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Research Article
Analysis of Agro-Ecological Factors Related to the Prevalence and Diversity of Badnavirus in the Banana Production Areas of Burkina Faso

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Abstract
Background and Objective: Banana (*Musa* spp.) is a herbaceous plant native to the Tropical Region of South East Asia. Banana belonging to the genus *Musa* of the family *Musaceae*. For vegetatively propagated crops such as banana and plantain, viruses are important constraints to the movement and propagation of plant germplasm. Badnaviruses are important pathogens of banana and plantain. The present study was to determine the agroecological factors that could influence the emergence of the Banana streak virus (BSV) and sugarcane bacilliform virus (SCBV) in the banana-producing areas of Burkina Faso. **Materials and Methods:** Sixty-five plantations were surveyed in nine main producing regions and data were collected at two levels: From the farmers and by observation in the plantation. Mapping based on the prevalence and diversity of Badnavirus was performed. The data on prevalence and survey data were analysed with XLSTAT 2016 software. **Results:** The role of agricultural practices, mainly the uncontrolled use of plant material and climatic conditions in the distribution of Badnaviruses, with high prevalence and diversity of viruses in the plantations located in the Sudanian Zone. The results revealed two phylogenetic groups 1 and 4 most present in the Sudanian Zone and groups 2 and 3 specific to the Sudano-Sahelian Zone. However, the Boucle of Mouhoun Region, although located in the Sudan-Sahelian Zone, recorded a similar distribution of viruses. The AHC analysis was grouped the hight badnavirus prevalent regions into a single class on the basis of agricultural practices. **Conclusion:** These results suggested a real need for certified healthy plant material for farmers in these different regions.

Key words: Banana streak virus, Sugarcane bacilliform virus, farmers, *Musa* spp., agro-ecological factors, Burkina Faso

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Bananas are one of the main fruit crops grown in all types of farming systems in the tropics and subtropics[1,2]. In Africa, banana production is often severely hampered by environmental and biological constraints. Viruses are important constraints to the movement and spread of plant germplasm, introduced to the continent from infected planting material[3,4]. Banana streak virus (BSV) and Sugarcane bacilliform virus (SCBV) are two virus's species belonging Badnavirus genus, infecting bananas and resulting diseases are limiting factors of banana production and exchange planting material.

The BSV is currently considered a major obstacle to banana improvement and a threat to *Musa* production worldwide[5]. The disease can cause yield losses ranging from 7 to 100% in a plot depending on the cultivar, virus species present and environmental conditions[6]. These rates may be lower for resistant cultivars[7,8]. Disease symptoms are highly variable and can include chlorotic and necrotic streaking on leaf[9]. The BSV can be spread by the action of vectors, infected planting material and the genome of the plants with endogenous viral sequences (eBSV)[10-12].

The SCBV is able to infect banana plants by agroinoculation[13], but not by use of cutting implements or machinery[14,15]. Though, the transmission of SCBV by *Saccharicoccus sacchari* from sugarcane to banana was experimentally proven[16]. Banana-infected plants exhibit symptoms indistinguishable from those described for BSV[14,17,18]. Recently, natural infections of bananas by SCBV have been reported in China[19].

In Burkina Faso, banana is grown throughout the country in all agro-ecological conditions and serves as a key component of food security and unemployment. On dessert banana in Burkina Faso, we reported the BSV and SCBV, with high genetic diversity[20]. The BSV is the main viral disease in the country, present in most of the banana producing regions[21].

Environmental constraints, such as drought, wind, chilling and nutritional deficiencies, can cause damage to banana planting[22,23], usually for short periods and might enhance outbreaks of diseases and pest infestation[3] by favouring the emergence of pathogens. Several authors have shown the influence of agroecological factors on the emergence of viruses in banana[7,24,25]. As a result, it is therefore important to understand the agroecological conditions that may affect the epidemiology of particular diseases such as BSV and SCBV in banana producing regions. This study was therefore initiated to determine the agroecological factors that may influence the prevalence and diversity of Badnavirus in the banana producing areas of Burkina Faso.

MATERIALS AND METHODS

Study area: The study was conducted in farmers' fields in Burkina Faso, in the growing seasons July-September, 2018 and October-December, 2020. Due to its continental location and its position on the edge of the Sahara, Burkina Faso's climate is highly variable. It is characterised by large variations in rainfall within its borders, with annual amounts varying along a North-South gradient. As a result, the country is frequently divided into three climatic zones that follow longitudinal bands, depending on the amount of annual rainfall: Sudanian, Sudano-Sahelian and Sahelian. The study was conducted in banana plantations in localities of nine producing regions (Fig. 1). These regions belong to two climatic zones that are mainly differentiated by their level of rainfall and temperature, the Sudanian and Sudano-Sahelian Zones[26].

