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DOCTORATE THESIS

THEME :

CASSAVA BACTERIAL BLIGHT DEVELOPMENT IN THE AGRO-ECOLOGICAL ZONES OF COTE D'IVOIRE

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A THESIS

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DEDICATION

TO ALL WHO BELIEVED IN ME.

ACKNOWLEDGMENT

LIST OF ACRONYMS AND ABBREVRIATIONS

AEZ: Agro-ecological zones

AFLP: Amplified Fragment length Polymorphism

ANOVA: Analysis Of Variance

AUDPC: Area under the disease progress curve

APA: Agence Presse Africaine

Bp : Base pairs

°C: Celsius degree

CBB: Cassava bacterial blight

Cm: Centimeter

CFU: Colony Forming Unit

CIAT: Centre International d'Agriculture Tropicale

CMA/AOC: Conférence des Ministres de l'Agriculture de l'Afrique de l'Ouest et du Centre

CO_2: Carbone dioxide

DNA: Desoxyribonucleic acid

DPSA/MINADRI/DR: Direction de la Production et de la Sécurité Alimentaire du Ministère Ivoirien de l'Agriculture et du Développement Rural

EDSCI-II: Enquête Démographique et de Santé, Caractéristiques du pays et méthodologie de l'enquête

FAO: Food and Agricultural Organisation of the United Nations

FCFA : Franc des Communautés Financières d'Afrique

GHGs: Greenhouse gases

GDP: Gross domestic product

GPS: Global Positioning System

G: Gram

H: Hours

IITA: Institut International d'Agriculture Tropicale

IPCC: Intergovernmental Panel on Climate Change

IRAD : Institut de Recherche Agricole pour le Développement

IRD : Institut de la Recherche et de Développement

Kb: Kilobase

kg: Kilogram

Km: Kilometer

Min: Minute

MAAF: Ministère de l'Agriculture, l'Agroalimentaire et de la Forêt Agricultural

MADR: Ministère de l'agriculture et du développement rural

MHz: Mega Hertz

M: Meter

CH4: Methane

µl: Microlitre

Ml: Milliliter

Mm: Millimeter

Minagri: Ministère de l'Agriculture, Annuaire des Statistiques Agricoles

MLVA: MultiLocus VNTR Analysis

N_2O: Nitrous oxide

PACIR: Programme d'Appui au Commerce et à l'Intégration Régionale

PCR: Polymerase Chain Reaction

%: Percentage

pH: Potential oh Hydrogen

RAPD: Random Amplification of Polymorphism

RFLP: Restriction Fragment Length Polymorphism

S: Seconds

Sodexam: Société d'exploitation de développement aéroportuaire aéronautique météo

UNESCO: United Nations Educational, Scientific and Cultural Organization

UNFCCC: United Nations Framework Convention on Climate Change

UV: Ultraviolet

V: Volts

VNTR: Variable number of tandem repeat

W: Watts

WMO: World Meteorological Organization

Xpm: *Xanthomonas phaseoli* pv. *manihotis*

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RESUME

La croissance du manioc en Côte d'Ivoire est affectée par la variation des paramètres climatiques et la bactériose vasculaire du manioc. C'est une maladie destructive influencée par les conditions climatiques pouvant entraîner une perte totale du rendement. Il était donc essentiel d'étudier l'évolution de la bactériose vasculaire du manioc dans différentes zones agro-écologiques de la Côte d'Ivoire pour une bonne gestion de la maladie dans un contexte de changement/variabilité climatiques. A cette fin, des prospections ont été menées dans les champs de manioc de 2014 à 2017 dans les sept zones agro-écologiques ivoiriennes et les variétés ont été évaluées dans des conditions naturelles et artificielles. Les producteurs ont également été interrogés sur leur perception du changement climatique et la bactériose vasculaire. Les résultats ont montré une prévalence de la maladie dans la zones agro-écologique 6, la zones agro-écologique 4 et la zones agro-écologique 1 avec la mort des plants dans des conditions extrêmes et favorables. Les producteurs de manioc interrogés ont pu identifier les changements des paramètres climatiques, leurs caractéristiques et leurs impacts sur le manioc. Cependant, la bactériose vasculaire du manioc était méconnue de la majorité. Trois variétés ont été principalement enregistrées et sont localement connues comme Akama, Yace et Yavo. Yavo a été trouvé plus sensible à la maladie qu'Akama qui était plus sensible que Yace. Les variétés de manioc sont sensibles à la maladie à des niveaux différents dans les différentes zones agro-écologiques. Cependant, certaines semblaient être moins susceptibles que d'autres. Les conditions climatiques constituent l'un des principaux obstacles à la culture du manioc en Côte d'Ivoire et aggravent l'expression de la bactériose vasculaire du manioc. Les pertes liées à la maladie restent imprévisibles. Il est donc urgent de mettre en œuvre des stratégies de contrôle en réponse aux diverses conditions climatiques afin de prévenir et de réduire les impacts de la variation des paramètres climatiques et de la maladie.

Mots-clés: Variation des paramètres climatiques, Bactériose vasculaire du manioc, Producteurs, variétés de manioc, Côte d'Ivoire

ABSTRACT

Cassava growth in Côte d'Ivoire is affected by the variation of climatic parameters and Cassava Bacterial Blight (CBB). CBB is a destructive disease influenced by climatic conditions which can lead to 100 % yield loss. For a better management of CBB in the context of climate change/variability, it was essential to study the evolution of the disease under different agro-ecological zones in Côte d'Ivoire. For this purpose, surveys were conducted out in cassava fields from 2014 to 2017 in the seven agro-ecological zones of Côte d'Ivoire and the varieties were assessed under natural and artificial conditions. Farmers' knowledge on both climate change and CBB were also assessed. The results showed a prevalence of the disease in the agro-ecological zone 6, the agro-ecological zone 4 and the agro-ecological zone 1 with dieback incidence under extreme and favourable conditions. Cassava farmers interviewed were able to identify changes occurred in climate, their characteristics and their impacts on cassava. However, cassava bacterial blight was unknown by the majority. Three varieties were predominately recorded and are locally known as Akama, Yace and Yavo. Yavo was found more susceptible than Akama that was more susceptible than Yace to the disease. Cassava varieties are susceptible to the disease at different rates in the different agro-ecological zones. However, some of them appeared to be more tolerant than others. Climatic conditions constitute one of the major constraints to cassava cultivation in Côte d'Ivoire and are aggravating cassava bacterial blight expression. Therefore, the losses related to CBB remains unpredictable. All these aspects should be considered in the selection of tolerant varieties across different agro-ecological zones. It is therefore urgent to implement control strategies in response to the varying climatic conditions to prevent and reduce the impacts of both the variation of climatic parameters and the disease.

Keywords: Variation of climatic parameters, Cassava bacterial blight, Farmers, Cassava varieties, Côte d'Ivoire

CHAPTER 1 : INTRODUCTION

1.1.   Problem and Justification

The world's population is growing. Estimated at 7.6 billion people in 2017, this population is projected to reach 9.9 billion people by 2050 (Population Reference Bureau, 2018). The increase in population is accompanied by an increase in needs and then, leading to a need for a large-scale sustainable production, thus undermining food security (Burns *et al*, 2010). Food security is also subject to the pressure of climate change that according to Ahanger *et al* (2013), refers to a long-term change in meteorological statistics. Climate change constitutes the most severe threat the world is facing (Gautam *et al*, 2013) and according to Shanahan *et al* (2013), Earth's climate is changing at a faster rate than before. This situation results from the significant increase in temperature caused by concentrations of the main greenhouse gas (CO_2) in the atmosphere (Kliejunas *et al*, 2009; Gautam *et al*, 2013) due to intense human activities since the Industrial Revolution (Ghini *et al*, 2008). Climate change is manifested, among other things, by floods, lack or low rainfall, drought, reduced arable land, environmental degradation, etc… (Rosegrant *et al*, 2008). Agriculture has long been dependent on climate patterns such as solar radiation, temperature and precipitation (Rosenzweig *et al*, 2001), and thus changes in these components directly affect the productivity of roots and tuber crops (Duruigbo, 2012). In Côte d'Ivoire, since 1950, there have been variations in climatic parameters, with a decrease of rainfall between 25 and 28 %, an increase of temperature, floods, coastal erosion, irregularity of rainfall, displacement of seasons (rainy, dry and cultural), desertification, increase of water shortage, loss of production (N'Guessan A and Dje K, 2012; Comoe, 2013; Cherif, 2014). Ivorian agricultural sector is counted among the most vulnerable to climate change (Cherif, 2014; Fondio *et al*, 2016). Some climatic parameters are now unpredictable and the main characteristic of climate change is the significant decrease of rainfall delaying the sowing dates (Noufé *et al*, 2011; Sodexam, 2017). This makes the impacts more visible in the agriculture sector (Sadia, 2014).

As global food is based primarily on plant-based consumption, addressing the challenge of food security and coping with climate change requires an orientation towards crops that are permanently available and able to tolerate the effects of climate change (Burns *et al*, 2010). Among these crops, cassava, also known as "drought, war and famine" food, mainly in developing countries can be cited (Pearce, 2007). Indeed, cassava is naturally drought tolerant, has a greater adaptability to climate and soil, thrives in different texture of soil and can even

grow on poor and acid soils, which are often detrimental to other crops such as maize, millet and sorghum. It is also useful for the prevention of hunger through the gradual harvesting of tuberous roots and leaving the surplus in the soil. It is also available throughout the year for households and in times of agricultural and social instability (Burns *et al*, 2010; PACIR, 2013; Bodnar, 2012; Yao *et al*, 2013). According to FAO (2013) and Chege (2018), cassava provides half of daily calories to about 280 million people in Sub-Sahara Africa and is suitable for farmers with low incomes.

In Côte d'Ivoire, although dependent on coffee and cocoa since 1960s (Ducroquet *et al*, 2017), the GDP rose from 14.1 % in 2000 to 15 % in 2001 due mainly to the increase in cassava production (BAFD/OCDE, 2003). The growing interest in cassava cultivation lead to an increase in cultivated area from 271,000 hectares in 2000 to 353,000 hectares in 2011. With an increase of 8.5 % from 2005 to 2015, its current production was estimated at 4.54 million tons in 2016 (Minagri, 2012; Mendez del Villar *et al*, 2018; DPSA/MINADRI/DR cited by APA, 2017). More than 80 % of the production is for the Ivorian's population consumption. However, the growth of the international demand for cassava and cassava products increased between 2007 and 2011 and then, + 4 % per year, in value terms (PACIR, 2013).

Despite cassava's adaptive capacity to drought, the variation in climatic parameters could impact on the yield. Sodexam in Côte d'Ivoire (2016, 2017) reported changes in climatic parameters and in the growing seasons. This led to a decrease in cassava production due to the drought in 2016 was estimated at 11 % in Abidjan (Mendez del Villar *et al*, 2018).

In addition to these climatic constraints, farmers are dealing with plant diseases. A disease occurrence is strongly related to the interaction between plants-pathogens-environment. The prediction of climate change impacts revealed that climatic conditions would affect plant diseases spatial distribution, incidence and severity. They would also affect the interactions between plants and pathogens and increase risks of plants infection (Ghini *et al*, 2008; Rana I and Randhawa S, 2014). Plant diseases are responsible for great damages and can significantly reduce crops performances and yield (Reynolds, 2010; Ikram K and Sarra B, 2017). Under favourable environmental conditions, they can significantly reduce crops performances and yields (Reynolds, 2010; Ikram K and Sarra B, 2017). These losses have been estimated at 10 - 20 % of global food production, becoming a threat to food security (Strange R and Scott P, 2005; Rana I and Randhawa 2014).

Plant pathogens infect diverse hosts and in the case of cassava, the major diseases are caused by viruses, fungi and bacteria (Bart R and Taylor N, 2017). The main bacterial disease is cassava bacterial blight (CBB) caused by *Xanthomonas phaseoli* pv. *manihotis* (*Xpm*)

(Constantin *et al*, 2016). The infectious cycle is strongly dependent on environmental conditions and takes place in two synchronous stages: the survival phase in the dry season and the parasitic phase corresponding to the disease expression in the rainy season (Daniel J and Boher B, 1982). The two major climatic parameters involved in its manifestation are temperature and relative humidity (Fanou *et al*, 2018). These environmental factors also impact on the genetic diversity of the bacterial strains (Dixon *et al*, 2002). CBB is responsible for high economic losses up to 100 % of the total production (Restrepo *et al*, 2000; Mamba-Mbayi *et al*, 2014). Losses of fresh roots, planting material, low accumulation of starch in edible roots and leaves which affect the availability of leafy vegetables for humans and reduces cash income in communities where cassava leaves are sold, have also been observed and can be high under favourable environmental conditions (Fanou *et al*, 2018). CBB is present in countries where cassava is produced, but its incidence and severity are variable (Fanou *et al*, 2017; Fanou *et al*, 2018). In Côte d'Ivoire, favourable environmental conditions and the use of varieties susceptible to the disease in the different cassava production areas pose a threat to both producers and consumers. CBB was reported for the first time in the North-western part of the country in 1979 after significant damages were caused by the disease (Aïdara, 1984). Its presence was confirmed by Kone *et al* in 2013 (2013) through surveys in the central part of the country and studies made by Affery *et al* (2016) helped to establish the health map of the disease in six agro-ecological zones. They also undertook some works on the varieties screening in two agro-ecological zones and the use of biopesticides against the disease.

There is still a lack of information on the relationship between the climatic parameters, susceptible varieties and virulent strains. This increase the vulnerability of cassava production to both climate change/variability and the disease. Given that cassava bacterial blight is a cassava production threat, it is important to undertake relevant management strategies. For that purpose, it is necessary to understand its evolution under climatic parameters and to monitor its distribution. There was also a need to highlight the most widespread varieties and their level of susceptibility to CBB in the agro-ecological zones. Farmers' constituting an important part of cassava sector and, by considering the potential impacts of both climate change and cassava bacterial blight on their yields, it was important to assess their awareness of these constraints. The assessment of the varieties and the impacts of both the disease and the environmental conditions in the critical agro-ecological zones, the virulence and the genetic diversity of the strains from diverse zones constituted also a need for the development of control strategies.

1.2. State of the knowledge

1.2.1. Climate change/Climate variability

1.2.1.1. Weather and climate

The weather refers to the direct measurements of the related variables of the atmosphere such as temperature, precipitation, humidity, atmospheric pressure, wind direction and speed, cloud cover and type (Cunningham *et al*, 2005; Rholi and Vega, 2011; WMO, 2019). The measure of these variables also defined as climatic elements, are extended on a short given time and location, a day to day measurements (Rholi R and Vega A, 2011; UNESCO, 2013). Climate contrarily, refers to the description of the weather, the state of the atmosphere over a period of time and a given area (Cunningham *et al*, 2005; Goosse *et al*, 2010; Rholi R and Vega A, 2011).

1.2.1.2. Climate change and climate variability

According to WMO (2019), the climate system is determined by the assemblage of the atmosphere, living organisms, land surface, snow, ice, oceans and other waterbodies. The interactions among them under the influence of solar radiation and radiative properties defined the Earth's climate. The ultraviolet rays from the sun as energy are received by the Earth and a part of this energy is reflected as infrared rays in the space. A part of this released energy as heat is absorbed by gases such as water vapour, carbon dioxide, methane, nitrous oxide together known as greenhouse gases (GHGs) (UNESCO, 2013). These gases are playing an essential role also called greenhouse effect by keeping the Earth warmer otherwise, the Earth's temperature would have not allow living life because of the cold. Greenhouse effect previously referred to natural trace gases in the atmosphere without having a negative impact (UNESCO, 2013; Kweku *et al*, 2017).

Because of the population growth and the economic aspects, human activities among others deforestation, fossil fuels burning, waste from incineration processes and industrial activities increased during the pre-industrial era and the Industrial Revolution in the mid-18th – 19th centuries. These activities resulted in the increase of the concentration of greenhouse gases (GHG), mainly CO_2, CH_4, and N_2O in the atmosphere. These gases, also known as anthropogenic greenhouse gases because of human activities, have been largely released. Their release caused subsequent warming of the atmosphere and induced climate change (IPCC, 2001; UNESCO, 2013; IPCC, 2014). Climate change manifestation is observed through changes nature, short-lived extreme weather events and through incremental changes that build up over decades. These can interact and reinforce one another (IPCC, 2018).

According to FAO (2008), there is no international agreed definition of both climate change and climate variability. However, climate change is defined by IPCC as « any change in climate over time, whether due to natural variability or as a result of human activity». By contrast, the Framework Convention on Climate Change defined climate change as «a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods» (IPCC, 2007). According to Niasse *et al* (2004) cited by Ake (2010), the definition of climate change in the specific case of Africa is coupled with those of climate variability and is defined as the variations in climate conditions observed over comparable time periods and due to natural or human factors (UNFCCC, 1992; WMO, 2019). Both climate change and climate variability could affect each other due to the possible interactions between climate variations on different space and timescales and their impacts are more visible in the countries where agriculture is rain-fed dependent (IPCC, 2007; Antle, 2009).

According to the IPCC (2007), the estimation of the global temperatures near the earth surface will be by about 6.4 ° C on average in the 21st century. Climate change models predicted its acceleration and the changes and in climate variables (IPCC, 2007; Chaudhary P and Aryal K, 2009). Climate change is affecting precipitation, melting snow and ice water resources, species habitats, seasonal activities, decrease in cold and increase in warm temperature extremes, increase in extreme high sea levels and in the number of heavy precipitation events (WMO, 2019).

Climate change also affects Africa. Its impacts are traduced among others by the prolongation and intensification of droughts, unknown floods, depletion of rain forests and increase in ocean acidity. In Côte d'Ivoire, since 1950, there have been changes in climatic parameters with a decrease in rainfall between 25 and 28 %, an increase in temperature but also floods, coastal erosion, irregularity of rainfall, displacement of seasons (rainy, dry and cultural), desertification, increase of water shortage, loss of production (N'Guessan A and Dje K, 2012; Comoe, 2013; Cherif, 2014). All these impacts constitute a big threat to agricultural production and food security in Africa (Shaw *et al*, 2009), especially in Côte d'Ivoire where agriculture is the main driving force of the Ivorian economy. It contributes up to 22.3 % of the gross domestic product (GDP) and 47 % of the country's total exportations (MAAF, 2015 cited by N'Guessan, 2016).

1.2.1.3. Impacts of climate change/climate variability on agriculture

Agriculture is the most important sector in Africa since it employs about three-quarters of Africa's population. Because this sector is mainly rain-fed dependant and susceptible to climate conditions, it constitutes the most vulnerable sectors to the risks and impacts of global climate change (Parry *et al*, 1999; Shaw *et al*, 2009). The changes of the climate parameters have been predicted to be severe through extreme and extended periods of droughts, flooding, desertification and soil erosion leading to the loss of arable land, reduced agricultural yields and crop failure (Antle, 2009; Shaw *et al*, 2009).

The variation of the main climatic parameters in Côte d'Ivoire in 2016 had an impact on the agricultural sector mainly on cassava cultivation. The mean temperature was 26.78 ° C with a gap of +1.13 ° C compared to the mean 1961-1990 (25.65 ° C) for the whole country, a drop in rainfall (1530.4 mm in 2016 compared to 1666.5 mm for 1981-2010 then, a gap of-8.2 %) on the Ivorian coastline; -6.6 % (1135.9 mm in 2016 compared to 1216.4 mm for 1981-2010) in the Southern part, -2.5 % (1205.9 mm in 2016 compared to 1236.3 mm for 1981-2010) and an increase of +5 % (1324.7 mm compared to 1261.1 mm for 1981-2010) have also been noticed (Sodexam, 2016). The result of this variation led to a decline of 11 % of the production due to the drought causing a shortage of cassava in Abidjan (Mendez del Villar *et al*, 2018). The beginning as well as the end planting dates also saw variation (normal to late) in 2017 leading to the delay of cassava planting in some areas. The rainy season has known excess in some regions and a decrease in others with a worse distribution of the rainfall (Sodexam, 2017).

1.2.1.4. Impacts of climatic parameters on plant diseases

The prediction of climate change impacts implies that climate conditions would also affect plant pollinators, plant diseases expression, the interactions between plants and pathogens and increase risks of plants infection, since the occurrence of a disease depend on the variation of the climatic variables. The main climate factors influencing diseases development are temperature, light and water (Ghini *et al*, 2008; Agrios, 2005; UNESCO 2013). Also based on the disease triangle where the disease occurrence is strongly related to the interaction between plants-pathogens-environment, climate change will impact the spatial distribution, incidence and severity of plant diseases (Ghini *et al*, 2008; Rana I and Randhawa S, 2014). Severe epidemics and unpredictable disease outbreaks in plants are expected to happen in case of rapid changes and since some pathogens will tend to be favoured by others (Kliejunas *et al*, 2009; Coakley *et al*, 1999; Chakraborty, 2005; Rosenzweig C and Tubiello F, 2007). According to Rana I and Randhawa S (2014), plant diseases constitute one of the major constraints to

agricultural productivity. High moisture and temperature must be generally, both involved in the disease initiation and development. Precipitation and greater number of rainy days were involved in disease expression (Garett *et al*, 2013, Yáñez-López *et al*, 2012). These parameters have been described by Garett *et al*, 2013, Yáñez-López *et al* (2012), and Rana I and Randhawa S (2014) as part the major climatic parameters involved in plant diseases occurrence and development.

1.2.1.5. Cassava (*Manihot esculenta* Crantz)
1.2.1.5.1. Origin and distribution of cassava

Cassava is a perennial plant native to tropical America (Nassar, 1978; Olsen K and Schaal B, 2001). Its culture is widespread in South America, Central America and in the Caribbean Islands. It was imported in the 16th century by the Portuguese slave traders on the coast of West Africa, to Sao Tome and Fernando Po during the conquests of Spanish and Portuguese then to Congo (Guthrie, 1990; FAO, 2013). From the 18th century, it was spread on the coast of East Africa, in Madagascar, on Reunion Island, Zanzibar and South Asia. Cassava crop, initially confronted with the reluctance of the Africa's people, was widely disseminated in the nineteenth century throughout the continent. It has also been widespread in India, Indonesia and the Philippines (Were, 2001; FAO, 2013). Because of its susceptibility to cold and the duration of its growth, it is preferentially planted in tropical and subtropical areas (FAO, 2013). Cassava was introduced during of the nineteenth century in Côte d'Ivoire by the Akan people, in particular Aladjan and the Abouré, from South Ghana (N'Zué *et al*, 2005). From the coastline, cassava has been spread to almost all parts of the country (N'Dabalishye, 1995). This culture initially considered as a poor food and used to fight famine has now become one of the most important arable crop.

1.2.1.5.2. Botanical classification and variety diversity

Cassava previously called *Manihot ultissima* Pohl or *Manihot dulcis* Pax was renamed *Manihot esculenta* Crantz thanks to the work of Rogers D and Fleming H (1973). According to the systematic classification, it belongs to:

Kingdom: ....Plantae

Branching: ....Magnoliophyta

Class: ....Magnoliopsida

Order: ....Ephorbiales

Family: ....Ephorbiaceae

Genre: .... *Manihot*

Species: ....*Manihot esculenta* Crantz

Cassava is preferentially allogamous but can self-fertilize in case of limited quantity of allopollen (McKey *et al*, 2012). It is diploid with $2n = 36$ as chromosome number. According to Rogers and Appan (1973), the genus *Manihot* contains 98 species divided into 17 sections :

- a section represented by the cultivated species *Manihot esculenta* Crantz,

- two sections containing 17 species present in Central America and North America,

- 14 sections consisting of 80 species are present in South America with 77 of them present in Brazil.

In Côte d'Ivoire, there are more than one hundred cultivated varieties (Aïdara, 1984). These are divided into sweet and bitter varieties based on their cyanidric acid content (the bitter varieties contain more). This acid is produced by the plant in case of attack or of injury as a defence. They are distinguished from each other by the colour of stem, leaves, petioles and root phelloderm. Some varieties like Bonoua and Bingerville bear the names of two Ivorian towns while others such as Yace, Céline (Zoundjihekpon, 1986) and Diarrassouba are designated by the names of people who introduced them to the locality. The lack of molecular characterization may cause one variety be named differently in certain regions. However, according to N'Zué *et al*, (2005, 2013a) more than ten improved varieties are grown in Côte d'Ivoire including Bocou 1, Bocou 2, Bocou 3, IM 84, IM 89, IM 93, TMS 30572 and TMS 4 (2) 1425. Different cassava varieties, local and improved cultivars are grown in Côte d'Ivoire. Examples of locally well-known varieties are Akama (also called 'Six mois' or Kaman), Yace, Tambou and Bonoua (Dje Bi *et al*, 2018; Perrin *et al*, 2015). The improved ones include Yavo or TME07, Bocou 1, IM8 and TMS4(2)14254 (Akpingny *et al*, 2017; Mendez del Villar *et al*, 2017, N'Zue *et al*, 2013b). The adoption of these varieties by the growers depends on factors such as yield, taste and semi-industrial processing aspects. The most adopted and cultivated varieties are Yace, Akama, Bonoua and Yavo (Kouassi *et al*, 2018; Mendez del Villar *et al*, 2017).

1.2.1.5.3. Description and biology of the reproduction

Cassava is a shrub (Figure 1A) with a size range between 1 and 5 meters (CMA/AOC, 2004; FAO, 2013). Its root system differs according to the mode of multiplication. It presents a swivel root and secondary roots when it derived from a seed. When it comes of a cutting, its roots are either nodal (roots coming from the knots in contact with the ground) or basal (roots from the basal part of the cutting). There is however, a third type of roots called stem roots, which are similar to the first type. They develop when the moisture is strong at the base of the main stems whose insertion point on the cutting is underground (Komi, 1992). These different roots sink into the soil and produce tubers following the accumulation of reserves. The number and size of tubers vary from five to ten depending on the variety and culture conditions (Figure 1B). Their length is between 15 and 100 cm and their weight can reach 3 kg (IITA, 1982, IITA and IRAD, 2008). There are tubers attached directly to the cuttings that gave them birth (sessile tubers) and tubers connected by a peduncle to the cuttings (tubers pedunculated).

Figure 1. A: Cassava shrub; B: Tubers

The same cutting can have or not several ramifications can produce one or more stems, of varying colours depending on the variety and age. The right plants with no ramification have a better yield in terms of cuttings which number is about 30 (Ceballos H and De la Cruz G, 2002). The deciduous, alternate, simple leaves and spirally arranged on the stem, have a leaf blade membranous composed of lobes ranging from one to eleven (Cours, 1951; Aïdara, 1984; Verdier, 1988). They are 10 to 20 cm long (ITTA and IRAD, 2008) and have an elongated petiole green or red.

Cassava although monoecious, reproduces by cross fertilization, thus the female organs of one foot are pollinated by the male reproductive organs of another foot. This is called allogamous (Zohary, 2004). Pollination is entomo-anemophilous (Dulong, 1970). Insects responsible for the spread of pollen are bees, ants, flies and wasps. The female flowers are located at the base of the inflorescence and flourish the first while the male flowers, more abundant (Figure 2A), flourish late, especially after fruit formation (Figure 2B) (Zoundjihekpon, 1986). Some varieties do not flower during the cropping cycle while others present up to 10 successive flowerings on the stem in a single crop year. Flowering ability is controlled by temperature, drought and photoperiod (Matthews R and Hunt L, 1994). Two to three months after pollination, the fruit shaped capsule three-chamber dehiscent matures (Rogers D and Appan M, 1973) and contains one or three more or less mottled reddish-brown seeds (Dulong, 1970; Komi, 1992). The crop cycle varies between eight and twelve months or more depending on the variety. The multiplication is usually done by cutting because of its ability to produce a large number of tubers and its richness in nutrient stores (McKey *et al*, 2012). The seed multiplication is carried out by the research stations for crosses and the selection of new varieties (ITTA and IRAD, 2008).
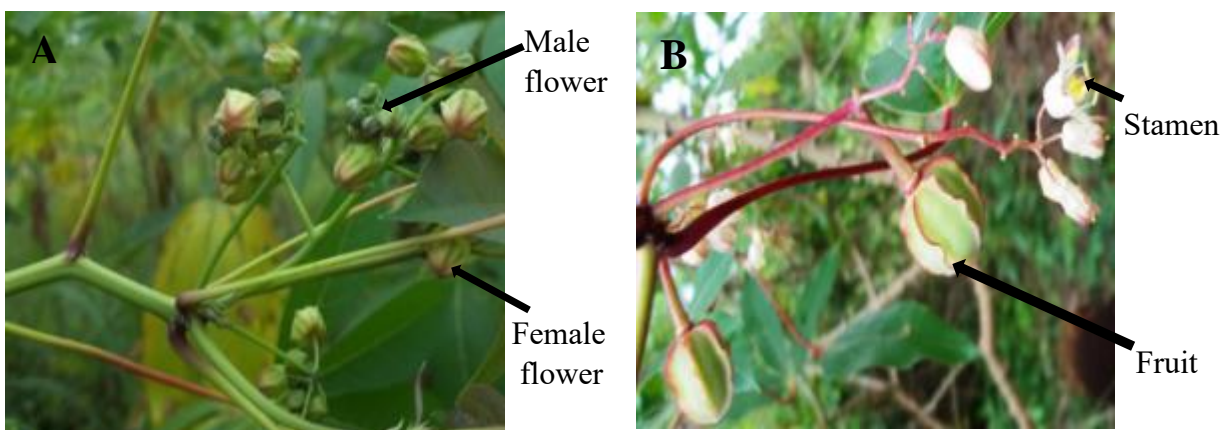
Figure 2. A: Male and female flowers; B: Fruit and stamen

1.2.1.5.4. Cassava ecology

Cassava is grown in tropical regions where rainfall varies between 600 and 4,000 mm or more. Its culture also extends to the equatorial zone. The optimal temperature of growth is between 25 and 29 ° C but can grow under temperatures up to 12 ° C (CMA/AOC, 2004). In the specific case of Côte d'Ivoire, a rainfall of 1,200 to 1500 mm, an average temperature of 23 to 24 ° C and a dry season of 2 to 3 months is ideal to obtain the maximum yield (Yao et al, 2013). It also supports periods of prolonged drought (CMA/AOC, 2004) if it receives sufficient rain

during the first three months of planting (IITA and IRAD, 2008). Although cassava cultivation is mainly characterized by small-scale, it is widespread all over the country with its high yields recorded in the forest zone (Mendez del Villar *et al*. 2018; N'Zue *et al*, 2013a; N'Zue *et al*, 2014).

The cassava varieties can be divided into two major groups, the sweet ones and the bitter ones according to the content of hydrocyanic acid which is very high in bitter varieties (Akpingny *et al*, 2017). This characteristic plays a role in their adaptive resilience to environmental conditions. For instance, according to Perrin *et al* (2015), some bitter varieties can be grown in some places of the northern part of Côte d'Ivoire whereas the sweet ones cannot.

As everywhere else, cassava grows on sandy-clay soils, deep and well drained, of stable structure and pH = 5.5. It requires low soil and can even grow on soils that are low in nutrients as well as acid soils that are often unfavourable to other crops. Moreover, it gives poor yields on hydromorphic soils. In Côte d'Ivoire, cassava cultivation is associated with those of maize and cocoa in the West as well as those of yams, bananas, plantain and vegetables in the Central and East (Yao et al, 2013).

1.2.1.5.5. Socio-economic importance of cassava in Côte d'Ivoire and uses

Cassava is the second food crop after yam (FAO, 2013). Its cultivation extends over most of the country. The cultivated area increased from 271,000 hectares in 2000 to 353,000 hectares in 2011 (Minagri, 2012). It experienced a growth of 53,351 tons from the year 2011 to the year 2012. It was estimated at 2,412,371 in 2012 (Minagri, 2012). Côte d'Ivoire is self-sufficient in cassava and more than 80% of the production is destined for local consumption. It contributed in 2011 with Ghana and Nigeria to 98 % of exports from West Africa. Its main importers are the European countries such as France and African countries like Burkina Faso (PACIR, 2013). Cassava is mainly grown for its tuberous roots rich in starch (FAO, 2013). The production is first intended for human consumption, then for animal consumption and finally for industry. With regard to human nutrition, only the roots and leaves are used. The roots are transformed into attiéké, gari, flour (CMA/AOC, 2004; PACIR, 2013). They are also used for manufacturing alcoholic beverages and the leaves make it possible to make different kind of food. For animals, the plant is used in its entirety. The roots are consumed in the fresh state (raw or cooked) or in the dry state (chips, granules, flours), or in silage form in the case of irregular supply. Leaves and root peels are also eaten fresh or dried by the animals. The tender

stems are completely consumed by herbivores whereas for older stems only bark are consumed (Komi 1992; CMA/AOC, 2004; PACIR, 2013). In industry, starch is used in the manufacture of textiles, plywood, veneers, glues, dyes, drugs, alcohol and paper products (Komi, 1992; CMA/AOC, 2004; Djouldé, 2005; PACIR, 2013). It is also used in the manufacture of various chemicals as well as ethanol that can be used as agrofuel for environmentally friendly vehicles thus reducing greenhouse gas emissions.

1.2.1.6. Constraints related to cassava production

Cassava is infested with many pests including the green mite or Mononychellus tanajoa Bondar (Tetranychidae), responsible for the acariosis, the stinking grasshopper Zonocerus variegatus Linnaeus (Pyrgomorphidae) that eats the leaves, the cochineal also called Phenacoccus manihotis Matile-Ferrero (Pseudococcidae).

The diseases are caused by fungi (e.g. anthracnose), viruses (e.g. African Cassava Mosaic Virus) and bacteria (e.g. Cassava bacteria blight).

1.2.1.7. Cassava bacterial blight (CBB) and its causal agent *Xanthomonas phaseoli* pv. *manihotis* (*Xpm*)

1.2.1.7.1. Systematic and identification of *Xpm*

The bacterium *Xanthomonas phaseoli* pv. *manihotis* was previously called *Xanthomonas campestris* pv. *manihotis* (Arthaud-Berthet and Bondar) Starr. It belongs to the phylum Proteobacteria, to the class of Gamamaproteobacteria, to the order Xanthomonadales, to the family Xanthomonadaceae and *Xanthomonas* genus (Saddler G and Bradbury J, 2005 cited by Hamza, 2010). It has been reclassified to the *axonopodis* species thanks to the work of Vauterin *et al* (1995) on DNA-DNA hybridizations (Fargier, 2007).

Constantin *et al* (2016) through their works on the genetic characterization of the strains *Xanthomonas axonopodis* pv. *dieffenbachiae* including some *Xanthomonas* strains of other pathovars reclassified *Xanthomonas phaseoli* pv. *manihotis*. These works were based on the average nucleotide identity values, DNA–DNA hybridization data and phenotypic characteristics.

Xpm is the causal agent of cassava bacterial blight (CBB), a disease of great economic importance. It is then, a Gram-negative bacillus, motile by a flagellum polar. Its growth on the YPGA medium is slow and the colonies are visible after 48 hours incubation (Daniel, 1977). Their diameter after two days of culture varies between 1.5 to 3 mm (Ogunjobi *et al*, 2008). They do not form spores, have no pigment, are smooth and white glittering ivory. They have a

convex appearance with regular contours (Onyeka *et al*, 2008). The pathogen produces xanthan (an extracellular polysaccharide) which gives a viscous appearance in colonies (Fargier, 2007). *Xpm* is a strict aerobic Gram-negative bacterium that does not reduce nitrate and does not denitrify it. It responds negatively to KOVACS oxidase tests (Boher B and Agboli C, 1992) and has catalase and DNAse activity.

1.2.1.7.2. Genetic variability of *Xanthomonas phaseoli* pv. *manihotis*

Bacterial diseases are a major global threat to crop production (Sundin *et al*, 2016). Although causative agents reproduce asexually primarily by division (binary fission), they exhibit great diversity through conjugation, transduction, and transformation (Vernière *et al*, 2014; Yin K and Qui J-L 2019). *Xyllela* and *Xanthomonas* bacteria were among the first phytopathogenic bacteria on which the study of applications of genetic diversity was undertaken (Guinard, 2015; Xu J and Wang N, 2018)

According to Rache *et al* (2019), previous studies on *Xpm* genetic diversity and structure have been conducted in Colombia (Restrepo S and Verdier V, 1997; Restrepo *et al*, 1999a, 2000, 2004, Trujillo *et al*, 2014a, b), Venezuela (Verdier *et al*, 1998), Brazil (Restrepo *et al*, 1999b), Nigeria (Ogunjobi *et al*, 2006, 2010). These studies relied on the use of molecular markers such as RFLP, RAPD and AFLP (Verdier *et al*, 1993; Ogunjobi *et al*, 2006, 2010). The great diversity of *Xpm* populations was observed in South America, while African strains were more homogeneous (Verdier *et al*, 1993; Verdier *et al*, 1998; Restrepo S and Verdier V, 1997). Additional work undertaken by Ogunjobi *et al* (2010) on *Xpm* strains in some states of Nigeria have highlighted the diversity of strains evaluated.

Because of the low repeatability, reproducibility, and portability of these markers (Roumagnac *et al*, 2007), new typing technologies based on variable number of tandem repeat (VNTR) markers are used (Davey *et al*, 2011; Guinard, 2015). These VNTRs refer to genes or intergenic regions containing loci with portions of DNA repeated in tandem and varying from one strain to another (Guinard, 2015). The MultiLocus VNTR (MLVA) assay used for typing these markers provides more information on repeated sequences, determines the VNTR profile at different loci, and is discriminatory, reproducible and portable among other things (Guinard, 2015; Arrieta-Ortiz *et al*, 2013; Li *et al*, 2009).

