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Assessing incidence, development and distribution of banana bunchy top disease across the main plantain and banana growing regions of the Democratic Republic of Congo

Faustin Ngama Boloy[1], Bonaventure Ibanda Nkosi[2], Joseph Komoy Losimba[3], Crispin Lebisabo Bungamuzi[3], Honoré Muhindo Siwako[1], Franck Walunkonka Balowe[1], Jérôme Wembonyama Lohaka[1], Benoit Dhed'a Djailo[3], Pascale Lepoint[4], Charles Sivirihauma[5] and Guy Blomme[6]*

[1]Institut Facultaire des Sciences Agronomiques (IFA-Yangambi), DR Congo.
[2]Faculté des Sciences Agronomiques, University of Kisangani (UNIKIS), DR Congo.
[3]Faculté des Sciences, University of Kisangani (UNIKIS), DR Congo.
[4]Bioversity International, CIALCA Project, Bujumbura Office, P. O. Box 1893, Bujumbura, Burundi.
[5]Bioversity International, CIALCA Project, Butembo, North Kivu, DR Congo.
[6]Bioversity International, Uganda office, P. O. Box 24384, Kampala, Uganda.

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Banana bunchy top disease (BBTD) was first identified in DR Congo in 1958. Previously, the disease's distribution throughout the Congo basin had not been studied, so an initial study, to determine the incidence and severity of BBTD in banana and plantain producing regions of Oriental province, was carried out during 2009 to 2010. Three hundred (300) farms were surveyed across 4 districts and 19 territories, with 30 mats assessed per farm. Visible disease symptoms were recorded and serological tests using triple antibody sandwich enzyme-linked immunosorbent assay (TAS-ELISA) were carried out on collected samples. Additional surveys were conducted during 2010 to 2012 in Maniema, Northern Katanga, Eastern and Western Kasai, Bandundu and Equateur provinces to assess the distribution of the aphid vector (*Pentalonia nigronervosa*), BBTD incidence and severity. 92% of mats observed across Oriental province manifested BBTD symptoms but severity levels were low. All plantain and banana cultivars grown in farmers' fields were susceptible to the disease. The vector, *P. nigronervosa*, was found on 89% of all assessed mats. In Tshopo district, all samples collected on plants showing disease severity scores 2, 4 and 5 tested positive for the presence of the virus. However, only 48% of plants with severity score 1 and 33% of plants with score 3 gave positive TAS-ELISA results. More importantly, 40% of symptomless plants (score 0) tested positive. The average BBTD incidences in Bandundu, Equateur, Eastern and Western Kasai, Katanga and Maniema were lower than levels observed in Oriental province. The lowest incidence levels were observed in Equateur (43%) and Katanga (35%). Although, BBTD is widespread in the surveyed provinces, the generally observed low severity levels result in limited impact on production. The generalized spread of BBTD in surveyed areas nevertheless underlines an urgent need to identify virus-free plants for multiplication and distribution of disease-free materials to small-scale farmers.

Key words: Aphid, Bandundu, Equateur, Maniema, oriental province, triple antibody sandwich enzyme-linked immunosorbent assay (TAS-ELISA).

INTRODUCTION

Banana (*Musa* spp., including plantain) is an important food crop in the Democratic Republic of Congo (DR Congo). Plantain (*Musa* ABB group) is widely cultivated across the Congo basin, while East African highland banana (*Musa* AAA-EA group) dominates the production landscape in the Eastern Kivu region (De Langhe et al., 1994). *Musa* cultivation in DR Congo is hampered by several pests, including nematodes and weevil (*Cosmopolites sordidus*) (Mobambo and Naku, 1993), and diseases such as banana bunchy top disease (BBTD) (Mobambo, 2010; Kumar et al., 2011), *Fusarium* wilt and *Xanthomonas* wilt (Ndungo et al., 2006).