Tropical ferruginous soils leached with concretions represent a high proportion of the soils in Burkina Faso. These are deep soils (>1.2 m) with a variable rate of rough elements (5 to 40-60% of concretions) depending on the depth. They were poor in organic matter, nitrogen, phosphorus, potassium and have a low total exchange capacity[27].

Epidemiological survey: Data on the diversity[21] and prevalence[22] of BSV and SCBV in the study area were used to determine the geographical distribution of the virus. Owner farmers randomly selected plots were identified for individual interviews on their plantations using a questionnaires'. The information provided was supplemented by direct observations of the plots.

Agro-ecological data collected and statistical analysis: Data on the agro-ecological factors of the surveyed areas were collected. They included the origin and sanitary status of the plant material, age of the plantation, type of fertilization, phytosanitary treatment, genotype, cropping system, type of cultivation, other types of maintenance and plantation area. The data on prevalence and survey data were processed using an Ms Excel spreadsheet and analysed with XLSTAT 2016 software. The Kruskal-Wallis Test was performed to determine significant differences ($p<0.05$) among the regions. A hierarchical ascending classification (HAC) was performed to group individuals with similar characteristics.

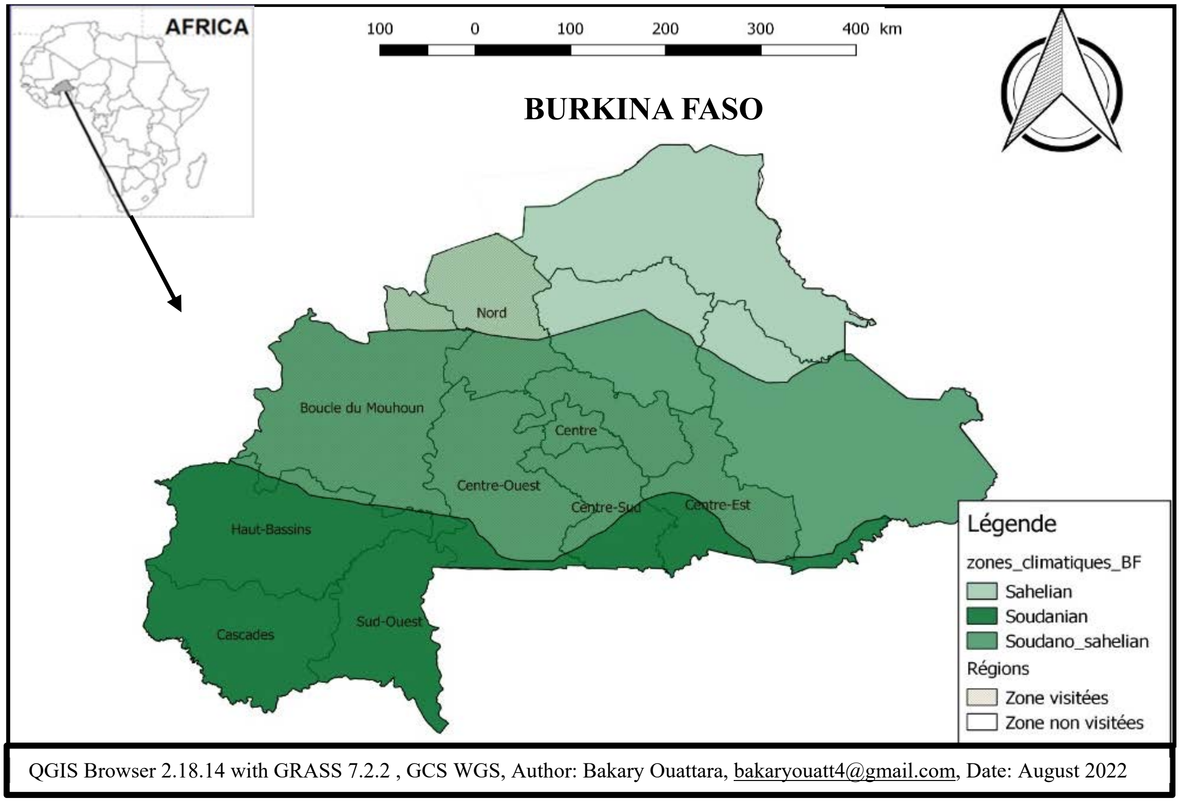

Fig. 1: Map showing 09 regions of the study areas in Burkina Faso

RESULTS

Distribution of Badnavirus in Burkina Faso: Banana streak virus (BSV) was detected in 07 out of 09 (77.78%) banana producing regions visited in this study (Fig. 2). Statistical analysis revealed that the prevalence of BSV was significantly different ($p < 0.05$) among regions. Plantations located in the Boucle of Mouhoun, Hauts Bassins, Cascades, Central East and Central West Regions recorded the highest infection rates ranging from 33.5 to 100% (Fig. 3). Plantations in the South Centre, South West, Centre and North Regions have low infection rates of less than 16.7%. The SCBV frequency level was 4.35 and 12.5% in Centre East and Cascades (Fig. 3), respectively.