Used initially for the typing of *Xylella fastidiosa* (Coletta-Fhilo *et al*, 2001), responsible for citrus variegated chlorosis, the MLVA scheme was subsequently applied to *Xanthmonas citri* pv. *citri* (*Xcc*) (Ngoc *et al*, 2009; Pruvost *et al*, 2014; Vernière *et al*, 2014), *Xanthomonas oryzae* pv. *oryzicola* (*Xoo*) (Zhao *et al*, 2012; Poulin *et al*, 2015), and *Ralstonia solanacearum*,

the respective causative agents of citrus canker, bacterial leaf streaks of rice, and bacterial wilt of *Solanacearum* (N'Guessan *et al*, 2013; Parkinson *et al*, 2013). It was extended to *Xpm* and revealed 60 VNTR loci as the overall diversity of bacterial strains, with 16 markers (Arrieta-Ortiz *et al*, 2013 cited by Rache *et al*, 2019; Guinard, 2015).

In 2017, Flores used the MLVA-14 microsatellites scheme to determine the genetic diversity of 202 *Xpm* strains collected in 2015 and 80 strains from the 1990s collection in Venezuela. Recent and historical collections also exhibited pronounced genetic diversity.

1.2.1.7.3. Geographical distribution and economic importance of CBB

Cassava bacterial blight was identified for the first time in Brazil in 1912 and in other Latin American countries (Lozano J and Sequeira L, 1974). In Africa, its presence has been reported in Nigeria in 1972 (Daniel, 1977), in Togo in 1975 (Boher B and Agboli C, 1992). Following rapid spread, the disease was subsequently observed in Ghana, Cameroon, Gabon, Congo, Zaire (Maraite H and Meye J, 1975). It has also been identified in Asia (Leu L and Chen C, 1972; Booth R and Lozano J, 1978). It was reported in Touba in the Northwest of Côte d'Ivoire in 1979 following many damage caused by the bacteria (Aïdara, 1984). Cassava bacterial blight is a disease of great economic losses. In Colombia, tuber losses ranging from 12 to 100 % were reported in 2000 by Restrepo *et al* In the 1970s, Aklé J and Gnonhoué H (1979) in Ghana as well as Korang- Amoakoh S and Oduro K in Benin (1979) estimated the damage to 75 % of production following a severe infection. The same observation was made in other African countries, such as Togo and Cameroon. In the Democratic Republic of Congo, a total loss of production causing famine has been reported (Hillocks R and Wydra K, 2002). CIAT in 1996 assessed falls in the main African production areas (wet plains) at 3.2 million tons. Damage of 75% of production in Nigeria, 90 % to 100 % in Uganda was also recorded (Ohunyon P and Ogio-Okirika J, 1979; Otim-Nape, 1980). The characteristic symptoms of the disease are the wilting of leaves, blighting, angular leaf lesions and stem cankers, stem and leaf exudates production and dieback of stems (Jorge *et al*, 2001). The loss caused by *Xpm* relate to tuberous roots, leaves and planting material. According to Mamba-Mbayi *et al* (2014), losses can reach 90 % in the absence of control.

1.2.1.7.4. Epidemiology

The pathogen cycle is divided into a survival and a parasitic phases. The survival is characterized by a halt of CBB expression, a considerable decrease or sometimes a temporary absence of bacterial populations during the dry season (Daniel J and Boher B, 1982). This

phase is vital for the primary inoculum establishment, useful for the disease occurrence by the secondary inoculum at the end of the dry season and the beginning of the rainy season. The rainy season is the best period for the manifestation of the symptoms that are caused by rainfall, temperature, high relative humidity and high differences between day and night time temperatures (Fanou *et al*, 2018).

Xpm is a leaf and vascular bacterium. It enters in the plant through openings in stomata or foliar wounds (Verdier *et al*, 2004). It can also infect the stems due to insect bites or anthracnose lesions (FAO, 2005a). Once inside the plant, it multiplies in the intercellular spaces at the surrounding cells. It moves gradually through the tissues to prevent the circulation of raw sap. This shutter is done thanks to polysaccharide and pectic proteins surrounding the bacterium. These come from both pathogen and host. Stopping the transport of raw sap results in wilting and drying out of the stems (Verdier, 1988; Verdier *et al*, 2004). Cassava bacterial blight is characterized by oily and translucent angular spots on the surrounding leaves or not with chlorotic halo. They are more visible on the underside of leaves. These spots develop, become brown and surround themselves with a circular range of burn. This leads to wilting and falling of the affected leaves. The presence of exudate gummy on veins, petioles and stems, cankers on stems and necrosis vascular means the vascular infection of the plant. The infection spreads to the whole plant leading to the death or die-back of infected feet (Lozano J and Sequiera L, 1974; Maraite *et al*, 1981; Maraite, 1993; ITRA, 2008).

The infectious cycle of the bacterium takes place in two phases, namely the survival phase and the parasitic phase. The survival phase is essentially in the dry season while in rainy season, the two stages are synchronous. During the survival period, there is a cessation of the disease expression. It is translated also by a considerable decrease or sometimes by a temporary absence of bacterial population (Daniel J and Boher B, 1982). The pathogen survives nevertheless in plant debris, stems, leaves, fruits, seeds of the plant host until rains appear (Daniel J and Boher B, 1982, 1985). According to Dedal *et al* (1980), Elango F and Lozano J (1981) and Ikotun (1981), it can also be stored in host plants reservoirs such as *Manihot glaziovii*, *Euphorbia pulcherima* (Euphorbiaceae) and *Amaranthus dubius* (Amaranthacées) (Verdier, 1988). Insects *Chrysolagria cuprina* Thomson, *Gonocephalum simplex* Fab., *Ischnothrachelus* sp. Thomson, *Zonocerus variegatus* L., *Pseudotheraptus devastans* Distant and an unidentified Heteroptera are considered as hosts of *Xpm* (Daniel J and Boher B, 1985). The survival phase is important for the establishment of the primary inoculum, useful for the occurrence of the disease by the secondary inoculum. The parasitic phase corresponds to the expression of the disease. Thanks to rain, the number of the bacterial population conserved

during the dry season increases (Verdier, 1988; Daniel J and Boher B, 1985). The parasites then enter the leaves and cause the characteristic symptoms of the disease.

1.2.1.7.5. Factors of dissemination of the pathogen and disease development

One of the essential factors for the spread of *Xpm* is the use of infected planting material (Restrepo S and Verdier V, 1997). Rain, splash, relative humidity, wind, temperature variations between day and night, insect vectors, working tools, picking leaves and soil also play a role in the spread of the bacteria (Verdier, 1988; FAO, 2005a; ITRA, 2008; N'Zué *et al*, 2013b).

1.2.1.7.6. Control methods

The Preventive measures go through several simple methods such as treating seeds with heat and microwave (1400 W, 2450 MHz, 77 ° C, 120 s) recommended by Lozano *et al* (1986). This method helps to rid them of bacteria. Similarly, the sanitation of seeds and tools recommended by Persley (1979), Elango F and Lozano J (1981) contribute to the restriction of the effect of the disease. The intercropping with other crops such as taro and maize favour the considerable reduction of the disease. They are more effective in cassava monoculture (ITRA, 2008). Removal of infected material, selection of propagation material affect the reduction of bacterial wilt incidence (Williams *et al*, 1973; Lozano, 1975). Quarantine any new plant material could contribute to the fight against this disease.

The agronomic struggle can be undertaken at the seed treatment level. These include the use of hot water, hydrogen peroxide, copper acetate and sulphate zinc (Walker, 1952; Humaydan *et al*, 1980; Schaad *et al*, 1980; Huang T and Lee H, 1988). However, these treatments have a limited effect: they slow down the development of the disease without eradicating it and do not lead to the elimination of the bacteria (Fargier, 2007). They also affect germination quality and variety vigour (Patel *et al*, 1949; Williams, 1980).

Chemical control consists of the use of chemicals to combat pathogens. In the case of bacteria, the expensive cost of the products, the risks of phytotoxicity to plants and the possibility of developing resistance to antibiotics by bacteria limit its action (Xiong *et al*, 2006; ITRA, 2008). Some zinc and copper products, however, are used but their action fails not to eradicate the disease (Messiaen *et al*, 1991).

Biological control consists of using living organisms for the prevention or reduction of damage caused by a pathogen (Fargier, 2007). Regarding *Xpm*, attempts to fight have been made in Congo (Verdier, 1988). Poundzou (1987) has shown that the use of *Pseudomonas sp* appears to reduce the epiphytic multiplication of the bacteria. The amount of angular stains and leaf

wilting are reduced by the use of *Pseudomonas fluorescens* and *Pseudomonas putida* on leaves (Lozano, 1986).

Integrated struggle, the most effective struggle strategy against cassava bacterial blight is the use of resistant varieties. This requires knowledge of the genes responsible for resistance in cassava (Verdier, 1988). The selection of resistant cultivars must be carried out in areas where the disease is endemic by taking into account the environmental conditions.

1.2.1.7.7. Host-parasite interactions

Plants naturally have mechanisms of recognition and defence that overcome pathogen attacks. During the aggression, these parasites attempt to suppress the defence responses put in place by the plant (Hamza, 2010). It gives rise to non-host, incompatible and compatible interactions between the two protagonists.

A non-host interaction occurs when the pathogen is unable to penetrate or reproduce in the plant. The physico-chemical barriers of the host such as cuticular waxes, plant walls and constitutive production of antimicrobial compounds (Garcia-Brugger *et al*, 2006; Boulanger, 2009) favour it. This interaction is called passive resistance because of its independence with the presence of the parasite.

The incompatible and compatible interactions involve one or more resistance genes (R) of the plant and a gene avirulence (Avr) of the pathogen (Flor, 1971; Fargier, 2007). In the specific case of cassava, several genotypes involved in the resistance of the plant to cassava bacterial blight have been observed (Sanchez *et al*, 1999). This resistance was developed from introgression between wild *Manihot esculenta* and *Manihot glaziovii* (Hahn, 1978; Hahn *et al*, 1979). Jorge *et al* (2000) highlighted six genomic regions of cassava intervening in the resistance. This observation confirms its polygenic character: this is the horizontal resistance. It is partially hereditary, depends largely on the environment and inoculum pressure (Hahn *et al*, 1979; Wydra, 2002). In addition, additive and heritability of the trait varies between 25 and 66% (Hahn *et al*, 1979; Jorge *et al*, 2000). Inoculations made by Zinsou (2003) showed a specificity of these genes with the strains used. As for the pathogen, it has an avirulence gene which is carried by the plasmid p44. It is involved in the pathogenicity of strains (Verdier *et al*, 1997).

Incompatible host interaction occurs in the presence of a pair of dominant genes. These include the resistance gene (s) and the corresponding avirulence gene. In case of aggression, the plant is likely to cause a hypersensitivity reaction (Fargier, 2007). This is achieved by the production of defence molecules. These are released by the plant cells and cause the death of surrounding

living cells. This isolation contributes with secreted molecules to reduce the multiplication of the pathogen (Hamza, 2010). There is in this case no symptoms of the disease but rather the appearance of non-progressive necrosis level of the tissues in contact with the parasite. The bacterium is then called avirulent (Fargier, 2007; Hamza, 2010).

Compatible host interaction when one of the two protagonists' genes is absent. It takes place between a susceptible host and a virulent pathogen. In the case of a bacterial attack, the plant does not involve any defence process. The bacterium colonizes the intercellular spaces in addition to the conductive vessels for some species. By activating its functions, it uses for its multiplication some metabolites developed by plant cells. It destroys the defence mechanisms of the plant and causes the characteristic symptoms of the disease (Hamza, 2010).

1.3.   Research hypothesis

The research hypothesis of this study was that the changes in climate parameters would affect the expression of cassava bacterial blight in the agro-ecological zones of Côte d'Ivoire and increase the risk of cassava yield losses.

1.4.   Objectives

1.4.1.   Overall objective

The overall objective is to understand the behaviour of cassava bacterial blight under the varying climatic parameters for a better management of the disease and the insurance of food security.

1.4.2.   Specific objectives

The study specifically seeks to:

(i)   Highlight the key climate parameters involved in the evolution of cassava bacterial blight the agro-ecological zones;

(ii)   Assess the susceptibility to cassava bacterial blight of the varieties the agro-ecological zones

(iii)   Identify the pathogenic and genetic structures of the *Xanthomonas phaseoli* pv. *manihotis* strains

CHAPTER 2: MATERIAL AND METHODS

2.1. The highlight the key climate parameters involved in the evolution of cassava bacterial blight the agro-ecological zones

2.1.1. Distribution and evolution of cassava bacterial blight under climate parameters

2.1.1.1. Study areas

Surveys were conducted from 2014 to 2017 in Côte d'Ivoire. Six on the seven agro-ecological zones in 2014 were considered and the seven agro-ecological zones for the remaining years were considered for the surveys. These zones were identified and defined by Halle B and Bruzon V (2006) according to the pedoclimatic conditions (Figure 3; Table 1). The agro-ecological zones 1, 2, 4 and 5 are characterized by two dry seasons (long and short dry seasons) and two rainy seasons (long and short dry seasons as well). The AEZ3 is characterized by a short dry season and a long rainy season while the AEZ6 and 7 are characterized by a long dry and a long rainy season (EDSCI-II, 1999; FAO, 2005b).
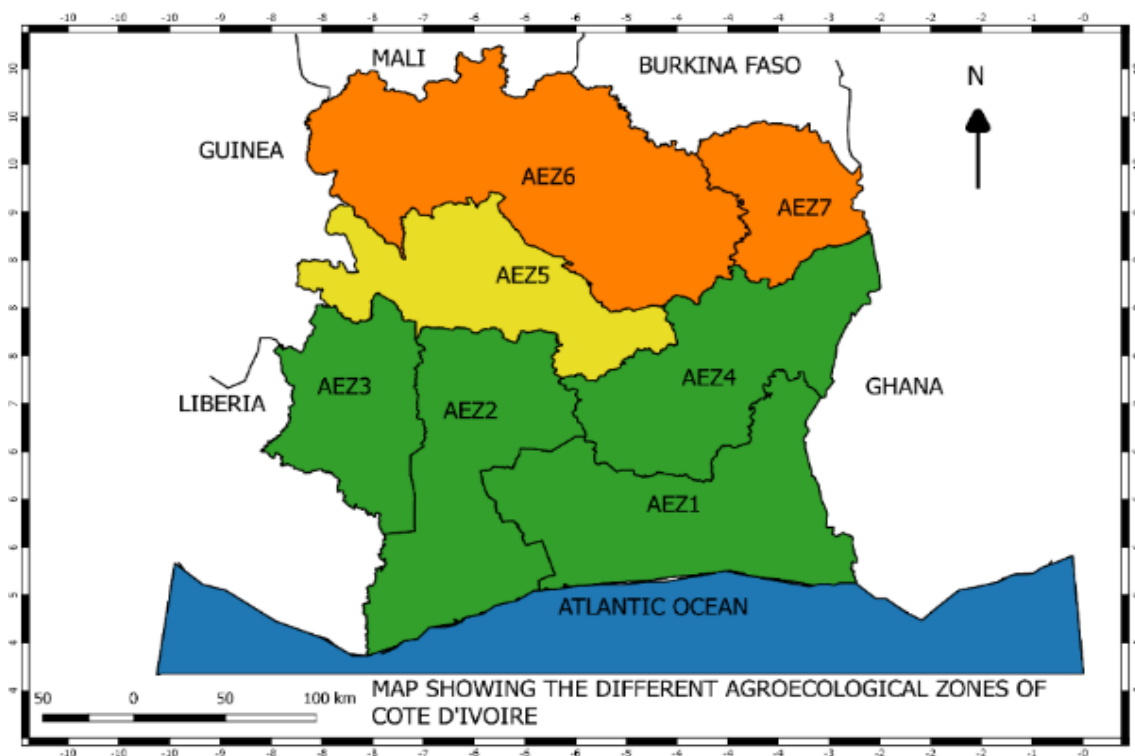
Figure 3. Agro-ecological zones of Côte d'Ivoire based on Halle and Bruzon description

Table 1 . Description of the season in Côte d'Ivoire and Characteristics of the seven agro-ecological zones where VZ= Vegetative zones; F= Forest, T= Transition; S=Savannah; AEZ= Agro-Ecological Zones; SDS= Short Dry Season; LRS= Long Rainy Season; LDS= Long Dry Season (EDSCI-II, 1999; FAO, 2005b; Halle B and Bruzon V, 2006)

AEZ	VZ	Characteristics	Altitude (m)	Rainfall (mm)	Annual Temperature (°C)	SDS	LRS	LDS	SRS
1	F	Southern humid dense forest area	0-200	1400-2500	29 (5.6)	July-August	April-July	December-March	September-November
2	F	Wet dense forest area of the west	~1000 (Daloa)	1300-1750	23.5 (13.4)	July-August	April-July	December-March	September-November
3	F	Semi-mountainous forest area of West	> 1000 (Man)	1300-2300	24.5 (7.7)	November-February	March-October		
4	F	Semi humid dense forest zone deciduous	0-200	1300-1750	23.5 (13.4)	July-August	April-July	December-March	September-November
5	T	Transitional forest area	300-600	1300-1750	23.5 (13.4)	July-August	March-June	November-February	September-October
6	S	Tropical humid savannah zone	300- 500	1150-1350	26.7 (1.1)		May-October	November-April	
7	S	Dry tropical savannah zone	300-500	1150-1350	26.7 (1.1)		May-October	November-April	

2.1.1.2. Equipment

The equipment was constituted of GPS, leaves and stems samples, refrigerated cooler, envelopes, markers, scorecards, alcohol, bleach, sterile distilled water, microtube, grinder (Tissue Lyser II), agitator, Petri dishes, LPGA (Yeast, Peptone, Glucose and Agar) selective medium, antibiotics and an oven.

2.1.1.3. Methods

Surveys were conducted during the rainy seasons (short rainy season for the AEZ1, AEZ2, AEZ4 and AEZ5, the rainy season in the AEZ3, AEZ6 and AEZ7). In each AEZ, three fields/area were considered for the high cassava production areas. For areas with very low cassava production, one to two fields were considered. They were chosen at the entrance, in and outside of the locality and their geographical coordinates were recorded using a GPS GARMIN OREGON 550. Each field was assessed for CBB presence/absence taking into account thirty cassava plants. The meeting point of two diagonal lines was taken as a reference point for the plants assessment. The severity and incidence were evaluated based on assessment sheets.

Ten samples of leaves, stems and leafstalks per field showing CBB symptoms were collected. The rating scale of CBB severity described by Wydra and Msikita (1995) was used. The ratings ranged from 1 to 5 and describe as followed: 1: no symptom, 2: only angular leaf spot, 3: angular leaf spots, wilting, blighting, defoliation, and some exudates on stems/leafstalks, 4: blighting of leaves, wilting, defoliation, exudates, and tip die-back, 5: blighting of leaves, wilting, defoliation, exudates, tip die-back, and plant stunting (Figure 4). The severity index (SI) and disease incidence (DI) were calculated for each parcel following the formulas below, used by Mamba-Mbayi *et al.* (2014).

$$SI=\sum \frac{\text{Number of affected plants per scale} \times \text{the scale}}{\text{Total number of observed plants} \times \text{the high scale}} \times 100$$

$$DI=\frac{\text{Number of affected plants}}{\text{Total number of observed plants}} \times 100$$

Microbial analysis

The isolations were performed according to the methodology of Trujillo *et al*, 2014a with the strain CI1 used as reference. It is an Ivorian strain isolated in 2014 and tested by the PCR diagnosis. For each leaf sample, a fragment exhibiting the symptoms and surrounded by a healthy portion were cut with a sterile pair of scissors.

Figure 4. CBB symptoms identified according to Wydra and Msikita scoring scale

Using a sterile forceps, the leaf fragment was disinfected successively in 70 ° C alcohol, 0.1 % bleach and rinsed three times in sterile distilled water. After each step, the fragment was dried on blotting paper. It was put in a 1 ml microtube containing two beads and grinded with a grinder (Tissue Lyser II) for 2 min. 350 μl of sterile water were added to each milled sample and all was passed to the agitator for a few seconds.

Fifty microliters of each ground material were spread in three on Petri dishes containing the LPGA (Yeast, Peptone, Glucose and Agar) selective medium whose composition is 5 g for the first three elements and 15 g for the agar in a volume 1 L of water). Antibiotics and Kasugamicyne Fungicide (1 ml / L), Cephalexin (0.5 ml / L) and Cycloheximide (1 ml / L) were added to the medium.

The dishes were placed in an oven at 28 ° C for 72 h for growth of bacterial colonies. After 72 hours, a bacterial colony from each Petri dish was selected, purified and kept in an oven for 24 hours. The strains obtained were used for the diagnostic PCR.

2.1.1.4.Data analysis

Statistical analyses were done with the software R version 3.3.3 to highlight the more and less affected areas by CBB, its incidence and severity according to the years. Shapiro statistical tests performed gave significant p-values (p < 2.2e-16) and showed that the residues didn't follow the normal distribution so, the non-parametric Kruskal-Wallis test at a threshold of 5 % was performed to show the significant differences between the values.

The Multiple Linear regression model was used for the impacts of climate parameters on CBB expression. The selection of the predictive variables explaining the dependent variable has been done by the comparison of AIC (Akaike Information Criteria). The residues didn't follow the normal distribution and since the explanatory variables were quantitative and continue, the non-parametric test included the link function Family Gamma was used to highlight the climatic factors explaining CBB parameters. The correlations (using Spearman test) and interactions were studied in the case of presence of climatic factors explaining the dependent variable.

Maps were developed using the software QGIS version 2.18.4. Climatic data (Temperature, Relative Humidity and Rainfall) were collected from 14 meteorological stations by Sodexam, the weather monitoring institution.

2.1.2. Farmers' awareness of cassava bacterial blight and climate change

2.1.2.1. Study areas

Farmers' interviews were conducted between September and November in the seven agro-ecological zones in 2017.

2.1.2.2. Equipment

The equipment was constituted of GPS, recording device, markers and a questionnaire.

2.1.2.3. Methods

The country was divided into 75 x 75 Km (Figure 5 A) on QGIS in order to cover all the agro-ecological zones. This was done according to the method used by Poubom *et al*. (2005) in Cameroon. Within each block, sampling sites were selected randomly from grids measuring 18 x 18 Km (Figure 5 B) in the seven agro-ecological zones (AEZ). A total number of 84 localities with 32 for the AEZ1, 14 the AEZ2, 13 for the AEZ3, 10 for the AEZ4, 5 for the AEZ5, 9 for the AEZ6 and 1 for the AEZ7 were visited depending on the production areas. Fields coordinates were recorded with a Global Positioning System (GPS) Garmin.
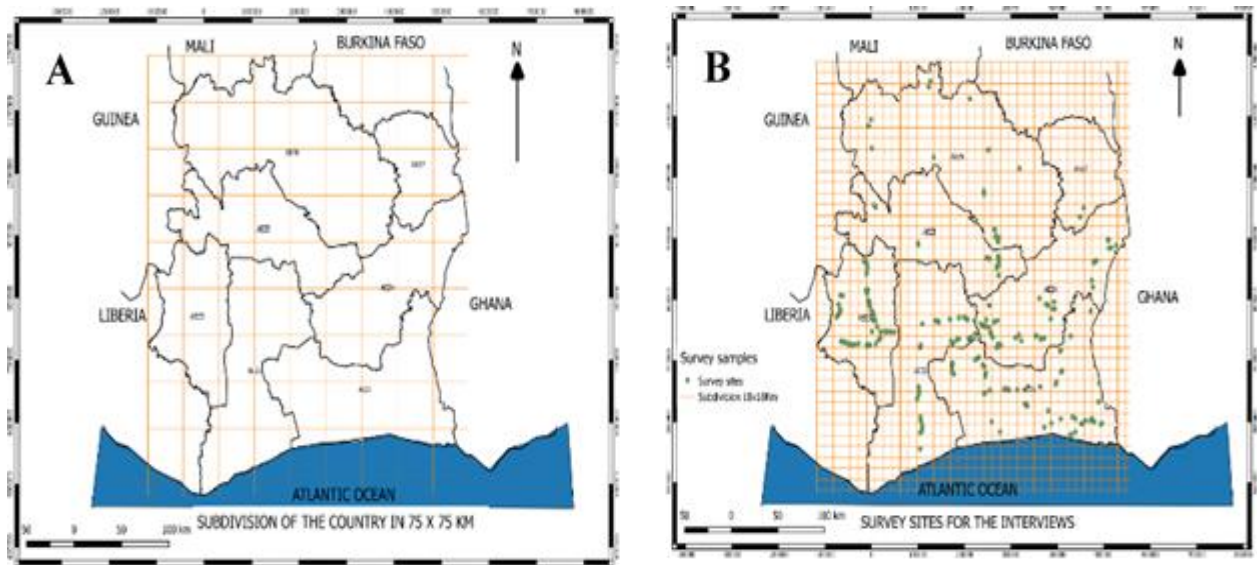
Figure 5. A and B. Division of the country respectively into 75 x 75 Km and 18 x and 18 Km

Surveys were conducted in two ways using the same structured questionnaire (Annex 1). The first phase was performed during the assessment of the cassava fields against CBB. The owners of these fields were interviewed. It was the face to face interview (Figure 6). The second phase was done during meetings organized between the interviewers and group of farmers. For these group meetings, farmers were contacted through farmers' associations. A total of 302 farmers

were interviewed. Interviews were conducted mainly in French, but also in local languages for those who didn't understand French (mostly in Malinké, Baoulé, Agni).

A direct observation was also made in order to see first-hand and verify the information collected during the interviews on cassava-related problems (malformation of cuttings and low tuber development, death of seedlings and drying of leaves).

Figure 6. Face to face interview with a farmer

The information collected also took into account the socio-economic characteristics, the information on the producer's activity, farmers' knowledge and perception of climate change and their knowledge and perception of cassava bacterial blight and the impact of climate change on its evolution.

For the socio-economic aspects, they were asked about their name, nationality, mother tongue (for Ivoirians), level of study, sex, level of literacy, age, marital status, size of the family, number of people by age group. Information about the region, the town and the village were also collected.

The information about the farmers' activity concerned the land tenure, number of years spent on the field, possession of others cassava field, size and age of the field concerned by the study, use, nature and number of manpower, practice of fallow, intercropping, mean of acquiring the cuttings, training on cassava cultivation, use of the tubers and the modalities of selling in case

of commercialization, the problems they are facing during cassava cultivation, the selling of the tubers and their expectations.in the case where they want to continue the cultivation.

Their knowledge was assessed on note of any changes in the climatic parameters (rain, temperature, air humidity) since they started cultivating cassava and what are they, if they have ever heard of climate change and where did they hear about it, what do they think climate change is, what are the causes of climate change for them and if climate change has an impact on their cassava cultivation.

They were asked if they know CBB, how did they get to know about it, how long have they seen the presence of the disease in their field, have they ever observed losses related to the disease, have they observed changes in the evolution of the disease with changing climatic parameters, are these changes insignificant or significant and how do they fight against the disease.

Farmers' responses on Climate Change and the disease were compared respectively by the data provided by Sodexam and the assessment of the fields.

2.1.2.4. Data analysis

Data were analysed by using Rstudio version 3.3. The Chi square test was performed for the proportion's comparisons.

2.2. The assessment of the susceptibility to cassava bacterial blight of the varieties the agro-ecological zones

2.2.1. Identification and assessment of the most grown cassava varieties

2.2.1.1. Study areas

The study was carried out during the rainy seasons from July to the beginning of November in different cassava producing areas of the seven Ivorian agro-ecological zones.

2.2.1.2. Equipment

The equipment was constituted of GPS, refrigerated cooler, envelopes, markers, scorecards.

2.2.1.3. Methods

The varieties assessment followed the same principle than the disease assessment and took into account the different varieties found in the fields. Each field was assessed for CBB presence/absence, the severity and the incidence of the disease, taking into account thirty cassava plants.

2.2.1.4.Data analysis

Statistical analyses were done with the software Rstudio version 3.3 in order to classify the varieties according to their level of susceptibility to CBB, the zones where they were more susceptible. The Kruskal-Wallis test with a threshold of 5 % was performed for the comparison of the SI and DI means according to the varieties. These parameters were compared for each field and each AEZ where the varieties were encountered.

Maps have been built by using the software QGIS version 2.18.4 based on the longitudes and latitudes of each field recorded during the survey. A georeferenced map of Côte d'Ivoire was used for the projection of the points.

2.2.2. Screening of the cassava varieties under climate parameters

2.2.2.1.Study areas

For the field trials, four sites (Figure 7) were considered: Ferkessédougou or Ferke (North, savannah zone, agro-ecological zone 6), Aboisso (South-East, forest zone, agro-ecological zone 1), Yamoussoukro or Yakro (Centre, Forest-savannah Transition Zone, agro-ecological zone 4). The fourth site, the control was in Man (West, Forest Zone, agro-ecological zone 3). The choice of the first three sites follows the first surveys which showed that they were very affected by the disease.
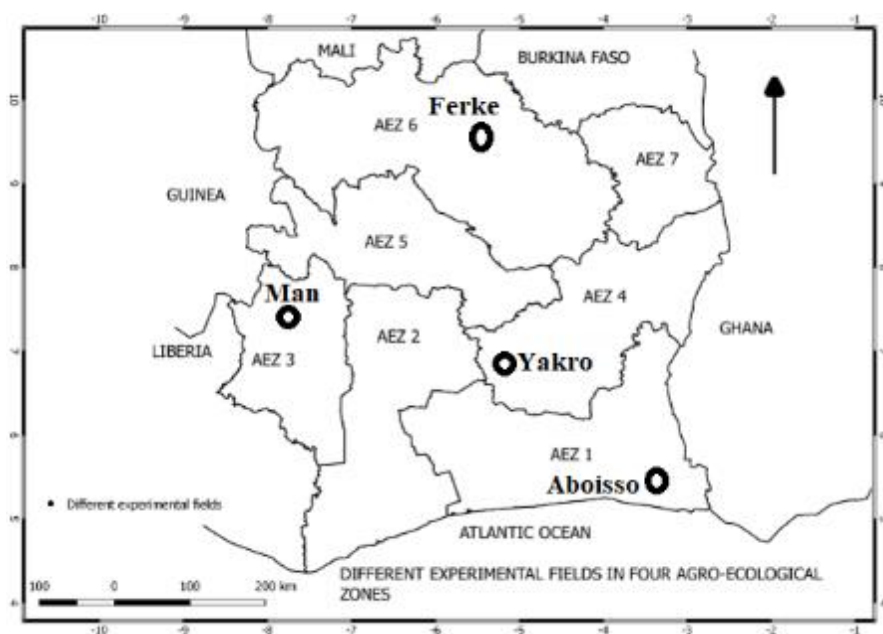
Figure 7. Experimental fields in the agro-ecological zones of Côte d'Ivoire

2.2.2.2. Equipment

The equipment was constituted of GPS, cassava cuttings, labels, weighing machine, data loggers and rain gauges, sheet for the assessment.

2.2.2.3. Methods

Each trial was set up according to a Fisher completely randomized design. The sites constituted the blocs. Within each bloc, there were 3 parcels that contained eight treatments/eight most grown varieties in Côte d'Ivoire randomly distributed (Annex 2). These varieties were constituting of four local (Yace, Akama, Dankwa and Diarrassouba) and four improved (Yavo, Bocou1, Bocou2 and Bocou3) varieties (Annex 3). The design makes it possible to overcome the difficulty of soil fertility. The planting density used was 5,000 feet per ½ hectare with dimensions of 98×10 m per parcel with a separation of 1 m in all directions. The parcels were separated by 2 m from each other (Raffaillac, 1997). Thirty plants per variety were used. Data loggers and rain gauges were used to collect climatic parameters (precipitation, relative humidity, temperature).

The observations started two months after the setting up of the trials because at this stage, some varieties can show the disease symptoms. Data were collected every two months and the assessment were based on Wydra and Msikita's (1995) rating scale. After each evaluation, samples were collected for laboratory analysis to confirm that the observed symptoms were those of CBB. The assessments were done until harvest to determine the impact of the disease on yield. The total number and weight of the fresh roots were compared and estimated for each variety and site following Azorji *et al* (2016) methodology. For each assessment, the incidence and severity of the disease were determined for each area in order to rank the varieties according to their susceptibility level and the areas where they were more susceptible.

2.2.2.4. Data analysis

For the varieties assessment, Kruskal-Wallis test was performed to highlight the level of the varieties susceptibility on the different sites. The correlation tests between climatic conditions and CBB parameters on each variety and each site were performed with Spearman correlation test. Shapiro and Fligner-Killeen tests were performed respectively for the normal distribution of the residues and the homogeneity of variances in the case of the roots number and weight. ANOVA was done in case of normal distribution of the residues and homogeneity of variances while Kruskal-wallis was done in case of where the residues were not normally distributed and there was a homogeneity of variances. These tests were performed for the comparison of the

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variances. The correlation tests between yield and CBB parameters were performed with the Pearson correlation test. In case of significant differences, the Turkey-HSD has been performed to distinguish the different groups. The graphs were built with R and Excel version 2016.

2.3. The identification of the pathogenic and genetic structures of the *Xanthomonas phaseoli* pv. *manihotis* strains

2.3.1. Pathogenicity of *Xanthomonas phaseoli* pv. *manihotis* strains

2.3.1.1. Study areas

These tests were conducted in a greenhouse under a monitoring of the evolution of symptoms depending on the temperature, relative humidity and the dew point.

2.3.1.2. Equipment

The equipment was constituted of 10 bacterial strains, eight cassava varieties, labels, syringes, microtubes, alcohol, sterile distilled water, loggers, and sheet for the assessment.

2.3.1.3. Methods

The methodologies used by Verdier *et al* (1998) and Banito *et al* (2010) were employed for the inoculations and the assessment. Suspensions of 10^8 CFU / ml were prepared from bacterial culture of 24 hours in 5 ml of sterile distilled water. The concentration was measured in a spectrophotometer at a wavelength of 600 nm and an optical density (OD) of 0.02 with an uncertainty of 10 % according to the formula below :

Volume of distilled water to add = (OD obtained-desired OD) / (desired OD) $\times$ Vr

Vr = volume remaining after reading the first OD.

Three one month old plants per strain and per variety were inoculated between the secondary vein using syringes without needles under a temperature of 25 to 30 ° C and about 90 % of relative humidity. Disease progress was monitored 5, 10, 15, 20, 25 and 30 days after inoculation using a symptom severity scale of : 1 = no symptoms; 2 = wilting of one leaf; 3 = wilting of 2 to 4 leaves; 4 = wilting of more than 4 leaves; 5 = dieback of the plant.

2.3.1.4. Data analysis

Data analysis was performed by following the methodology used by Ogundjobi *et al* (2010). They took into account the calculation of the area under the disease progress curve (AUDPC). It was calculated based on the trapezoidal integration of a single plant over the whole observation period. The following formula was used :

AUDPC = Σi[(DSi + DSi-1) x (ti – ti-1)]/2 where "i" = {5; 10; 15; 20; 25; 30} represent the days of observation, "DS" represents the disease score using the above severity presented in the above method and "t" represents the number of days post-inoculation (Shaner G and Finney R, 1977; Jeger M and Viljanen- Rollinson S, 2001). For a good performance of the analyses, each DS has been subtracted of 1 before using them in the formula. The percentages of AUDPC of the different strains were used for the comparison of the varieties susceptibility. They were classified in groups of resistant (0-33.2 %), moderately resistant (33.3-49.9 %) and susceptible genotypes (50-100 %). Principal component analysis (PCA) of disease severity represented by AUDPC values of the ten strains was done to identify the groups of differential strains. Pearson correlation analysis was performed to identify the existing correlations between the strains and to classify them according to their susceptibility.

2.3.2. Study of the genetic diversity of *Xpm* strains

2.3.2.1.Study areas

The analyses were done at IRD (Institut de Recherche pour le Développement)/Montpellier-France. They were based on the strains of the agro-ecological zones grouped into four vegetative zones (EDSCI-II, 1999; FAO, 2005b; Halle and Bruzon, 2006).

The vegetatives zones were defined as followed : Forest Zone or Zone 1 grouping the agro-ecological zones 1, 2 and 4; Mountain Zone or Zone 2 representing the agro-ecological zone 3; Transition Zone or Zone 3 representing the agro-ecological zone 5 and Savanah Zone or Zone 4 grouping the agro-ecological zone 6 and 7 (Figure 8).
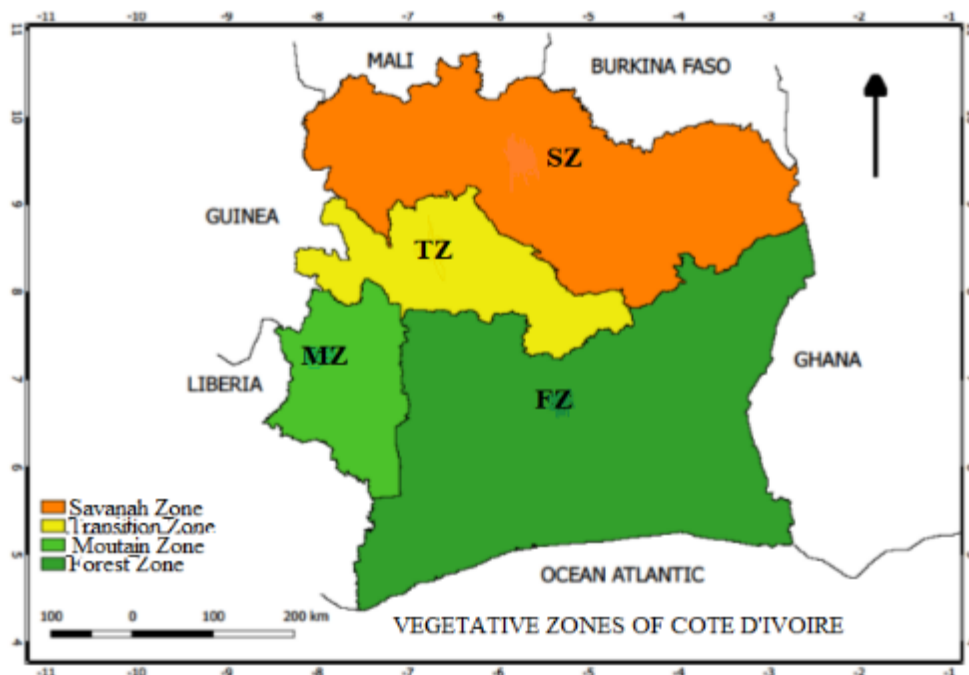
Figure 8. Vegetative zones of Côte d'Ivoire

2.3.2.2.Equipment

The equipment was constituted of leaves samples, bacterial strains, DNA, Kits for the PCR and the strains typing, a grinder (Tissue Lyser II), spectrophotometer, thermal cycler (PTC-200) and electrophoresis tank.