BBTD is the most severe viral disease affecting banana production in at least 14 African countries (Kumar et al., 2011). No bunches are produced on plants which get infected in their early development stage. In Africa, the disease was first reported in Egypt in 1901 (Fahmy, 1924; Magee, 1927, 1953), in Eritrea in 1964 (Saverio, 1964) and was first identified elsewhere in sub-Saharan Africa, in DR Congo, in 1958 at the "Institut National pour l'Etude Agronomique du Congo" (INEAC) Yangambi research station (Wardlaw, 1961; Fouré and Manser, 1982). Yangambi is centrally located in the Congo basin on the banks of the mighty Congo River. Since 1958, it has been reported in Bas Congo (Mobambo, 2010) and the Kivus (Sebasigari and Stover, 1988) of the DR Congo. The geographical distribution of the disease throughout the vast Congo basin, has, however, not been studied. Banana bunchy top virus (BBTV), a luteovirus, multiplies in the phloem and is transmitted by the aphid vector *Pentalonia nigronervosa* (Magee, 1927; Burns et al., 1995). Once established, it is extremely difficult to eliminate or manage, even in large-scale plantations (Dale, 1987). *P. nigronervosa* is the only known vector able to transmit BBTV (Yasmin et al., 2001). Winged aphids are mainly responsible for short distance spread, while the movement of infected planting materials from farm to farm or village to village also significantly contributes to disease spread (Dale, 1987; CTAHR, 1997).

This study was undertaken to determine incidence and severity of BBTD and aphid colony presence in infected villages across Oriental, Maniema, Katanga, Eastern and Western Kasai, Equateur and Bandundu provinces in DR Congo. In addition, surveys in the districts of Ituri, Haut Uélé and Bas Uélé of Oriental province assessed disease incidence and severity levels and aphid numbers in both older perennial backyard plots and newly-established distant fields, in order to assess a possible gradient in disease parameters across field types. Triple antibody sandwich enzyme-linked immunosorbent assay (TAS-ELISA) tests were carried out to confirm BBTV presence in sampled mats across all surveyed provinces.

MATERIALS AND METHODS

In-depth BBTD surveys were carried out during 2009 to 2010 in 4 districts (Tshopo, Ituri, Haut-Uélé and Bas-Uélé) of Oriental province located in north-eastern DR Congo (Figure 1, Table 1). Additional surveys were carried out during 2010 to 2012 in Maniema, Northern Katanga, Eastern and Western Kasai, Bandundu and Equateur provinces (Table 1). In Tshopo district, surveys were carried out in 7 territories in addition to Kisangani town and LubuyaBera (Kisangani outskirts), while in Ituri, Haut Uélé and Bas Uélé surveys were carried out in 3 territories. All visited territories had BBTD. Three villages, with a clear presence of BBTD, were selected per territory in Tshopo district, while 1 village was selected per territory in Ituri, Haut Uélé and Bas Uélé. Ten (10) farms were randomly selected per village giving a total of 390 farms in Oriental province (Table 1). The surveyed villages represented locations with the highest observed incidence and severity levels within a territory. The collected data thus reflects the worst case scenario within a given location. The predominant *Musa* cultivar group and source(s) of planting material were assessed at each surveyed farm in Oriental province. *Musa* plots were mainly located next to the house (that is, backyards) but some were at a distance from the house on cleared primary or secondary forest land. BBTD incidence and severity and aphid colony presence and type were assessed on 30 *Musa* mats per selected farm. Diagonal lines were drawn in each field and 15 mats were selected on each line.

In the districts of Ituri, Haut Uélé and Bas Uélé, half of the 30 mats were selected in perennial plantain fields next to the house, while the other half were selected in plantain fields on cleared forest land. It was postulated that the older perennial backyard plots would have a higher disease incidence and aphid colony presence compared to younger and often newly-established distant fields.

A mat that contained at least one plant with visible BBTD symptoms was regarded as infected. Disease incidence was calculated as the number of infected mats divided by the total number of assessed mats. Disease severity was assessed using a scale from 0 to 5 (0: no symptoms, 1: dark green streaks on the leaf lamina, 2: dark green streaks on the leaf petiole, 3: chlorosis of the leaf margin, 4: reduction in leaf size and 5: bunchy top appearance). Aphid colony type was assessed using a scale from 0 to5 (0: no aphids; 1: a single simple colony; 2: several simple colonies; 3: a large colony with one or more winged individuals; 4: several colonies with one or more winged individuals and 5: generalized colonies at the level of the leaves and the pseudostem) (Niyongere et al., 2011).