Three species banana streak Obino l'ewaï virus (BSOLV), Goldfinger virus (BSGFV) and imove virus (BSIMV) have been identified in the banana production areas of Burkina Faso. In Sudanian Zone, these three species was present in the Hauts Bassins. The BSOLV and BSGFV species were identified in the Central East and Cascades Regions. In Sudano-Sahelian Zone, the three main species was found in Boucle of Mouhoun Region and one species BSOLV in Centre East Region. But, in the North and Centre Regions, although infected by BSV, none of the main species were found (Fig. 2).

The molecular diversity of BSV in the regions surveyed in Burkina Faso is characterized by four phylogenetic groups (G1, G2, G3 and G4) distributed in two agro-climatic zones. Groups 1 and 4 were mainly present in the Sudanian Zone and are also found in the Boucle of Mouhoun Region located in the Sudano-Sahelian Zone. Groups 2 and 3 were present in the regions located in the Sudano-Sahelian Zone. All groups were present in the Boucle of Mouhoun (Fig. 2).

Analysis of agro-ecological factors

Origin and health status of planting material: The results of current investigations showed that the majority (78.4%) of farmers in the regions visited use planting material consisting of suckers from previous plantations to establish new plots (Table 1). All plantations (100%) surveyed in the Central West, North and South West Regions used this type of suckers. In addition to these, 18.5% of the plantations were created with suckers obtained from growers/nurserymen who have plantations from which they take suckers to make them available to other farmers. In the Central South, all the

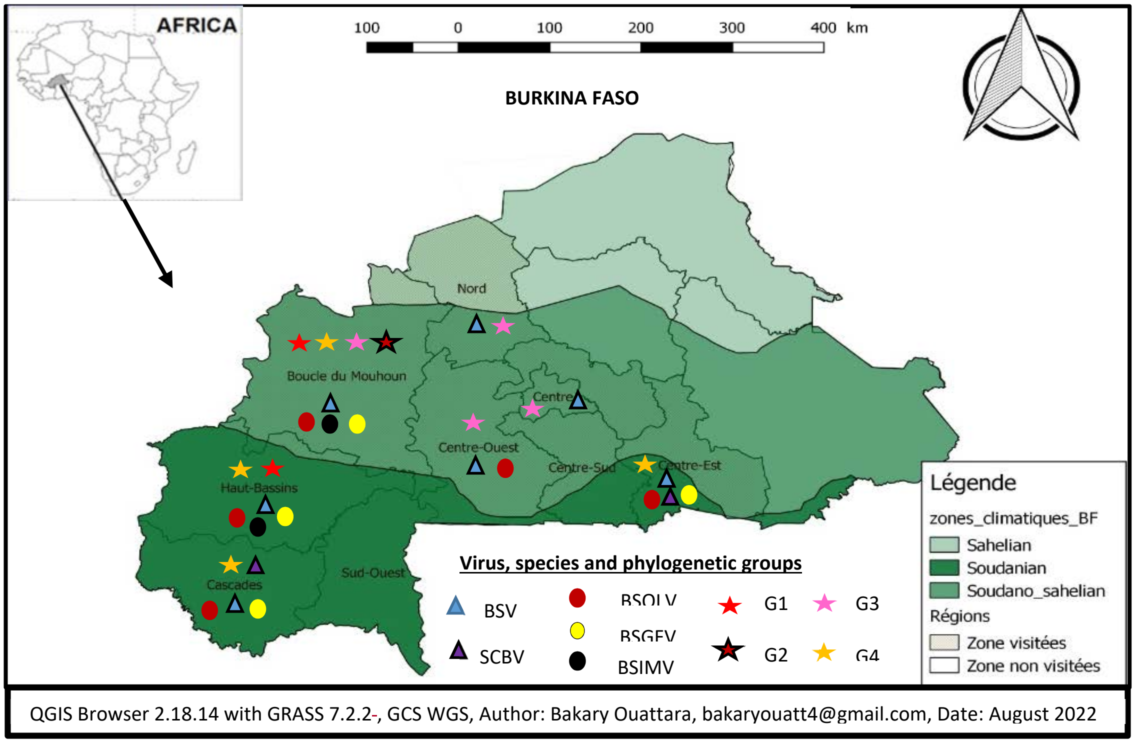

Fig. 2: Mapping of Badnaviruses, main species and phylogenetic groups in 09 surveyed regions

plantations visited were established with suckers obtained from the latter. In the other regions (Boucle of Mouhoun, Hauts Bassins, Cascades and Centre Est), suckers from previous plantations and growers/nurserymen were used. The health status of the planting material used by these growers for the establishment of plots in these two cases, corresponding to 96.9% of the plantations surveyed, was unknown. Only 3.1% of the plantations in the Hauts Bassins were established with seedlings from research centres whose health status was known.