2.3.2.3.Methods

A set of 60 samples were used (15 samples per zone) and *Xpm* strains were isolated from them. The origin of these samples is shown in the Annex 4.

For the validation of the strains by PCR diagnosis, the lysis of the bacterial colonies were carried out with the strain CIO151 as reference. This is a strain from collection of IRD. It was performed in 96-well plates containing 100 µl of PBS buffer (Phosphate Buffered Saline) of 1X concentration and half of a 10 µl loop of each *Xpm* strain. The suspension was homogenized and lysed in a thermal cycler (PTC-200) at 94 ° C for 15 minutes.

The Duplex PCR based on the methodology of Bernal-Galeano *et al* (2018) has been completed. It allows the amplification of two genomic specific fragments of *Xpm*, the rpoB housekeeping gene (944 bp) and the coding fragment for the C-terminal portion of TAL effectors of *Xpm* (570 bp) whose sequences are in the Annex 5.

The reaction mixture was prepared with the various components as summarized in the Annex 6. The positive and negative controls used were bacterial strain and water, respectively.

The amplification of the PCR products was carried out according to the program summarised in the Annex 7. The migration of the PCR products was carried out on a 1 % agarose gel placed in an electrophoresis tank containing buffer 0.5 X TBE (10.8 g of Tris, 5.5 g of boric acid, 0.6 1 g of EDTA for 1 L of solution) for 30 min at 100 V. The gel is then incubated in a 1 % ethidium bromide bath (intermediate layer of DNA) and water for 10 minutes for each step in order to stain the DNA and visualize the amplicons under UV radiation. A 1 Kb reference fragment was used to identify the desired fragments. The strains validated by the diagnostic PCR were stored at - 80 ° C in a cryotube containing 1 ml of LPG and 350 µl of diluted glycerol at 80 %.

For the typing of *Xpm* strains using the MLVA scheme, bacterial lysis of the strains validated by the PCR diagnosis was performed. For that purpose, 150 µl of water was put in a microplate with the addition of half a loop of bacterial colony; then lysis was done in Tissue Lyser II.

The typing was carried out on the basis of 14 loci. The amplification was done through a multiplex PCR. This one-time amplification took into account several domains of DNA. Four pools containing 4 pairs of different fluorochrome labelled primers (Annex 8) were used for

the PCR mix. The sizes of the amplified VNTRs were measured by capillary electrophoresis, and then these profiles were converted into the number of pattern repeats for each VNTR. The Qiagen Kit whose composition for a sample is recorded in Annex 9 was used for the realization of the mixes.

Once the reaction mixture was prepared, 9 μl was dispensed into each well of a 96-well microplate and 1 μl of each bacterial suspension was added. Centrifugation and amplification were performed. The amplification program is shown in Annex 10.

Genetic analysis by capillary electrophoresis

Genetic analysis by capillary electrophoresis (ABI 3130xl Sequencer) allows evaluation of fragment size. It promotes the separation of a large quantity of molecules by migration; and therefore, the separation of DNA strands and the genotyping of bacterial strains. The migration of the samples is done in a polymer according to their sizes and through capillaries. The excitation of fluorochromes fixed on the primers by a laser leads to a specific signal emission for each fluorochrome and thus allow to have the size of each associated fragment.

The PCR amplicons were diluted 1 / 150^e in water (149 μl of sterile water + 1 μl of amplicons) in new mircoplates to reduce the magnitude of the signal. The amplicons were diluted in a solution containing lysis buffer 500 and formamide (CMR) for genotyping.

Each peak obtained allowed the calculation of the number of repetitions of the VNTR loci (alleles) whose chain combination represents the MLVA scheme. The calculation was done by removing the size of the two flanking regions x and y from the repeated pattern of the size of the amplicons. The length of the VNTR was divided by the size of the base pattern to give the number of repetitions of the pattern retained as the value of the allele.

2.3.2.4. Data analysis

The processing of the genotyping data was done using the GeneMapper software (Applied Biosystems). These data include the observed alleles for the 14 VNTR loci analysed for each strain. The analysis of the genetic diversity and the construction of the tree of descent were carried out using the softwares below:

• GenAlex software (Peakall R and Smouse P, 2012) for observing allelic frequencies and estimating the number of haplotypes.

• The Arlequin software (Excoffier L and Lischer H, 2010) for statistical tests to determine allelic richness (number of alleles per population) and inter-population diversity by calculating

the frequencies of alleles and haplotypes. The differentiation coefficients FST (model with infinite alleles) and RST (step model) were used to verify the presence of genetic differentiation between the three populations.

• The Phyloviz software for the construction of the progeny tree to group haplotypes into clonal complexes (haplotypes varying at a locus into clonal complexes as a function of distance as well as the number of repetitions) and to deduce the pathway of *Xpm* strains. The goEBURST Full MST algorithm associated with Euclidean distance has been used to link haplotypes. The tree of descent makes it possible to determine the genetic links existing between the individuals of the same parcel or of different parcels to establish possible epidemiological relations between the individuals (Francisco *et al*, 2012).

CHAPTER 3 : RESULTS

3.1. The highlight the key climate parameters involved in the evolution of cassava bacterial blight the agro-ecological zones

3.1.1. Distribution and evolution of cassava bacterial blight under climate parameters

3.1.1.1. Phenotypical aspects of the strains isolated

These have the same characteristics as the reference strain CI1, no pigmented, of a convex appearance with regular contours, smooth and shimmering ivory white (Figure 9).

Figure 9. Colonies of *Xanthomonas phaseoli* pv. *manihotis*

3.1.1.2. CBB dispersion

Cassava Bacterial Blight was present in all the agro-ecological zones visited during the four years period. The year 2017 recorded the most affected localities and fields. Although the year 2016 recorded the least affected localities, the fields visited were more affected than those of 2014 and 2015. Both the localities and fields of 2014 were more diseased than those of 2015. During the four years, the AEZ1 was the most diseased. In 2014, the AEZ6 was the least diseased while in 2015, the AEZ5 and AEZ7 presented the least affected localities and fields. The year 2016 was characterized by the absence of the disease in the AEZ3, AEZ5 and AEZ7. In 2017, both AEZ3 and AEZ7 were the least diseased (Figure 10 A, B, C and D).
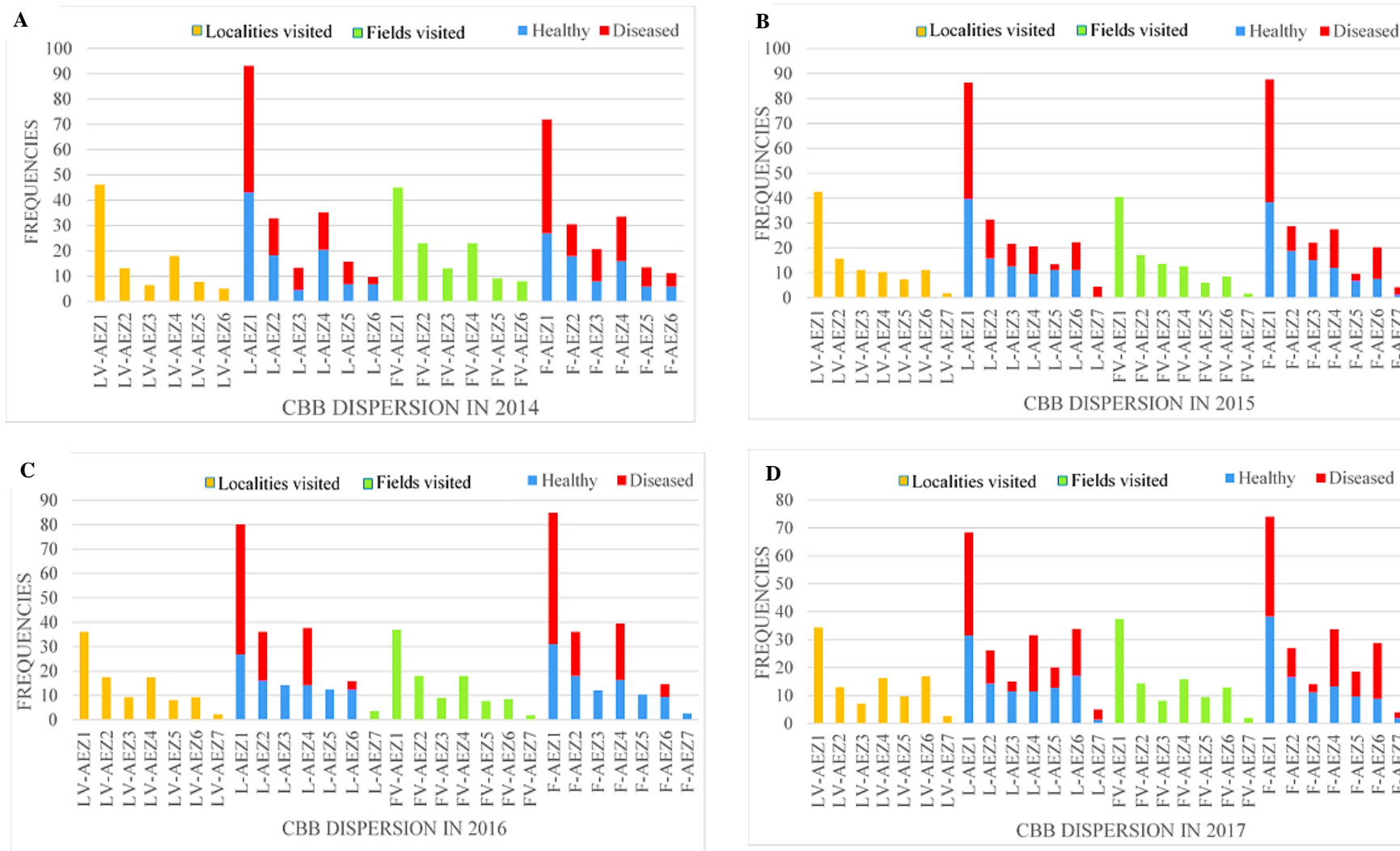
Figure 10. A, B, C and D: Healthy status of the localities and fields visited in the Agro-ecological zones (AEZ) respectively in 2014, 2015, 2016 and 2017 where LV: Localities Visited; L: Localities; FV: Fields Visited; F: Fields

3.1.1.3. CBB evolution under climatic parameters

The amount of Rainfall (RF), Temperature (Temp), Relative Humidity (RH) and Number of Rainy season days (NRD) collected from the meteorological stations were respectively 143.47 $\pm$ 68.06 mm, 26.17 $\pm$ 0.61 ° C, 81.09 $\pm$ 3.73 % and 14.79 $\pm$ 6.74 days when considering all the years. RF, Temp, RH and NRD of the dry season before the rainy season of the surveys were respectively 66.44 $\pm$ 47.32 mm, 25.52 $\pm$ 1.11 ° C, 77.5 $\pm$ 13.67 % and 9.72 $\pm$ 4.51 days. CBB severity and incidence under these conditions were estimated at respectively 10.16 $\pm$ 20.64 and 11.27 $\pm$ 23.28 for the four years.

Statistical analyses showed significant differences for CBB parameters (p_{SI} = 2.042e-08, p_{DI} = 1.645e-08) and climatic parameters ($p < 2.2$e-16).

At the agro-ecological zones level, the highest rates of CBB severity and incidence were found in the AEZ6 and the lowest rates were found in the AEZ3. The evolution of the disease and the climatic parameters (dry season that prevailed before the rainy season and the rainy season) are summarized in Figure 11 A and B.

There were significant differences in CBB expression (p_{SI}= 0.00023, p_{DI} = 0.00020) and climatic conditions for the set of the four years (p_{RF} = 0.01247, p_{Temp} = 3.491e-12, p_{RH} = 6.552e-06, p_{NRD} = 1.961e-11).
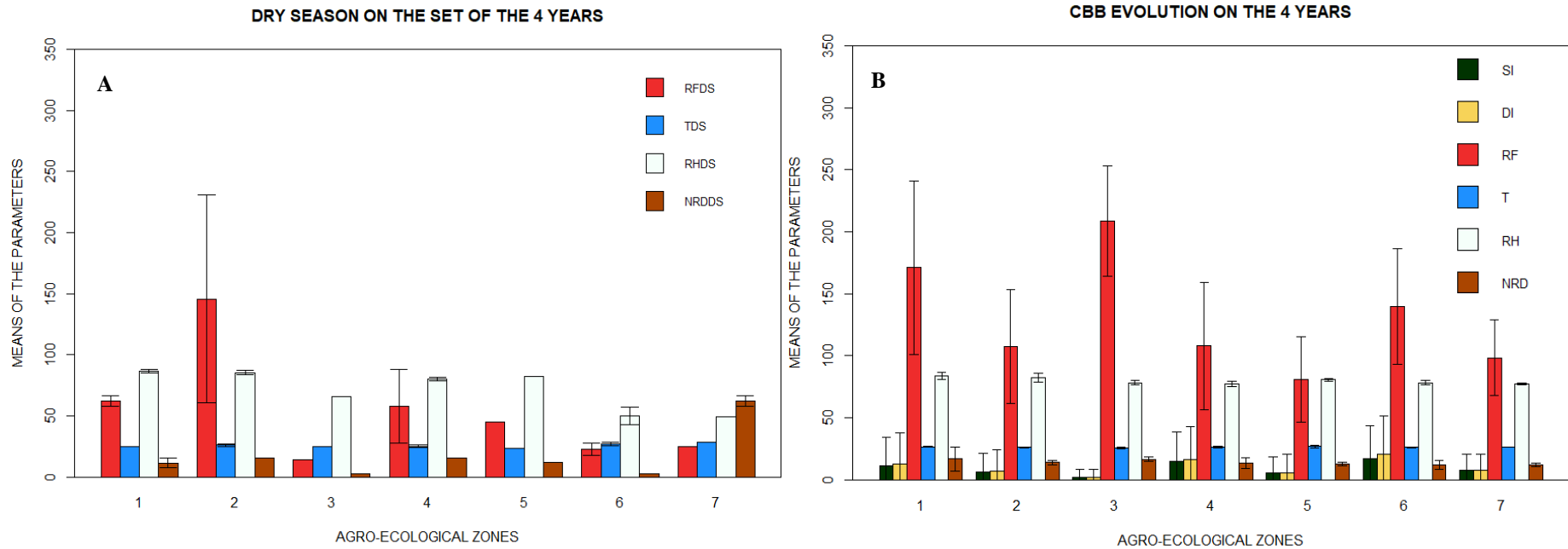
Figure 11. Climatic parameters during the dry season and CBB evolution in the agro-ecological zones on the set of the 4 years

A: Climatic parameters during the dry season in the agro-ecological zones on the set of the 4 years where RFDS: Rainfall of the Dry Season; TDS: Temperature of the Dry Season; RHDS: Relative Humidity of the Dry Season; NRDDS: Number of Rainy Days of the Dry Season.

B: Cassava Bacterial Blight (CBB) evolution during the rainy season in the agro-ecological zones on the set of the 4 years where SI: Severity Index; DI: Disease Incidence; RF: Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days.

3.1.1.4. CBB evolution in 2014

This year was characterized by an amount of RF equal to 126.14 ± 42.66 while Temp was equal to $26.1 \pm 0.47 \,°C$, RH was of 80.73 ± 3.9 % and the NRD was of 16.01 ± 18.05 days. The dry season that preceded this rainy season had a mean of 97.54 ± 50.61 mm for RF, $25.3 \pm 0.65 \,°C$ for Temp, 79.11 ± 12.14 % for RH and 10.96 ± 4.21 days. DI and SI of the year were respectively of 18.46 ± 32.79 and 16.79 ± 29.47.

CBB presented the highest severity and incidence rates in the AEZ4 and the lowest ones in the AEZ5. The relative information on CBB evolution and the climatic conditions are presented in Figure 12 A and B.
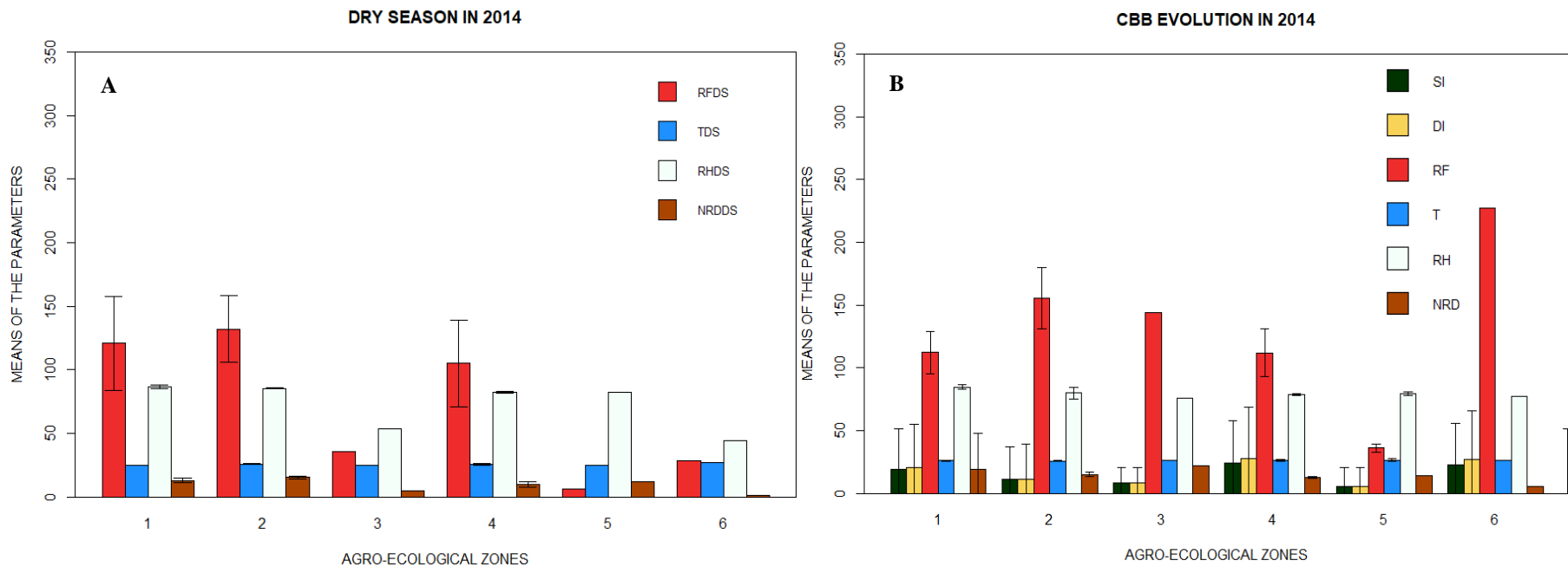
Figure 12. Climatic parameters during the dry season and CBB evolution in the agro-ecological zones in 2014
A : Climatic parameters during the dry season where RFDS: Rainfall of the Dry Season; TDS: Temperature of the Dry Season; RHDS: Relative Humidity of the Dry Season; NRDDS: Number of Rainy Days of the Dry Season. B: Cassava Bacterial Blight evolution during the rainy season where SI: Severity Index; DI: Disease Incidence; RF: Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days.

The healthy maps showing the details of the incidences and severities in the agro-ecological zones are shown in Figure 13 A and B. Statistical analyses did not show significant differences for CBB parameters. However, differences were significant for climatic parameters.
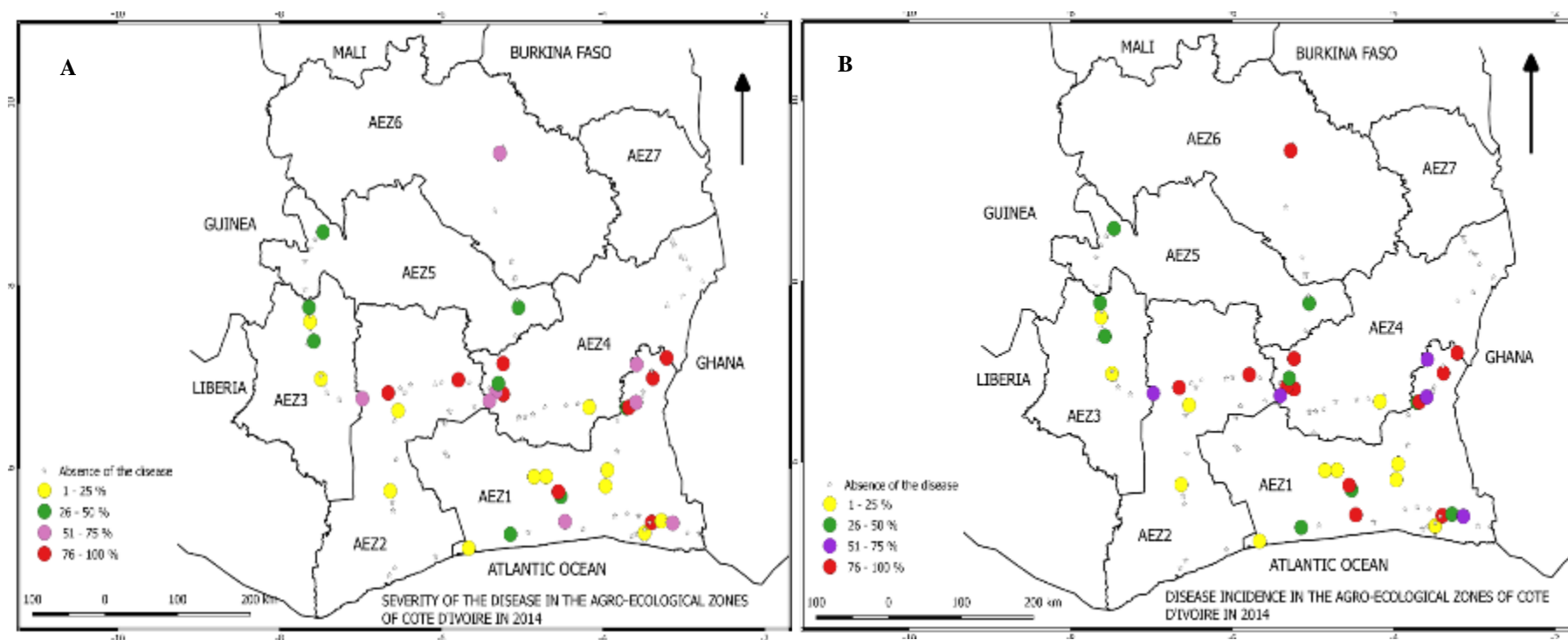
Figure 13. Overview of CBB severity and incidence in the Agro-ecological zones in 2014

A: CBB severity in the Agro-ecological zones. B: CBB incidence in the Agro-ecological zones

3.1.1.5. CBB evolution in 2015

In 2015, the means were 156 ± 79.28 mm, $26.31 \pm 0.43\,°$ C, 81.66 ± 3.64 % and 14.04 ± 1.94 days respectively for RF, Temp, RH and NRD. They were preceded by a RF of 64.43 ± 55 mm, a Temp of $25.28 \pm 0.98\,°$ C, a RH of 78.87 ± 12.14 % and a NRD of 15.5 ± 5.42 days for the dry season. SI and DI of the year were respectively 8.17 ± 19.03 and 8.61 ± 20.26.

The AEZ6 was the most affected by the disease with the highest severity and incidence while the least diseased was the AEZ5. The description of CBB evolution and the relative information on the dry and rainy seasons are summarized in Figure 14 A and B.
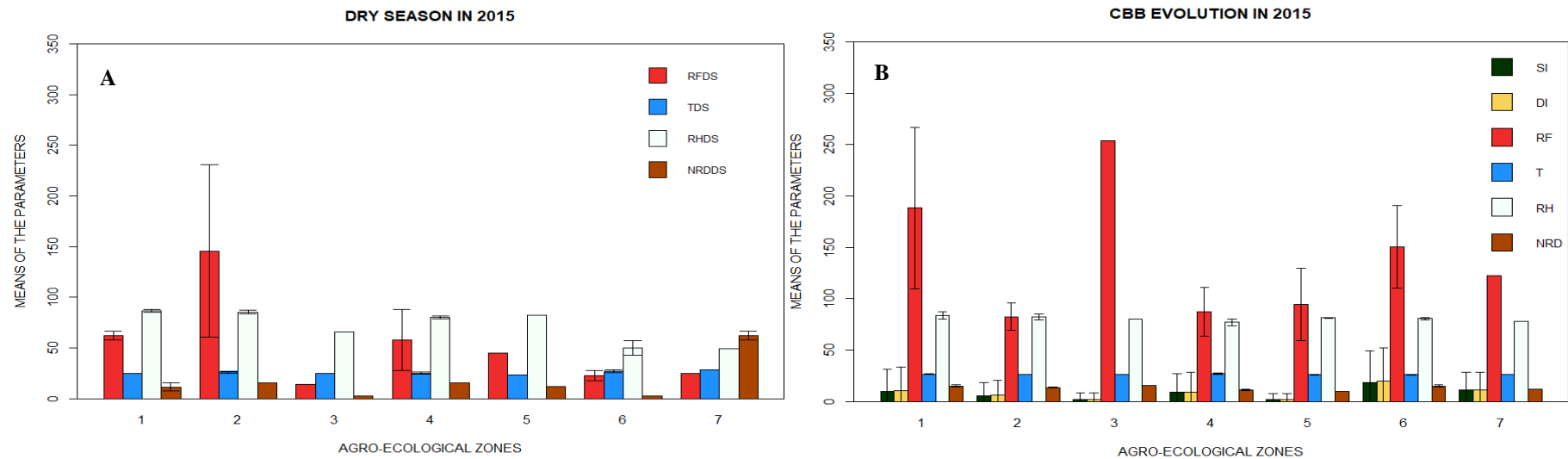
Figure 14. Climatic parameters during the dry season and CBB evolution in the agro-ecological zones in 2015

A: Climatic parameters during the dry season where RFDS: Rainfall of the Dry Season; TDS: Temperature of the Dry Season; RHDS: Relative Humidity of the Dry Season; NRDDS: Number of Rainy Days of the Dry Season. B: Cassava Bacterial Blight evolution during the rainy season where SI: Severity Index; DI: Disease Incidence; RF: Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days. Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days.

The healthy maps showing the details of the incidences and severities in the agro-ecological zones are show in Figure 15 A and B.

Statistical analyses didn't show significant differences for CBB parameters. However, they were significantly different for climatic parameters.
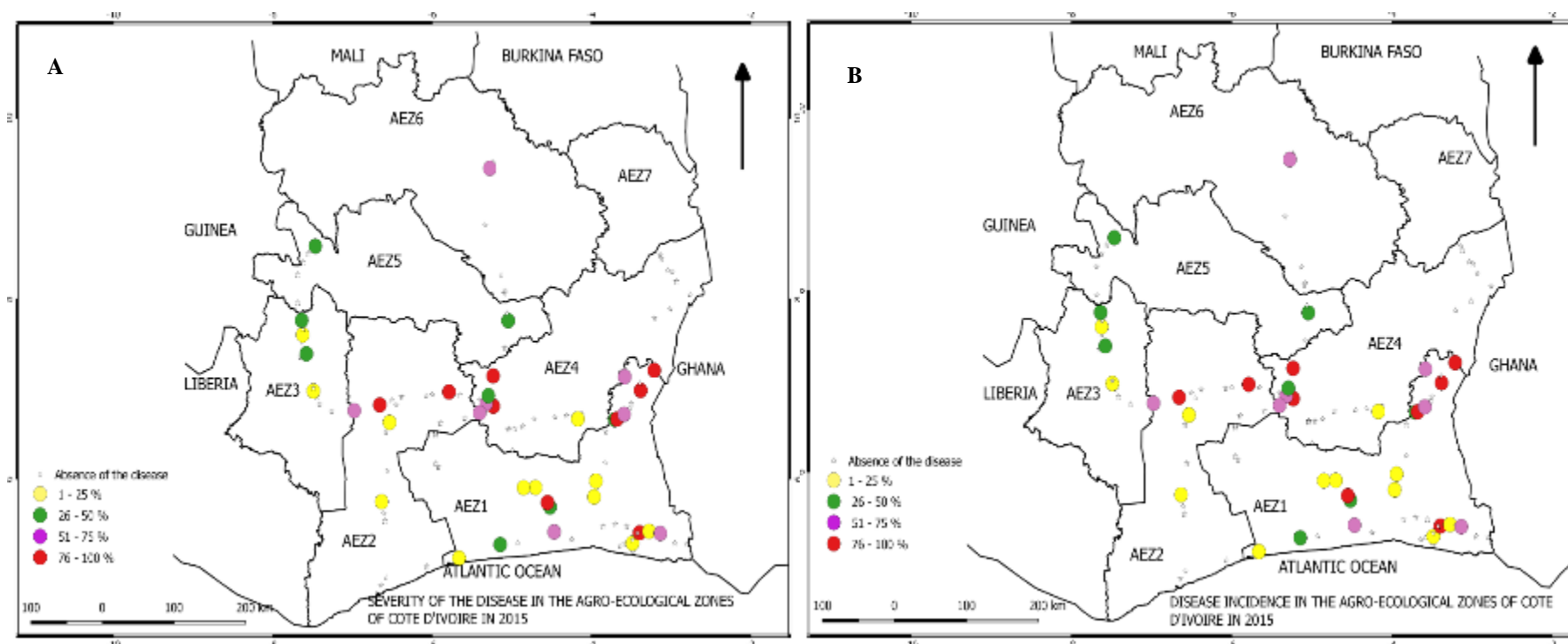
Figure 15. Overview of CBB severity and incidence in the Agro-ecological zones in 2015

A: CBB severity in the Agro-ecological zones. B: CBB incidence in the Agro-ecological zones.

3.1.1.6. CBB evolution in 2016

In 2016, the amount of RF was 130.86 ± 42.46 mm, Temp was 26.03 ± 0.97 ° C, RH was 81 ± 3.76 % and NRD was 14.56 ± 2.83 days. The dry season had means of 62.57 ± 50.72 mm for RF, 25.64 ± 1.07 ° C for Temp, 78.41 ±12.04 % for RH and 9.23 ± 4.34 days for NRD. SI and DI of the year were respectively 9.32 ± 19.32 and 11.51 ± 23.81.

CBB was more severe in the AEZ1 and less severe in the AEZ2. The relative information on CBB evolution and climatic parameters are described in the Figure 16 A and B.
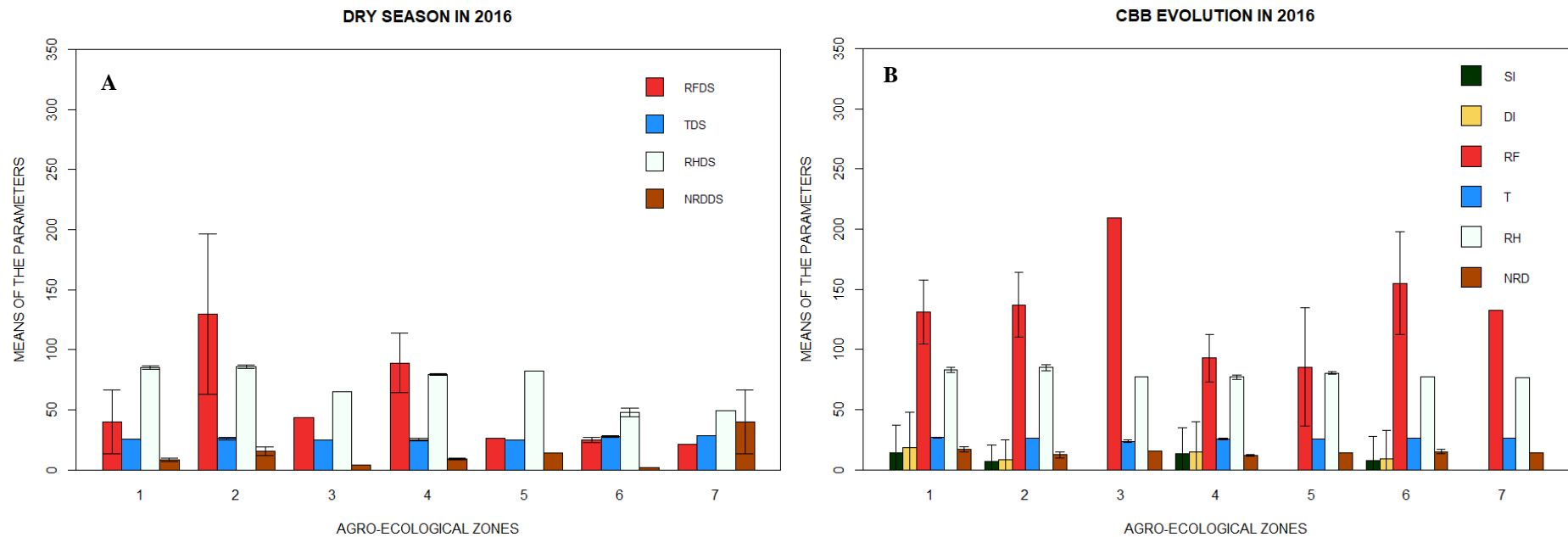
Figure 16. Climatic parameters during the dry season and CBB evolution in the agro-ecological zones in 2016

A: Climatic parameters during the dry season where RFDS: Rainfall of the Dry Season; TDS: Temperature of the Dry Season; RHDS: Relative Humidity of the Dry Season; NRDDS: Number of Rainy Days of the Dry Season. B: Cassava Bacterial Blight evolution during the rainy season where SI: Severity Index; DI: Disease Incidence; RF: Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days.

The healthy maps showing the details of the incidences and severities in the agro-ecological zones are shown in Figure 17 A and B. Statistical analyses showed significant differences for CBB parameters ($p_{SI} = 0.0174$, $p_{DI} = 0.01605$), and for climatic parameters ($p_{RF} = 9.925e-15$, $p_{Temp} = p_{RH} = p_{NRD} < 2.2e-16$).
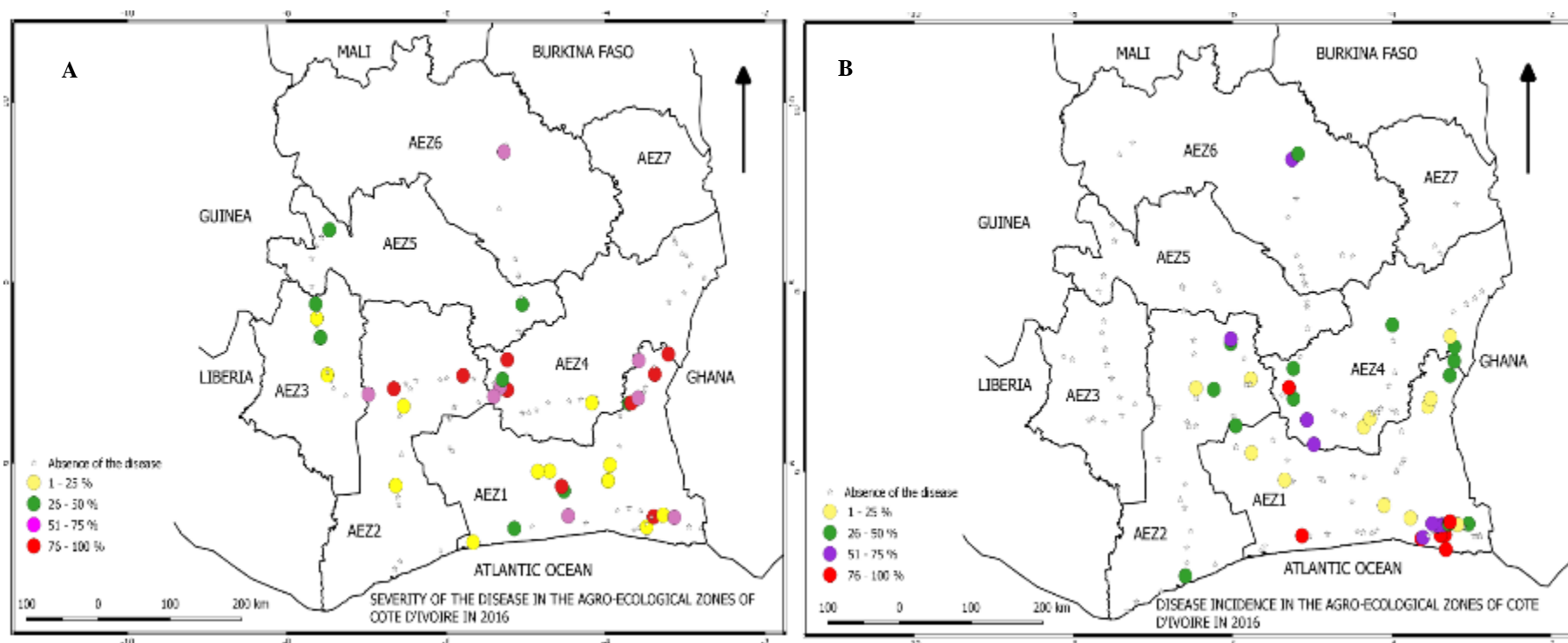
Figure 17. Overview of CBB severity and incidence in the Agro-ecological zones in 2016

A: CBB severity in the Agro-ecological zones. B: CBB incidence in the Agro-ecological

3.1.1.7. CBB evolution in 2017

In 2017, RF was 142.02 ± 69.29 mm, Temp was 26.13 ± 0.57 ° C, RH was 80.71 ±3.7 % and NRD was 15.20 ± 3.60 days while the dry season was characterized by an amount of RF of 60.42 ± 31.45 mm, Temp of 25.77 ± 1.27 ° C, RH of 75.45 ± 15.33 % and NRD of 8.84 ± 3.44 days. SI and DI of the year were respectively 10.28 ± 18.9 and 11.42 ± 21.76.