The surveys carried out in Maniema, Northern Katanga, Eastern and Western Kasai, Bandundu and Equateur provinces during the period 2010 to 2012 focused on disease presence and current geographical distribution, disease incidence and severity, and aphid presence and colony type. Aphid colony type was, however, not assessed in Bandundu province. A total of 25 territories were surveyed across these 6 provinces in 2010 to 2012 (Table 1). As in Oriental province, the surveyed farms and villages represent locations with highest observed incidence and severity levels within a territory. Disease presence was recorded in three villages per territory. In addition, a further in-depth survey was carried out in

*Corresponding author. E-mail: G.Blomme@CGIAR.org

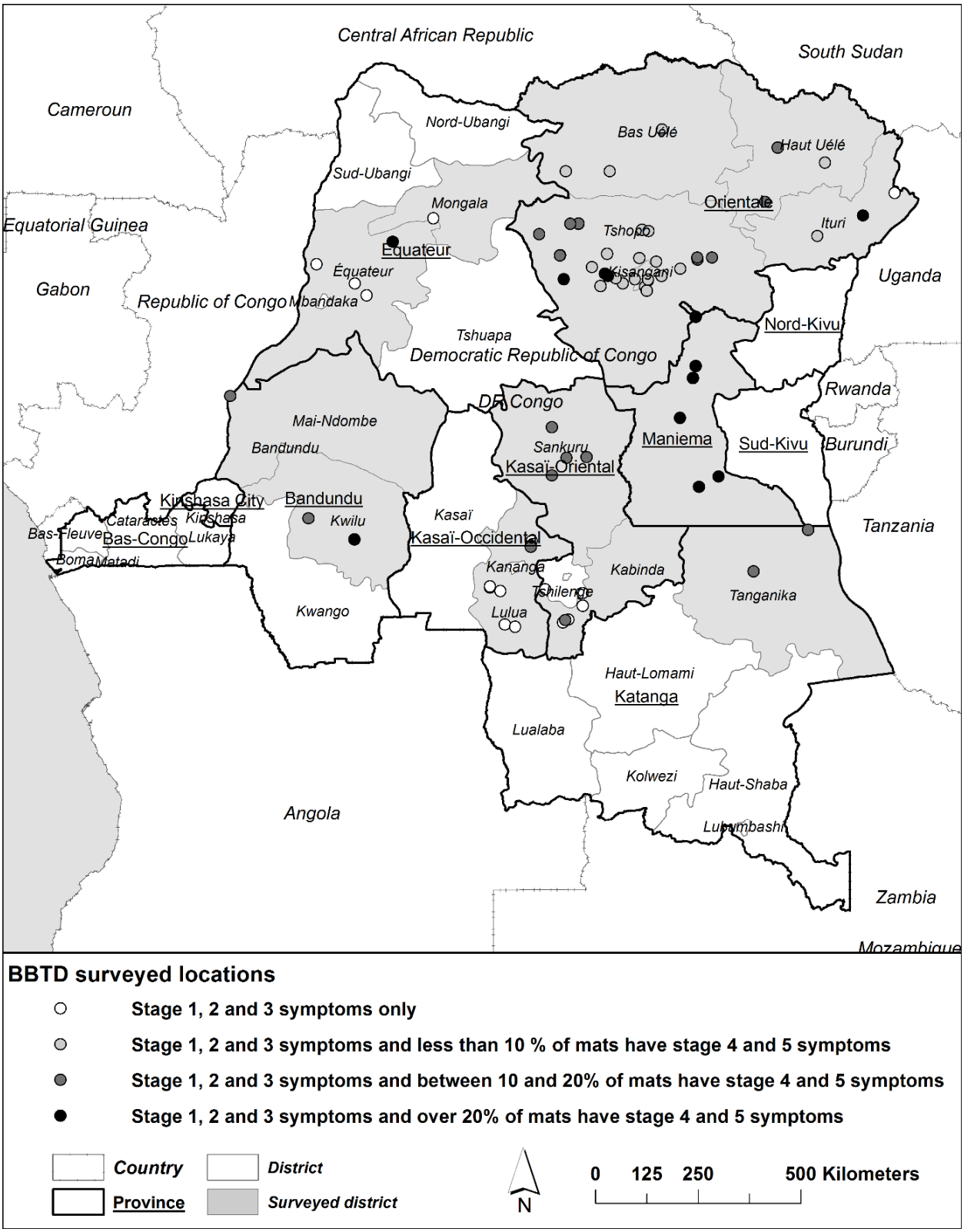

Figure 1. Map indicating the surveyed districts and study provinces (Oriental, Maniema, Katanga, Eastern and Western Kasai, Bandundu and Equateur) in DR Congo. The predominant mean BBTD severity levels for the surveyed villages are indicated with symbols (see map legend). The surveyed villages represent locations with highest observed incidence and severity levels within a territory or district. Disease severity was assessed using a scale from 1 to 5 (1: dark green streaks on the leaf lamina, 2: dark green streaks on the leaf petiole, 3: chlorosis of the leaf margin, 4: reduction in leaf size and 5: bunchy top appearance).

