure 14: Importance of the vector on the clumps chosen according to the BBTD rating scale (0-5)**

**Legend:** 0: No vector on the clump; 1: A single colony without winged insects; 2: Several single colonies; 3: One large colony with winged insects; 4: Several large colonies; 5: Widespread colonies on leaves and pseudostem.

Figure 14 indicates that all colonies of *P. nigronervosa* are present on banana clumps across the study area. However, a large colony with winged insects is the most common form at high rates in the study environment where the highest rate is found in the territory of Lubutu (44.44%) followed by Punia (44. 07%), Kabambare (40.74%), Kibombo (40.0%), Kasongo (38.89%), Kailo (38.52%) and Pangi (35.56%). On average 40.31% represents a large colony with winged insects in the entire study area. These values obtained in this medium and high altitude area of Maniema, however, are comparable to those found by Niyongere in the Great Lakes areas (Burundi, Rwanda and D.R. Congo) where wingless aphids in single colonies were more frequently observed ( 36%); while winged individuals were observed on an average of 9% of banana clumps surveyed. However, these values are less comparable to those of Ngama et al. (2014) where on average, a single colony of *P. nigronervosa* was the most represented form (37.8%), followed by several single colonies without winged insects (28.8%) and a large colony with winged insects (12.7%). The relatively lower rate of some colonies could be attributed to lower temperatures and higher altitudes. On the other hand, the lack of maintenance of the banana crop by farmers and the dense plant cover could also favor the increase in the population of the vector *P. nigronervosa* in the other territories of the Province of Maniema.

Analysis of different epidemiological parameters according to banana and plantain cultivars in the study area. Correlation between factors (cultivars and fields) and variables (incidence, severity of BBTD, presence and importance of vector) The results of the correlation between factors (cultivars and fields) and variables (incidence, severity of BBTD, presence and importance of the vector) in the study area are listed in Table 2.

**Table 2: Contribution of factors (cultivars and fields) to the observed variability and their correlation with the variables (incidence, severity of BBTD, vector presence and importance) assessed**

| Territories / Factors | Kailo | | Pangi | | Kibombo | | Punia | | Lubutu | | Kasongo | | Kabambare | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FI | FII | FI | FII | FI | FII | FI | FII | FI | FII | FI | FII | FI | FII |
| Eigenvalues | 2,32 | 1,05 | 1,93 | 1,09 | 2,36 | 1,11 | 2,31 | 0,94 | 2,30 | 0,95 | 2,26 | 0,85 | 2,63 | 0,73 |
| Relative variance | 58,05 | 58,05 | 48,31 | 48,31 | 59,00 | 59,00 | 57,76 | 57,76 | 57,45 | 57,45 | 56,39 | 56,39 | 65,77 | 65,77 |
| Cumulative variance | 26,19 | 84,24* | 27,49 | 75,80* | 27,63 | 86,63* | 23,57 | 81,33* | 23,73 | 81,18* | 21,31 | 77,70* | 18,31 | 84,08* |
| Impact | 0,82 | -0,46 | 0,79 | -0,44 | 0,77 | -0,53 | 0,82 | -0,46 | 0,83 | -0,42 | 0,83 | -0,43 | 0,85 | -0,19 |
| Severity | 0,80 | -0,50 | 0,81 | -0,39 | 0,79 | -0,50 | 0,82 | -0,42 | 0,81 | -0,45 | 0,82 | -0,35 | 0,88 | -0,37 |
| Presence or absence of the vector | 0,72 | 0,52 | 0,58 | 0,57 | 0,72 | 0,59 | 0,74 | 0,43 | 0,73 | 0,43 | 0,71 | 0,33 | 0,65 | 0,75 |
| Importance of vector | 0,70 | 0,56 | 0,54 | 0,63 | 0,79 | 0,47 | 0,66 | 0,61 | 0,64 | 0,62 | 0,62 | 0,66 | 0,85 | -0,00 |