The highest SI and DI were found in the AEZ6 and the lowest were presented by the AEZ3. The relative information on the disease evolution and the dry and rainy seasons are described in Figure 18 A and B.
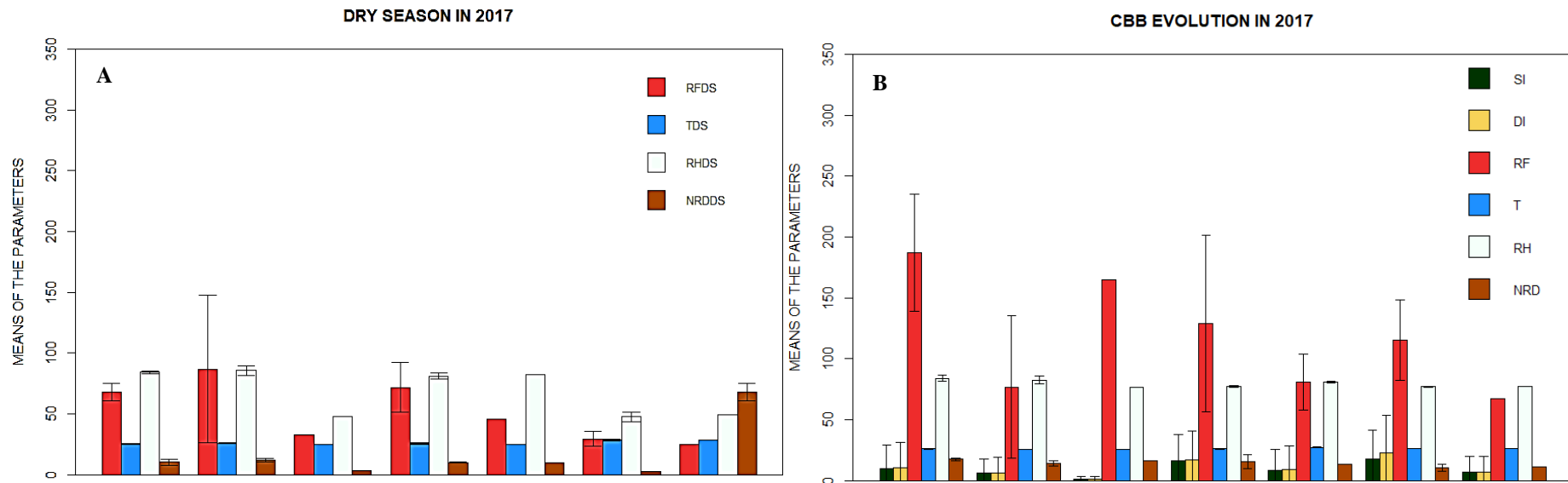
 Figure 18. Climatic parameters during the dry season and CBB evolution in the agro-ecological zones in 2017

A: Climatic parameters during the dry season where RFDS: Rainfall of the Dry Season; TDS: Temperature of the Dry Season; RHDS: Relative Humidity of the Dry Season; NRDDS: Number of Rainy Days of the Dry Season. B: Cassava Bacterial Blight evolution during the rainy season where SI: Severity Index; DI: Disease Incidence; RF: Rainfall; T: Temperature; RH: Relative Humidity; NRD: Number of Rainy Days.

The healthy maps showing the detail of the incidences and severities in the agro-ecological zones are presented in Figure 19 A and B. Statistical analyses showed significant differences for CBB parameters (p_{SI} = 5.226e-05, p_{DI} = 4.252e-05) and for climatic parameters (p < 2.2e-16).
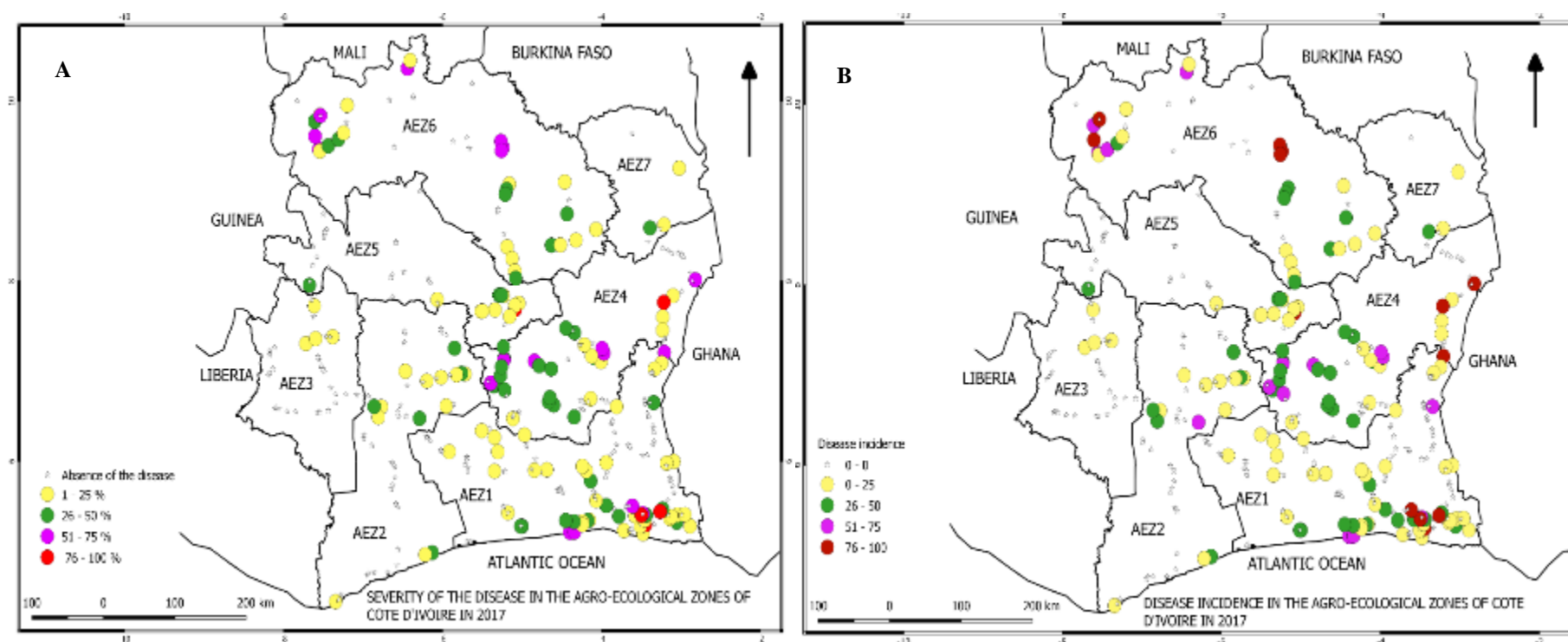
Figure 19. Overview of CBB severity and incidence in the Agro-ecological zones in 2017

A: CBB severity in the Agro-ecological zones. B: CBB incidence in the Agro-ecological

3.1.1.8. Impact of climatic factors on CBB evolution

Within the four years period, Rainfall was the factor that could explain SI and DI. The Generalized Linear Model showed that the presence of Rainfall lead to a significant expression of the disease with $p = 0.02$. Correlation tests showed that, when Rainfall increased, SI and DI decreased (rho = -0.07; $p = 0.03$ for both).

There was no relationship between CBB and climatic parameters in 2014. In 2015, both Rainfall and NRD explained SI and DI. The presence of Rainfall lead to a significant expression of SI ($p = 0.0004$) and DI ($p = 8.17e-06$). An increase in NRD also lead to a significant expression of SI ($p = 0.007$) and DI ($p = 0.002$). The interaction of the climatic parameters was not significant in disease expression ($p = 0.07$ for SI and $p = 0.09$). The correlation tests showed that the increased Rainfall amount decrease SI and DI while NRD increased SI and DI but this correlation was not significant (rhoRF = -0.08, pRF = 0.12, rhoNRD = 0.1, pNRD = 0.06 for both).

In 2016, there was a significant expression of CBB because of Temp presence ($p = 0.02$ for both). According to the correlation test, when Temperature increased, both SI and DI increased with rho = 0.17, $p = 0.03$ for both. In 2017, Temperature impacted significantly SI ($p = 0.03$). RH presence impacted SI while NRD presence impacted SI but not significant ($p = 0.07$ for both). The interaction between the Temperature and RH increased but not significant SI ($p = 0.92$). Those between RH and NRD decreased significantly SI ($p = 0.008$) and that between Temp and NRD decreased SI but not significant ($p = 0.094$). The interactions between the presence of these three parameters increased significantly SI ($p = 0.00014$).

The correlations tests showed that Temp significantly increased SI (rho = 0.1, $p = 0.04$). RH decreased SI but was not significant (rho = -0.03, $p = 0.6$). NRD increased SI but was, not significant (rho = 0.03, $p = 0.6$). The correlation test showed that Temp decreased significantly DI (rho = 0.1, $p = 0.04$).

3.1.1. Farmers' awareness of cassava bacterial blight and climate change

3.1.2 1. Farmers socio-economic characteristics

The interviewed farmers constituted 78,48 % men and 21.52 % of women ($p = 1.231e-08$). The average age was 42 years old with the majority ($p = 0.0137$) between 37-52 years old (44.7 %) followed by those between 21-36 years old (34.44 %) and those who had 53-70 years old (20.86 %). The age of the majority of the cassava farmers were comprised between 37-52 years with a mean of 42 years.

A total of 89.07 % farmers were Ivorian and 10.93 % were foreigners with 8.28 from Burkina, 1.99 % from Mali, 0.33 % from Togo and 0.33 % from Benin ($p < 2.2e-16$). Among them, 84.77 % were married, 7.62 % were fiance, 7.28 % were single and 0.33 % comprised widower ($p < 2.2e-16$).

For the level of education, 66.23 % had no level of education; 17.88 % had up to primary level; 15.23 % had up to secondary school while only 0.66 % completed the university ($p = 1.231e-08$). The percentage of farmers who could not read and write was 66.23 % against 33.77 % for those who could read and write. The average family size was 5 with the majority , 59,93 % between 0-5 members, 37.09 % between 6-10 members and 2.98 % had more than 10 members ($p = 5.143e-13$). The distribution of age category dependent on the family or households were 40 % for 0-5 years old, 25 % for 6-10 years old, 25 % for 11-18 years old and 10 % for over 18 years old ($p < 2.2e-16$).

3.1.2.2. Farmers' activity

The majority of the farmers (97.02 %) were owners of the land where cassava was cultivated while 1.66 % were renting and the others 1.32 % were on an administrative property ($p < 2.2e-16$). Majority, 75 % of farmers acquired the lands through inheritance from their relatives while 25 % spent 1-10 years on the fields ($p < 2.2e-16$).

A total of 15 % of the farmers had a field with ¼ ha, 35 % with ½ ha, 40 % with 1 ha and 10 % with more than 1 ha. Despite the importance of cassava cultivation in Côte d'Ivoire, the most important cassava farm area was estimated at 1 ha (40 %) in this study followed by the 0.5 ha (35 %), ($p < 2.2e-16$). For the age of the current cassava fields visited, 20 % were between 3-7 months, 45 % between 8-12 months and 35 % more than one year ($p < 2.2e-16$).

Most of the farmers ($p = 4.826e-07$) used manpower (72.19 %) mainly constituted at 46.36 % by the members of their family. Among them, 5.63 % were helped by their friends, 19.54 % required contractual and 0.66 % were helped by work groups ($p < 2.2e-16$). The remain 27.81 % did not use manpower. Fallow was practiced by 39.74 % of the farmers while 60.26 % did not practice it ($p = 3.87e-08$). Only 0.33 % had followed a training programme on cassava cultivation ($p < 2.2e-16$).

Majority of the cuttings for planting, 85.1 % were acquired from the farmers own field while 9.27 % were obtained from neighbouring farms and 5.63 % from their friends. Majority of the farmers 61.92 % practiced while 38.08 % cultivated only cassava ($p < 2.2e-16$). The other crops that were intercropped with cassava varied according to the agro-ecological zones. The South-East and the Eastern part of the country were mostly characterized by the growth of banana

trees, oil palm trees, eggplants, papaw, pineapple, pepper and rubber. The Southern and the Western parts were characterized by banana trees, a bit of oil palm trees, eggplants, pepper, tomatoes, Okra, pawpaw, sweet potatoes and mainly cocoa, coffee and rubber. In the Northern, North-West and North-Est, farmers cultivated yam, taro, sweet potatoes, cashew trees and maize.

In terms of the use of the tubers, 1 % cultivate for its own consumption, 7.28 % cultivate only for commercialization and 91.72 % used the tubers for both consumption and the commercialization (p < 2.2e-16). The majority of the farmers sold their tubers to the local market and almost all their production was intended for both consumption and commercialization.

Most of the farmers (99.67 %) sell their tubers at the market while 0.33 % sells them to a cooperative and for the modalities, 93.38 % sell them in detail (100-500 FCFA), 5.96 % by bag of 5000-10000 FCFA and 0.66 % by tricycle at 10000 FCFA (p < 2.2e-16).

With regards to problems, 5 % of farmers complained of clients because of the quality of the tubers, 15 % were confronted to the lack of clients, 20 % were faced with debts. There was also the lack of clients and destruction of farms by cattle mainly in the Northern part where farmers claimed that they are reducing the size of their lands. And in some cases, Farmers claimed they are abandoning the cultivation to other ones because of the menace caused by the cattle and they do not have the means to protect their lands (Figure 20).

Figure 20. Enclosure built by farmers against cattle

There was a complaint about the fluctuation of tubers prices by 25 % of the farmers, while 5 % had a problem with land acquisition for cultivation. Furthermore, 15 % had difficulties to transport their tubers, 10 % did not easily have access cuttings whiles 5 % had an issue of funding ($p < 2.2e-16$). Farmers wished to have enough lands to perpetuate their cultivation. They would also want to have easy access to planting materials, ready markets, common price for cassava as well as the regularization of the cassava sector to improve the value chain. In addition, regular trainings for farmers, provision of subsidised inputs such as fertilizers and funding should be provided to farmers. This they believe would help to improve the production of cassava for subsistence and commercial purposes.

3.1.2.3. Farmers' knowledge and perception of climate change

The survey shows that 43.7 % noticed an uncertainty in rainfall and the increase in heat, 32.77 % noticed a decrease in rain frequency and amount, 1.32 % noticed an increase in drought and heat ($p = 9.762e-13$). Furthermore, 15.89 % of farmers observed scarcity in rain, and 1.32 % noticed damage caused by rain while 5 % did not noticed a change ($p < 2.2e-16$). A total of 30.13 % of the respondents knew the designation "climate change" while 69.87 % doesn't know this designation ($p = 4.307e-16$). The term climate change has been heard by 14.57 % through television, 11.26 % through the radio, 0.33 % thanks to a parent, 3.31 % by a parent, 3.31 % by friends and 0.66 % through the school ($p < 2.2e-16$). With regard to the understanding of the term climate change, 60.9 % were unable to define it while 7.61 % of farmers explained it to be the changes that occurred in all the main climate patterns; the irregularity of rain and increase of heat were mentioned by 27.49 % of farmers and the drying up of rivers were mentioned by 4 % ($p < 2.2e-16$).

There was a diversity of answers about the causes of climate change ($p < 2.2e-16$). Among the respondents, 5.33 % of them attributed the causes to both the deforestation and development of industries, 56.95 % stated deforestation, 2.65 % to God (end of time) and 19.54 % to both deforestation and bushfires while 15.53 % do not know the causes. Concerning the causes of this phenomenon, farmers' responses were mostly oriented towards human activities that to say deforestation, development of industries and bushfires.

The impacts of climate change on cassava cultivation enumerated by the farmers were diverse. Majority of them (92.05 %), are aware of the impact of climate change on cassava cultivation. Change in the planting date (20.81 %), land depletion (2.65 %), decrease in yield (7.66 %), losses of cuttings and tubers sometimes (39.73 %), malformation of cuttings and low development of tubers (15.9 %), death of young plants (4.3 %) and drying of the leaves (1 %)

were the impacts mentioned by the farmers. However, 7.95 % of them did not have an idea of the impacts of climate change on cassava cultivation (p < 2.2e-16).

3.1.2.5. Impacts of climate change on cassava cultivation

Since most of the farmers never heard of climate change and did not know the designation climate change, this question has been asked to them by referring to the impacts of the changes they observed in climatic parameters on their cultivation.

They thus, gave diverse answers (p < 2.2e-16). For the majority of them (92.05 %), climate change has an impact on cassava cultivation through the change in the planting date (20.81 %), land depletion (2.65 %), decrease of yield (7.66 %), losses of cuttings and tubers sometimes (39.73 %), malformation of cuttings and low development of tubers (15.9 %), death of young plants (4.3 %) and drying of the leaves (1 %). Among them, 7.95 % did not have an idea of the impacts of climate change on cassava cultivation (p < 2.2e-16).

3.1.2.6. Farmers' perception of CBB and climate change impact on its evolution

Farmers' interview showed that cassava bacterial blight is unknown by them despite the presence of the disease in certain fields. By showing them the symptoms of the disease through a catolog of symptoms and also on cassava plants in the case of the presence of the disease, only 6.62 % claimed to have already seen the symptoms by didn't know that it was a disease. They generally attributed these symptoms to the effect of the soil. For the remaining questions, among others the impact of climate change on its evolution, no answer has been found.

3.2. The assessment of the susceptibility to cassava bacterial blight of the varieties the agro-ecological zones

3.2.1. Identification and assessment of the most grown cassava varieties

The results of the surveys highlighted that three cassava varieties, Akama, Yace and Yavo were the most grown.

3.2.1.1. Geographical distribution of the cassava varieties

A total of 249 fields was recorded for the presence of the three varieties during the surveys. The variety Akama was the most encountered with a frequency of 46.59 % (116 fields),

followed by Yace with a frequency of 38.55% (96 fields) and by Yavo with a frequency of 14.86 % (37 fields) as shown by Figure 21 A, B and C.
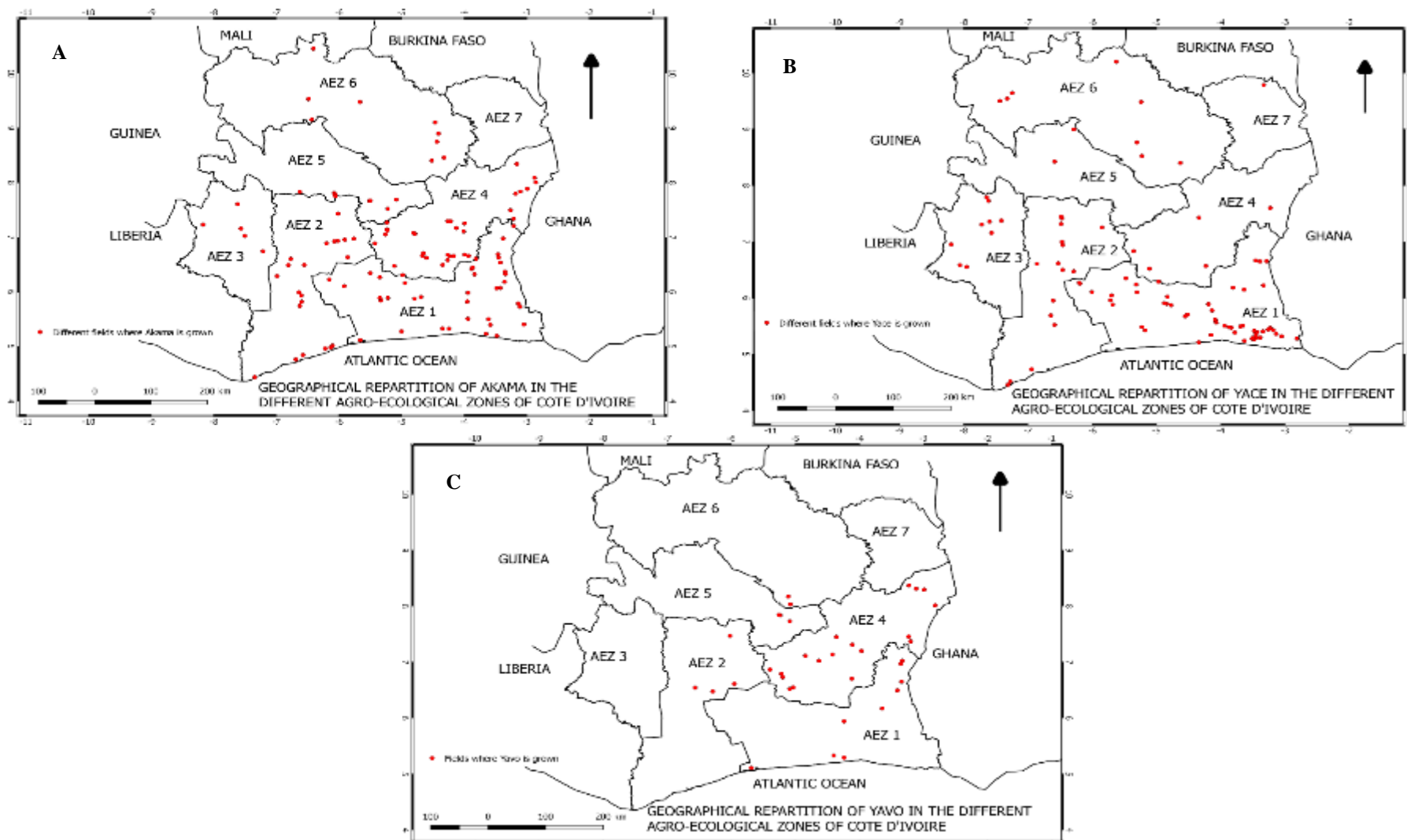
Figure 21. A, B and C: Respective geographical distributions of Akama, Yace and Yavo in the seven Agro-ecological zones of Côte d'Ivoire

The distribution of these varieties according to the AEZ was not the same. While Yace and Akama were mostly found in the AEZ1 respectively with 55.21 % and 36.21 %, Yavo was more present in the AEZ4 with 48.65 %. Yace was the only variety found in the AEZ7 with 1.04% considered as the lower rate of presence of the variety. The AEZ3 and 7 were characterized by the absence of Yavo. The lower presence of Akama with 4.31 % was in the AEZ3; while the AEZ6 was characterized by the lower presence of Yavo (5.41 %).

3.2.1.2. Disease repartition on the varieties in the agro-ecological zones

On the 116 fields where Akama is grown, 67 fields (57.76 %) were healthy while 49 fields (42.24 %) were affected by CBB. The AEZ4 recorded the most diseased fields followed by the AEZ1 while in the AEZ3, there was no diseased field (Table 2).

Table 2. Sanitary characteristics of the fields where Akama is grown showing the rates of healthy and diseased fields in each agro-ecological zones

AEZ	Number of Healthy Fields	Relative Frequency (%)	Number of Diseased fields	Relative Frequency (%)
1	29	43.28	13	26.53
2	13	19.4	7	14.29
3	5	7.46	0	0
4	14	20.9	17	34.69
5	4	5.97	6	12.24
6	2	2.99	6	12.24

Out of the total of the 96 fields obtained, 62 fields (64.58 %) where Yace is grown were healthy and 34 fields (35.42 %) were affected by CBB. The AEZ1 recorded the most diseased fields followed by the AEZ2 whereas the AEZ4 and AEZ5 fields where CBB free (Table 3).

Table 3. Sanitary characteristics of the fields where Yace is grown showing the rates of healthy and diseased fields in each agro-ecological zones

AEZ	Number of Healthy Fields	Relative Frequency (%)	Number of Diseased fields	Relative Frequency (%)
1	33	53.23	20	26.53
2	14	22.58	5	14.29
3	7	11.29	4	11.76
4	3	4.84	0	0
5	2	3.22	0	0
6	3	4.84	4	11.76
7	0	0	1	3

Out of the 37 Yavo fields sampled, 15 fields (40.54 %) were healthy while 22 fields (59.46 %) were affected by CBB. The AEZ4 recorded the most diseased fields followed by the AEZ1. However in the AEZ3, there was no diseased field (Table 4).

Table 4. Sanitary characteristics of the fields where Yavo is grown showing the rates of healthy and diseased fields in each agro-ecological zones

AEZ	Number of Healthy Fields	Relative Frequency (%)	Number of Diseased fields	Relative Frequency (%)
1	5	33.33	4	18.11
2	2	13.34	3	13.64
3	0	0	0	0
4	8	53.33	10	45.45
5	0	0	3	13.64
6	0	0	2	9.1

The AEZ5 was the third with 15.28 ± 22.88 for SI, 16.89 ± 27.3 for DI. The Kruskal-Wallis test showed a significant difference for SI and DI in the AEZ with a p = 0.02 for both.

The overall means of Akama for SI and DI were respectively 10.78 ± 17.75 and 11.98 ± 20.34. CBB expression on Akama was high in the AEZ6 and AEZ4. In the AEZ6, the mean of SI was 19.48 ± 19.97 and DI was 21.67 ± 24.88. In the AEZ4, the means were of 17.78 ± 22.98 for SI and 18.78 ± 25.41 for DI. In the AEZ5, the means of SI and DI were respectively 9.08 ± 13.67 and 9.67 ± 15.35. In the AEZ2, SI was estimated at 8.12 ± 14.85 and DI at 9.24 ± 17.67. In the AEZ3, Akama did not showed a susceptibility to CBB (Figure 22 A and B). SI and DI showed a significant difference between the AEZ with p_{SI} = 0.03 and p_{DI} = 0.04.
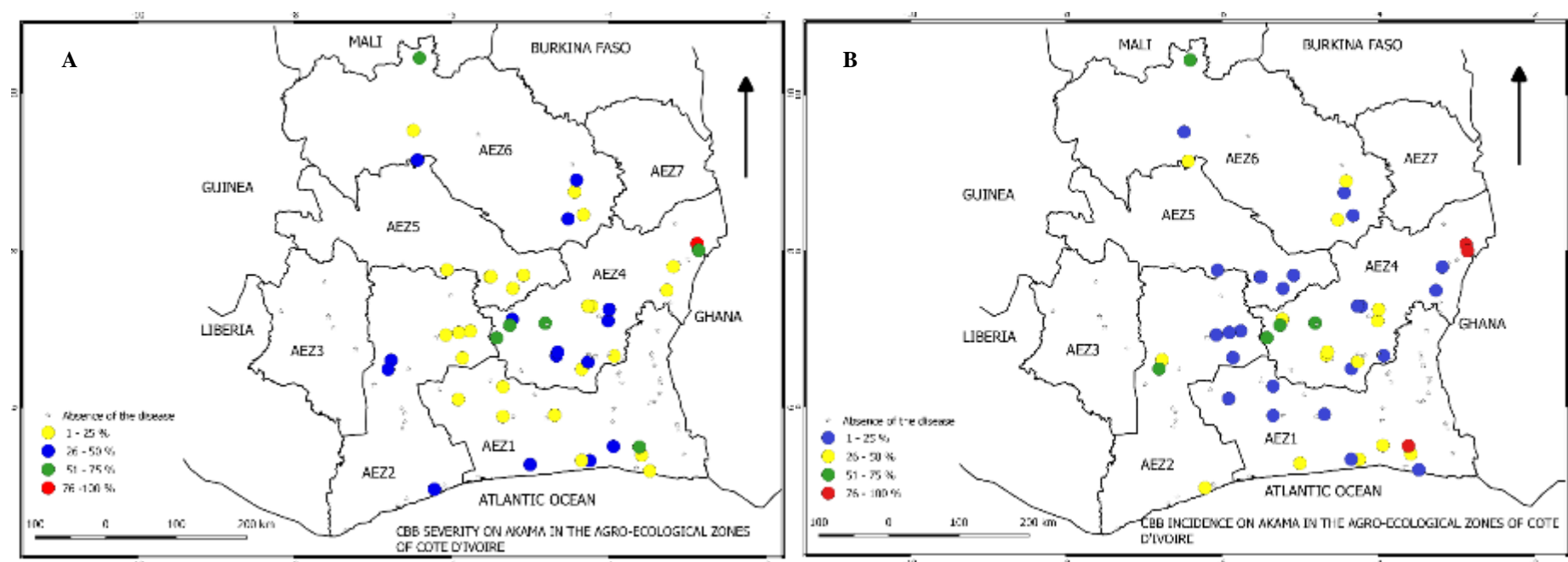
Figure 22. A : Repartition of CBB severity in the fields where Akama is grown; B : Repartition of CBB incidence in the fields where Akama is grown

The average SI and DI of Yace was respectively 9.5 ± 19.66 and 10.25 ± 21.06. While Yace didn't show any susceptibility to cassava bacterial blight in both AEZ4 and AEZ5, it was more susceptible in AEZ6 with SI and DI respectively equals to 16.6 ± 16.79 and 20.83 ± 22.3. In AEZ1, SI was of 12.15 ± 23.92 and 12.77 ± 25.08 for DI. SI and DI in AEZ2 were respectively 5.28 ± 13.09 and 5.37 ± 13.24. It was less susceptible in the AEZ3 and AEZ7. In the AEZ7, the relative SI and DI were both 3.33. In the AEZ3, Yace presented the lowest rate of susceptibility with SI of 2.78 ± 3.93 and DI of 3 ± 4.29 (Figure 23 A and B). There was no significant differences between the susceptibility of Yace in the AEZ with $p_{SI} = 0.45$, DI with $p_{DI} = 0.41$.
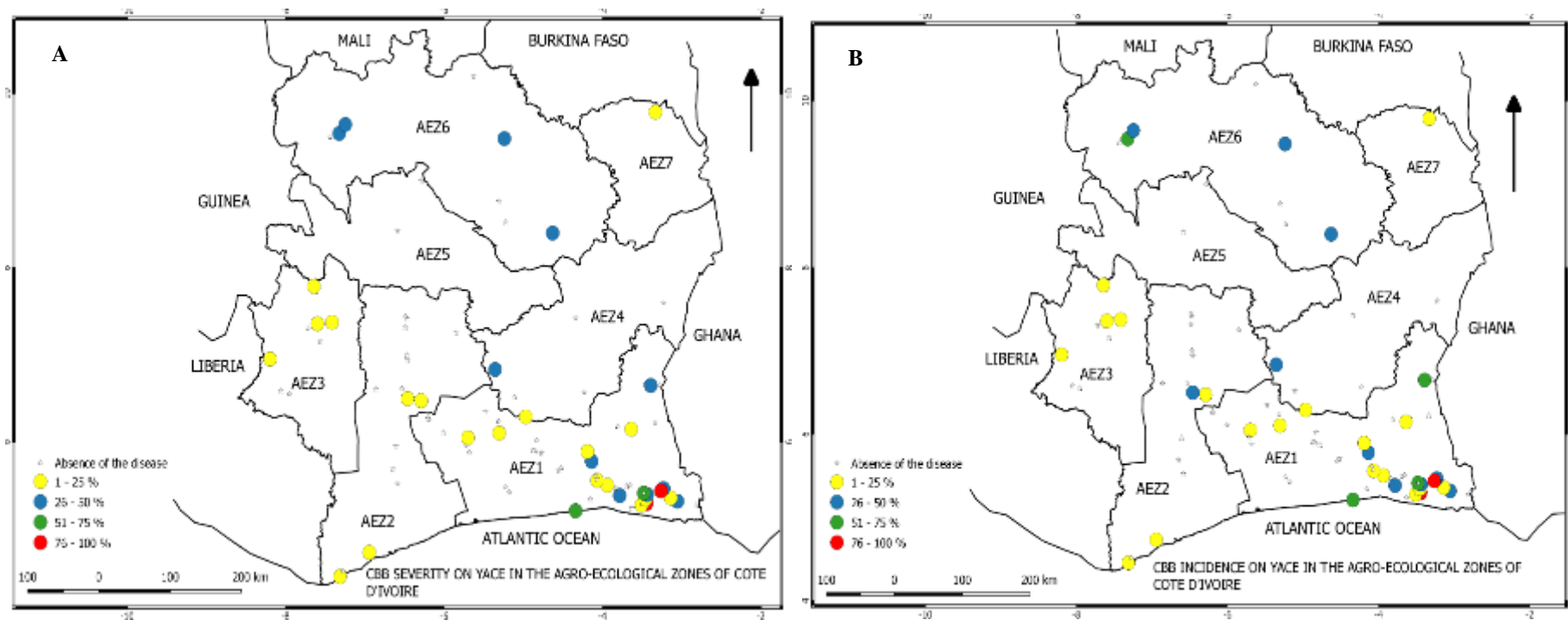
Figure 23. A : Repartition of CBB severity in the fields where Yace is grown; B : Repartition of CBB incidence in the fields where Yace is grown

Yavo presented overall means of SI and DI respectively equal to 19.61 ± 21.82 and 21.23 ± 24.67. SI and DI were the highest ones in the AEZ5 with respective averages of 46.11 ± 31.2 and 52.22 ± 41.68. In the AEZ4, SI and DI were respectively estimated at 18.99 ± 22.14 and 20.18 ±24.07. SI was estimated at 16.39 ± 24.11 in the AEZ1 whereas DI was 18.15 ± 26.83. In the AEZ6, the means of SI and DI were respectively 13.89 ± 2.55 and 15.56 ± 1.93.

In the AEZ2, the relative SI and DI were both equal to 12.78 ± 10.63 (Figure 24 A and B). There was no significant differences between the susceptibility of Yavo in the AEZ with p_{SI} = 0.45, DI with p_{DI} = 0.44.
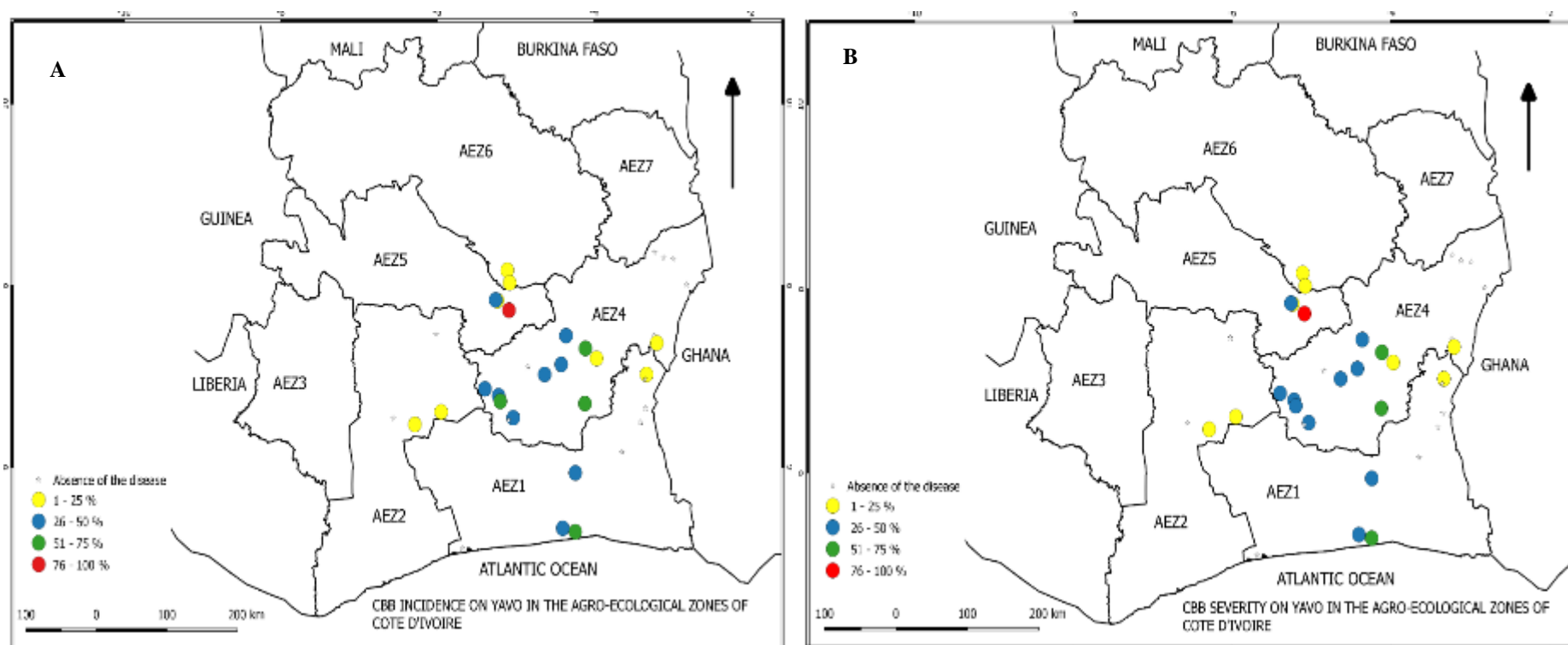
Figure 24. A : Repartition of CBB severity in the fields where Yavo is grown; B : Repartition of CBB incidence in the fields where Yavo is grown

SI and DI of the varieties were significantly different with respectively $p_{SI} = 0.007$, $p_{DI} = 0.009$.