Table 1. Overview of number of surveyed farms, villages, territories, districts and provinces across the Congo basin of the Democratic Republic of Congo.

Period of survey	Province	Districts	Territories	No of villages with a clear presence of BBTD which were selected per territory	Total number of surveyed villages per district	No of farms randomly selected per village	Total number of farms per district
2009 - 2010	Oriental province	Tshopo	Isangi, Basoko, Yahuma, Opala, Ubundu I and II, Bafwasende, Banalia, Kisangani town and Lubuyabera (Kisangani outskirts)	3	30	10	300
		Ituri	Mambasa, Djugu and Mahagi	1	3	10	30
		Haut-Uélé	Wamba, Watsa and Niangara	1	3	10	30
		Bas-Uélé	Buta, Aketi and Ango	1	3	10	30
				No of villages where disease presence was recorded (3 villages per territory)	Further in-depth surveys (1 village per per territory)	One farm was selected per village representing the highest observed incidence and severity levels	Total number of farms per province
2010 - 2012	Maniema	-	Kailo, Kasongo, Kibombo, Lubutu, Pangi and Punia	18	6	1	6
	Northern Katanga	Tanganyika	Kalemie and Nyunzu	6	2	1	2
	Eastern Kasai	Kabinda	Katako-kombe, Kole, Lodja, Lomela, Luilu and Ngandajika	18	10	1	10
	Western Kasai	Lulua	Dimbelenge, Kazumba and Luiza	9	9	1	9
	Bandundu	Plateau	Bolobo	3	1	1	1
		Kwilu	Bulungu and Masi-manimba	6	2	1	2
	Equateur	Equateur	Basankusu, Bikoro, Bolomba, and Ingende	12	4	1	4
		Tshuapa	Monkoto	3	1	1	1

one village per territory - in Bandundu, Maniema, Equateur, North Katanga and the Katako-kombe, Kole, Lodja and Lomela territories in Eastern Kasai, while 3 villages were selected in Western Kasai and in the Luilu and Ngandajika territories in Eastern Kasai, thus giving a total of 35 surveyed villages (Table 1). No disease incidence and severity assessments were carried out in Sankura district of Eastern Kasai. Surveys and field assessments were carried out on one farm per village representing the highest observed incidence and severity levels. A total of 30 mats were assessed on each farm in all villages, except in Western Kasai and in the Luilu and Ngandajika territories in Eastern Kasai, where 10 mats were assessed per farm in 3 different villages to achieve a total of 30 mats.

Niyongere et al. (2013) reported that an increase in altitude and the associated lower temperatures negatively influence the virus transmission rate and lengthen the disease incubation period. In order to assess a possible relationship between altitude and BBTD incidence and aphid presence, the altitude of each surveyed farm across all the surveyed provinces was measured using a global positioning system (GPS) receiver.

BBTV presence was confirmed using the commercial AGDIA (Agdia-Biofords, Evry, France) kit for TAS-ELISA. TAS-ELISA tests were carried out at the laboratory of the University of Kisangani (UNIKIS). Four plantain maiden sucker samples were collected in the 7 territories of Tshopo district, Oriental province for each of the five disease severity levels in each territory to confirm field observations of visible symptoms, and especially for the minor streak symptoms of severity levels 1 and 2, and for leaf lamina chlorosis symptoms of severity level 3. In addition, four symptomless suckers were collected in all the 7 territories of Tshopo district from symptomless mats in infected fields. In addition, four stage 5 sword suckers were collected in the other 3 districts (Ituri, Haut Uélé and Bas Uélé) of Oriental province, while three stage 4 or 5 suckers were collected in all the other surveyed provinces in order to confirm disease presence. Finally, eight visibly diseased suckers (severity level 5) were collected in Butembo town, North Kivu in order to confirm the presence of the disease in this province.