Age of the plantation: The banana plantations were classified on the basis of the different vegetative stages into three age classes, based on the date of the plantation. A first class of 1-6 months of planting, a second class of 7-12 months and a third class regrouping plantations older than 12 months (Table 1). The surveys revealed that 54% of the plantations are at least 12 months old. Plantations between 7 and 12 months old represent 40% of the plantations visited and only a few plantations, i.e., 6%, were between 1 and 6 months old. All the plantations (100%) in the South Centre and South West Regions and almost all in the North, were between 7 and 12 months old. Current surveys revealed 33.3 to 80% and 20 to 66.7% plantations between 7 and 12 months old and over 12 months old in Boucle of Mouhoun, Centre West, Cascades and North respectively. In Centre, Centre East and Hauts Bassins all three age classes were encountered.

Type of fertilization: Results of current surveys was presented in Table 1 showed that single mineral fertilization is the most common practice in banana plantations in the different regions surveyed. It is practised in 30.8% of the plantations at the expense of single organic fertilization which is used in only 12.3% of the plantations. Fertilisation is mainly organic in the South Centre (100%), Centre (75%) and Hauts Bassins (16%) and mineral in the North (70%), Centre West (66.7%), Centre East (44.4%) and Hauts Bassins (28%). Mixed organic and mineral fertilization was applied in 36.9% of the plantations visited. It was found mainly in Boucle of Mouhoun (100%) and Cascades (100%) and in other regions such as Centre East (22.2%), Centre West (33.3%) and Hauts Bassins (36%). On the other hand, on 20% of the plantations, no fertilisation was applied by the farmers. The latter was found in the Centre (25%), Centre East (33.3%), Hauts Bassins (20%), North (30%) and South West (100%). Fertilisation as a whole was characterised by irregularity and non-compliance with input doses.

Table 1: Characteristic of the regions according to some key factors

Observed parameters	Region surveyed (%)									
	Boucle of Mouhoun	Centre	Centre East	South Centre	Central West	Cascades	Hauts-Bassins	North	South West	Total
Health status of planting material										
Known (controlled and certified)	0	0	0	0	0	0	8	0	0	3.1
Unknown (not certified. not checked)	100	100	100	100	100	100	92	100	100	96.9
Origin										
Research centre	0	0	0	0	0	0	8	0	0	3.1
Growers/nurserymen	44.4	50	33.3	100	0	33.3	4	0	0	18.5
Previous crop	55.6	50	66.7	0	100	66.7	88	100	100	78.4
Age of plantation (month)										
1 to 6	0	25	22.2	0	0	0	4	0	0	6
7 to 12	55.6	50	44.4	100	33.3	33.3	12	80	100	40.0
More than 12	44.4	25	33.3	0	66.7	66.7	88	20	0	54
Type of fertilization										
No fertilizer	0	25	33.3	0	0	0	20	30	100	20.0
Organic	0	75	0	100	0	0	16	0	0	12.3
Mineral	0	0	44.4	0	66.7	0	28	70	0	30.8
Org. and Min.	100	0	22.2	0	33.3	100	36	0	0	36.9
Phytosanitary treatment										
No treatment	0	75	11.1	100	33.3	0	20	0	100	18.5
Herbicide	100	25	88.9	0	0	100	64	100	0	72.3
Herbicide and Insecticide	0	0	0	0	66.7	0	4	0	0	4.6
Herbicide and Fungicide	0	0	0	0	0	0	12	0	0	4.6
Genotype										
Dessert banana	100	100	100	100	100	100	92	100	100	97
Plantain	0	0	0	0	0	0	8	0	0	3
Cropping system										
Planting around dwellings	22.2	100	11.1	0	33.3	0	8	40	0	21.5
Forest plantation	77.8	0	88.9	100	66.7	100	84	60	100	75.4
Experimental plantation	0	0	0	0	0	0	8	0	0	3.1
Type of crop										
Monoculture	77.8	50	77.8	0	66.7	100	88	90	100	81.5
Association	22.2	50	22.2	100	33.3	0	12	10	0	18.5
Other types of maintenance*										
Yes	100	100	88.9	100	100	100	100	0	100	98.5
No	0	0	11.1	0	0	0	0	0	0	1.5
Area of the plantation (ha)										
0.25-1	44.4	100	22.2	100	33.3	100	52	30	100	49.2
1.1-2	33.3	0	55.6	0	66.7	0	44	70	0	43.1
2.1-4	22.2	0	22.2	0	0	0	4	0	0	7.7
Cultivar	Grande naine Petite naine	Grande naine	Grande naine	Grande naine	Grande naine Petite naine	Grande naine Petite naine	Grande naine Petite naine William, Big Ebanga, FHIA 21, PITA 3	Poyo	Grande naine	-