3.2.1.3. Varieties behaviour

From the agro-ecological zones perspective, the varieties displayed the highest mean of SI and DI in the AEZ6, respectively 17.61 ± 17.34 and 20.74 ± 22.1. AEZ4 came in the second place with an SI of 17.40 ± 22.35 and DI of 18.43 ± 24.53. The AEZ5 was the third with 15.28 ± 22.88 for SI, 16.89 ± 27.3 for DI. The Kruskal-Wallis test showed a significant difference for SI and DI in the AEZ with a $p = 0.02$ for both.

The overall means of Akama for SI and DI were respectively 10.78 ± 17.75 and 11.98 ± 20.34. CBB expression on Akama was high in the AEZ6 and AEZ4. In the AEZ6, the mean of SI was 19.48 ± 19.97 and DI was 21.67 ± 24.88. In the AEZ4, the means were of 17.78 ± 22.98 for SI and 18.78 ± 25.41 for DI. In the AEZ5, the means of SI and DI were respectively 9.08 ± 13.67 and 9.67 ± 15.35. In the AEZ2, SI was estimated at 8.12 ± 14.85 and DI at 9.24 ± 17.67.

3.2.2. Screening of the cassava varieties under climate parameters

All the 8 varieties used for the trials had different behaviour to the disease in the fields except the control site (Man, Agro-ecological 3) were they were diseased-free. The susceptibility of the varieties varied from one site to another.

For the first year, the experimentation was stopped at the 8th month because of the death of the plants on two sites, Ferke (Agro-ecological zone 6) and Yamoussoukro (Agro-ecological zone 4). Ferke was the site where the varieties were the most affected by cassava bacterial blight. It was followed by Aboisso. The disease rates were SI = 15.94 ± 12.25 and DI = 18.27 ± 21.98 for the second year in Yakro. During the first year in Aboisso, there were a severity of 11.96 ± 12.45 and an incidence of 16.19 ± 12.56 for the set of the varieties screened. The second year was characterised by a severity of 27.46 ± 12.48 and an incidence of $32.97. \pm 19.99$. In Ferke, the screening of the varieties showed a severity of 34.2 ± 19.28 and an incidence of 35 ± 18.89 for the first year. For the second year, the severity on the site was 35.45 ± 21.89 and the incidence, 37.38 ± 23.34.

In Ferke, the disease had a severe impact on the varieties with the action of the drought observed during the extension of the dry season. In Yamoussoukro, the planting did not succeed after two attempts and the results were not useful. In Aboisso (Agro-ecological zone 1), the disease was present with different levels and according to the different levels of susceptibility of the varieties. The first observations (two months after planting) in Ferke and Aboisso showed a manifestation of the disease. In Aboisso, Bocou1 showed the lowest of SI (3.61 ± 1.2) while

Bocou2 showed the lowest rate of DI (4.44 ± 1.5). In Ferke, the lowest rates of both SI (13.33 ± 16.65) and DI (17.78 ± 15.75) were observed on Bocou2.

In Aboisso, Diarrassouba showed the highest rate of both SI (27.78 ± 23.4) and DI (33.33 ± 14.6). There was CBB expression on this site usually during the dry season because of the continual rain even if the rates were low. The highest rates of CBB parameters were observed during the 8th month mainly on Diarrassouba with SI = 66.89 ± 32.67 and DI = 81.11 ± 32.2. It was the most susceptible variety to CBB. The least susceptible (tolerant) was Bocou2 with 12.22 ± 1.21 for SI and DI respectively.

Apart from Ferke where cassava bacterial blight was absent during the dry season, Yakro and Aboisso were characterised by the presence of the disease during this period because of the continual rainfall. Diarrassouba presented the highest rates of 100 % for both SI and DI in Ferke while in Yakro, it presented the lowest rates with 52.16 ± 22.95 for SI and 53.25 ± 27.45 for DI at the end of the experimentations. There was a progressive increase of the disease after the dry season and the maximum rates were reached on the 12th month. Diarrassouba, Yace and Yavo were the most susceptible on all the sites while Bocou2, Bocou3 and Bocou1 were the less susceptible even though some dieback were observed on all of them mainly in Aboisso and Ferke (Annexes 11 to 16).

The correlation tests in Yakro showed that the effects of rainfall and relative humidity were positively correlated with the disease parameters on all the varieties. These correlations were non-significant for the relative humidity and the disease parameters. They were also non-significant for the rainfall and the disease parameters on Bocou1, Bocou2 and Dankwa. The effects of temperature and dew point and the disease parameters were negatively but not significantly correlated on the varieties (Annexes 17 and 18). The climatic conditions during the second year in Yakro are summarised in the Figure 25.
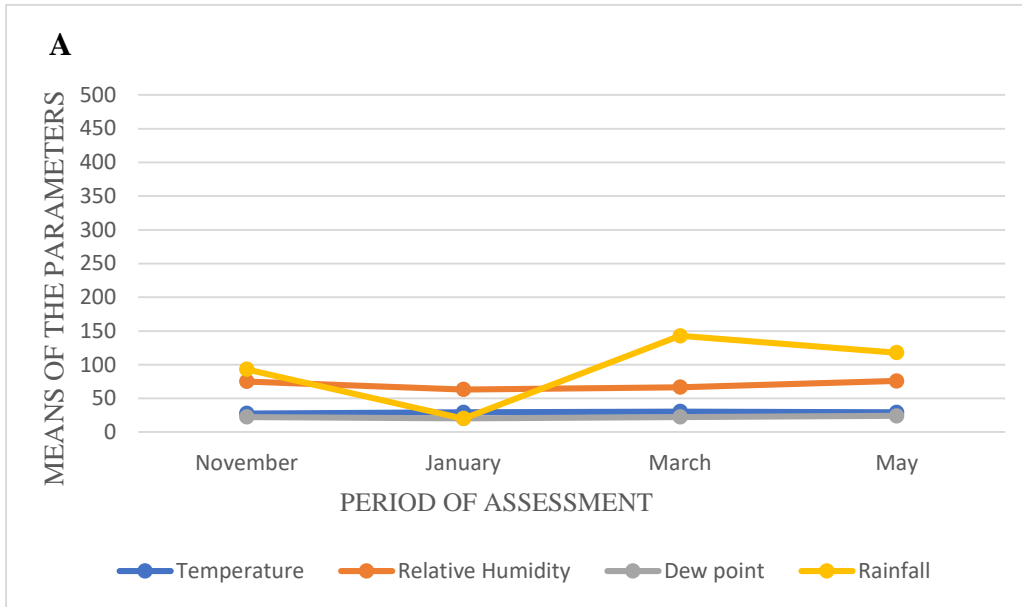
Figure 25. Climatic conditions during the second year of the experimentation in Yakro

In Aboisso, the effects of rainfall and relative humidity were negatively correlated with the disease parameters while temperature and dew point were positively correlated with CBB parameters on Akama for the first trial. By contrast, the effects of rainfall and relative humidity were positively correlated with the disease parameters while temperature and dew point were negatively correlated with CBB parameters on the other varieties (Annexes 19 and 20). For the second trial, rainfall and relative humidity were negatively correlated with CBB parameters. Temperature and dew point were positively correlated with CBB parameters (Annexes 21 and 22). All these correlations were non-significant on the varieties. The climatic conditions during the two years are summarised in the Figure 26.
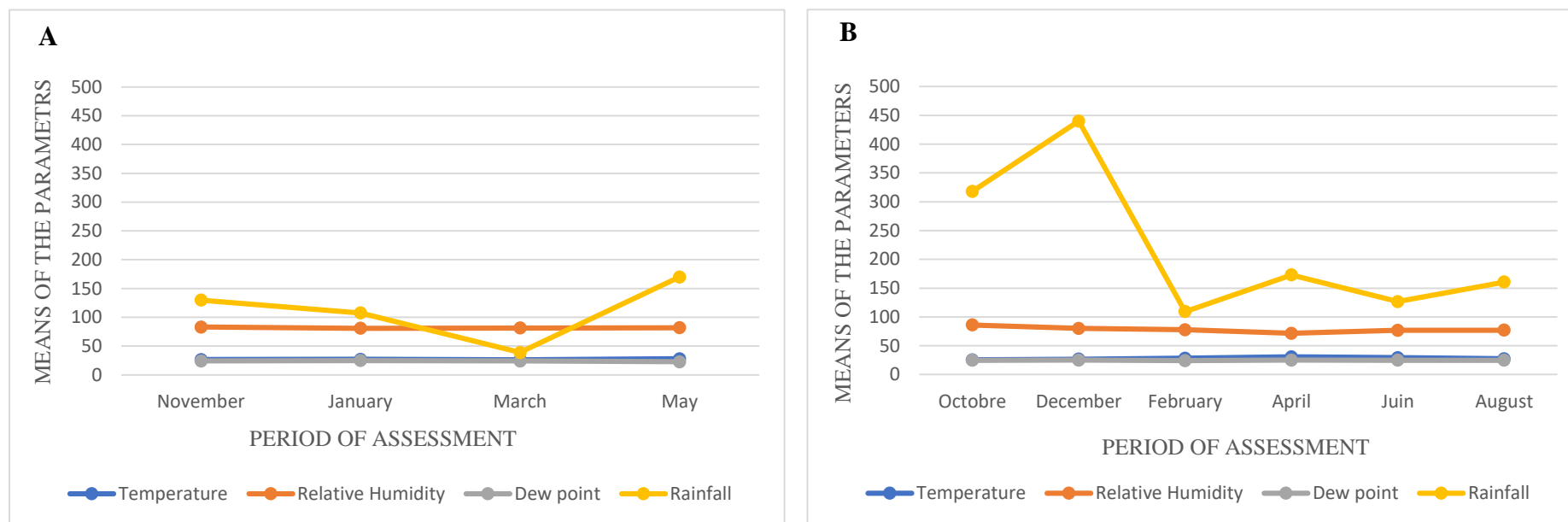
Figure 26. A and B. Climatic conditions during respectively the first year and the second year of the experimentation in Aboisso

In Ferke, all the climatic parameters were positively correlated with the disease parameters on the varieties on both trials. These correlations were mostly significant for the correlations between rainfall, dew point and the disease parameters (Annexes 23 to 26). The climatic conditions during the two years are summarised in the Figure 27.
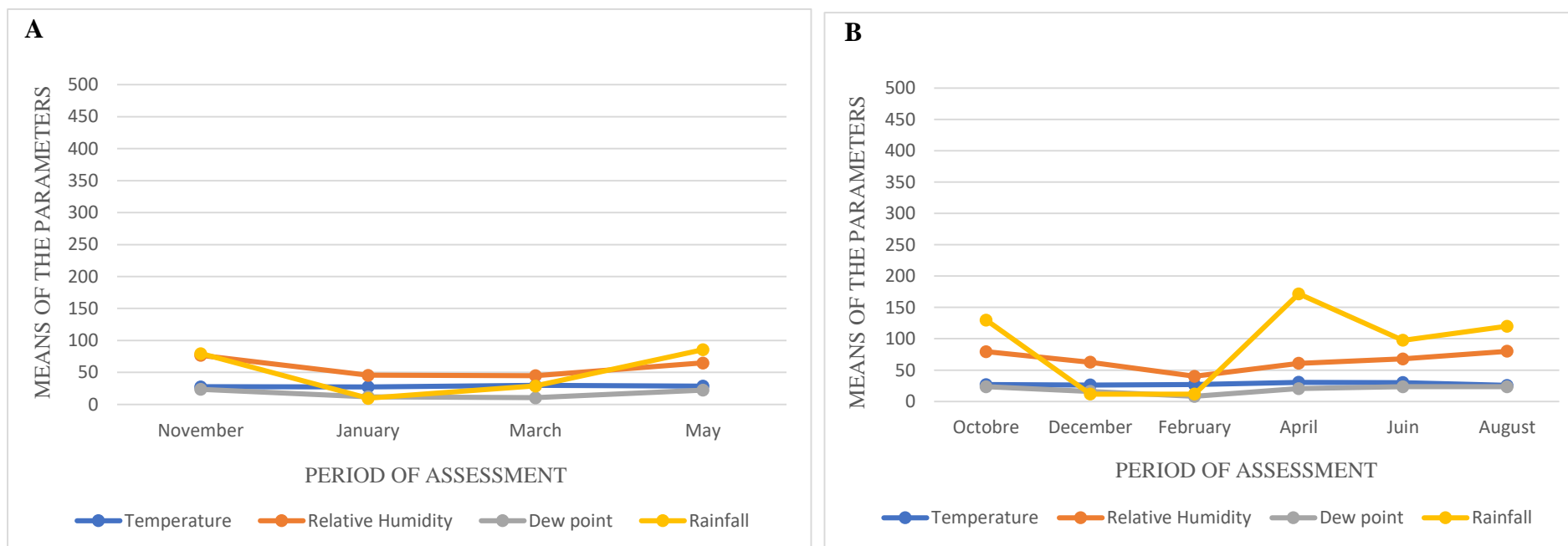
Figure 27. A and B. Climatic conditions during respectively the first year and the second year of the experimentation in Ferke

The climatic conditions during the two years in the control site Man are summarised in the Figure 28.
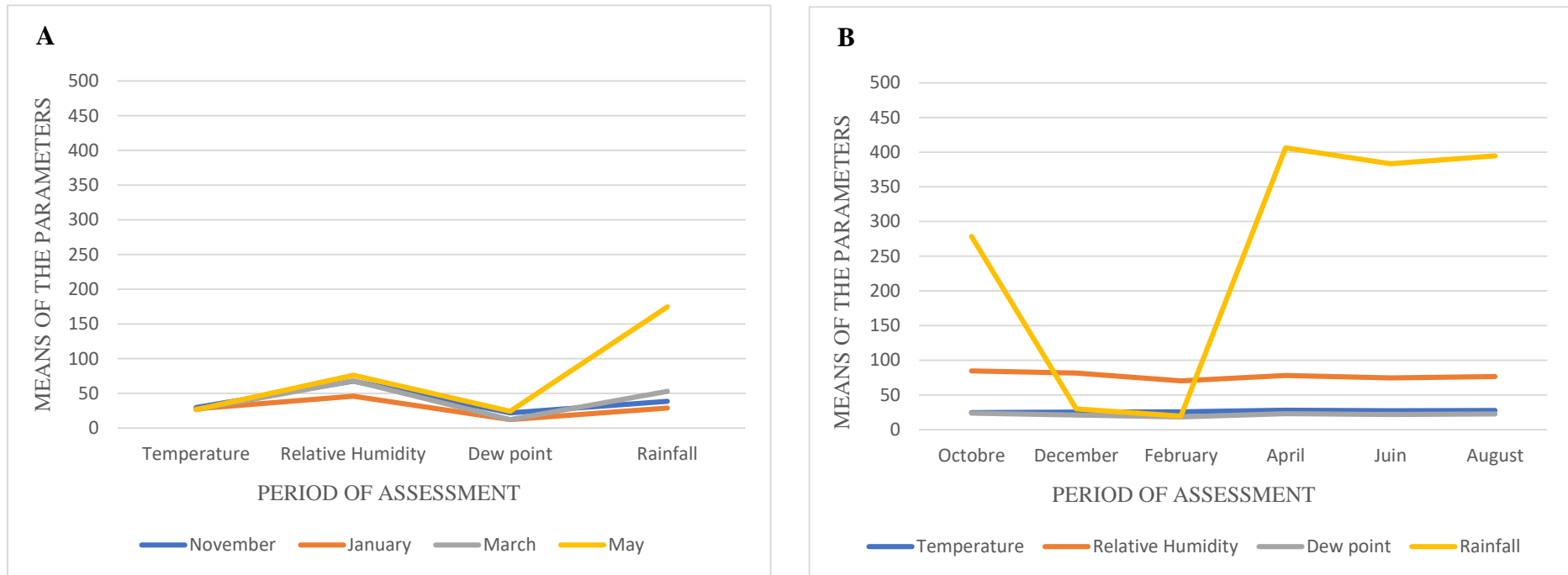
Figure 28. A and B. Climatic conditions during respectively the first year and the second year of the experimentation in Man

There were a normal distribution of the residues and homogeneity of variances for roots number and weight by considering the set of the sites and each site. The averages of the total number and weight of roots varied from one variety to another and from one site to another. Man presented the highest of roots number and weight with respectively 5.93 ± 2.3 and 383.2 ± 179.29 Kg. Regarding the diseased fields, the lowest mean of roots number was found in Yakro with 3.8 ± 1.72 while the highest was in Aboisso with 4.69 ± 2.14. The highest rate of roots weight was found in Yakro with 333.8 ± 206.6 while the lowest was found in Ferke with 254.1 ± 183.77 Kg. There was no significant difference for the number and weight of roots for the set of the sites (p = 0.77). The roots number and weight recorded in the sites were significantly different (p = 0.01) and this difference was presents between Ferke and Aboisso (p = 0.01).

On each site, the residues were normally distributed but there was no homogeneity of variances. In Aboisso, the roots number varied from 2.8 ± 2.15 for Bocou1 to 4.8 ± 1.03 for Yace and the roots weight varied from 222.5 ± 104.38 Kg for Diarrassouba to 417.4 ± 291.96 Kg for Bocou3. In Yakro, Diarrassouba presented the lowest rates for both roots number and weight with respectively 3.5 ± 1.56 and 193.58 ± 104.38 Kg respectively while Bocou3 presented the highest rate of roots number and Bocou2, the highest rate of roots weight with 385.2 ± 176.81 Kg. In Ferke, Akama presented the lowest rate of roots number with 3.7 ± 2 and the highest rate of roots weight with 466.4 ± 307.47 Kg while Diarrassouba presented the highest rate of roots number with 5.6 ± 2.01 and Bocou3, having the lowest rate of roots weight with 167.8 ± 86.68 Kg. The roots number and weight of the varieties were not significantly different (p = 0.43) (Annexes 27 to 31).

The correlation was positive and not significant between DI and the roots weight (Cor = 0.11, p = 0.52). DI was positively and significantly correlated with the roots number (Cor = 0.36, p = 0.04). There was a non-significant and positive correlation between SI and the roots weight (Cor = 0.11, p = 0.55) and SI and the roots numbers (Cor = 0.27, p = 0.13) for the set of the sites. In Aboisso, DI was positively but non significantly correlated with the roots weight (Cor = 0.37, p = 0.36) while its correlation with the roots number was negative and non-significant (Cor = -0.32, p = 0.44). The same results were observed for SI and the roots weight (Cor = 0.55, p = 0.15) and SI and the roots number (Cor = -0.43, p = 0.29). The results of the correlations between the disease parameters and the roots number and weight were the same in Ferke and Yakro, apart from the correlation between SI and the roots weight that was significant in Yakro (Cor = 0.32, p = 0.02).The positive correlation refers to an increase of the

roots number and weight when the disease increase and the negative correlation refers to a decrease of the roots number and weight when the disease increase.

3.3. The identification of the pathogenic and genetic structures of the *Xanthomonas phaseoli* pv. *manihotis* strains

3.3.1. Pathogenicity of *Xanthomonas phaseoli* pv. *manihotis* strains

Xanthomonas phaseoli pv. *manihotis* strains showed various behaviours. They induced disease symptoms that occurred from after the first observation (5 days post-inoculation) until varieties dieback. For the varieties Bocou2, Bocou3, Bocou1 and Yace, only the top of the plants died. The third half of Dankwa and Akama died while the whole plants of Diarrassouba and Yavo were dead.

Except the strain S1 that did not cause any symptoms on the varieties, the other strains led to the disease expression. Globally, the strain S2 had the lowest AUDPC value (199.8) while the strains S6 and S7 presented the highest AUDPC values with 528.3 and 523.1 respectively. They were the most virulent. Regarding the pathogenicity of each strain on each variety, S7 with the higher AUDPC was more virulent on Akama (74.17 ± 5.99). It was followed by S8 that was more virulent on both Diarrassouba and Yavo with 60.17 ± 5.8. The strain S2 presented the lowest virulence on Bocou1 with 0.83 ± 0.79. All the varieties were susceptible to the strains actions. The variety Bocou2 was less susceptible with an AUDPC of 288 while Diarrassouba with 455.8 as AUDPC value and Yavo with 427.3 were more susceptible to the strains (Annex 32). Any of these varieties showed a tolerance to the strains. They presented a case of dieback during the experimentation.

The results of the Principal Component Analysis (PCA) showed that the strains S8, S4, S3 and S5 constituted one group (Group1) of pathogenic strains while the strains S7, S10, S6 and S9 formed the second group (Group2) of pathogenic strains (Figure 29 A). The strains S1 and S2 because of the avirulence and low virulence respectively were not classified; they are confused with the origin of the axes. The Group1 was opposed to the Group2. The strains of each group were correlated and showed the same pathogenicity. The varieties Diarrassouba, Akama and Yavo were strongly linked in term of susceptibility. Dankwa was distant with all the vrieties while Bocou3 and Yace were linked. Bocou1 and Bocou2 were also linked (29 B).

Regarding the relationship between the strains and the varieties, S3,S4, S5 and S8 were similar with Diarrassouba, Yavo and Akama. These varieties were then, more susceptible to these

strains. Dankwa was more susceptible to the strains S6, S7, S9 and S10 since they were on the same side. Bocou1, Bocou2, Bocou3 and Yace were less susceptible to all the strains (29 C).
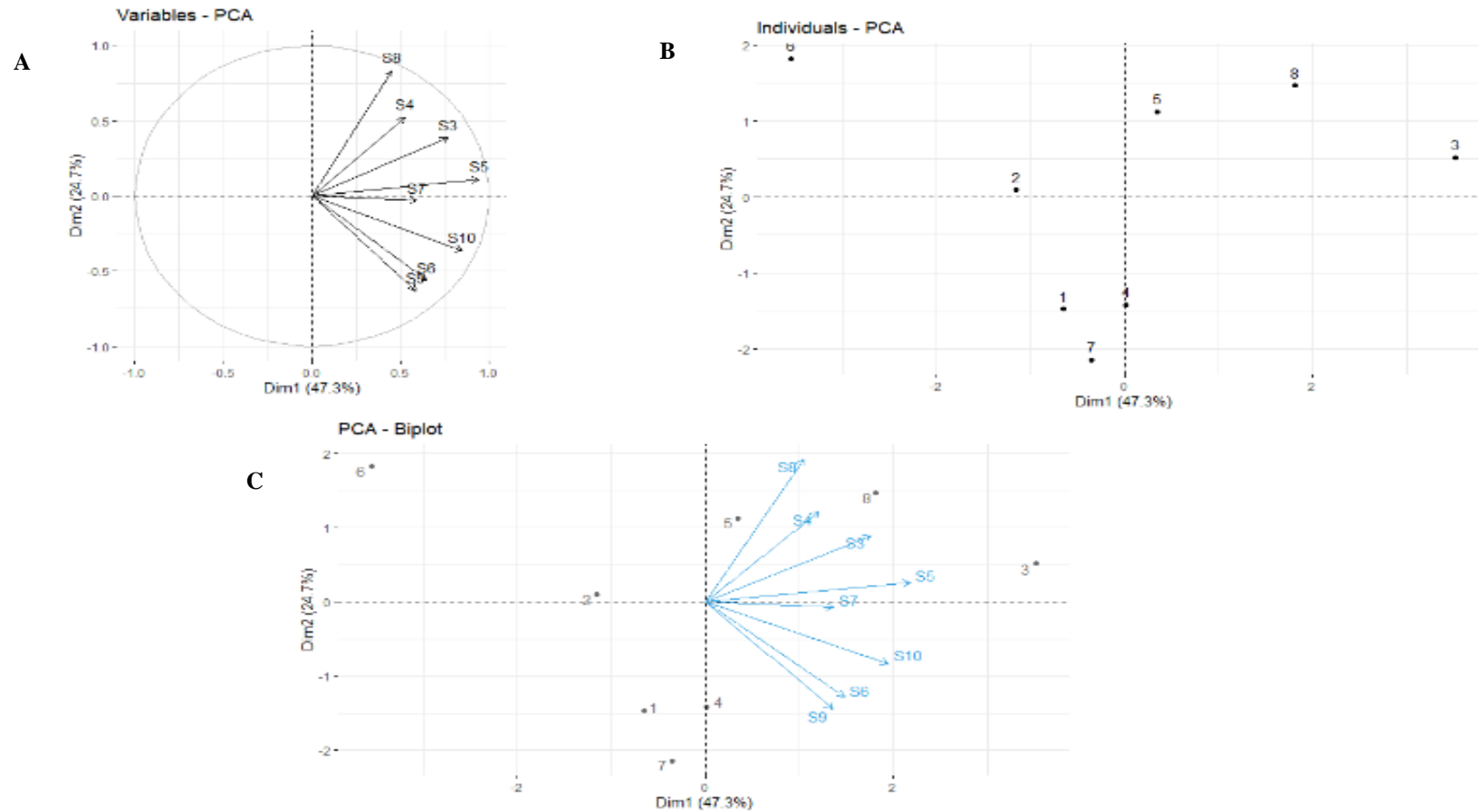
Figure 29. Results of the AUDPC. A : Classification of the strains in two groups; B : Classification of the varieties where 1: Bocou3; 2: Bocou1; 3: Diarrassouba; 4: Dankwa; 5: Akama; 6: Bocou2; 7: Yace; 8: Yavo. C: Classification of both strains and varieties

3.3.2. Study of the genetic diversity of *Xpm* strains

3.3.2.1. PCR diagnosis

Forty-two strains have been tested and they showed the same characteristic than those of the reference strain CIO151. They presented the two genomic specific fragments of *Xpm*, the rpoB housekeeping gene (944 bp) and the coding fragment for the C-terminal portion of TAL effectors of *Xpm* (570 bp) (Figure 30).
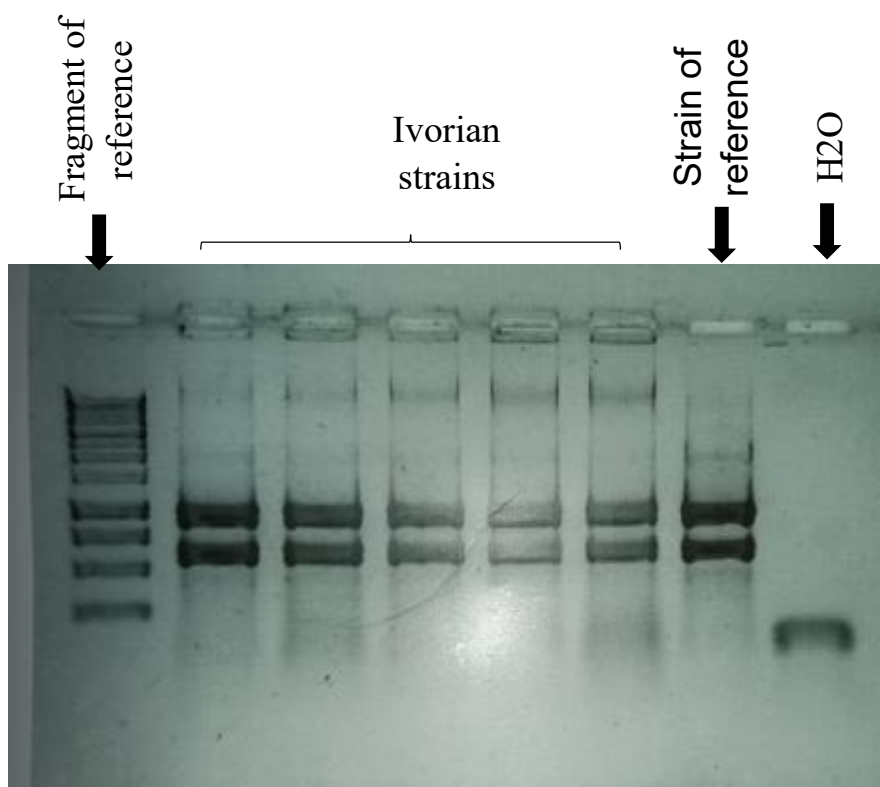
Figure 30. Result of PCR diagnosis of the Ivorian *Xpm* strains

3.3.2.2. Global diversity

Considering all the strains used in this study, the average genetic diversity of the Ivorian population of *Xpm* was estimated at 0.389 +/- 0.278. The average allelic richness of the *Xpm* population was 3.143 +/- 1.791 with a Nei diversity of 0.454 +/- 0.244.

Of the 14 loci considered, 12 were polymorphic. Locus 12 (VNTR-25) followed by locus 3 (VNTR-15) was the most polymorphic with 7 and 6 different alleles and Nei diversities of 0.727 and 0.702, respectively. Locus 5 (VNTR-21) with 2 alleles and a Nei diversity of 0.1 was the least polymorphic; the loci 10 (VNTR-38) and 11 (VNTR-19) are not polymorphic (Annex 33).

3.6.3. Intra and inter-population diversity

This analysis did not take into account the strains of zone 4 which were two in number. The numbers of Populations 1 (Zone 1), 2 (Zone 2) and 3 (Zone 3) were 13, 12 and 12, respectively. The average genetic diversity of Population 1 was 0.309 +/- 0.289 with 8 polymorphic loci or 6 non polymorphic loci. The allelic richness was 1,857 +/- 0.949 and the Nei diversity was 0.735. Population 2 had an average genetic diversity of 0.292 +/- 0.258 with an allelic richness of 1.929 +/- 0.917, a Nei diversity of 0.789 +/- 0.207 and 9 polymorphic loci. Population 3 showed the highest genetic diversity with an average of 0.502 +/- 0.286, with 12 polymorphic loci, one richness an average number of different alleles equal to 2.857 +/- 1.292 and a Nei diversity of 0.884 + / - 0.198.

Locus 12 showed 4 alleles (Nei diversity: 0.679) while loci 1 (Nei diversity: 0.692) and 3 (Nei diversity: 0.641) revealed 3 alleles. These three loci were the most polymorphic of the population 1.

Loci 2 with 4 alleles (Nei diversity: 0.636), 12 with 3 alleles (Nei diversity: 0.727) and 13 with 3 alleles (Nei diversity: 0.591) were the most variable in the population 2. As for the population 3, the most variant loci were loci 3 with 5 alleles (Nei diversity: 0.818), 12 with 5 alleles (Nei diversity: 0.727), 2 with 4 alleles (Nei diversity: 0.773) and 6 with 2 alleles (Nei diversity: 0.758) (Annexes 34 and 35).

3.6.4. Analysis of the genetic structure of populations

Of the two FST and RST coefficients, the RST is the one that best discriminates populations by presenting significant differences between them. Population 3 is significantly different from populations 1 and 2. However, populations 1 and 2 are not different (Table 5).

Table 5. Coefficients RST and FST for the discrimination of the genetic link between the Populations

FST RST	Population 1	Population 2	Population 3
Population 1		0.86706	0.04497
Population 2	0.81934+-0.0113		0.05963
Population 3	0.09180+-0.0075	0.05957+-0.0059	

P-value, threshold of significance:

***: P <0.001; **: 0.001 <P <0.01; *: 0.01 <P <0.05; NS: P> 0.05

The analysis showed that there were 15 different haplotypes and they constituted two main clonal complexes (group of haplotypes distant from a single variant locus). The first complex was constituted of the haplotypes 2, 3, 4, 5, 6, 7 and 12 and the second complex was constituted of the haplotypes 14 and 15.

The haplotypes 1, 8, 9, 10, 11 and 13 were distant from other haplotypes of more than one locus. The Haplotype 15 was found in the 4 vegetative zones while the haplotype 3 found in zones 1 and 2. The haplotype 12 was found in the zones 1 and 3. The haplotypes 1, 2 and 7 were found in the zone 4. The greatest genetic diversity was observed in Zone 3 where only the haplotypes 2, 7, 9, 10 and 13 were found (Figure 31).
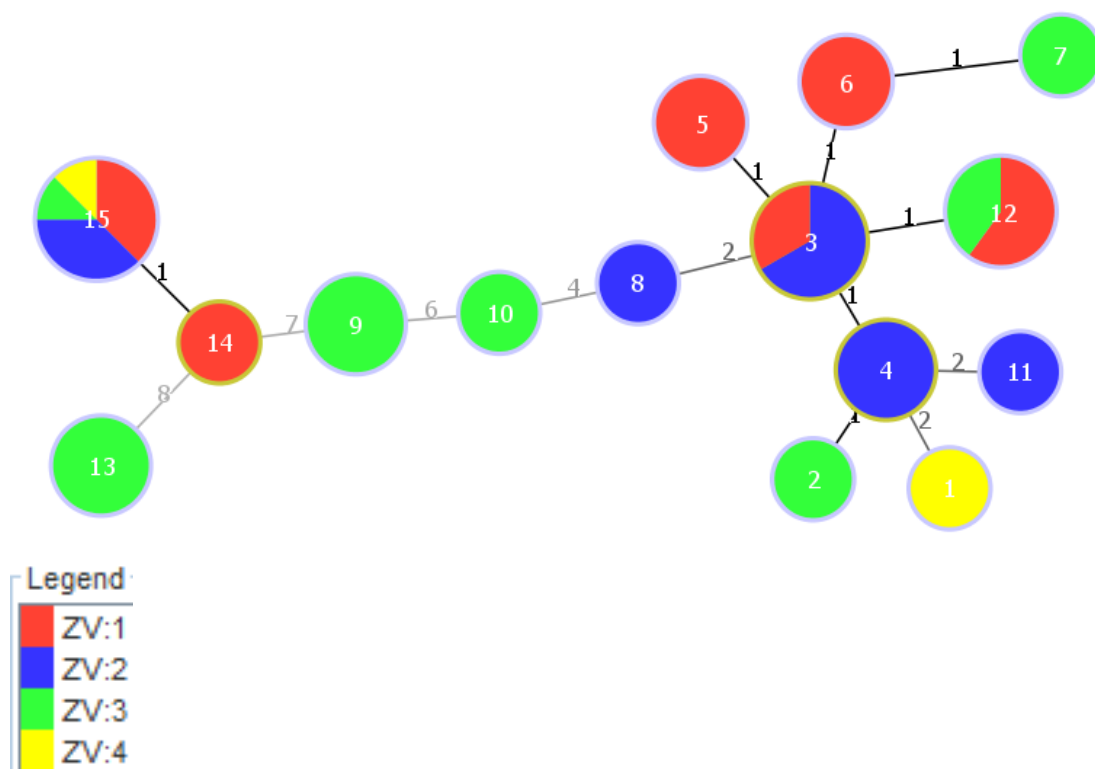
Figure 31. Progeny network showing the repartition of the haplotypes in the zones where ZV1: Vegetative Zone 1: Forest Zone; ZV2: Vegetative Zone 2: Mountain Zone; ZV3: Vegetative Zone 3: Transition Zone; ZV4: Vegetative Zone 4: Savannah Zone

CHAPTER 4 : DISCUSSION

4.1. The highlight the key climate parameters involved in the evolution of cassava bacterial blight the agro-ecological zones

4.1.1. Distribution and evolution of cassava bacterial blight under climate parameters

CBB was present in all Ivorian AEZ and its distribution varied from one year to another at different rates. Fanou *et al* (2018) found a similar conclusion on CBB distribution as well as in all worldwide cassava production zones regarding the years. Shaw and Osborne (2011) suggested that the persistence of plant pathogens can be infrequent or regular with a low severity in regions and without being a threat.

Considering the AEZ, CBB prevalence was high in the AEZ1; followed by the AEZ4 and the AEZ2. These results showed that the geographical distribution was more concentrated in the forest zone (mainly in AEZ1, AEZ2 and AEZ4; except in AEZ3). It could be explained by the fact that cassava is more grown in these zones as previously described by Perrin *et al* (2015). According to them, cassava cuttings are used for multiplication of plant material; and for the setting up of new cassava fields, farmers used cuttings already contaminated from their previous fields most of the time that could explain CBB persistence in the fields as highlighted by Fanou *et al* (2018). Coakley *et al* (1999) cited by Ghini *et al* (2008) also stated that the pathogen repartition is related to those of its host. Their statement could justify CBB distribution in the Ivorian forest zones. It could mean that the sharing and use of contaminated tubers could contribute to the disease dissemination.

In addition to this, the reduction of the forest, the high RH and lower temperatures could influence CBB expression as mentioned by Banito *et al* (2007, 2008). According to them, the degradation of the forest cover, the heavy rains, the RH, the variation of daily time and night time temperatures could play an essential role in the disease development. Moreover, in Côte d'Ivoire, the amount of forest estimated at 12 million ha in 1960 was reduced to 2.802 million ha in 2007 corresponding to a loss of more than 75 % (Sangare, 2009).

SI and DI mean observed during the four years and by taking each year are moderate, showing an average activity of the pathogen. It can be explained by the variation of the climatic conditions which are less favourable to a strong disease manifestation. Coakley *et al* (1999) explained that one of the possible effects of climate change on plant pathogen is a modification

of its development rate. The dry season parameters of the four years before the rainy season of the surveys varied from a minimum of 60.42 mm to a maximum of 88.95 mm for the RF, a Temperature of 25.28-25.77 ° C, RH going from 77.45-79.11 % and NRD of 8.84-10.96 days from one year to another. This showed that in Côte d'Ivoire, seasons are disturbed and the dry seasons are behaving like rainy seasons even if their rates are lower than those of rainy seasons. This could act on *Xpm* survival stage, an important part of its cycle.