All the collected suckers were first treated with a systemic insecticide (AMBUSH 500EC containing synthetic pyrethroid), to kill putative viruliferous aphids that could transmit the disease, before being planted out in pots at the UNIKIS screenhouse, which is free of aphids. Samples for TAS-ELISA testing were taken from the midrib of the youngest expanded leaf at 2 to 3 weeks after sucker establishment in the screen house.

Statistical analysis was carried out using the R language

Table 2. BBTD incidence and severity across territories and districts of Oriental province, north-eastern DR Congo. TAS-ELISA results are presented for samples collected from plants showing the full range of symptoms in Tshopo district and stage five symptoms in the other districts.

District	Territory	Altitude (masl)	Predominant genome group	Average BBTD incidence (% of assessed mats)	Average BBTD severity score (0 - 5)# (%)						TAS-ELISA (severity level) (%)					
					0	1	2	3	4	5	0 (n = 4)	1 (n = 4)	2 (n = 4)	3 (n = 4)	4 (n = 4)	5 (n = 4)
Tshopo	Basoko	390	AAB plantain	96.6	3.4	33.4	25.4	22.2	14.2	1.1	50	50	100	50	100	100
	Kisangani	416	AAB plantain	98.7	1.3	39.4	2.3	29.7	19.2	7.9	25	25	100	25	100	100
	Isangi	429	AAB plantain	92.1	7.8	7.7	72.6	6.2	4.3	1.2	50	75	100	25	100	100
	Banalia	433	AAB plantain	97.6	2.3	5.1	85.7	4.1	2.2	0.4	50	50	100	25	100	100
	Lubuyabera	435	AAB plantain	97.0	3.0	41.2	5.3	41.6	6.5	2.3	25	25	100	50	100	100
	Ubundu II	436	AAB plantain	94.0	6.0	35.8	16.0	37.8	4.0	0.3	50	25	100	25	100	100
	Yahuma	445	AAB plantain	97.9	2.2	25.0	19.7	32.9	19.0	0.9	50	25	100	25	100	100
	Opala	453	AAB plantain	97.6	2.5	1.3	88.3	4.1	3.7	0.0	25	50	100	50	100	100
	Ubundu I	457	AAB plantain	94.2	6.0	30.6	8.2	47.0	8.0	0.1	25	75	100	25	100	100
	Bafwasende	562	AAB plantain	99.1	1.1	58.6	8.6	20.4	9.4	1.9	50	75	100	25	100	100
	Mean			96.5	3.6	27.8	33.2	24.6	9.1	1.6	40.0	47.5	100.0	32.5	100	100
	SE			6.4	6.4	51.9	98.9	45.1	18.0	6.6						
																(n = 3*)
Ituri	Mambasa	901	AAB plantain	67.7	32.3	54.7	5.0	6.7	0.7	0.7	-	-	-	-	-	100
	Djugu	1117	AAA-EA	99.7	0.3	28.7	4.3	31.7	19.0	16.0	-	-	-	-	-	100
	Mahagi	1703	AAA-EA	43.3	56.7	40.7	0.7	2.0	0.0	0.0	-	-	-	-	-	100
	Mean			70.2	29.8	41.3	3.3	13.4	6.6	5.6	-	-	-	-	-	100
	SE			48.9	48.9	22.5	4.0	27.6	18.7	15.7						
																(n = 3*)
Haut Uélé	Niangara	724	AAB plantain	85.3	14.7	46.7	3.0	24.0	7.7	4.0	-	-	-	-	-	100
	Wamba	779	AAB plantain	96.0	4.0	59.0	2.7	23.3	8.7	2.3	-	-	-	-	-	100
	Watsa	988	AAB plantain	74.7	25.3	43.3	6.7	15.3	6.0	3.3	-	-	-	-	-	100
	Mean			85.3	14.7	49.7	4.1	20.9	7.4	3.2	-	-	-	-	-	100
	SE			18.5	18.5	14.3	3.8	8.4	2.3	1.5						
																(n = 4)
Bas Uélé	Buta	413	AAB plantain	83.7	16.3	55.7	5.0	19.3	2.0	1.7	-	-	-	-	-	50
	Aketi	414	AAB plantain	69.7	30.3	46.7	8.7	13.7	0.7	0.0	-	-	-	-	-	50
	Ango	611	AAB plantain	68.3	31.7	50.0	6.7	8.3	1.7	1.7	-	-	-	-	-	50
	Mean			73.9	26.1	50.8	6.8	13.8	1.4	1.1	-	-	-	-	-	50
	SE			14.7	14.7	7.9	3.2	9.5	1.2	1.7						
	Overall mean			91.9	8.2	32.3	26.6	22.6	8.2	2.0	-	-	-	-	-	91.4
	SE			75.6	9.6	29.8	60.8	31.2	12.4	4.1						