*Manual weeding, hilling, ridging, coppicing, staking and stem care, hot water treatment

Phytosanitary treatment: In general, phytosanitary treatments are widely used in the plantations visited to control pests. In most of the plantations, phytosanitary treatments were used by the farmers through herbicide (72.3%), herbicide and insecticide (4.6%), herbicide and fungicide (4.6%). The phytosanitary products most used by the farmers are mainly herbicides, followed by insecticides and in some cases, fungicides herbicide treatments were used in 72.3% of the plantations. They were used in all plantations (100%) in the Boucle of Mouhoun, Cascades and North and in some plantations in the Centre (25%), Centre East (88.9%) and Hauts Bassins (64%). Mixed herbicide-insecticide and herbicide-fungicide were used each in 4.6% of the plantations visited. The use of herbicide with insecticide was applied in 66.7 and 4% of the plantations in the Centre West and Hauts Bassins, respectively. Herbicide and fungicide were used in

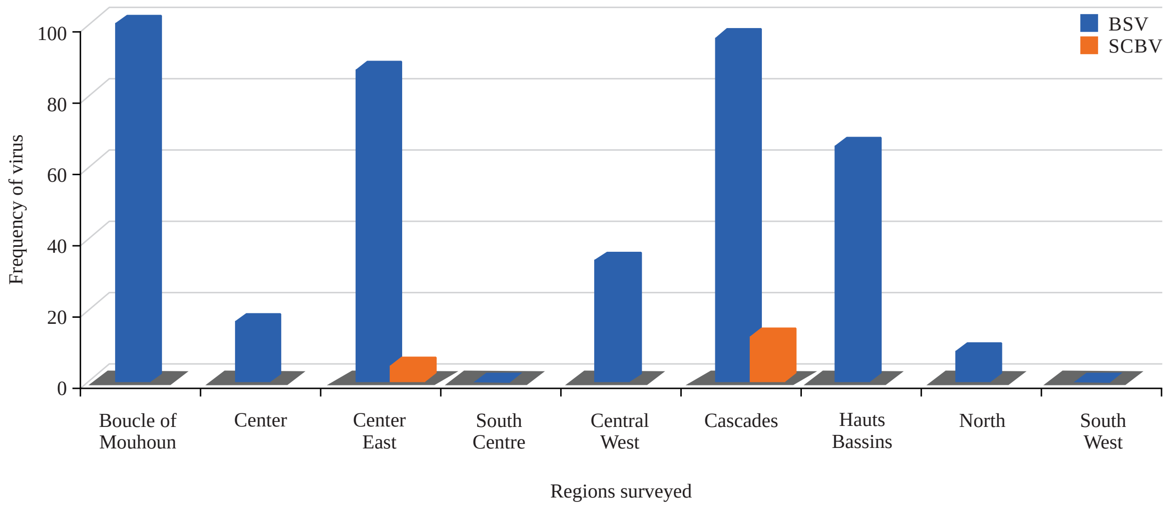

Fig. 3: Frequency of Badnavirus in 09 surveyed regions

12% of the Hauts Bassins plantations. On the other hand, no phytosanitary treatment was applied in 18.5% of the plantations (Table 1). These plantations were found in the Centre (75%), Centre East (11.1%), South Centre (100%), Centre West (33.3%), Hauts Bassins (20%) and South West (100%).

Genotype and variety: Among existing banana genotypes, only two were encountered during the survey of banana plantations in the producing regions. The dessert banana was the most widely grown. Almost all (97%) of the plantations were dessert banana plantations. It is mainly represented by the varieties "Grande Naine" and "Petite Naine" which are produced in almost all regions. The "William" variety is produced in the Hauts Bassins in addition to the two previous ones. "Poyo" is the only variety produced in the plantations visited in the North. The plantain banana was only produced in a few plantations (3%) visited. "Big Ebanga", "PITA 3" and "FHIA 21" were the plantain variety whose plantation was visited during the survey (Table 1).