In 2014 where CBB was higher than the other years. CBB manifestation could be explained by the possible ability of *Xpm* strains to overcome unfavourable environmental conditions. Since the pathogen needs both dry and rainy seasons for its development and to cause the disease, the absence of one of them can affect it. However, when organisms are under unfavourable conditions, only those that are more adapted can survive. This fact could explain CBB expression. *Xpm* strains were in an environment where the dry season useful for the setting up of the first inoculum was practically absent. Only those that were able to resist would have achieved their cycle. The dry seasons of 2015 were characterized by a decrease of climatic conditions; these parameters showed an increase during the rainy season unless NRD that was lower than those of 2014, whereas disease parameters decreased. The decrease of CBB parameters could be explained by the fact that during the dry season of 2015, bacteria strains would have faced a less hostile environment while they were adapted to an unfavourable environment in 2014. This would have played an important role in the setting up of the epiphytic period and also affected the parasitic period even if the conditions were more favourable than 2014 as predicted by Mboup *et al* (2012). For these authors, changes in climatic patterns may affect the pathogen in all its components.

In 2016, except Temperature, the other parameters decreased during the dry season. During the rainy season, the parameters decreased except NRD. CBB parameters increased. This can be related to the fact that *Xpm* strains would have already been adapted to this kind of environment with a decrease of almost all climatic patterns then, it would have been easier for them to do their survival phase and to cause disease symptoms during the parasitic phase. In 2017 dry season, climate parameters decreased except Temperature which increased. During the rainy season, they increased except RH that decreased. There was also an increase in CBB parameters. This could be due to a better adaptation of *Xpm* to their environment and an increase of their ability to cause CBB even if these rates remain lower than those of 2014.

During the four years, AEZ6, followed by the AEZ4 and the AEZ1 were more affected. CBB rates were very low in the AEZ3. The high disease level in the AEZ6 could be explained by the fact that in Côte d'Ivoire, the AEZ6 is characterized by a long dry season and a long rainy

season, constituting a good environment for *Xpm* conservation and CBB development. CBB expression in the AEZ3 is still low. The microclimate of the AEZ3 is still unfavourable for CBB development since it rains practically the whole year and *Xpm* needs a dry season.

In 2016, the absence of CBB could be explained by the late onset of RF and the delay in cassava planting as mentioned by Sodexam (2017), there was a late onset of RF which led to the delay in planting dates. The correlation test showing that when Rainfall increased CBB parameters decreased on the set of the 4 years could be explained by the continual rain in the dry and the rainy seasons as well, that disorganized the pathogen cycle and then, the occurrence of the disease. The absence of relationship between CBB and climate parameters in 2014 could be explained by the fact that the variation of climatic parameters would have an indirect effect on pathogen activity. Conditions that prevailed in the AEZ should have been either a total barrier in the forest zone where CBB was mostly found and severe or the main driving factor of its expression in the SZ represented by the AEZ6 and AEZ7. Nevertheless, under conditions where CBB should not occur or should occur at a low rate, *Xpm* strains were able to cause disease symptoms with different rates reaching high levels. It seemed that pathogen is adapting itself to the environmental conditions it is facing according to the years and the AEZ so that as soon as it is in the presence of a minimum of climatic conditions, it caused the disease. This changes in pathogens expression due to climate change has been predicted by Harvell *et al* (2002). Regarding the correlation tests, while Rainfall increased, SI and DI decreased. However, the increase of NRD led to an increase in CBB parameters. The extension of the number of rainy days could have affected the disease expression; bacteria strains could have tried to adapt to the unfavourable conditions even if SI and DI rates were lower.

The temperature has been described by Yáñez-López *et al* (2012) and Rana I and Randhawa S (2014) of the main climatic parameters involved in plant disease expression. It could explain the positive correlation between the Temperature and CBB parameters in 2016 where disease parameters increased with the increase of the Temperature. From 2016 to 2017, SI increased while DI decreased. The decreased of SI could be explained by the interaction between the Temperature, RH and NRD while the decrease of DI could be explained by the effect of the Temperature as shown by the interaction and correlation tests.

In addition to the climatic conditions, CBB expression also depends on the relationship between the pathogen and the host. Almost all Ivorian varieties are susceptible to CBB (Affery *et al*, 2016). According to Elad Y and Pertot I (2014), plants proceed to the regulation of their genes face to the modifications of their environment patterns. In the case of cassava, the resistance to CBB depends on many genes (Sanchez *et al*, 1999; Jorge *et al*, 2000). However,

this resistance, partially hereditary, depends largely on environment and inoculum pressure (Hahn *et al*, 1979; Wydra, 2002). This could explain the absence of symptoms in the AEZ3, 5 and 7 of 2016 where bacteria strains would have been unable to overcome cassava varieties defence reactions.

4.1.2. Farmers' awareness of cassava bacterial blight and climate change

Regarding farmers' perception of climate change cassava bacterial blight, the results showed that cassava cultivation is dominated by male farmers. It could be explained by the physical strength it require for the planting and the field maintenance and also by the fact that women are more involved in the transformation aspect. This result is in line with those found by Kouassi *et al* (2018) showing the predominance of male farmers in cassava cultivation in Côte d'Ivoire compared to the one found by Ifeany-Obi C and Issa F (2013) in the South of Nigeria where women were more involved than men. The age of the majority of the cassava farmers were between 37-52 years with a mean of 42 years revealed that mature and responsible farmers are involved in cassava farming. This is similar to the results of Ifeany-Obi and Issa (2013) and Chukwuka *et al* (2013) in Nigeria (respectively in the South and South-West) where the majority of cassava farmers were respectively between 41-50 years and 41-60 years. However, the result was contrary to that of Yemataw *et al* (2017) on Enset (*Ensete ventricosum* (Welw.) Cheesman) cultivation in Ethiopia and previous work of Kouassi *et al* (2018) on cassava cultivation in Côte d'Ivoire.

The high proportion related of cassava farmers' illiteracy in this study could be explained by the fact that in Côte d'Ivoire, only 45 % (MADR, 2017). These observations corroborate those of Kouassi *et al* (2018) and NZue *et al* (2017) in Côte d'Ivoire but contrary to the results of Ifeany-Obi and Issa (2013) and Yemataw *et al* (2017) who found that farmers were more educated. The results showed that farmers grown cassava on small-scales. It could be explained by the lack of clients as and the debt as they mentioned in their difficulties. According to Mendez del Villar *et al* (2018), cassava is cultivated on small farms estimated to 0.5 ha in Côte d'Ivoire. Ifeany-Obi C and Issa F (2013) and Chukwuka *et al* (2013) also showed that the lands cultivated for cassava alone were less than 5 ha in Nigeria.

PACIR (2013) in Côte d'Ivoire stated that more than 80 % of the production is for the local consumption. It could explain the sale of farmers' tubers in this study case. This is contrary to what Ifeany-Obi C and Issa F (2013) found. According to them, the large part of the production is reserved to the consumption.

The disturbances in climate parameters observed by the farmers could be explain the statements of Cherif (2014). According to him, in Côte d'Ivoire, farmers in the past centuries used their cultural knowledge through the observations of clouds, soil condition and orientation of the air flow to predict with certainty and accuracy the different rainy and dry seasons of the year; and therefore, the mastery by the farmers of the annual agricultural cycle. However, since the years 1950s climatic parameters have seen a lot of changes with a decrease of rainfall and an increase of the temperature but also floods, costal erosion, the irregularity of rainfall, displacement of seasons (rainy, dry and cultural), desertification, loss of production (N'Guessan A and Dje K, 2012; Cherif, 2014). This could explain the answers of the respondents of this study who enumerated the uncertainty, scarcity, decrease of the frequency and amount of rainfall and increase of heat, the increase of drought and the damages caused by the rain.

The fact that the majority of the farmers had not heard about the term climate change could be explain by the high level of illiteracy among them. This could be difficult for them to pay attention to that expression even if they have access to the means of information such as the television and the radio. Even though most the farmers did not know the term climate change, they were able to define it with their own terms regarding its manifestations. For them, it can be defined as the changes in rainfall occurrence, increase of temperature and the drying up of the rivers which is synonymous of a decrease of precipitation or prolonging the dry season.

Concerning the causes of climate change, farmers' responses were mostly oriented towards human activities that to say deforestation, development of industries and bushfires. Deforestation was the most cited by them and it could be corroborated by the statements of Boko *et al* (2016a) who estimated a loss of more than 67 % of the forest since 1960. According to Cherif (2014), this factor constitutes one of the main causes of the current and future changes of the climate. For the remaining ones, the causes of climate change were due to God. For them, this was sign about the end of time or a punishment of human bad behaviours. This perception is similar to that indicated by the study of Boko *et al* (2016b). This study highlights the mystical or metaphysical causes of climate variability in terms of non-respect of customary practices, fetishes, totems and nature-related taboos. These failings according to the populations provoked the anger of the gods which are manifested by the stop of the rains. All these responses were similar with those found by Cherif (2014) and Fondio *et al* (2016) during the studies respectively on western and northern farmers and vegetable farmers' perception of climate change in Côte d'Ivoire.

The change of planting date mentioned by farmers' as impact of climate change on cassava cultivation could be corroborated by the data from Sodexam (2017) that showed that cultural

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dates were delayed in Côte d'Ivoire because of the delay of rainfall. It implies that, according to the farmers would have to wait for the first rainfall before starting their cultivation. This factor has also been highlighted by N'Guessan A and Dje K (2012). According to PNIA (2014) in the context of Côte d'Ivoire, explained that a shortening of the average duration of growth periods (shift of the beginning of the cropping season), a weak growth of the biomass and a reduction of the productive potential of ecosystems (reduction of arable land due to their degradation, increased exposure of plants to water stress and dwindling water in most areas) constituted the directs consequences of climate change on agriculture. The decrease of yield as possible impact of climate change on cassava has been reported by Dibi Kangah P and Amon O (2016), and this conform to what farmers said. According to N'Guessan A and Dje K (2012), the change of planting date has as impacts on the resumption of sowing, the consequences of which are lower production and indirectly lower incomes. However, the displacement of planting date still the best way farmers found as their adaptation strategy against climate change.

Concerning the knowledge and awareness of cassava bacterial blight by the farmers, the study showed that they were not aware, and this that is in conformity with what Perrin *et al* (2015) said on the knowledge of cassava farmers on cassava biotic stressors. For them, these symptoms were due to the effects of the soil or the senescence of the leaves. This could be explained by the fact that they were not trained and then, they were not able to identified the symptoms of the disease despite the presence and the manifestation of CBB in some fields. This is similar to what Chukwuka *et al* (2013) found in Nigeria where the majority of farmers were not aware to the existence of the disease. About the possible losses of yields due to CBB and the impacts of climate change on it, they were not able to give a response since they ignored its presence.

4.2. The assessment of the susceptibility to cassava bacterial blight of the varieties the agro-ecological zones

4.2.1. Identification and assessment of the most grown cassava varieties

According to Kouassi *et al* (2018) and Mendez del Villar *et al* (2017) Yace, Akama, Yavo and Bonoua are the more disseminated cassava varieties in Côte d'Ivoire. The findings of this study indicated that the first three varieties were more disseminated than Bonoua. The dissemination of these varieties could be related to their yield, the taste, the processing aspects and the dry matter yield as mentioned by Kouassi *et al* (2018), Mendez del Villar *et al* (2017) and Perrin

et al (2015). Even though Perrin *et al* (2015) stated that Yavo was largely disseminated, the results of this study showed that it was less disseminated than Akama and Yace.

Although Akama was more widespread than the others, it was not found in the AEZ7 while Yace was found in all the AEZ and Yavo was not found in both AEZ3 and 7. Yace has been described as a bitter variety while Yavo has been described as a sweet variety by Akpingny *et al* (2017). Akama was described as a sweet variety by the farmers surveyed. These facts could explain their distribution. Indeed, Perrin *et al* (2015) stated that the varieties' ability to adapt themselves to the climatic conditions was also related to their bitterness feature. According to these authors, some bitter varieties can be cultivated in some northern parts of Côte d'Ivoire while the sweet ones cannot be grown there. This fact could explained the presence of Yace, a bitter variety in the AEZ6 and 7 and the absence of Akama and Yavo, sweet varieties in the AEZ7. However, unlike to what they said, Akama and Yavo were grown in the AEZ6 even if it was at lower rates. This finding could be explained by the fact that Akama and Yavo are in a process of adaptation to a new and hostile environment as said by Coakley *et al* (1999). According to these authors, the repartition and development of the plants were going to change under climate change.

Concerning the susceptibility of the varieties, Yavo described as resistant to cassava mosaic virus (Perrin *et al*, 2015; Akpingny *et al*, 2017) was the most susceptible to CBB. Akama was the second susceptible variety while Yace showed a lowest susceptibility.

The highest rates of Yace and Yavo diseased fields were found in AEZ where they mostly occurred: AEZ1, AEZ2 and AEZ3 for Yace and AEZ4, AEZ1 and AEZ2 for Yavo. This findings are consistent with the statements of Coakley *et al* (1999) who stated that the distribution of the pathogen would followed those of the host. Although Akama was mostly found in the AEZ1 and then in the AEZ4, the majority of diseased fields were found in the AEZ4, then secondly in the AEZ1 and lastly followed by the AEZ2. The AEZ5 and AEZ6 had the same rate of diseased fields. This may be due to the fact that the pathogen was able to be quickly widespread in the AEZ4 than the AEZ1 leading to a higher rate of diseased fields in the AEZ4.

According to Shaw M and Osborne T (2011), the persistence of plant pathogens can be infrequent or regular with a low severity in regions without being a threat for producers in these zones. This fact could explained the low impact of CBB on the varieties in the AEZ3 but also the adverse climatic conditions that prevailed there. This AEZ is characterized by a long rainy season and a short dry season that would have reduced the survival and the quantity of primary inoculum, hence the expression of the disease.

Akama and Yace were mostly susceptible in the AEZ6 but Akama was more susceptible than Yace in this AEZ. Although Yavo was also susceptible in the AEZ6, its SI and DI were lower than those of the two other varieties. Nevertheless, it was mostly susceptible to the disease in the AEZ5. It could be explained by the compatible host interaction where the bacteria strains penetrate into cassava and overcome host defence barriers causing the characteristic symptoms of the disease (Hamza, 2010). It seemed in this AEZ that this interaction was strong to cause hence a high CBB severity on the variety. In fact, Yavo susceptibility reached the higher levels of susceptibility while Yace didn't show a susceptibility to CBB. The absence of Yace susceptibility to CBB in the AEZ4 and AEZ5 could be due to the incompatible host interaction where bacteria strains would have been unable to overcome cassava varieties defence reactions (Fargier, 2007; Hamza, 2010). Yavo and Akama susceptibility to CBB was secondarily higher in the AEZ4 with the high rates recorded in Yavo fields. While Yace was secondarily susceptible in the AEZ1, Yavo was thirdly susceptible in the same AEZ with higher rates. The level of each variety susceptibility varied according to the AEZ. This behaviour regarding the disease in each AEZ could be explained by the interaction between the environment and the genotype as described by Zinsou *et al* (2005). In fact, according to Elad Y and Pertot I (2012), plants proceed to the regulation of their genes due to the modifications of their environment patterns. Though in the AEZ6, Yace and Akama had the highest susceptibility rates than those of Yavo, its susceptibility was very high than the two other varieties in the AEZ where they were all together. This is in contradiction to what Tindo *et al* (2016) found in their study which showed that local varieties where most attacked and susceptible to CBB than improved varieties.

4.2.2. Screening of the cassava varieties under climate parameters

Cassava varieties screening across the four agro-ecological zones showed an influence of climatic parameters mainly in Ferke (Agro-ecological 6) and Aboisso (Agro-ecological zone 1) on the expression of the disease and the varieties growth as well. The death of the plants in Ferke during the first year revealed that the combination of environmental conditions and CBB could be a disaster in cassava farming. By contrast, the continual rainfall during the dry season in Aboisso led to an expression of the disease. These conditions in this zone could also favoured disease outbreak and then, yield losses if the strains overcome the environmental constraints. In Yakro, almost the same observations were made for CBB expression during the dry season but less pronounced in Aboisso. Ferke and Aboisso constituted the most prevalent zones of CBB expression on the varieties.

The two years trials revealed that the varieties were more susceptible in Ferke, followed by Aboisso. They were less susceptible in Yakro than the two other sites. Ferke was a conducive environment for CBB expression since the disease triangle (Elad Y and Pertot I, 2014) was more established. The dry and rainy seasons were more or less well marked, the varieties used were susceptible and the strains were virulent.

The highest varieties susceptibility in Aboisso than in Yakro could be related to the impacts of the climatic parameters on the relationship varieties-*Xpm* strains. Indeed, the climatic conditions in Aboisso where the dry season were more confused with the rainy season were different to those of Yakro. The bacterial strains could have tried to survive in Aboisso where the conditions were not suitable for their survival and expression, leading to an increase of the pathogen activity. The high inoculum pressure could also be involved in the disease expression in these sites. In the most infected sites, pathogen pressure would have been high and increased the risk of disease expression as observed by Wydra (2002) and Wydra *et al* (2007).

The varieties Bocou1, Bocou2 and Bocou3 showed a lowest susceptibility to CBB in all the sites and according to the years. Bocou2 was the less susceptible. However, disease incidence and severity rates reaching 50 % were observed on these varieties mainly in Ferke. The variability of the varieties behaviour could be explained by the partial heredity of the resistance, largely dependent on the environment and inoculum pressure (Hahn *et al*, 1979; Wydra, 2002). The disease expression is then limited and not eliminated (Jorge *et al*, 2000). In Yakro and Aboisso, these rates were lower for the same varieties. The susceptibility of Yace, Akama and Dankwa varied according to the zones and the years. Yavo and Diarrassouba were more susceptible in all sites, Diarrassouba being the most susceptible. CBB rates in term of severity and incidence reached 100 % for Diarrassouba. The difference in the varieties responses to CBB could be explained by the genes expression involved in the resistance to the disease under environmental conditions. According to the environmental pressure these genes facing, the varieties were either tolerant or susceptible. In fact, Cockerham, (1963) and Falconer (1990) cited by Zinsou *et al* (2005) explained that the difference in disease expression of the varieties could be related to the diverse responses of the same set of genes to the environmental conditions or by the expression of different genes in different environments. The non-significant difference in the varieties susceptibility/tolerance revealed that these varieties cannot be considered as resistant across the zones.

For the yield assessment, Ferke and Aboisso, the most affected sites recorded the lower rates of roots number and weight; even though the differences were not significant. These lower rates could be explained by the relative susceptibility of the varieties in these sites. Regarding

the sites and the varieties, Diarrassouba, which was more susceptible recorded the lowest rate of roots weight in Aboisso and not those of roots number while in Yakro, for the two parameters, it recorded the lower rates. In Ferke where the variety was more susceptible, it did not record the lowest rates of the disease. By contrast, Bocou2, the more tolerant variety did not record the highest rates of roots number and weight in Aboisso and Ferke. In Yakro, it recorded the highest rate for only the roots weight. The positive correlation between CBB parameters and yield parameters traduced the low effect of the disease on the yield. In fact, even if the incidence of the disease reached 100 % and dieback were observed in some fields, the majority of the plants were alive. Zinsou *et al* (2005) highlighted in their study the low or absence of yield decreased on some susceptible genotypes which recovered after CBB infection. They underwent the disease pressure without yield decrease. Wydra (2002) also refers to the possible compensation of CBB negative impacts on some varieties under suitable growth period. A threshold for the yield decrease in case of disease infection in this situation cannot be established and the risk of yield loss remains difficult to predict (Zinsou *et al*, 2005).

4.3. The identification of the pathogenic and genetic structures of the *Xanthomonas phaseoli* pv. *manihotis* strains

4.3.1. Pathogenicity of *Xanthomonas phaseoli* pv. *manihotis* strains

The artificial inoculation with *Xpm* strains revealed that some varieties were more susceptible to some strains than the others. The varieties tested were the same than those used during the field trials. Diarrassouba was the most susceptible and Bocou2 the less susceptible. It could be due to the plant-pathogen interaction. Some varieties that are strains specific have different responses in the presence of these strains and some varieties can be resistant to some strains and susceptible to another ones as mentioned by Zinsou (2003) and Sanchez *et al* (1999). It could explain the susceptibility of Bocou2 to the strains even if its level of susceptibility was lower than those of the other varieties. Their susceptibility also showed that in case of a strong pressure of virulent strains, the disease can occur with high rates and could have dramatic impacts on the varieties.

4.3.2. Study of the genetic diversity of *Xpm* strains

The genetic diversity of the *Xpm* strains in this study was based on 39 strains. However, the result showed that there was an existed diversity among them. The scheme MLVA, due to its high discriminatory power (Guinard, 2015; Arrieta-Ortiz *et al*, 2013, Li *et al*, 2009) allowed

the identification of the diversity among a restricted number of strains from different zones. Cassava bacterial blight has been identified since 1979 in in the North-Western part of Côte d'Ivoire (Aïdara, 1989). From this time to nowadays, the disease has been widespread in all the Ivorian agro-ecological zones. The current diversity could be explain by this long-term establishment of the disease in these zones where the strains have faced to different environmental conditions in a process of adaptation and agricultural practices. Indeed, the environmental conditions are not the same in the areas and they could have affect the rate of strains diversification in the same zone and from one zone to another. The level of *Xpm* strains diversity has increased from 1993 where Verdier *et al* (1993, 1998) and Restrepo S and Verdier V (1997) found an homogeneity in the African strains.

This study revealed the presence of 15 different haplotypes, showing the diversity of the strains. However, some of these haplotypes are shared among the zones considered. The presence of the same haplotypes in a same zone could be explained by the use of the same cuttings from one cultural season to another. The rate of diversification in this case could be lower than if the cuttings used for the new cultural seasons were different with the previous cycle. Surveys undertaken towards cassava farmers' showed that most of them used the same cuttings, from their own fields, from one cultural cycle to another. It could explained the presence of the same haplotypes found in the same zones, mainly the zones 1 and 2, representing the higher cassava production areas, and the genetic link among the haplotypes.

The presence of the same haplotypes in different zones could be explained by the sharing of cuttings between farmers or their source of supplying. Some farmers during the interviews claimed to have obtained their cuttings from their friends, neighbours and also from some Ivorian research centres. If theses cuttings were already contaminated by the disease, it means that the same strains were already present in these cuttings and were also disseminated in the different zones. This fact could also explain the genetic link among them, traduced by a single locus variant between these strains.

The zone 3 showed the higher genetic diversity of the strains, contrarily to the other two. This zone could constitute a diversification centre for the strains. Farmers in the localities of the zones are using cuttings from different origins, including a research centre. These cutting could have contained different bacterial strains, and then, favoured the high diversification of the strains. It could also explained the genetic distance among them.

CHAPTER 5 : CONCLUSION AND OUTLOOK

Climate change and cassava bacterial blight have already been proven in Côte d'Ivoire and constitute a threat for farmers and food security as well.

Cassava Bacterial Blight evolution from 2014 to 2017 in Côte d'Ivoire showed that its geographical distribution was concentrated in the forest zone more than in the savannah and the transition zones. From one year to another, it was more found in the AEZ1, the greater cassava producing zone, with the higher rates of cassava varieties dieback. Its expression varied from one year to another and also from one agro-ecological zone to another. CBB severity and incidence were more or less moderate under the variation of environmental conditions. Dry and rainy seasons are disturbed in Côte d'Ivoire at a level where the dry season is less marked mainly in the AEZ1, AEZ2, AEZ3 and AEZ4; that impacted on CBB expression. However, while the AEZ6 had conducive conditions for its expression, CBB also reached higher rates in the AEZ4 and AEZ1 where environmental conditions were unfavourable. It means that CBB expression rates and varieties susceptibility could increase or decrease according to climatic conditions since the pathogen is trying to adapt to them. This would lead to dramatic damages if it occurred. Especially given that surveys were carried out during the short rainy season in the AEZ1, AEZ2, AEZ4 and AEZ5, disease rates could be higher than what these results gave in these zones in case of surveys in the long rainy season. Sustainable control strategies must be engaged to alleviate climate change effects on CBB evolution to ensure cassava food security in Côte d'Ivoire.

Cassava farmers in Côte d'Ivoire like many other farmers are aware of the changes in the climate patterns even if the term is unknown to the majority of them. It implies that their experiences on cassava fields helped them to notice these changes and to understand that something is happening. They were able to identify its causes and also its impacts on their cultivation irrespective of their age. The best way for them to overcome the impacts of climate change on their cultivation was to wait for the first rainfalls and then, to vary the planting date. It has also been established that the majority of farmers had any idea about cassava bacterial blight although it manifests in their fields.

The lack of deep knowledge on these phenomena must be fill by policies makers through the collaboration with the scientists. Some measures such as campaigns to sensitive famers on climate change and its impacts, explanations of the importance of reforestation through intercropping (mainly agroforestry), the reduction of bush fires, the use of toxic products for the environment must be undertaken. The ease and accessibility of appropriate weather forecast

(also in the local languages) should be provided to help farmers in their planting dates. Regular dissemination of scientific results could also be of immense help. They will also include the information on CBB and the sustainable management strategies against the disease.

This study showed the assessment of geographical repartition of the three cassava varieties and the most widespread in Côte d'Ivoire. It also showed that the local ones (Akama and Yace) were still very much accepted than the improved one (Yavo). The presence of Akama and Yavo considered as sweet varieties in the AEZ6 help to understand that the geographical distribution of the varieties is changing. The varieties are in a process of adaptation to a new environment previously defined as unfavourable for their growth. Except Yace which did not show a susceptibility to CBB in the AEZ4 and AEZ5, the others were susceptible in all the AEZ where they were found at different rates. Yavo was the most susceptible in all AEZ excluding in the AEZ6 where it was less susceptible than Akama and Yace. However, the varieties susceptibility differed from one AEZ to another. The AEZ6 was characterized by the high level of Akama and Yace susceptibility while the AEZ5 was characterized by those of Yavo. These zones were followed by the AEZ4 for Akama and Yavo and the AEZ1 for Yace. This behaviour in the AEZ pointed out an interaction between the varieties, the pathogen and the environment. Since these factors seems to affect the relationship between the disease and the varieties, it would be important to test these varieties for other control strategies in order to prevent yield losses due to the strong pressure of CBB.

Cassava varieties used by Ivorian farmers are susceptible to the disease at different rates in the different agro-ecological zones. However, some of them appeared to be more tolerant than others. They are enduring both disease and environmental conditions pressures that could lead to loss of farmers productions in severe case. Any variety at this time could be recommended to the farmers but the screening should continue by taking into account breeding aspects and the tolerant varieties. Climatic conditions constitute one of the major constraints to cassava cultivation in Côte d'Ivoire and are aggravating cassava bacterial blight expression. So even if the results did not show high impact of the disease on the yield, the losses related to CBB remains unpredictable. All these aspects should be considered in the selection of tolerant varieties across different agro-ecological zones.

The inoculations under controlled conditions showed that *Xpm* strains present in Côte d'Ivoire are pathogenic and their pathogenicity differed from one variety to another. Some varieties were susceptible to the same strains. These results could be used for the identification of the

zones of resistance of the Ivorian cassava varieties. It could be used during the breeding process to increase the varieties tolerance to the disease.

The genetic diversity of the *Xanthomonas phaseoli* pv. *manihotis* strains used in this study, showed an existence of a diversification among the Ivorian strains. The haplotypes identified presented different configurations. Some of them were present in all the zones while the others were different. The Zone 3 characterised by the Agro-ecological zone 5 contained the most diversified and genetically distant strains. The long-term existence of the disease in Côte d'Ivoire, farmers activities and environmental conditions constitute some factors to consider in the diversification of the strains.

As outlook,

- Surveys should continue in the seven agro-ecological zones for an epidemiological surveillance by taking into account climatic conditions
- Increase the number of strains for the genetic diversity and the molecular epidemiology, useful for the genetic struggle against the disease
- Continue the screening of the varieties and undertake the mapping of the tolerant varieties genes for a further breeding of these varieties with the susceptible ones
- Undertake the mapping of the bacterial strains genes for the identification of the genes involved in the disease expression.
- Identify the best biopesticides, period and doses for the disease struggle
- Increase farmers knowledge on both climate change and cassava bacterial blight.

REFERENCES

Affery AM, Abo K, Tuo S, N'Zue B, Kone D. Geographical Distribution and Incidence of Cassava Bacterial Blight (*Manihot esculenta* Crantz) Caused by *Xanthomonas axonopodis* pv. *manihotis* in Two Agro-ecological Zones of Côte d'Ivoire. Plant Pathology Journal. 2016; 16 (1): 1-11, 2017. doi: 10.3923/ppj.2017.1.11.

Agrios GN. Plant pathology. Elsevier Academic Press, Amsterdam, 5th Edition. 2005; 26-27,398-401.

Aïdara S. Aperçu sur la culture du manioc, Etude du système racinaire du manioc (Variété CB) suivant le système de coupe des boutures et le mode de planting. Rapport de stage. Institut Agricole de Bouaké (I.A.B.), Office de la Recherche Scientifique et Technique Outre-Mer (O.R.S.T.M.), Fonds Documentaire. 1984; 1-17.

Ake GE. Impacts de la variabilité climatique et des pressions anthropiques sur les ressources hydriques de la région de Bonoua (Sud-Est de la Côte d'Ivoire). Thèse de Doctorat de l'Université de Cocody en Sciences de la Terre Spécialité : Hydrogéologie, Option : Eau et Environnement. 2010; 49 (24) : 1- 234.

Aklé J, Gnonhoué H. CBB development in Benin. In cassava Bacterial Blight in Africa : past, present and future. Report of Interdisciplinary Workshop, IITA, Ibadan, Nigeria, 26-30 June 1978. Centre of overseas Pest Research, London. 1979; 43p.

Akpingny KLD, Koulou NY, Okou WCA. Fiche technicoéconomique du MANIOC. Agence Nationale d'Appui au Développement Rural (ANADER). Direction d'Appui aux Filières Agricoles. 2017; 2 :8.

Antle JM. Agriculture and the food system. Adaptation to climate change. 2009.

APA (Agence Presse Africaine). Production du manioc en Côte d'Ivoire, 2017; http://apanews.net/fr.

Arrieta-Ortiz ML, Rodriguez-R LM, Perez-Quintero AL, Poulin L, Diaz AC, et al. Genomic Survey of Pathogenicity Determinants and VNTR Markers in the Cassava Bacterial Pathogen *Xanthomonas axonopodis* pv. *manihotis* Strain CIO151. PLoS ONE. 2013; 8(11): e79704. doi:10.1371/journal.pone.0079704.

Azorji JN, Igwe CE, Kanu C. Screening of selected improved cassava varieties for bacterial blight and varietal performance under natural environment in Ibadan, south-western Nigeria. Journal of Molecular Studies and Medicine Research. 2016; 01(02), 63-69.

BAFD/OCDE. «Côte d'Ivoire», Perspectives économiques en Afrique. Certificat d'aptitude aux fonctions de directeur des réceptions collectives de mineurs/Organisation de coopération et de développement économiques. 2003; 4, 6:14.

Banito A, Verdier V, Kpémoua KE, Wydra K. Assessment of major cassava diseases in Togo in relation to agronomic and environmental characteristics in a systems approach. African Journal of Agricultural Research. Vol. 2. 2007; (9), 418-428p.

Banito A, Kpémoua KE, Wydra K. Expression of resistance and tolerance of cassava genotypes to bacterial blight determined by genotype x environment interactions. Journal of Plant Diseases and Protection. 2008; 115 (4), 152–161p.

Banito A, Kpémoua KE, Wydra K. Screening of cassava genotypes for resistance to bacterial blight using strain x genotype interactions. Journal of Plant Pathology. 2010; 92 (1), 181-186p.

Bart RS, Taylor NJ. New opportunities and challenges to engineer disease resistance in cassava, a staple food of African small-holder farmers. PLOS Pathology. 2017; 13(5):e1006287. https://doi.org/10.1371/journal.ppat.1006287.

Bernal-Galeano V, Ochoa JC, Trujillo C, Rache L, Bernal A, López CA. Development of a multiplex nested PCR method for detection of *Xanthomonas axonopodis* pv. *manihotis* in Cassava. Trop. Plant Pathology. 2018; 1–10.

Bodnar AM. Function of cassava bacterial blight in TALE1 *Xam*: A transcriptomic approach. Universidad Nacional de Colombia. Facultad de ciencia, Biología Departamento de Bogotá, Colombia. 2012; 18, 24: 178.

Boher B, Agboli CA. La bactériose vasculaire du manioc au Togo : Caractérisation du parasite, répartition géographique et sensibilité variétale. 1992; 132 : 131-132p.

Boher B, Verdier V. Cassava bacterial blight in Africa: the state of knowledge and implications to designing control strategies. African Crop Science Journal. 1994; 2, 1-5.

Boko KANN, Gueladio C, Kone B, Dedy S. Variabilité Climatique Et Changements Dans L'environnement À Korhogo En Côte D'ivoire : Mythes Ou Réalité ? European Scientific Journal. Edition vol.12, No.5. 2016a, doi: 10.19044/esj.2016.v12n5p158. 158-176.

Boko ANN, Cisse G, Kone B, Dedy SF. Croyances locales et stratégies d'adaptation aux variations climatiques à Korhogo (Côte d'Ivoire). Tropical. 2016b; 44, 40-46.

Booth RH, Lozano JC. Cassava bacterial blight in South East Asia. Plant Disease Report. 1978; 62: 529-530p.

Boulanger A. Analyse d'un nouveau système CUT impliqué dans l'acquisition et l'utilisation du N-acétylglucosamine par *Xanthomonas campestris* pathovar *campestris*, Université de Toulouse III - Paul Sabatier, Microbiologie. 2009; 10 : 248p.

Burns A, Gleadow R, Cliff J, Zacarias A, Cavagnar T. Cassava: The Drought, War and Famine Crop in a Changing World. Sustainability. 2010; 2, 3572-3607; doi:10.3390/su2113572.

Ceballos H, De la Cruz GA. Taxonomía y Morfología de la Planta. In: H. Ceballos and B. Ospina (eds.) La Yuca en el Tercer Milenio. CIAT, Cali, Colombia. 2002.

Chakraborty S. Potential impact of climate change on plant–pathogen interactions. Australasian Plant Pathology. 2005; 34, 443–8.

Chaudhary P, Aryal KP. Global Warming in Nepal: Challenges and Policy Imperatives. Journal of Forest and Livelihood. 2009; 8, 5-14.

Chege MN. Phenotypic and genotypic diversity of *Xanthomonas axonopodis* pv. *manihotis* causing cassava bacterial blight disease in Kenya. (Bioinformatics and Molecular Biology) Jomo Kenyatta University of Agriculture and Technology. 2018; 1-71.

Cherif S. Construire la résilience au changement climatique par les connaissances locales : le cas des régions montagneuses et des savanes de Côte d'Ivoire. FMSH-WP-2014-83. 2014 ; <halshs-01081449, 7:28, HAL.

Chukwuka, KS, Okechukwu RU, Azorji. JN. Farmer perceptions of cassava bacterial blight disease in Oyo State, South-West, Nigeria. African Journal of Root and Tuber Crops. Vol. 10 No.1. 2013; 69, 67-74.

CIAT (Centre International d'Agriculture Tropicale). Global cassava trends. Reassessing the crop's future. In Henry, G and Gottret, V. (eds) Working document no. 157. CIAT, Cali, Colombia. 1996.

CMA/AOC (Conférence des Ministres de l'Agriculture de l'Afrique de l'Ouest et du Centre). Note technique sur le manioc dans la zone CMA/AOC. 2004; 2-4 : 15p.

Coakley SM, Scherm H, Chakraborty S. Climate change and plant disease management. Annual Reviews of Phytopathology. 1999; 399-426. 0066-4286/99/0901-0399$08.00. www.annualreviews.org

Cockerham CC. Estimation of genetic variance components. In: Hanson WD, Robinson HF (eds) Statistical Genetics and Plant Breeding. Pub. National Academy of Science and National Research Council Publishers, UK. 1963; 982: 53–94.

Coletta-Filho HD, Takita MA, De Souza AA, Aguilar-Vildoso CI, Machado MA. Differentiation of strains of *Xylella fastidiosa* by a variable number of tandem repeat analysis. Applied Environmental Microbiology. 2001; 67:4091-4095.

Comoe H. Contribution to food security by improving farmers' responses to climate change in northern and central areas of Cote d'Ivoire. Doctoral Thesis, ETH Zurich Research Collection. 2013; https://doi.org/10.3929/ethz-a-009910109.

Constantin EC, Cleenwerck I, Maes M, Baeyen S, Van Malderghem C, De Vos P. Genetic characterization of strains named as *Xanthomonas axonopodis* pv. *dieffenbachiae* leads to a taxonomic revision of the *X. axonopodis* species complex. Plant pathology. 2016; 65, 792-806. doi: 10.1111/ppa.12461.

Cours G. Le manioc à Madagascar, Mémoire de l'Institut Scientifique de Madagascar, Série B, Tome III, Fascicule. 1951; 2 : 203-400p.

Cunningham WP, Cunningham MA, Saigo B. Environmental Sciences: A Global Concern. 8thed. New York: Published by McGraw-Hill. 2005; 16-316.

Daniel JF. Un nouveau dépérissement en Empire Centrafricain, La bactériose vasculaire à *Xanthomonas manihotis*. 1977; 3, 14p.

Daniel JF, Boher B. Some aspects of survival and dissemination causal agent of cassava bacterial blight: *Xanthomonas campestris* pathovar *manihotis*. 1982; 1: 10.

Daniel JF, Boher B. Etude des modes de survie de l'agent causal de la bactériose vasculaire du manioc, *Xanthomonas campestris* pathovar *manihotis*. Agronomie. 1985; 5 (4), 343 : 339-346.

Davey JW, Hohenlohe PA, Etter PD, Boone JQ, Catchen JM, et al. Genome-wide genetic marker discovery and genotyping using next-generation sequencing. Nature Reviews Genetics. 2011; 12: 499–510.

Dedal OI, Palomar MK, Napiere CM. Host range of *Xanthomonas manihotis* Starr. Annals of Tropical Research. 1980; 2, 149-155.