#: 0: no symptoms, 1: dark green streaks on the leaf lamina, 2: dark green streaks on the leaf petiole, 3: chlorosis of the leaf margins, 4: reduction in leaf size and 5: bunchy top appearance.
*: although four suckers were collected, some suckers did not survive the long journey back to Kisangani.

and environment (R Development Core Team, 2010). The relationship between altitude and BBTD incidence and aphid presence was assessed through correlation analysis. The Student test ($P \leq 0.05$) was used to compare BBTD incidence and severity, aphid presence and type of aphid colony between districts or between provinces. In addition, comparisons were also made between backyard plots adjacent to the house and distant plots on cleared forest land for the Ituri, Haut Uélé and Bas Uélé districts of Oriental province.

RESULTS

Surveys in Oriental province

Plantains are predominantly cultivated across the Tshopo, Haut Uélé and Bas Uélé districts of Oriental province (Table 2). These districts are also characterized by lower elevations, ranging from 390 to 988 m above sea level (masl). In contrast, East African highland cultivars dominate the production landscape in the Djugu and Mahagi territories of Ituri district (Table 2). These

Table 3. Source of planting material in surveyed districts and territories of Oriental province, north-eastern DR Congo.

District	Territory	Altitude (masl)	Predominant genome group	Source of planting material (% of farmers)[#]				
				1	2	3	4	5
Tshopo	Basoko	390	AAB plantain	82.7	10.3	7.0	0.0	0.0
	Kisangani	416	AAB plantain	56.2	43.2	0.6	0.0	0.0
	Isangi	429	AAB plantain	89.3	10.4	0.0	0.0	0.0
	Banalia	433	AAB plantain	90.3	9.7	0.0	0.0	0.0
	Lubuyabera	435	AAB plantain	82.7	17.3	0.0	0.0	0.0
	Ubundu II	436	AAB plantain	88.7	10.3	1.0	0.0	0.0
	Yahuma	445	AAB plantain	94.2	4.2	1.6	0.0	0.0
	Opala	453	AAB plantain	96.1	3.9	0.0	0.0	0.0
	Ubundu I	457	AAB plantain	93.4	6.4	0.0	0.0	0.0
	Bafwasende	562	AAB plantain	96.8	3.4	0.0	0.0	0.0
Ituri	Mambasa	901	AAB plantain	62.9	25.9	11.1	0.0	0.0
	Djugu	1117	AAA-EA	79.2	12.5	8.3	0.0	0.0
	Mahagi	1703	AAA-EA	56.5	34.8	8.7	0.0	0.0
Haut Uélé	Niangara	724	AAB plantain	61.9	28.6	9.5	0.0	0.0
	Wamba	779	AAB plantain	68.2	18.2	13.6	0.0	0.0
	Watsa	988	AAB plantain	63.7	18.2	18.2	0.0	0.0
Bas Uélé	Buta	413	AAB plantain	52.4	23.8	23.8	0.0	0.0
	Aketi	414	AAB plantain	55.0	25.0	20.0	0.0	0.0
	Ango	611	AAB plantain	68.0	25.0	7.0	0.0	0.0
Mean				81.5	14.6	3.9	0.0	0.0

#: 1: From own farm, 2: from neighbouring farm (<1 km), 3: from a friend's farm (>1 km), 4: tissue culture plantlets distributed by a government agency and 5: tissue culture plantlets bought from a private laboratory.

territories are located at higher elevations, which range from 1,117 to 1,703 masl. All the *Musa* cultivars grown in farmers' fields across Oriental province were susceptible to BBTD.

Farmers mainly obtain planting material from their own fields (81% of respondents), or from neighboring farms located less than 1 km away (15%) (Table 3). A few farmers (4%) obtained suckers from distant farms, while no tissue culture plantlets were used. The movement of planting materials is not regulated though quarantine agencies in DR Congo and diseased suckers are often selected as planting material.