**Legend:** FI: factor 1 FII: factor 2 *: Combination of two factors (cultivars and fields).

Table 2 shows that the banana cultivars and the different banana plantations were extracted with an average variance of 81.56% where, in a positive way, the banana cultivars had a 57.53% influence on the incidence, the severity of bushy top disease, the presence and importance of the vector (*Pentalonia nigronervosa*). These values are illustrated by graphs 25, 26, 27, 28, 29, 30 and 31 at the bottom. The genus Musa has more than 1000 varieties of bananas among which the most important cultivars are dessert type bananas (mostly AAA) and cooking bananas (AAA, AAB and AAB) (Dhed'a, 2011). According to the same author, AA varieties are mostly found in the East. The triploid varieties AAA (dessert and cooking banana), AAB (plantain and cooking banana) and AAB (cooking banana) are widely distributed throughout the world, particularly in Latin and Central America, the Caribbean, South and Central Asia. Southeast and Africa adds Dhed'a (2009). Furthermore, Karamura et al. (2004) report that there is a wide range of banana varieties in Central Africa, some of which are specifically adapted to these different agro-ecological regions and cultivated for different uses. In the eastern highlands, AAA cooking bananas and beer bananas dominate the landscape and the area is considered a center of secondary banana diversity. Other types such as plantains (AAB), dessert varieties (Gros Michel and Cavendish AAA), Kahinja and Kivuvu (AAB) and AB diploids are also widely distributed. In addition to local varieties, new cultivars developed by international banana improvement programs have been introduced in the various banana production areas and several of them have already been distributed to farmers. Lately, market trends in production areas have led farmers to select and grow only varieties that immediately meet consumer needs. Moreover, demographic pressure did not allow observance of fallow periods or restoration of soil fertility. These two phenomena, coupled with the selective effects of diseases and pests, have led to increased genetic erosion of Musa diversity in producing regions (Ngama, 2015).

## CONCLUSION AND RECOMMENDATIONS

This research on the spatial distribution of banana bushy top disease in the different banana production areas of Maniema has set itself the main objective of highlighting the spatial distribution of the biological constraints of banana cultivation linked to BBTD in the different banana production zones in the Province of Maniema, in order to envisage the control of this virus which would contribute to the decline in banana production and the disappearance of banana genetic resources in the Province of Maniema and its surroundings.

Starting from study questions, we used a total of 1890 clumps of banana trees and plantains analyzed in 63 fields, at the rate of 3 fields per village and 3 villages per territory throughout the Province. Cultivation conditions (source of planting materials, age of the banana plantation and cultivation system) as well as knowledge of BBTD (identification of symptoms by farmers, probable origin of BBTD in the study area, dispersion of BBTD in the region and knowledge of the mode of transmission of BBTD by the farmer) were analyzed. From this study, the results obtained showed that: banana bushy top disease is widely spread throughout the banana production area of Maniema Province; the cultivation conditions vary relatively according to the territories of this Province where 100% of banana trees are cultivated in association with rice, cassava, corn or other crops; 95.24% of farmers use suckers from neighboring fields. On average, 42.86% of banana plantations are over 10 years old, 38.10% of banana plantations are 5-7 years old and 8.33 banana plantations are less than 3 years old. The incidence of the disease was very high in all territories and varied from 78.52% in Kailo territory to 88.15% in Kibombo territory with an average of 82.85% incidence over the whole the extent of the Province of Maniema. As for the severity of BBTD starting from the rating scale (0 to 5), the different levels of symptoms are present on the majority of banana trees in the territories of Maniema. The discoloration of leaves with normal size (level 3) is more remarkable and higher with an average of 31.90% on banana trees. The presence of the vector on the clumps of banana trees was on average 94.44% and with an average importance of 40.31% of large colonies with winged insects throughout the study area. Banana cultivars and banana fields contribute significantly to the variation of BBTD disease in this study area, with an average of 81.56% where banana cultivars have an average influence of 57.53% on the incidence, the severity of BBTD, the presence and importance of the *Pentalonia nigronervosa* vector. From the multivariate factorial analyses, it was classified in each territory of Maniema, the different groups of banana cultivars susceptible and less susceptible to the BBTD disease where, the groups made up of the less susceptible cultivars are characterized by the absence of symptoms. (Incidence and severity nil) but, generally with the presence and importance of the vector (*Pentalonia nigronervosa*) of level 2 and 3 of the aphid rating scale in all the territories of Maniema. The majority of bananas and plantains in the different territories are affected by BBTD, while some of them are asymptomatic or less susceptible. In general, the less sensitive banana trees are of the AAB genotype (plantains) with 74.22% on average, against 25.76% of the AAA type (bananas) for the whole of this Province. From all of these results, it appears that BBTD is widespread in the banana production area of Maniema but still with low severity in most of the territories surveyed. This indicates that a good sensitization of the farmers in terms of the management of banana clump top disease, the eradication of clumps of banana trees infected with BBTV, the use of healthy planting materials, the adoption of good cultural practices aimed at controlling the *Pentalonia nigronervosa* aphid population are determining factors for the sustainable management of this disease. In addition, quarantining planting materials from infected areas to areas not yet affected can help prevent the spread of BBTD to other areas not yet affected.

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