Dibi Kangah PA, Amon OH-J. Variabilité pluviométrique et rendement du manioc dans l'Est et le Sud-Est de la Côte d'Ivoire de 1951 à 2013. Regardsuds; Premier numero. 2016; ISSN-2414-4150.

Dixon AG, Ngeve JM, Nukenine EN. Genotype× environment Effects on Severity of Cassava Bacterial Blight Disease caused by *Xanthomonas axonopodis* pv. *manihotis*. European Journal of Plant Pathology. 2002; 108(8), 763-770.

Dje Bi IR, Kouassi KI, Koffi KK, Kouakou KL, Baudoin JP, Zoro Bi IA. Evaluation of cassava varieties for weed tolerance ability, Experimental Agriculture. Cambridge University. 2018; 443–451. doi:10.1017/S0014479717000151.

Djouldé DR. Mise au point d'un ferment mixte destiné à la bioconversion des tubercules de manioc cyanogène, l'Ecole Nationale Supérieure Des Sciences Agroindustrielles (ENSAI) de l'Université de Ngaoundéré. 2005; 12 : 203.

DPSA/MINADRI/DR (Direction de la Production et de la Sécurité Alimentaire du Ministère Ivoirien de l'Agriculture et du Développement Rural). Annuaire des Statistiques Agricoles. 2017.

Ducroquet H, Tillie P, Louhichi K, Gomez-Y-Paloma S. L'agriculture de la Côte d'Ivoire à la loupe: Etat des lieux des filières de production végétales et animales et revue des politiques agricoles. EUR 28754 FR. 2017; 1-244. doi:10.2760/126254.

Dulong R. Le manioc à Madagascar : IRAT-IRAM. Station agronomique du lac Alaotra. Division amélioration des plantes. Section manioc, Madagascar. 1970; 10p.

Duruigbo CI. Indigenous Climate-Change Adaptation and Mitigation Technologies for Sustainable Roots and Tuber Crop Productivity in Africa. 16th Triennial Symposium International Society for Tropical Root Crops Federal University of Agriculture, Abeokuta, Nigeria. 2012 ; 16(52):116.

EDSCI-II. Enquête Démographique et de Santé, Caractéristiques du pays et méthodologie de l'enquête. 1999; 11.

Elad Y, Pertot I. Climate Change Impacts on Plant Pathogens and Plant Diseases. Journal of Crops Improvement. 2014; 28:99–139. doi: 10.1080/15427528.2014.865412.

Elango F, Lozano JC. Pathogenic variability of *Xanthomonas manihotis*, the causal agent of cassava bacterial blight. Fitopatologia Brasileria. 1981; 6 : 57-63.

Excoffier L, Lischer HE. Arlequin suite ver 3.5: a new series of programs to perform population genetics analyses under Linux and Windows. Molecular ecology resources. 2010; 10(3), 564-567.

Falconer DS. Selection in different environments: effects on environmental sensitivity (reaction norm) and on mean performance. Genetic Research Cambridge. 1990; 56: 57–70.

Fanou AA, Zinsou VA, Wydra K. Survival of *Xanthomonas axonopodis* pv. *manihotis* in weed species and in cassava debris: Implication in the epidemiology of cassava bacterial blight. International Journal of Advance Research. 2017; 5(4), 2098-2112. DOI: 10.21474/IJAR01/4057.

Fanou AA, Zinsou VA, Wydra K. Cassava Bacterial Blight: A Devastating Disease of Cassava, IntechOpen. 2018; 1-25. http://dx.doi.org/10.5772/intechopen.71527.

FAO (Food and Agricultural Organisation of the United Nations). Atelier de formation sur la mosaïque sévère du manioc. 2005a; 15, 18 : 70.

FAO (Food and Agricultural Organisation of the United Nations). L'irrigation en Afrique en chiffres – Enquête AQUASTAT; 2005, 1-10.

FAO (Food and Agricultural Organisation of the United Nations). Climate Change and Food Security: A Framework Document. 2008; 1-107.

FAO (Food and Agricultural Organisation of the United Nations). Production of Cassava in Africa and in the World. 2013; Retrieved from: http://faostat3.fao.org/browse/Q/QC/E.

Fargier E. L'étude de la pathologie de *Xanthomonas campestris* et de la structure génétique de ses pathovars a permis l'amélioration de la détection du pathogène dans les semences de Brassicacées. Ecole Doctorale d'ANGERS. 2007; 65, 66-67 : 236.

Flor H. Current status of the gene-for-gene concept. Annual Review of Phytopathology. 1971; 9, 275-296.

Flores C. Cassava Bacterial Blight: Development of a performant molecular detection tool and diversity analysis of *Xanthomonas axonopodis* pv. *manihotis* populations in Venezuela. Thèse

pour obtenir le grade de Docteur de l'Université de Montpellier en Evolutions des systèmes infectieux École doctorale GAIA Unité de recherche IPME. 2017; 1-184.

Fondio L, Coulibaly DN, N'zue B, N'gbesso M, François DP, Doumbia B. Preliminary study on vegetables small scale farmers' perceptions of climate change in the centre of Côte d'Ivoire. ResearchGate. 2016; https://www.researchgate.net/publication/320803248.

Francisco AP, Vaz C, Monteiro PT, Melo-Cristino J, Ramirez M, Carriço JA . PHYLOViZ: phylogenetic inference and data visualization for sequence based typing methods. BMC bioinformatics. 2012; 13(1), 1.

Garcia-Brugger A, Lamotte O, Vandelle E, Bourque S, Lecourieux D, Poinssot B, Wendehenne D, Pugin A. Early signaling events induced by elicitors of plant defences. Molecular Plant Microbe Interaction. 2006; 19: 711-724.

Garrett KA, Dobson ADM, Kroschel J, Natarajan B, Orlandini S, Tonnang HEZ, Valdivia C. The effects of climate variability and the color of weather time series on agricultural diseases and pests, and on decisions for their management. Agricultural and Forest Meteorology. Vol. 170. 2013; 216–227.

Gautam HR, Bhardwaj ML, Kumar R. Climate change and its impact on plant diseases. Current Science. VOL. 105, NO. 12. 2013; 1-7.

Ghini R, Hamada E, Bettiol W. Climate change and plant diseases. Science of Agriculture (Piracicaba, Braz.), v.65, special issue. 2008; 98-107.

Goosse H, Barriat PY, Lefebvre W, Loutre MF, Zunz V. Introduction to climate dynamics and climate modelling –Chap1. Description of the climate system and its components. 2010; 1-24. http://www.climate.be/textbook.

Guinard J. Dynamique évolutive de *Ralstonia solanacearum* en réponse aux pressions de sélection de l'aubergine résistante: approche populationnelle, de génétique évolutive et fonctionnelle de la durabilité de la résistance. Thèse de Doctorat en Sciences Spécialité: Génétique des populations, phytopathologie, bactériologie, épidémiologie moléculaire. 2015; 1-416.

Guthrie J. Contrôler la mosaïque du manioc. Centre technique de coopération agricole et rurale (CTA). 1990; 1 : 20.

Hahn SK. Breeding cassava for resistance to bacterial blight. PANS. 1978; 24, 480-485.

Hahn SK, Terry ER, Leuschner K, Akobundu IO, Okali C, Lal R. Cassava improvement in Africa. Field Crops Research. 1979; 2, 193-226.

Halle B, Bruzon V. Profil Environnemental de la Côte d'Ivoire. Commission Européenne. Offre de service dans le secteur de la coopération relatif au Contrat Cadre Europe Aid/119860/C/SV/Multi, Consortium AGRIFOR Consult, Rapport final. 2006; 23, 133.

Hamza AA. Taxonomy and diagnosis of *Xanthomonas* species associated with scabies of tomato and Capsicum spp.: situation in the South West Islands of the Ocean Indian, University of Reunion, Faculty of Science and Technology, UMR Peuplements Plants and Bio-aggressors in Tropical Environment CIRAD - University of Reunion. 2010; 33, 34: 234.

Harvell HC, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD. Climate warming and disease risks for terrestrial and marine biota. Science. 2002; 296: 2158-2162.

Hillocks RJ, Wydra K. Bacterial, Fungal and Nematode diseases. CAB International. Cassava: Biology, Production and Utilization. 2002; 263 : 261-280.

Huang TC, Lee HL. Hot acidified zinc sulfate as seed soaking agent for the control of crucifer black rot. Plant Protection Bulletin (Taiwan). 1988; 30, 245-258.

Humaydan HS, Harman GE, Nedrow BL, Di Nitto LV. Eradication of *Xanthomonas campestris*, the causal agent of black rot from Brassica seeds with antibiotics and sodium hypochlorite. Phytopathology. 1980; 70, 127-131.

Ifeany-Obi CC, Issa FO. Barriers faced by Cassava Farmers in Adapting To Climate Change in Oron Agricultural Zone of Akwa Ibom State. Journal of Agriculture and Veterinary Sciences (IOSR-JAVS). Volume 4, Issue 6 (Sep. - Oct. 2013). 2013; 19-26. www.iosrjournals.org.

Ikotun I. Studies on the host range of *Xanthomonas manihotis*. Fitopatologia Brasileira. 1981; 6, (l), 15-21.

Ikram K, Sarra B. Algorithmes de classification pour la prévision des maladies agricoles. Thesis, ResearchGate, 2017; DOI:10.13140/RG.2.2.22515.84009.

IPCC. Climate Change 2001. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge. 2001; 1-1042.

IPCC. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK. 2007; 976.

IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 2014; 151.

IPCC. Special report "Global warming of 1.5 °C, Summary for teachers. Office for Climate Education, Intergovernmental Panel on Climate Change. 2018; 1-24.

IITA (Institut International d'Agriculture Tropicale), IRAD (Institut de Recherche Agricole pour le Développement). Production et transformation du manioc (*Manihot esculenta*). 2008; 1 : 13.

IITA (Institut International d'Agriculture Tropicale). Root and tuber cross production. Manual series, n°9, 1982.

ITRA (Institut togolais de recherche agronomique). Rapport de l'ITRA. www.itranet.tg. 2008, 1-61.

Jeger MJ, Viljanen-Rollinson SLH. The use of the area under the disease-progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. Theoretical and Applied Genetics. 2001; 102: 32-40.

Johnson R: A critical analysis of durable resistance. Annual review of phytopathology. 1984; 22(1):309-330.

Jorge V, Fregene MA, Duque MC, Bonierbale MW, Tohme J, Verdier V. Genetic mapping of resistance to bacterial blight disease in cassava (*Manihot esculenta* Crantz). TAG Theoretical and Applied Genetics. 2000; 101: 865-872.

Jorge V, Fregene MA, Velez CM, Duque MC, Tohme J, Verdier V.QTL analysis of field resistance to *Xanthomonas axonopodis* pv. *manihotis* in cassava. Theoretical and Applied Genetics. 2001; 101(5-6), 865-872.

Kliejunas JT, Geils BW, Glaeser JM et al. Review of Literature on Climate Change and Forest Diseases of Western North America. United States Department of Agriculture Forest Service

Pacific Southwest Research Station General Technical Report PSW-GTR-225. 2009; 2-5(6-9):60.

Komi E (1992). Etude de la variabilité des composantes du rendement du manioc (*Manihot esculenta* CRANTZ, var. 312-524) en fonction de la fertilité du sol. 10, 11 : 102.

Kone D, Dao S, Tekete C, Doumbia I, Koita O, Abo K, Wicker E, Verdier V. Confirmation of *Xanthomonas axonopodis* pv. *manihotis* Causing Cassava Bacterial Blight in Ivory Coast. Disease Notes. 2013; 1-2. http://dx.doi.org/10.1094/PDIS-02-15-0172-PDN.

Kouassi KM, Mahyao A, N'zue B, Koffi E, Koffi C. Status of Cassava (Manihot Esculenta Crantz) in Côte d'Ivoire: From Production to Consumption and Evaluation of Technology Adoption. European Scientific Journal. 2018; 285-296. doi: 10.19044/esj.2018.v14n9p285.

Korang-Amoakoh S, Oduro KO. Present situation of Cassava bacterial blight in Ghana. In cassava Bacterial Blight in Africa : past, present and future. Report of Interdisciplinary Workshop, IITA, Ibadan, Nigeria, 26-30 June 1978. Centre of overseas Pest Research, London. 1979; 58.

Kweku DW, Bismak O, Maxwell A et al. Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. Journal of Scientific Research & Reports, 2017; Article no.JSRR.39630 ISSN: 2320-0227. 2017; 17(6): 1-9. DOI: 10.9734/JSRR/2017/39630.

Leu LS, Chen CT. Bacterial wilt of cassava (*Manihot utilissima* Panh.) caused by *Xanthomonas manihotis* (Arthaud-Berthet) Starr. Plant Protection Bulettin. Taiwan. 1972; 3 : 17-26.

Li W, Raoult D, Fournier PE. Bacterial strain typing in the genomic era. FEMS Microbiology Review. 2009; 33: 892–916.

Lozano JC. Bacterial blight of cassava. PANS. 1975; 21 : 38-43.

Lozano JC. Cassava bacterial blight: A manageable disease. Plant Diseases. 1986; 70 : 1089 1093.

Lozano JC, Laberry R, Bermudez A. Microwave treatment to eradicate seed-borne pathogens in cassava true seed. Journal Phytopathology. 1986; 117.

Lozano JC, Sequeira L. Bacterial blight of cassava in Colombia Etiology. Phvtopathology. 1974; 64 : 74-82.

MADR (Ministère de l'agriculture et du développement rural). Recensement des exploitants et exploitations agricoles 2015/2016. VOL 1. 2017; 1:59.

MAAF (Ministère de l'Agriculture, l'Agroalimentaire et de la Forêt Agricultural). Les politiques agricoles à travers le monde: quelques exemples. Côte d'Ivoire. 2015; 1-10. www.agriculuture.gouv.fr/sites/minapri/files/1506-ci-resinter-fr-Côte-ivoire.pdf.

Mamba-Mbayi G, Tshilenge-Djim P, Nkongolo KK, Kalonji-Mbuyi A. Characterization of Congolese Strains of *Xanthomonas axonopodis* pv. *manihotis* associated with Cassava Bacterial Blight. American Journal of Plant Sciences. 2014; 5,1191-1201. http://dx.doi.org/10.4236/ajps.2014.59132.

Maraite H. *Xanthomonas campestris* pathovars on cassava: cause of bacterial blight and bacterial necrosis. In: J.G. Swings & E.L. Civerolo (Eds.), *Xanthomonas*. Chapman and Hall, Ltd., London. 1993; 18–24.

Maraite H, Meye J. *Xanthomonas manihotis* (Arthaud-Berthet) Starr, causal agent of bacterial wilt, blight and leaf spots of cassava in Zaire. PANS. 1975; 21: 27-37.

Maraite, H, Weyns J, Yimkwan O, Lipembra P, Perreaux D. Physiological and pathogenic variations in *Xanthomonas campestris* pv. *manihotis*, 358–368p. In J. C. Lozano. 1981; 55. Gwin (ed.), Plant pathogenic bacteria. Proceedings of the 5th International Conference on Plant Pathogenic Bacteria. CIAT, Cali, Colombia.

Matthews RB, Hunt LA. Gumcas: a model describing the growth of cassava (*Manihot esculenta* Crantz),.Field Crops Research. 1994; 36: 69-84.

Mboup M, Bahri B, Leconte M, De Vallavieille-Pope C, Kaltz O, Enjalbert J. Genetic structure and local adaptation of European wheat yellow rust populations: the role of temperature-specific adaptation. Evolutionary Applied. 2012; 5: 341–352.

McKey D, Elias M, Pujol B, Duputié A, Delêtre M, Renard D. Maintien du potentiel adaptatif chez les plantes domestiquées à propagation clonale Leçons de gestion par les cultivateurs de manioc amérindiens. 2012; 6 : 19.

Mendez del Villar P, Adaye A, Tran T, Allagba K, Bancal V. Analyse de la chaîne de Manioc en Côte d'Ivoire. Rapport pour l'Union Européenne, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804). 2017; 157p + annexes.

Mendez del Villar P, Adaye A, Tran T, Allagba K, Bancal V. Analyse de la chaîne de Manioc en Côte d'Ivoire. Rapport pour l'Union Européenne, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D) N°3 – Janvier. 2018; 4:6.

Messiaen CM, Blancard D, Rouxel F, Lafon R. Les maladies des plantes maraîchères. INRA, Paris, France. 1991; 552.

Minagri: Ministère de l'Agriculture, Annuaire des Statistiques Agricoles, 2012.

Nassar NMA. Conservation of the genetic resources of cassava (*Manihot esculenta*): determination of wild species localities with emphasis on probable origin. Economic Bototany. 1978; 32: 311-320.

Niasse M, AFouda A, Amani A. Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification. Eléments de stratégie régionale de préparation et d'adaptation. UICN. 2004; 58.

N'Dabalishye I. Agriculture Ouest-africaine à travers le cas de la Côte d'Ivoire : Monographie. 1995; 151, 158 : 383.

Ngoc L, Verniere C, Vital K, Guerin F, Gagnevin L, Brisse S, AH-YOU N, Pruvost O. Development of 14 minisatellite markers for the citrus canker bacterium, Xanthomonas citri pv. citri. Molecular and Ecological Resources. 2009; 9(1):125-127.

N'Guessan MSA. Projet de création d'une société industrielle de transformation du manioc en produits dérivés en Côte d'Ivoire: Elohim Transformation, Centre Africain d'études Supérieures en Gestion (CESAG). Master en Banque et Finance (MBF) Option : Gestion Bancaire et Maitrise des risques, Projet Professionnel. 2016; 7:55.

N'Guessan CA, Brisse S, Le Roux-Nio A-C, Poussier S, Koné D, Wicker E: Development of variable number of tandem repeats typing schemes for Ralstonia solanacearum, the agent of bacterial wilt, banana Moko disease and potato brown rot. Journal of Microbiological Methods 2013, 92(1):366-374.

N'Guessan AAB, Dje KB. Changements climatiques, agriculture et sécurité alimentaire en Afrique Subsaharienne : Le cas de la Côte d'Ivoire. Revue de Géographie Tropicale et d'Environnement n°2. 2012; 11.

N'Zué B, Zohouri GP, Yapi-Gnaoré V. Bien cultiver le manioc en Côte d'Ivoire. Direction des programmes de recherche et de l'appui au développement. CNRA, Cote d'Ivoire. 2005; 1 : 4.

N'Zue B, Bouan B, Dibi KEB, Kouakou AM, Djedji C, Kouassi KF, Zohouri GP, Ehounou E. PSTAD (DONATA), Rapport d'activités 1er trimestre 2013. CNRA, www.cnra.ci, Côte d'Ivoire. 2013a; 7.

N'Zue B, Zohouri GP, Djedji C, Tahouo O, Keli J, Beninga MB. Bien cultiver le manioc en Côte d'Ivoire. Direction des programmes de recherche et de l'appui au développement - Direction des systèmes d'information, Centre national de recherche agronomique (CNRA). 2013b; 1:4.

N'Zue B, Okoma MP, Kouakou AM, Dibi KEB, Zohouri GP, Essis BS, Dansi AA. Morphological Characterization of Cassava (*Manihot esculenta* Crantz) Accessions Collected in the Centre-west, South-west and West of Côte d'Ivoire. Greener Journal of Agricultural Science. 2014; 4(6):220-231.

Noufé D, Lidon B, Mahé G, Servat E, Yao TB, Zueli KB, Chaléard JL. Variabilité climatique et production de maïs en culture pluviale dans l'est Ivoirien. Hydrological Sciences Jounal. 2011; 56:1, 152-167. DOI:10.1080/02626667.2010.545247.

Ogunjobi AA, Fagade OE, Dixon AGO. Molecular variation in population structure of *Xanthomonas axonopodis* pv. *manihotis* in the south eastern Nigeria. African Journal of Biotechnology. 2006; 5:1868-1872.

Ogunjobi AA, Fagade OE, Dixon AGO. Physiological Studies on *Xanthomonas axonopodis* pv. *manihotis* (*Xam*) Strains Isolated in Nigeria, Advances in Biological Research. 2008; 2 (5-6) 90 : 90-96.

Ogunjobi AA, Fagade OE, Dixon AGO. Comparative analysis of genetic variation among *Xanthomonas axonopodis* pv. *manihotis* isolated from the western states of Nigeria using RAPD and AFLP. Indian Journal of Microbiology. 2010; 50:132-138.

Ohunyon PU, Ogio-Okirika JA. Eradication of cassava bacterial blight/ cassava improvement Niger delta of Nigeria. In Cassava Bacterial Blight in Africa, Past, Present and Future. Report of Interdisciplinary Workshop, IITA, Ibadan, Nigeria. Centre of overseas Pest Research, London. 1979; 55-57.

Olsen KM, Schaal BA. Microsatellite variation in cassava (*Manihot esculenta*, Euphorbiaceae) and its wild relatives: further evidence for a southern Amazonian origin of domestication. American Journal of Botany. 2001; 88:131–142, 2001.

Onyeka TJ, Owolade OF, Ogunjobi AA, Dixon AGO, Okechukwu R, Bandyopadhyay R, Bamkefa B. Prevalence and severity of bacterial blight and anthracnose diseases of cassava in different agroecological zones of Nigeria. African Journal of Agricultural Research. Vol. 3. 2008; (4), 299, 297-304.

Otim-Nape GW. Cassava Bacterial Blight in Uganda. Tropical Pest Management. 1980; 26: 274-277.

PACIR (Programme d'Appui au Commerce et à l'Intégration Régionale). Evaluation du potentiel à l'exportation du manioc - Côte d'Ivoire – 2013. Soutien institutionnel et opérationnel pour améliorer l'environnement des entreprises et améliorer la compétitivité des exportations de la Côte d'Ivoire. 2013; 3-4, 11, 16 : 43.

Parkinson N, Bryant R, Bew J, Conyers C, Stones R, Alcock M, Elphinstone J: Application of Variable Number Tandem Repeat (VNTR) Typing to Discriminate *Ralstonia solanacearum* Strains Associated with English Watercourses and Disease Outbreaks. Applied and Environmental Microbiology. 2013; 79(19):6016-6022.

Parry M, Rosenzweig C, Iglesias A, Fischer G, Livermore M. Climate change and world food security: A new assessment. Global Environmental Change. 1999; 9: 5167.

Patel MK, Abhyankar SG, Kulkarni YS. Black rot of cabbage. Indian Phytopathology. 1949; 2, 58-61.

Pearce F. Cassava comeback. New Scientist. 2007; 38-39.

Peakall R, Smouse PE. GenAlEx 6.5: genetic analysis in Excel: population genetic software for teaching and research–an update. Bioinformatics. 2012; 28(19):2537–2539.

Perrin A, Ricau P, Rabany de Rongead C. Etude de la filière Manioc en Côte d'Ivoire Projet « Promotion et commercialisation de la Banane Plantain et du Manioc en Côte d'Ivoire » financé par le Comité Français pour la Solidarité Internationale (CFSI). 2015; 87.

Persley GJ. Studies on the survivant and transmission of *Xanthomonas manihotis* on cassava seeds. Annals of applied Biology. 1979; 93, 159-166.

PNIA (Programme National d'Investissement Agricole). L'agriculture Intelligente face au Climat en Côte d'Ivoire : état des lieux et besoins d'appui pour mieux intégrer l'Agriculture Intelligente face au Climat (AIC) dans le Programme National d'Investissement Agricole (PNIA). 2014; 3:15.

Population Reference Bureau. World population data sheet. 2018; 1-20. worldpopdata.org.

Poubom CFN, Awah ET, Tchuanyo M, Tengoua F. Farmers' perceptions of cassava pests and indigenous control methods in Cameroon. International Journal of Pest Management. 2005; 51(2): 157 – 164.

Poulin L, Grygiel P, Magne M, Gagnevin L, Rodriguez-R L, Serna NF, Zhao S, El Rafii M, Dao S, Tekete C: New multilocus variable-number tandem-repeat analysis tool for surveillance and local epidemiology of bacterial leaf blight and bacterial leaf streak of rice caused by *Xanthomonas oryzae*. Applied and environmental microbiology. 2015; 81(2):688-698.

Poundzou J. Contribution à la mise au point de techniques de lutte contre la bactériose vasculaire dans le cadre d'un parc à multiplication végétative de manioc. Mémoire d'Ingénieur. ORSTOM, Brazzaville, République Populaire du Congo. 1987; 62.

Pruvost O, Magne M, Boyer K, Leduc A, Tourterel C, Drevet C, Ravigné V, Gagnevin L, Guérin F, Chiroleu F. A MLVA genotyping scheme for global surveillance of the citrus pathogen *Xanthomonas citri* pv. *citri* suggests a worldwide geographical expansion of a single genetic lineage. PloS one. 2014; 9(6):e98129.

Rache L, Blondin L, Flores C et al. An optimized microsatellite scheme for assessing populations of *Xanthomonas phaseoli* pv. *manihotis*. Phytopathology. 2019; 1-11. https://doi.org/10.1094/PHYTO-06-18-0210-R.

Raffaillac JP. Le rôle de la densité de plantation dans l'élaboration du rendement du manioc. In : Biarnès Anne édition : La conduite du champ cultivé : points de vue d'agronomes. Paris : ORSTOM. (Colloques et Séminaires). La Conduite du Champ Cultivé : Points de Vue d'Agronomes : Séminaire, Montpellier (FRA), 1994/09. ISBN 2-7099-1387-9. 1997; 75-93p.

Rana I, Randhawa SS. Impact of Climate variations on Plant Diseases. State Centre on Climate Change (H.P State Council for Science Technology & Environment) Block-34, SDA Complex, Kusumpti, Shimla (H.P)-71009. 2014; 1-20.

Restrepo S, Duque M, Tohme J, Verdier V. AFLP fingerprinting: An efficient technique for detecting genetic variation of *Xanthomonas axonopodis* pv. *manihotis*. Microbiology. 1999a; 145:107-114.

Restrepo S, Valle TL, Duque MC, Verdier V. Assessing genetic variability among Brazilian strains of *Xanthomonas axonopodis* pv. *manihotis* through restriction fragment length

polymorphism and amplified fragment length polymorphism analyses. Canadian Journal of Microbiology. 1999b; 45:754-763.

Restrepo S, Vélez CM, Verdier V. Measuring the Genetic Diversity of *Xanthomonas axonopodis* pv. *manihotis* in Different Fields in Colombia. Phytopathology. 2000; 90, 683: 683-690.

Restrepo S, Verdier V. Geographical differentiation of the population of *Xanthomonas axonopodis* pv. *manihotis* in Colombia. Applied of Environmental Microbiology. 1997; 63:4427-4434.

Restrepo S, Velez CM, Duque MC, Verdier V. Genetic structure and population dynamics of *Xanthomonas axonopodis* pv. *manihotis* in Colombia from 1995 to 1999. Applied of Environmental Microbiology. 2004; 70:255-261.

Reynolds MP. Climate Change and Crop Production, CAB International. 2010; 1-311. www.cabi.org.

Rogers DJ, Appan M. *Manihot*, Manihotoides (Euphorbiaceae). New York, Etats- Unis, Hafner Press. Flora Neotropica Monograph. n° 13. 1973; 274 .

Rogers DJ, Fleming H. A monograph of *Manihot esculenta* with an explanation of the taximetrics methods used. Economic Botany. 1973; 27 : 1-113.

Rohli R, Vega Anthony J. Climatology. ISBN0763791016, 9780763791018. Jones and Bartlett Learning. 2011; 432.

Rosegrant MW, Ewing M, Yohe G, Burton I, Huq S, Valmonte-Santos R. Climate Change and Agriculture Threats and Opportunities. Technische Zusammenarbeit (GTZ) GmbH Climate Protection Programme for Developing Countries. Postfach 5180 65760 Eschborn / Germany. 2008; 1-36. climate@gtz.de I http://www.gtz.de/climate.

Rosenzweig C, Iglesias A, Yang XB, Epstein PR, Chivian E. Climate change and extreme weather events Implications for food production, plant diseases and pests. Global Change Biology. 2001; 1(90):15.

Rosenzweig C, Tubiello FN. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. Mitigation Adaptation Strategies to the Global Change. 2007; 12: 855-873.

Roumagnac P, Gagnevin L, Pruvost O, Achtman M. Insights into structure and evolution of bacterial species that are revealed by molecular methods. In: Encyclopedia of Infectious Diseases: Modern Methodologies. Edited by Tibayrenc M: John Wiley and Sons. 2007; 475-494.

Sadia C. Building resilience to change climate change by local knowledge: the case of mountain regions and savannahs of Cote d'Ivoire, FMSH-WP-2014-83. 2014. <halshs-01081449. 2014; 7:28.

Saddler GS, Bradbury JF. Family I. Xanthomonadaeae fam. nov. In Bergey's Manual of Systematic Bacteriology second edition. Vol. 2. Garrity, G.M., Brenner, D.G., Krieg, N.R. & Staley, J.T. (eds). New York: Springer. 2005; 63-90.

Sanchez G, Restrepo S, Duque MC, Bonierbale M, Verdier V. AFLP assessment of genetic variability in cassava accessions (*Manihot esculenta*) resistant and susceptible to the cassava bacterial blight (CBB). Genome. 1999; 42, 163-172.

Schaad NW, Gabrielson RL, Mulanax MW. Hot Acidified Cupric Acetate Soaks for Eradication of *Xanthomonas campestris* from Crucifer Seeds. Applied and Environmental Microbiology. 1980; 39, 803-807.

Shanahan M, Shubert W, Scherer C, Corcoran T, Banda F. Climate Change in Africa: A Guidebook for Journalists. UNESCO Series on Journalism Education. 2013; 10:91. ISBN 978-92-3-001234-2.

Shaner G, Finney RE. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology. 1977; 67: 1051-1056.

Shaw E, Besada FL, James IS, et al. Climate Change in Africa: Adaptation, Mitigation and Governance Challenges CIGI Special Report. The Centre for International Governance Innovation. 2009; .1-52. Copyright © 2009.

Shaw MW, Osborne TM. Geographic distribution of plant pathogens in response to climate change. Plant Pathology. 2011; 60, 31–43. Doi: 10.1111/j.1365-3059.2010.02407.x.

Sodexam (Société d'exploitation de développement aéroportuaire aéronautique météo). Etat du Climat de l'année 2016, Côte d'Ivoire. 2016; 1-20.

Sodexam (Société d'exploitation de développement aéroportuaire aéronautique météo). Etat du Climat de l'année 2017, Côte d'ivoire. 2017; 1-25.

Sundin GW, Castiblanco LF, Yuan X, Zeng Q, Yang CH. Bacterial disease management: challenges, experience, innovation and future prospects. Challenges in Bacterial Molecular Plant Pathology. Molecular Plant Pathology. 2016; 17(9): 1506–1518 DOI: 10.1111/mpp.12436.

Tindo M, Njukwe E, Mbairanodji A, Tenkouano. A. Survey on the current diseases status of local versus improved cassava varieties and their management strategies in Cameroon. Sciences, Technologies et Développement. 2016; http://www.univ-douala.com/std/, ISSN 1029-2225-e-ISSN 2313-6278.

Trujillo, CA, Arias-Rojas N, Poulin L, Medina CA, Tapiero A, Restrepo S. Population typing of the causal agent of cassava bacterial blight in the Eastern Plains of Colombia using two types of molecular markers. BMC Microbiology. 2014a; 14:161.

Trujillo CA, Ochoa JC, Mideros MF, Restrepo S, Lopez C, Bernal A. A complex population structure of the cassava pathogen *Xanthomonas axonopodis* pv. *manihotis* in recent years in the Caribbean Region of Colombia. Microbial Ecology. 2014b; 68:155-167.

UNESCO (United Nations Educational, Scientific and Cultural Organization). Climate Change in Africa: A Guidebook for Journalists. UNESCO Series on Journalism Education. 2013; 1-90. ISBN 978-92-3-001234-2.

UNFCCC. United Nations Framework Convention on Climate Change, 1992; 2: 25 http://unfccc.int/resource/docs/convkp/convfr.pdf.

Vauterin L, Hoste B, Kersters K, Swings GJ. Reclassification of *Xanthomonas*. International Journal System Bacteriology. 1995; 45, 472-489.

Verdier V. Contribution à l'étude de la variabilité de *Xanthomonas campestris* pv. *manihotis* (Arthaud Berthet et Bondar) Starr. Agent causal de la bactériose du manioc (*Manihot esculenta* Crantz), Université de Paris-Sud, Centre d'Orsay. 1988; 6 : 196.

Verdier V, Dongo P, Boher B. Assessment of genetic diversity among strains of *Xanthomonas campestris* pv. *manihotis*. Journal of Genetics and. Microbiology. 1993; 139:2591-2601.

Verdier V, Mosquera G, Assigbétsé K. Detection of the Cassava Bacterial Blight Pathogen, *Xanthomonas axonopodis* pv. *manihotis*, by Polymerase Chain Reaction. Plant Disease. Vol. 82 No. 1. 1997; 79-83.

Verdier V, Restrepo S, Mosquera G, Duque M, Gerstl A, Laberry R. Genetic and pathogenic variation of *Xanthomonas axonopodis* pv. *manihotis* in Venezuela. Plant Pathology. 1998; 47:601-608.

Verdier V, Restrepo S, Mosquera G, Jorge V, Lopez C. Recent progress in the characterization of molecular determinants in the *Xanthomonas axonopodis* pv. *manihotis* cassava interaction. Plant Molecular Biology. 2004; 56, 573-84.

Verniere C, Ngoc LBT, Jarne P, Ravigne V, Guerin F, Gagnevin L. Highly polymorphic markers reveal the establishment of an invasive lineage of the citrus bacterial pathogen *Xanthomonas citri* pv. *citri* in its area of origin. Environmental Microbiology. 2014; 16:2226-2237.10. doi:10.1111/1462-2920.12369.

Walker JC. Disease of crucifers. In Diseases of vegetable crops. McGraw Hill, New York. 1952; 128-131.

Were HK. Serological and molecular characterization of begomoviruses infecting cassava (*Manihot esculenta* Crantz) in Africa, BSc, MSc, Nairobi geborenam 30.11.1967 in Busia, Kenia. 2001; 187.

Williams PH. Black Rot: A continuing threat to world crucifers. Plant disease. 1980; 64, 736-742.

Williams RJ, Agboola SD, Schneider RW. Bacterial wilt of cassava in Nigeria. Plant Disease. Reovirus1973; 57, (l0), 824-827.

WMO (World Meteorological Organization). Statement on the State of the Global Climate in 2018. ISBN 978-92-63-11233-0. 2019; 1-44.

Wydra K. The concept of resistance, tolerance and latency in bacterial diseases: examples from cassava and cowpea. New Aspects of Resistance Research on cultivated Plants. Beitr. Züchtungsforsch., BAZ. 2002; 9 (3), 36-43.

Wydra K, Banito A, Kpémoua KE. Characterization of resistance of cassava genotypes to bacterial blight by evaluation of symptom types in different ecozones. Euphytica. 2007; 155, 337-348.

Wydra K, Msikita W. An overview of the present situation of cassava diseases in West Africa. In: Proceedings of the 6th ISTRC-AB Symposium, Lilongwe, Malawi, October 22–28 (in press). 1995; 198-206.

Xiong Z, Liu C, Geng B. Phytotoxic effects of copper on nitrogen metabolism and plant growth in Brassica pekinensis Rupr. Ecotoxicology and Environmental Safety. 2006; 64, 273-280.

Xu J, Wang N. Where are we going with genomics in plant pathogenic bacteria? Genomics. 2018; 1-8. https://doi.org/10.1016/j.ygeno.2018.04.011.

Yáñez-López R, Torres-Pacheco I, Guevara-González RG, Hernández-Zul MI, Quijano-Carranza JA, Rico-García E. The effect of climate change on plant diseases. African Journal of Biotechnology. Vol. 11(10), 2 February. 2012; 2417-2428. Available online at http://www.academicjournals.org/AJB. DOI: 10.5897/AJB10.2442 ISSN 1684–5315.

Yao NR, Oule AF, N'Goran KD. Study of the Vulnerability of the Agricultural Sector to Climate Change in Côte d'Ivoire. Final Report. 2013; 53: 105.

Yemataw Z, Mekonen A, Chala A, Tesfaye K, Mekonen K, Studholme DJ, Sharma K. Farmers' knowledge and perception of *enset Xanthomonas* wilt in Southern Ethiopia. Agriculture and Food Security. 2017; 6: 62, DOI 10.1186/s40066-017-0146-0.

Yin K, Qiu J-L. Genome editing for plant disease resistance: applications and perspectives. Philosophical Transactions Royal Society. 2019; 374:20180322. http://dx.doi.org/10.1098/rstb.2018.0322.

Zhao S, Poulin L, Rodriguez-R LM, Serna NF, Liu S-Y, Wonni I, Szurek B, Verdier V, Leach JE, He Y-Q: Development of a variable number of tandem repeats typing scheme for the bacterial rice pathogen *Xanthomonas oryzae* pv. *oryzicola*. Phytopathology. 2012; 102(10):948-956.

Zinsou V. Studies on host plant resistance to cassava bacterial blight in combination with cultural control measures in ecozones of West Africa. PhD thesis, University of Hannover, Germany. 2003; 1-135.

Zinsou V, Wydra K, Ahohuendo B, Hau B. Genotype · environment interactions in symptom development and yield of cassava genotypes with artificial and natural cassava bacterial blight infections. European Journal of Plant Pathology. 2005; 111: 217–233.

Zohary D. Unconscious selection and the evolution of domesticated plants. Economic Botany 2004; 58 : 5-10.