Cropping system: Three banana cropping systems were identified in this survey (Table 1). The most common is the forest plantation system, which is practised in 75.4% of the plantations visited. It was observed in all plantations (100%) in the Centre-South, Cascades and North (60%). Banana production in the vicinity of dwellings represented 21.5% of the plantations visited. This system was practiced in all the plantations visited in the Centre. Both systems were found in the Boucle of Mouhoun, the Centre East, the Centre West, the Hauts Bassins and the North. Experimental plantations represented 3.1% of plantations in the Hauts Bassins Region only.

Type of crop: Banana monoculture is the most commonly used practice. Results of the survey carried out in 65 plantations show that in 81.5% of them, bananas were produced in monoculture. These plantations were found in all regions on at least 50% of the plantations, except in the South Centre where only associated cultivation was observed. This type of banana cultivation was observed in 18.5% of plantations (Table 1). It was also observed in North, Hauts Bassins, Boucle of Mouhoun, Centre East, Centre West, Centre and South Centre in proportions of 10, 12, 22.2, 33.3, 50 and 100%, respectively.

Other types of maintenance: Almost all the plantations visited (98.5%) practise other types of banana maintenance as shown in Table 1. Only 1.5% of the plantations, corresponding to 11.1% of those in the Centre East, do not practise other types of maintenance. Following the survey carried out in the banana plantations of the nine main producing regions, various other types of crop maintenance were identified. The most common types of maintenance are manual weeding, hilling, coppicing, staking, hot water treatment and stem care such as removal of the male flower, removal of the false and first true hands and stem clearing.

Plantation area: From the results of the survey, the areas of the plantations visited can be grouped into three classes 0.25-1 ha, 1.1-2 ha and 2.1-4 ha (Table 1). The majority of the plantations visited were small, including 0.25 and 1 ha, i.e., 49.2% of the plantations. All (100%) of the plantations visited in the Centre, South Centre, Cascades and South West had this size, but these plantations were found in all regions visited. Medium size plantations with an area included 1.1 and 2 ha

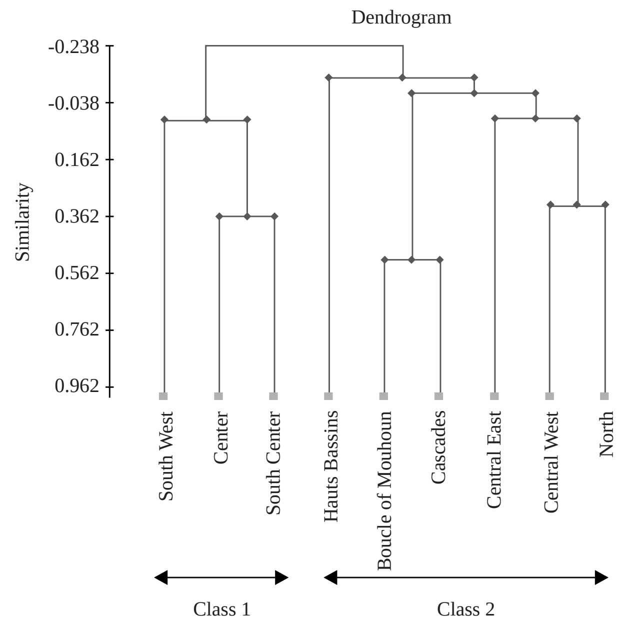

Fig. 4: Hierarchical classification of the 9 regions according to their agricultural practices

represent 43.1% and large plantations of 2.1-4 ha constitute 7.7% of the plantations. Medium size plantations were found in Boucle of Mouhoun, Hauts Bassins, Centre East, Centre West and North in proportions of 33.3, 44, 55.6, 66.7 and 70%, respectively. As for the larger ones, they were found in Boucle of Mouhoun (22.2%), Centre East (22.2%) and Hauts Bassins (4%).

Classification of crop areas: More homogeneous and unified sets were obtained by hierarchical clustering (Fig. 4). The hierarchical clustering made it possible to distinguish two large distinct classes on the basis of the agroecological factors identified. The first class is made up of the three regions South Centre in one sub-class and Central and South West grouped in the second sub-class. The second class was subdivided into four sub-classes: Boucle of Mouhoun and Cascades, Centre West and North, Centre East and Hauts Bassins were distinct sub-class.

DISCUSSION

As with other viruses, various factors including agro-climatic conditions and cultivar/virus genotype can influence the expression of BSV and SCBV symptoms. In order to remedy this, conventional control methods based on good agricultural practices, including preventive control, chemical control of vectors and their hosts, quarantine measures and the use of healthy planting material, were used to control viral diseases fairly effectively and in many cases limit the damage they cause. The results of the study on the prevalence of BSV and SCBV in nine main banana-producing regions of Burkina Faso was revealed a high presence of the virus in 77.78% of the regions with BSV prevalence varying between 8.3% and 100%. The High prevalence of BSV could be due to the use of planting material whose health status was unknown. Current study surveys revealed that 96.9% of the plantations visited use suckers whose health status is unknown. As 78.4% of these suckers came from previous plantations and 18.5% were acquired from nursery growers. The uncontrolled exchange of uncertified healthy planting material of various origins observed during current surveys contributes significantly to the spread of the disease. Current findings join those of Kumar *et al.*[28] who highlighted the role of planting material in the spread of BBTV in RDC. This situation was aggravated by the non-renewal of planting material, which would favour the spread of the disease in the plantations. In Burkina Faso, until the introduction of *in vitro*-plants of the varieties Grande naine and William by the PDI-PSAB/FONRID project of the Institute of Environment and Agricultural Research (INERA) in 2019, production was ensured by plant material (sucker, stump) from banana plants introduced since 1976. The main route of BSV transmission is vegetative propagation from contaminated suckers[28]. However, infection through activation of viral sequences integrated into the genome of *M. balbisiana* species can also occur under some stress conditions such as *in vitro* culture[29] or prolonged drought[30]. The previous hypothesis was more likely. But mealybug vector transmission was less probable because there were less active in long-distance spread of BSV[28]. In addition, the majority of the plantations visited (81.5%) was applied phytosanitary treatments, thus reducing the rate of insect vectors and, in turn, their responsibility in the spread of the virus. The study conclusion was closely in line with those of Kouadio *et al.*[24]. These authors suggested that in Côte d'Ivoire virus transmission was due to contaminated planting material from transfers of planting material between countries. This deduction follows the high prevalence of BSOLV and BanMMV recorded in banana producing areas. This study revealed that 54% of the plantations were more than 12 months old. In addition to the non-renewal of banana germplasm, the ageing trend of the plantations visited was a factor favouring the installation of the viruses in the plantations. These results call for phytosanitary and legislative measures to prevent the introduction of BSV in Burkina Faso Regions where it was absent and to renew the germplasm with BSV-resistant banana plants. Therefore, it was necessary to set up a structure for the production of healthy seedlings in order to ensure a permanent renewal of the banana germplasm.

The most commonly used varieties in the plantations visited during the survey were the dessert banana varieties Grande naine, William, Poyo belonging to the Cavendish subgroup (AAA) and the plantain varieties Big Ebanga, PITA 3 and FHIA 21 belonging to the plantain subgroup (AAB). Many authors[8,31] showed the susceptibility of Cavendish subgroup varieties to BSV with production losses of up to 100%. North, South Centre and South West Regions, although using susceptible varieties, have a low prevalence of BSV. Not withstanding the cultivation practices and climatic conditions that could be unfavourable to the emergence of the virus. These results could be due to varietal resistance induced by the environmental conditions. In this case, these varieties would be sources of resistance that could be used for varietal improvement.

A comparison of the results of the data on the prevalence of BSV in the different regions according to climatic zones shows that almost all of the regions located in the Sudanian Zone (Hauts Bassins, Cascades and Centre East) have a fairly high prevalence of BSV varying between 65.6 and 95.8% and have more species diversity. In addition, the presence of SCBV was recorded in the Cascades and Centre East Region. These results highlight the role of climate in the emergence of the virus. The major difference between the climatic zones corresponds to rainfall and temperature[26]. The localities in this zone would have favourable humidity and temperature conditions for virus emergence and development[7,9,30]. Sorho[32] and Pinel-Galzi *et al.*[33] workings respectively on the biogeography and phylogeny of Rice yellow mottle virus (RYMV) have highlighted an adaptation of isolates according to agro-climatic conditions. Especially since the collection of samples was carried out in the rainy season (July to October 2018) and in the cool season (September to December 2020). Dahal *et al.*[7,34], showed the effect of temperature and rainfall on BSV expression, respectively.

The results of the current study revealed phylogenetic groups specific to the two agro-climatic zones with groups 2 and 3 presents only in the Sudano-Sahelian Zone. Although present in the Sudano-Sahelian, zone groups 1 and 4 are mainly found in the Sudanian Zone. This specificity could result from the climatic conditions of these zones, notably rainfall and temperature[26]. Chikoti *et al.*[35] revealed that variability in the pathological variables of Cassava mosaic disease is often attributed to several factors such as different strains of virus, susceptibility and age of the host plant and environmental factors such as soil fertility, soil moisture, solar radiation and temperature. Also, the presence of the four groups in the Boucle of Mouhoun could be linked to the uncontrolled exchange of plant material of various origins and the health status of planting material which is unknown in this region. The high diversity of BSV in the Boucle of Mouhoun (3 species and 4 phylogenetic groups) suggested a large flow of plant material between this region and the other producing regions of the country. Indeed, the Boucle of Mouhoun is the main banana-producing region of Burkina Faso and our surveys revealed that 44.4% of the farmers surveyed in this region used non-certified plant material from growers/nurserymen often from other regions.