Zoundjihekpon J. Etude de la variabilité morphophysiologique et enzymatique de cultivars de Manihot esculenta Crantz, Université Nationale de Côte d'Ivoire. 1986; 10, 16 : 120.

ANNEXES

Annex 1

SURVEY SHEET FOR PRODUCER PERCEPTION ON CASSAVA BACTERIAL BLIGHT AND CLIMATE CHANGE IN COTE D'IVOIRE

QUESTIONNAIRE FOR CASSAVA PRODUCERS IN THE PRODUCTION AREAS OF THE SEVEN AGRO-ECOLOGICAL ZONES OF COTE D'IVOIRE

I. IDENTIFICATION OF THE SURVEY

Identification Number (IN) : (*Starts with P01= Producer 01*)	**P :**
Begining of the interview	
Region	
Departement (*If necessary*)	
Town	
Village (*If necessary*)	
Geographical coordinates	**N :** **W :** **Altitude :**
Date	**dd/mm/yy :** / /
First and last names of the investigator	
End of the interview	

II. SOCIO-ECONOMIC CHARACTERISTICS OF THE PRODUCER AND INFORMATION ON THE ACTIVITY

Q1. First and last names	
Q2. Nationality (*1= Ivorian, 2= Foreigner, specify the nationality for the foreigners*)	
Q3. Mother tongue (*For the ivorians, to be specified*)	
Q4. Level of study (*Check the correct answer*)	
No level	**University**

Primary	Other (*To be specify*)
Secondary	
Q5. Sexe (*1 = Male, 2 = Female*)	
Q6. Level of literacy ((*Check the correct answer*)	1. Know how to read and write 2. Know how to read 3. Cannot read or write
Q7. Age (*Year only*)	
Q8. Marital status (*1 = single, 2 = married*)	
Q9. Size of the family (*Number of people in direct charge*)	
Q10. Number of people by age group (To be *Specified*) a. 0-5 years b. 6-10 years c. 11-18 years d. Over 18 years	
Q11. Land title (To be *Specified 1 = Landowner, 2 = Land tenant*)	
Q12. How many years have you spent on the field?	
Q13. Do you have others cassava field? (*1= Yes, 2= No*)	
Q14. What is the area of this field?	
Q15. What is the age of this field ?	
Q16. Do you use manpower (*1= Yes, 2= No*) ?	
Q17. What is the nature of this manpower used?	
Women	Friends
Men	Contractuals

Mixte	Others (*To be specified*)
Parents	
Q18. What is the number of the manpower used?	
Q19. Do you practice fallow in your field? (*1= Yes, 2= No*)	
Q20. Do you only grow cassava in your field? (*1= Yes, 2= No*)	

Q21. If not, what other crops are associated with cassava? (*Check the correct answer*)			
Maize		Coffee	
Banana		Cocoa	
Okra		Sweet potatoes	
Pepper		Guava	
Eggplant		Rubber tree	
Yam		Pineapple	
Pawpaw		Taro	
Oil palm tree		Others (*To be specified*)	

Q22. Where do you get the cuttings? (*Check the correct answer*)	
The same field	
Extension services (*CNRA, ANADER, …*), *Specify the service*	
Others (*Other fields, Neighbours, Friendss, Parents, …*)	
Q23. Do you benefit from a training for cassava cultivation? (1= Yes, 2= No)	

Q24. If so, which ones? (*Check the correct answer*)		
Choice of cuttings		Fertilizers to use
How to plant		Others (*To be specified*)

Q25. From whom do you receive this coaching? (1= *CNRA, 2= ANADER, 3= Cooperatives, 4= Other to be specified*)	
Q26. Have you ever participated in a training on cassava cultivation? (*1= Yes, 2= No*)	
Q27. If so, what type of training did you received?	
Q28. Give the name of the structure that trained you	
Q29. How do you use the tubers you grow? (*1 = Marketing, 2 = Personal consumption 3 = Other to be specified*) ?	
Q30. If marketing, where do you sell cassava? (*1 = Market, 2 = Cooperatives, 3 = Other to be specified*)	
Q31. To whom do you sell it? (*1 = Companies; 2 = Particular, 3 = Other to be specified*)	
Q32. How do you sell it? (1= *Kg, 2= Detail, 3 = Other to be specified*)	
Q33. How much do you sell it?	
Q34. Do you encounter problems when selling tubers? (*1= Yes, 2= No*)	
Q35. If so, which ones?	
Q36. What are your expectations or needs in case you want to continue growing cassava? (*1 = Cuttings, 2 = Training, 3 = Other to be specified*)	

III. KNOWLEDGE OF THE PRODUCER ON CLIMATE CHANGE

Q37. Have you noticed any changes in the climatic parameters (*Rain, Temperature,* ...) since you started cultivating cassava (*1 = Yes, 2 = No*)	
Q38. If so, what are these changes? (*Characterize them*)	
Q39. Have you ever heard of climate change? (*1 = Yes, 2 = No*)	
Q40. If so, where did you hear about it? (*1 = TV, 2 = Radio, 3 = Training, 4 = Other to be specified*)	
Q41. What do you think climate change is?	
Q42. What are the causes of climate change for you?	
Q43. In your opinion, does climate change have an impact on cassava cultivation? (*1 = Yes, 2 = No*)	
Q44. If so, what are these effects?	

IV. PRODUCER KNOWLEDGE OF CASSAVA BACTERIAL BLIGHT (CBB) AND THE EFFECTS OF CLIMATE CHANGE ON ITS EVOLUTION

Q45. Do you know some diseases of cassava? (*1 = Yes, 2 = No*)	
Q46. If so, what are these diseases?	
Q47. Do you know CBB? (*1 = Yes, 2 = No*)	
Q48. How did you hear it? (*Check the correct answer*)	
1= Researchers from Universities, Students	
2= Research Structure Agents (*Specify CNRA, ANADER or Others*)	

3= Others to be specified (*Parents, Neighbours, Friends, …*)	
Q49. How long have you seen the presence of the disease in your field?	
Q50. Have you ever observed losses related to bacterial disease? (*1 = Yes, 2 = No*) ; (*Give an estimate in case of loss*)	
Q51. Have you observed changes in the evolution of the disease with changing climatic parameters? (*1 = Yes, 2 = No*)	
Q52. If so, indicate the perceived changes	
Q53. Are these changes insignificant or significant? Justify your answer.	
Q54. How do you fight against the disease? (*Check the correct answer*)	
1 = No fight (specify why) **a = Not necessary** **b = Lack of financial means** **c = Products and devices too expensive** **d = Ignore the fight method** **2 = If you struggle, what are your endogenous strategies?**	

SYMPTOMS OF SOMES DISEASES

Cassava Mosaic Virus

Cercosporiose

Acariose

Anthracnose

SYMPTOMS OF CASSAVA BACTERIAL

Annex 2 : Fisher completely randomized experimental design

Bloc 1: Feke

Parcel 1	Dankwa ↔ Akama ↔ Yavo ↔ Bocou1	2 m	Bocou3 ↔ Yace ↔ Bocou2 ↔ Diarassouba		

2 m

Parcel 2	Diarassouba ↔ Dankwa ↔ Akama ↔ Yavo ↔ Bocou1 ↔ Bocou3 ↔ Yace ↔ Bocou2

Parcel 3	Yavo ↔ Yace ↔ Bocou1 ↔ Dankwa ↔ Akama ↔ Bocou3 ↔ Diarassouba ↔ Bocou2

Climate data collected :

Rainfall

Temperature

Relative Humidity

Bloc 2: Yakro

Parcel 1	Dankwa ↔ Akama ↔ Yavo ↔ Bocou1	2 m	Bocou3 ↔ Yace ↔ Bocou2 ↔ Diarassouba

2 m

Parcel 2	Diarassouba ↔ Dankwa ↔ Akama ↔ Yavo ↔ Bocou1 ↔ Bocou3 ↔ Yace ↔ Bocou2

Parcel 3	Yavo ↔ Yace ↔ Bocou1 ↔ Dankwa ↔ Akama ↔ Bocou3 ↔ Diarassouba ↔ Bocou2

Climate data collected :

Rainfall

Temperature

Relative Humidity

Bloc 3: Aboisso

Parcel 1	Dankwa ↔ Akama ↔ Yavo ↔ Bocou1	2 m	Bocou3 ↔ Yace ↔ Bocou2 ↔ Diarassouba

2 m

Parcel 2	Diarassouba ↔ Dankwa ↔ Akama ↔ Yavo ↔ Bocou1 ↔ Bocou3 ↔ Yace ↔ Bocou2

Parcel 3	Yavo ↔ Yace ↔ Bocou1 ↔ Dankwa ↔ Akama ↔ Bocou3 ↔ Diarassouba ↔ Bocou2

Climate data collected :

Rainfall

Temperature

Relative Humidity

Bloc 4: Man

Parcel 1	Dankwa ↔	Akama ↔	Yavo ↔	Bocou1 ↔ 2 m	Bocou3 ↔	Yace ↔	Bocou2 ↔	Diarassouba

2 m

Parcel 2	Diarassouba ↔	Dankwa ↔	Akama ↔	Yavo ↔	Bocou1 ↔	Bocou3 ↔	Yace ↔	Bocou2

Parcel 3	Yavo ↔	Yace ↔	Bocou1 ↔	Dankwa ↔	Akama ↔	Bocou3 ↔	Diarassouba ↔	Bocou2

Climate data collected :

Rainfall

Temperature

Relative Humidity

Annex 3. Description of the varieties used for the screening

	Status	Coloration (stem)	Coloration (leafsteak)	Cycle (months)	Estimated yield/ha (tons)
Dankwa	Local	Brown	Red	12-22	15
Diarrassouba	Local	Brune	Yellowish	12-22	15
Yace	Local	Green-red	Red	11-20	20
Akama	Local	Brown	Red	6-18	15
Bocou1	Improved	Green-brown	Green	12-20	25
Bocou2	Improved	Green-brown	Red	11-16	25
Bocou3	Improved	Green-brown	Green	12-16	25
Yavo	Improved	Green-red	Red	6-12	25

Annex 4. Origin of the strains used for the study of the genetic diversity and repartition of the haplotypes

Haplotypes	Strains	VZ	AEZ	Localities
1	4.4.2	4	6	Kaniasso
2	3.6.2	3	5	Sakassou
3	1.3.1	1	1	Aprompronou
3	1.3.2	1	1	Divo
3	2.4.1	2	3	Biankouma
3	2.5.2	2	3	Biankouma
3	2.6.1	2	3	Man
3	2.7.1	2	3	Man
4	2.6.2	2	3	Man
4	2.8.1	2	3	Man
4	2.8.2	2	3	Man
5	1.4.1	1	1	Adiaké
5	1.4.2	1	1	Samo
6	1.5.1	1	2	Bouaflé
6	1.5.2	1	2	Bonon
7	3.7.2	3	5	Sakassou
8	2.2.2	2	3	Biankouma
9	3.3.2	3	5	Béoumi
9	3.5.1	3	5	Béoumi
9	3.5.2	3	5	Sakassou
10	3.7.1	3	5	Sakassou
11	2.1.2	2	3	Biankouma
12	1.1.1	1	1	Aboisso
12	1.1.2	1	1	Aboisso
12	1.2.1	1	1	Songon
12	3.1.2	3	5	Bouaké
12	3.2.1	3	5	Bouaké
13	3.3.1	3	5	Bouaké
13	3.4.1	3	5	Béoumi

13	3.4.2	3	5	Béoumi
14	1.7.1	1	4	Zatta
15	1.2.2	1	1	Jacqueville
15	1.6.1	1	2	Bouafla
15	1.6.2	1	4	Yakro
15	2.3.1	2	3	Biankouma
15	2.3.2	2	3	Biankouma
15	2.5.1	2	3	Biankouma
15	3.6.1	3	5	Sakassou
15	4.5.2	4	6	Samatiguila

Annex 5. Sequences of the two pairs of oligonucleotides used for the PCR diagnosis

Fragment	Sequences	Size of the amplicons (pb)
C-Term	F: GCA-TGC-GAC-GCA-GTT-CGG-GAT-GAG R: ACT-AGT-TCA-CTG-AGG-AAA-TAC-CTC-CAT	570
rpoB	F: TGG-AAC-AGG-GCT-ATC-TGA-CC R: ATT-CYA-GGT-TGG-TCT-GRT-T	944

Annex 6. Composition of the PCR diagnostic mix

Reagents	Volumes (µl) 1 sample
Buffer 5X	2
dNTPs (10mM)	0,4
Mix of primer pairs AM1 and AM2 at 10µM	0,8
GotaQ	0,05
Sterile distilled water	5,75
Volume	9
Denatured bacterial suspension	1
Final volume	10

Annex 7. Different steps in carrying out amplification of PCR products

Steps	Temperatures	Time	Cycle numbers
Denaturation	93 ° C	3 min	
Denaturation	93 ° C	30 s	
Hybridization	65 ° C	30 s	35 cycles
Elongation	72 ° C	45 s	
Finale elongation	72 ° C	5 min	
Storage	4 ° C	∞	

Annex 8. Table showing the different pools and the pairs of primers used for the mix

Pools	Microsatellites	Fluorochromes
1	37	PET
	08	VIC
	15	NED
2	18	6-FAM
	21	NED
	31	PET
	35	VIC
3	06	6-FAM
	07	NED
	38	VIC
4	19	6-FAM
	25	NED
	27	PET
	30	VIC

Annex 9. Composition of the multiplex PCR mix for MLVA

Reagents	For each well
Buffer 2X Qiagen (MgCl2, Taq Polymerase)	5 µl
Solution Q 5X	1 µl
10X primer (2µM)	1 µl
Sterile distilled water	2 µl
Final volume	9 µl

Annex 10. Amplification Program for Multiplex PCR Products

Steps	Temperatures	Time	Cycle numbers
Denaturation	94 ° C	15 min	
Denaturation	94 ° C	30 s	
Hybridization	60 ° C	1 min 30	35 cycles
Elongation	72 ° C	1 min	
Finale elongation	72 ° C	20 min	

Annex 11. CBB Severity on the varieties in Yakro

Varieties	October	December	February	April	June	August
Akama	19.16±11.05	0	0	8.67±9.06	15.78±17.65	27.3±19.15
Dankwa	17.17±21.35	1.11±3.34	0	31.94±29.28	41.11±21.95	44.44±21.78
Bocou3	9.63±13.45	1.11±3.34	0	12.22±23.67	19.33±22.31	21.33±34.58
Bocou1	5.56±11.97	0	0	10.37±12.67	13.11±23.98	17.89±22.78
Diarrassouba	29.5±23.39	4.44±8.78	0	34.44±33.33	51.11±23.33	52.16±22.95
Bocou2	3.33±11.11	0	0	8.33±10.79	13.06±23.45	17.65±22.55
Yace	19.57±22.75	0	0	21.11±22.21	25.78±33.84	35.45±13.86
Yavo	21.11±11.11	0	0	21.11±31.01	42±21.79	43.33±13.33

Annex 12. CBB incidence on the varieties in Yakro

Varieties	October	December	February	April	June	August
Akama	21.5±31.4	0	0	12.79±21.1	22.22±11.11	28.2±22.83
Dankwa	21.16±12.7	1.11±3.34	0	41.11±29.87	42.57±28.89	45.6±25.64
Bocou3	12.05±21.04	1.11±3.34	0	15.67±23.45	21.79±27.86	22.89±19.89
Bocou1	7.47±15.61	0	0	14.44±21.66	17.78±23.45	21.67±17.53
Diarrassouba	30.1±35.62	4.44±9.98	0	45.56±15.78	51.11±29.83	53.25±27.45
Bocou2	5.56±10.06	0	0	13.33±23.33	14.44±21.67	19.01±21.24
Yace	23.67±35.61	0	0	25.89±29.89	29.56±11.15	37.78±27.89
Yavo	24.59±26.3	4.44±9.98	0	26.76±31.08	45.65±16.71	47.51±29.43

Annex 13. CBB Severity on the varieties in Aboisso

Varieties	November	January	March	May	October	December	February	April	June	August
Akama	7.78±12.64	4.81±2.79	0	40±27.88	39.44±21.76	0	0	57.5±29.45	59.78±18.89	61.2±38.87
Dankwa	10.67±16.91	0	0	26.11±08.18	32.5±31.09	0	0	24.72±17.14	32.22±25.98	40.5±27.36
Yace	24.72±19.98	0	0	18.06±21.09	23.61±17.67	0	0	24.72±12.78	34.67±27.31	37.3±19.78
Yavo	22.22±12.12	0	0	46±31.86	19.44±21.45	0	0	23.61±21.9	35.11±19.74	37.5±21.67
Diarrassouba	27.78±23.4	0	2.78	66.89±3.67	40.66±25.92	0	0	60.44±25.14	75±59.19	100
Bocou1	3.61 ± 1.2	5.56±5.67	0	25±17.01	28.33±19.91	0	0	35±21.79	40±27.71	42.5±21.86
Bocou2	4.44±3.33	0	0	12.22±12.22	17.41±13.83	0	0	23.61±19.87	33.61±	35.2±19.15
Bocou3	5.93±1.95	0	3.61±1.89	25±17.01	28.33±13.33	0	0	23.33±16.66	34.22±21.22	38±15.65

Annex 14. CBB incidence on the varieties in Aboisso

Varieties	November	January	March	May	October	December	February	April	June	August
Akama	7.78±11.34	5.56±1.34	0	58.89±29.85	53.33±26.78	0	0	44.44±21.22	55±21.8	61.33±37.56
Dankwa	12.56±17.78	0	0	52.22±29.89	48.89±23.31	0	0	41.11±21.23	52.22±21.45	53.5±27.45
Yace	32.22±12.12	0	0	26.67±17.98	27.78±16.78	0	0	36.67±19.35	51.11±21.15	53.33±23.33
Yavo	27.78±15.21	0	0	64.44±24.18	24.44±12.22	0	0	51.5±27.1	55.56±23.67	61.11±21.11
Diarrassouba	33.33±14.6	0	3.33±0.33	81.11±32.28	40±13.45	0	0	82.22±23.22	83.33	100
Bocou1	7.78±11.34	5.56±1.34	0	35.56±18.34	38.56±17.93	0	0	40±11.45	55.56	50.5±27.86
Bocou2	4.44 ± 1.5	0	0	12.22±11.21	22.22±11.11	0	0	38.89±19.89	45.89	47±21.09
Bocou3	7.78±11.34	0	5.56±1.34	33.33±13.33	35.44±18.82	0	0	38.89±19.92	52.22	51.11±21.98

Annex 15. CBB Severity on the varieties in Ferke

Varieties	November	January	March	May	October	December	February	April	June	August
Akama	34.67±19.29	0	0	100	51±19.87	0	0	36.94±15.86	50.44±18.82	67.45±25.49
Dankwa	39.17±20.09	0	0	100	30.56±19.78	0	0	37±15.57	55.55±11.11	69.5±21.78
Yace	45.11±19.85	0	0	100	60.1±21.29	0	0	48.05±26.67	66.66±22.22	73.33±23.33
Yavo	48.89±21.78	0	0	100	64.33±23.33	0	0	48±25.89	52.72±23.76	65±29.91
Diarrassouba	71.33±29.39	0	0	100	90±14.67	0	0	75.5±36.78	88.88±28.84	100
Bocou1	18.33±11.29	0	0	100	25.28±12.34	0	0	23.56±16.82	47.56±21.39	56.66±23.33
Bocou2	13.33±16.65	0	0	100	28.15±12.35	0	0	12.67±14.34	46.78±19.98	51.11±21.11
Bocou3	23.56±14.18	0	0	100	36.7±12.45	0	6.39±2.18	37±14.17	45.5±21.13	53.33±23.33

Annex 16. CBB Incidence on the varieties in Ferke

Varieties	November	January	March	May	October	December	February	April	June	August
Akama	44.87±21.35	0	0	100	56.64±25.76	0	0	45.7±16.72	63.33±23.73	75.47±24.95
Dankwa	47.78±22.25	0	0	100	37.45±12.16	0	0	44.44±21.22	49.05±18.26	59.8±17.56
Yace	48.07±19.72	0	0	100	65.56±24.75	0	0	57.98±16.92	65.56±29.91	77.77±21.25
Yavo	48.89±18.85	0	0	100	65.56±19.92	0	0	36.67±14.83	61.11±21.35	69.79±20.09
Diarrassouba	62.22±32.21	0	0	100	90±23.67	0	0	79.5±27.31	87.54±28.91	100
Bocou1	20.23±14.18	0	0	100	31.42±14.72	0	0	30.89±21.23	50±14.65	57.79±13.34
Bocou2	17.78±15.75	0	0	100	31.42±14.72	0	0	21.56±12.62	45.55±13.45	49.67±15.26
Bocou3	30.21±15.42	0	0	100	37.1±14.15	0	8.89	44.44±21.22	47.83±19.39	53.33±13.33

Annex 17: Correlation between SI and climatic parameters in Yakro during the 2^d year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.95	0.00	-0.1	0.86	0.04	0.95	-0.02	0.96
Dankwa	0.8	0.06	-0.45	0.37	0.2	0.71	-0.14	0.8
Yace	0.91	0.01	-0.36	0.49	0.06	0.9	-0.16	0.76
Yavo	0.88	0.02	-0.22	0.67	0.29	0.58	-0.06	0.9
Diarrassouba	0.89	0.02	-0.32	0.53	0.15	0.78	-0.09	0.86
Bocou1	0.79	0.06	-042	0.4	0.24	0.64	-0.09	0.87
Bocou2	0.74	0.09	-0.38	0.45	0.38	0.45	-0.03	0.95
Bocou3	0.86	0.03	-0.33	0.53	0.23	0.66	-0.04	0.94

Annex 18: Correlation between DI and climatic parameters in Yakro during the 2^d of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.98	0.00	-0.18	0.74	0.02	0.97	-0.09	0.87
Dankwa	0.78	0.07	-0.52	0.29	0.06	0.91	-0.27	0.6
Yace	0.91	0.01	-0.38	0.45	0.01	0.99	-0.23	0.66
Yavo	0.89	0.02	-0.27	0.6	0.23	0.67	-0.01	0.99
Diarrassouba	0.84	0.04	-0.44	0.38	0.04	0.94	-0.23	0.65
Bocou1	0.8	0.06	-0.46	0.36	0.21	0.7	-013	0.8
Bocou2	0.75	0.08	-0.5	0.31	0.2	0.71	-0.16	0.76
Bocou3	0.87	0.02	-0.37	0.47	0.14	0.79	-0.13	0.81

Annex 19: Correlation between SI and climatic parameters in Aboisso during the 1st year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	-0.21	0.79	0.89	0.12	-0.26	0.74	0.46	0.54
Dankwa	0.85	0.15	0.73	0.27	0.48	0.52	-0.92	0.08
Yace	0.72	0.28	0.17	0.83	0.93	0.07	-0.51	0.49
Yavo	0.85	0.15	0.69	0.3	0.55	0.45	-0.89	0.11
Diarrassouba	0.82	0.18	0.72	0.28	0.49	0.51	-0.93	0.07
Bocou1	0.83	0.17	0.9	0.1	0.19	0.81	-0.89	0.11
Bocou2	0.84	0.16	0.76	0.24	0.44	0.56	-0.93	0.07
Bocou3	0.71	0.29	0.78	0.22	0.29	0.71	-0.98	0.02

Annex 20: Correlation between DI and climatic parameters Aboisso during the 1st year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	-0.06	0.94	0.9	0.1	-0.11	0.89	0.44	0.56
Dankwa	0.8	0.2	0.81	0.19	0.33	0.67	-0.94	0.06
Yace	0.76	0.24	0.25	0.75	0.9	0.1	-0.57	0.43
Yavo	0.85	0.15	0.72	0.28	0.5	0.5	-0.91	0.15
Diarrassouba	0.82	0.18	0.72	0.28	0.48	0.52	-0.93	0.07
Bocou1	0.84	0.16	0.9	0.1	0.2	0.8	-0.89	0.11
Bocou2	0.84	0.16	0.76	0.24	0.44	0.56	-0.93	0.07
Bocou3	0.69	0.31	0.77	0.23	0.29	0.71	-0.98	0.02

Annex 21: Correlation between SI and climatic parameters in Aboisso for the 2^d year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	-0.44	0.39	0.34	0.51	-0.33	0.52	0.4	0.43
Dankwa	-0.31	0.55	0	1	-0.01	0.99	0.37	0.47
Yace	-0.42	0.41	0.18	0.73	-0.19	0.72	0.36	0.49
Yavo	-0.45	0.37	0.23	0.66	-0.25	0.63	0.45	0.52
Diarrassouba	-0.46	0.36	0.24	0.65	-0.32	0.54	0.33	0.52
Bocou1	-0.42	0.41	0.26	0.62	-0.26	0.63	0.39	0.44
Bocou2	-0.46	0.36	0.24	0.65	-0.32	0.54	0.33	0.52
Bocou3	-0.36	0.48	0.07	0.89	-0.07	0.9	0.36	0.48

Annex 22: Correlation between DI and climatic parameters in Aboisso during the 2d year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	-0.32	0.53	0.07	0.9	-0.04	0.94	0.39	0.44
Dankwa	-0.33	0.53	0.09	0.87	-0.05	0.93	0.39	0.44
Yace	-0.46	0.36	0.27	0.6	-0.29	0.58	0.35	0.5
Yavo	-0.5	0.31	0.48	0.33	-0.47	0.35	0.37	0.46
Diarrassouba	-0.49	0.33	0.4	0.44	-0.45	0.37	0.36	0.48
Bocou1	-0.41	0.42	0.22	0.68	-0.17	0.74	0.37	0.46
Bocou2	-0.49	0.33	0.4	0.44	-0.45	0.37	0.36	0.48
Bocou3	-0.42	0.41	0.22	0.67	-0.2	0.7	0.37	0.47

Annex 23: Correlation between SI and climatic parameters in Ferke for the 1st year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.84	0.16	0.07	0.93	0.61	0.27	0.78	0.22
Dankwa	0.9	0.1	0.05	0.95	0.64	0.36	0.81	0.19
Yace	0.89	0.11	0.02	0.98	0.71	0.79	0.84	0.16
Yavo	0.91	0.09	0	1	0.72	0.28	0.86	0.14
Diarrassouba	0.96	0.04	0.11	0.89	0.85	0.15	0.95	0.05
Bocou1	0.74	0.26	0.15	0.85	0.46	0.54	0.66	0.34
Bocou2	0.71	0.29	0.17	0.83	0.42	0.58	0.62	0.38
Bocou3	0.78	0.22	0.12	0.88	0.51	0.49	0.7	0.3

Annex 24: Correlation between DI and climatic parameters in Ferke during the 1st year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.89	0.12	0.02	0.98	0.69	0.31	0.84	0.16
Dankwa	0.9	0.1	0.04	1	0.71	0.29	0.86	0.14
Yace	0.9	0.1	0	1	0.71	0.29	0.86	0.14
Yavo	0.91	0.09	0	1	0.72	0.28	0.86	0.14
Diarrassouba	0.95	0.05	0.07	0.93	0.81	0.19	0.92	0.08
Bocou1	0.76	0.24	0.14	0.86	0.48	0.52	0.67	0.33
Bocou2	0.74	0.26	0.15	0.85	0.46	0.54	0.66	0.34
Bocou3	0.82	0.18	0.09	0.91	0.57	0.43	0.75	0.25

Annex :25 Correlation between SI and climatic parameters in Ferke during the 2^{d} year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.88	0.02	0.21	0.69	0.81	0.05	0.9	0.01
Dankwa	0.72	0.12	0.2	0.7	0.7	0.12	0.82	0.05
Yace	0.82	0.04	0.25	0.64	0.79	0.06	0.91	0.01
Yavo	0.88	0.02	0.21	0.69	0.81	0.05	0.9	0.01
Diarrassouba	0.87	0.02	0.27	0.6	0.79	0.06	0.91	0.01
Bocou1	0.64	0.17	0.15	0.78	0.71	0.11	0.81	0.05
Bocou2	0.54	0.27	0.06	0.91	0.74	0.09	0.80	0.05
Bocou3	0.83	0.04	0.27	0.6	0.71	0.12	0.84	0.04

Annex 26: Correlation between DI and climatic parameters Ferke during the 2^d year of the experimentation

Varieties	Rainfall	p-value	Temperature	p-value	Relative humidity	p-value	Dew point	p-value
Akama	0.76	0.08	0.13	0.81	0.84	0.04	0.9	0.01
Dankwa	0.86	0.03	0.3	0.56	0.72	0.1	0.87	0.02
Yace	0.88	0.07	0.26	0.62	0.78	0.06	0.9	0.01
Yavo	0.76	0.08	0.13	0.81	0.84	0.03	0.9	0.01
Diarrassouba	0.89	0.02	0.29	0.58	0.78	0.07	0.91	0.01
Bocou1	0.73	0.1	0.22	0.68	0.73	0.1	0.85	0.03
Bocou2	0.68	0.14	0.16	0.76	0.77	0.08	0.86	0.03
Bocou3	0.87	0.02	0.37	0.47	0.64	0.17	0.82	0.05

Annex 27. Averages of roots number and weight on the different sites

Localities	N°Roots	Weight (Kg)
Aboisso	4.69 ± 2.14	271.5 ± 159.14
Man	5.93 ± 2.3	383.2 ± 179.29
Ferke	4.54 ± 1.75	254.1 ± 183.77
Yakro	3.8 ± 1.72	333.8 ± 206.6

Annex 28. Averages of roots number and weight in Man

Varieties	N°Roots	Weight (Kg)
Akama	4.90 ± 2.56	490.3 ± 238.36
Dankwa	5.6 ± 2.95	290.9 ± 125.6
Diarrassouba	7 ± 2.11	310 ± 109.02
Bocou2	6.5 ± 1.35	388.5 ± 100.3
Bocou3	6.5 ± 2.51	349 ± 128.17
Yace	6.6 ± 1.96	330.9 ± 73.7
Yavo	4.9 ± 2.33	393 ± 179.25
Bocou1	5.4 ± 2.07	513 ± 286.84

Annex 29. Averages of roots number and weight in Aboisso

Varieties	N°Roots	Weight (Kg)
Akama	3.8 ± 1.55	319.1 ± 300.78
Dankwa	4.4 ± 1.65	365.3 ± 274.59
Bocou1	2.8 ± 2.15	304.9 ± 129.15
Bocou2	4.7 ± 1.64	315.6 ± 96.9
Bocou3	3.7 ± 1.83	417.4 ± 291.96
Yace	4.8 ± 1.03	296.4 ± 114.63
Yavo	3.2 ± 1.48	428.8 ± 194.2
Diarrassouba	3 ± 1.56	222.5 ± 104.38

Annex 30. Averages of roots number and weight in Yakro

Varieties	N°Roots	Weight (Kg)
Akama	4.7 ± 1.77	295.8 ± 153
Dankwa	4.7 ± 2.54	301.7 ± 210.39
Bocou1	3.7 ± 1.34	247.4 ± 180.78
Bocou2	4.9 ± 2.23	385.2 ± 176.81
Bocou3	6.3 ± 2.21	296.1 ± 132.72
Yace	6.1 ± 2.13	243.7 ± 137.61
Yavo	3.6 ± 1.58	208.58 ± 85.64
Diarrassouba	3.5 ± 1.56	193.58 ± 104.38

Annex 31. Averages of roots number and weight in Ferke

Varieties	N°Roots	Weight (Kg)
Akama	3.7 ± 2	466.4 ± 307.47
Dankwa	3.8 ± 2.1	184.77 ± 215.67
Bocou1	5 ± 1.41	282.1 ± 171.28
Bocou2	4.6 ± 1.84	203.3 ± 96.51
Bocou3	4.9 ± 1.79	167.8 ± 86.68
Yace	4.6 ± 1.17	208.05 ± 91.39
Yavo	4.1 ± 1.1	268.5 ± 166.53
Diarrassouba	5.6 ± 2.01	251.6 ± 55.69

Annex 32. Summarised of the AUDPC

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	AUDPC-Total
Bocou3	0	21±9.82	20±2.67	39.83±4.87	41.5±4.05	59.33±5.69	44.33±6.33	36.5±2.25	35.67±2.61	35.67±2.53	333.8
Bocou1	0	0.83±0.79	34.17±3.45	25±2.89	41±3.98	51.83±4.89	45.17±2.65	43.5±3.56	28.67±1.57	34.17±3.31	304.3
Diarrassouba	0	32.33±5.67	44.33±6.33	63.5±4.87	57.33±5.98	57.33±5.9	55.67±3.21	60.17±5.8	40.33±2.56	44.83±2.34	455.8
Dankwa	0	30±4.87	38.17±4.45	15±2.86	43.33±4.56	50.17±3.46	65.83±5.67	33.5±2.21	37±2.06	38.17±2.65	351.2
Akama	0	2.5±1.26	38.17±4.45	54.67±4.99	42±3.78	48.17±3.87	74.17±5.99	44.83±3.5	27.33±2.16	38.5±3.24	370.3
Bocou2	0	19.83±3.46	19.83±3.25	43.33±4.56	36.67±4.67	39.17±2.98	30.83±2.38	49.5±4.4	27.83±2.14	21±9.92	288
Yace	0	21±3.26	20±4.47	42.33±3.89	44±2.09	59.33±5.96	46.83±3.45	27.6±2.3	38.67±3.18	35.67±3.32	335.4
Yavo	0	32.33±5.68	44.33±6.33	58.5±5.01	52.33±3.33	57.33±5.9	55.67±4.67	60.17±4.5	33.1±2.11	33.5±1.74	427.3
AUDPC-Total	0	199.8	323.8	427.7	447.7	528.3	523.1	444.7	335.8	351.9	

Annex 33. Summarise of the global diversity in Côte d'Ivoire

Locus	Correspondent VNTR	Number of alleles	Diversity of Nei (H)
1	VNTR-37	3	0.586
2	VNTR-8	5	0.650
3	VNTR-15	6	0.702
4	VNTR-18	3	0.534
5	VNTR-21	2	0.1
6	VNTR-31	4	0.571
7	VNTR-35	2	0.146
8	VNTR-6	2	0.146
9	VNTR-7	2	0.146
10	VNTR-38	1	0
11	VNTR-19	1	0
12	VNTR-25	7	0.727
13	VNTR-27	3	0.619
14	VNTR-30	3	0.517
Mean		3.143+/- 1.791	0.454 +/- 0.244

Annex 34. Number of alleles in each Population

Locus	Correspondent VNTR	Pop 1	Pop 2	Pop 3	Mean	sd
1	VNTR-37	3	2	3	2.667	0.577
2	VNTR-8	2	4	4	3.333	1.155
3	VNTR-15	3	2	5	3.333	1.528
4	VNTR-18	2	2	3	2.333	0.577
5	VNTR-21	1	2	2	1.667	0.577
6	VNTR-31	2	2	4	2.667	1.155
7	VNTR-35	1	1	2	1.333	0.577
8	VNTR-6	1	1	2	1.333	0.577
9	VNTR-7	1	1	2	1.333	0.577
10	VNTR-38	1	1	1	1	0
11	VNTR-19	1	1	1	1	0

12	VNTR-25	4	3	5	4	1
13	VNTR-27	2	3	3	2.667	0.577
14	VNTR-30	2	2	3	2.333	0.577
Mean		1.857	1.929	2.857	2.214	0.558
sd		0.949	0.917	1.292	1.053	0.208

Annex 35. Diversity of Nei in each Population

Locus	Correspondent VNTR	Pop 1	Pop 2	Pop 3	Mean	sd
1	VNTR-37	0.692	0.409	0.667	0.589	0.157
2	VNTR-8	0.462	0.636	0.773	0.624	0.156
3	VNTR-15	0.641	0.409	0.818	0.623	0.205
4	VNTR-18	0.462	0.409	0.712	0.528	0.162
5	VNTR-21	0	0.167	0.167	0.111	0.096
6	VNTR-31	0.462	0.409	0.758	0.543	0.188
7	VNTR-35	0	0	0.409	0.136	0.236
8	VNTR-6	0	0	0.409	0.136	0.236
9	VNTR-7	0	0	0.409	0.136	0.236
10	VNTR-38	0	0	0	0	0
11	VNTR-19	0	0	0	0	0
12	VNTR-25	0.679	0.53	0.727	0.646	0.103
13	VNTR-27	0.462	0.712	0.591	0.588	0.125
14	VNTR-30	0.462	0.409	0.591	0.487	0.094
Mean		0.309	0.292	0.502	0.368	0.117
sd		0.289	0.258	0.28	0.275	0.002

PUBLICATIONS

ASSESSMENT OF THREE CASSAVA VARIETIES RESPONSES TO CASSAVA BACTERIAL BLIGHT (CBB) IN THE SEVEN AGRO-ECOLOGICAL ZONES OF CÔTE D'IVOIRE DURING A SURVEY IN 2017
Link: DOI URL: http://dx.doi.org/10.21474/IJAR01/9776

Identification and Characterizations of Pathogenic Fungal Species Associated with Symptoms of Cassava Anthracnose in Ivory Coast
Link: DOI: 10.9734/arrb/2018/v30i430017

CONFERENCES

Advanced Courses / Tutorials on Adaptation Metrics and Techniques for Agriculture, Water and Resilient Cities & the International Conference on «Adaptation Metrics for Agriculture, Water and Resilient Cities» IN MORROCO FROM 24-27/10/2018
Link: https://adaptation.um6p.ma/wp-content/uploads/2018/12/24-HOWELE-Michaelle-P3-S3-Conference-UM6P-27102018.pdf

CONFERENCE WASCAL-UCAD-ZEF on Climate change and food security in West Africa FROM 18 - 19 November 2019, Dakar, SENEGAL
Link: http://wascal.ucad.sn/images/wascal/Wascal_conf/presentation-howele-michaelle-toure%20.pdf