The hierarchical ascending classification carried out on the basis of data on agronomic practices collected groups Hauts Bassins, Cascades, Centre East and Boucle of Mouhoun which recorded high BSV prevalence and viruses' diversity into the same class. These results showed a possible influence of agricultural practices on the prevalence and distribution of the virus. These three regions were in the same class as the Boucle of Mouhoun Region. The latter, although located in the Sudano-Sahelian Zone recorded a fairly high infection rate of 100% and a wide range of species. Not withstanding the favourable agro-climatic conditions for the emergence of the virus. the particularity of this region has already been highlighted in the study of RYMV with the identification of the Sa strain specific to the locality of Dedougou (Boucle of Mouhoun Region) by Traore *et al.*[36].

Nitrogen, phosphorus and potassium were major elements essential to the growth of bananas. Calcium and magnesium were also necessary for the crop[37]. Burkina Faso's soils are poor in organic matter, nitrogen, phosphorus, potassium and have a low total exchange capacity[27]. This nutrient deficiency in the soil could be a limiting factor for banana productivity[22,23]. Current survey revealed that a low proportion of farmers in the high prevalence and most diversified regions Boucle of Mouhoun, Hauts Bassins, Cascades and East Centre recorded a low rate of mineral fertilizer ranging from 0 to 44.4%. However, if properly managed, amendments could reduce the effect of BSV and SCBV on banana productivity. In this sense, Guinagui *et al.*[38] showed a reduction in the average severity and virus load of RYMV under the action of mineral fertilization, thus improving rice growth and yield. Bouet *et al.*[39] showed a significant effect of nitrogen on RYMV incidence. However, in the case of cassava mosaic disease (CMD). Sseruwagi *et al.*[40] and Muengula-Manyi[41] studies showed that the applications of chemical fertilizers have been associated with an increase in CMD incidence, severity and gravity in several field trials. Therefore, it would be interesting to conduct a study to determine the appropriate fertilizer amount and to sensitize growers on the value of applying recommended fertilizer amount in the control of the virus. However, organic amendments would be an alternative to restoring soil fertility in Burkina Faso and, in turn, to reduce the effects of viruses on banana productivity. Generally applied to the plot in the plantations visited during the current study, organic amendments would be more beneficial to the plant in the form of basic manure.

According to this study, 21.5% of the plantations were located in the vicinity of the dwellings. In this system, the banana was very often produced for local consumption or to be sold on the local market, in contrast to the forest production system where the banana is most often intended for export. In the production around dwellings, the plantation does not benefit from enough care (no tillage, no fertiliser, no phytosanitary treatment, etc.). According to current surveys, banana plantations were characterised by small areas, mostly (49.2%) between 0.25 and 1 ha, on which bananas are produced mainly on 81.5% of the monoculture plantations in the forest and around dwellings.

The main factors responsible for the development of BSV and SCBV in farmers' plantations would be the sanitary status and the planting material used. Most of the farmers use suckers of various origins without concern for their health status. These results suggested that there is a real need for certified and improved planting material. Present study does not provide any information on the impact of viruses on banana in Burkina Faso. However, there is a need to develop indexing and certification tools for use in the production of healthy plant material. Many other factors such as fertilizer, phytosanitary treatment, age of plantation and genotype might play a limited role in the spread of the disease in the farmer's fields of the virus.

CONCLUSION

The results of current study revealed the traditional nature of the banana cropping system in the production areas visited. The planting material used is the main source of contamination and virus spread. As a result, it is necessary to improve banana production conditions by adopting good agricultural practices, technical itineraries integrating the state of constraints and diagnostic tools. This work is only a preamble to the development of management and control strategies and to the improvement of banana production in Burkina Faso.

SIGNIFICANCE STATEMENT

This study was initiated with the aim of analysing the agro-ecological factors that may influence the distribution of Badnaviruses in Burkina Faso. It appears that in addition to climatic conditions, some agricultural practices, notably the uncontrolled use of plant material of diverse origin, are responsible for the high prevalence and diversity of Badnaviruses in Burkina Faso. The adoption of good agricultural practices through the use of certified healthy plant material could allow for effective control of the viruses.

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