An overall average disease incidence of 92% was observed across Oriental province (Table 2). Disease severity levels were, however, low and 81.5% of all assessed mats had a disease severity score ranging from 1 to 3 (Table 2). Only 10% of mats had advanced disease symptoms (that is, dwarfing of leaves, bunched leaves which stand upright and are brittle) corresponding to disease severity scores 4 and 5. Disease incidence was above 90% in all surveyed territories of Tshopo district (Table 2) and reached almost 100% in Djugu (Ituri district) and Bafwasende (Tshopo district).

The territories of Djugu (Ituri), Kisangani (Tshopo), Yahuma (Tshopo) and Basoko (Tshopo) had the highest proportion of mats (respectively, 35, 27, 20 and 15%) with advanced disease symptoms (scores 4 plus 5). In contrast, very few mats with advanced disease symptoms were observed especially in Bas Uélé (Buta, Aketi and Ango), but also in Mahagi and Mambasa (Ituri district) and in the Banalia and Opala territories of Tshopo district (Table 2).

The aphid vector was present in all districts and surveyed territories and was found on 89% of all assessed mats across the province. Aphid presence was at least 92% across the territories of Tshopo district, while a lower aphid presence was observed across the three other districts (Table 4). A single simple aphid colony without winged insects was most frequently observed in Ituri (37% of mats), Haut Uélé (49%) and Bas Uélé (43%), while Tshopo district had a considerable presence (43%) of several simple colonies without winged aphids.

A slightly higher BBTD incidence was observed in home gardens (79%) compared to the distant plots on cleared forest land (74%) across Ituri, Haut and Bas Uélé

Table 4. Aphid vector presence and colony typology across districts and territories of Oriental province, north-eastern DR Congo.

District	Territory	Altitude (masl)	Predominant genome group	Aphid presence (% of assessed mats)	Aphid colony typology[#] (%)					
					0	1	2	3	4	5
Tshopo	Basoko	390	AAB plantain	93.3	3.5	25.1	56.2	9.8	3.7	1.6
	Kisangani	416	AAB plantain	98.7	1.3	31.2	42.9	20.3	4.1	0.0
	Isangi	429	AAB plantain	92.2	7.8	29.0	32.6	26.9	3.7	0.0
	Banalia	433	AAB plantain	97.6	2.4	32.7	43.9	13.2	7.4	0.2
	Lubuyabera	435	AAB plantain	97.0	3.0	31.7	35.2	20.8	8.8	0.7
	Ubundu II	436	AAB plantain	94.0	5.9	37.9	40.6	10.9	4.4	0.0
	Yahuma	445	AAB plantain	97.8	2.2	38.8	52.3	4.8	1.7	0.1
	Opala	453	AAB plantain	97.4	2.6	42.7	31.2	21.1	2.3	0.0
	Ubundu I	457	AAB plantain	94.2	5.8	32.1	41.9	14.1	3.5	2.4
	Bafwasende	562	AAB plantain	96.0	0.9	29.3	54.5	12.1	2.9	0.2
	Mean			95.8	3.5	33.1	43.1	15.4	4.3	0.5
	SE			6.3	6.3	15.0	25.3	19.0	6.3	2.4
Ituri	Mambasa	901	AAB plantain	60.3	39.7	39.7	13.7	6.3	0.7	0.0
	Djugu	1117	AAA-EA	78.3	21.7	35.0	21.7	16.0	5.7	0.0
	Mahagi	1703	AAA-EA	36.3	63.7	35.3	1.0	0.0	0.0	0.0
	Mean			58.3	41.7	36.7	12.1	7.4	2.1	0.0
	SE			36.5	36.5	4.5	18.0	14.0	5.4	0.0
Haut Uélé	Niangara	724	AAB plantain	70.7	29.3	46.3	11.3	11.0	2.0	0.0
	Wamba	779	AAB plantain	87.7	12.3	54.7	12.0	19.3	1.7	0.0
	Watsa	988	AAB plantain	60.0	40.0	46.7	5.3	6.0	2.0	0.0
	Mean			72.8	27.2	49.2	9.6	12.1	1.9	0.0
	SE			24.2	24.2	8.2	6.4	11.7	0.3	0.0
Bas Uélé	Buta	413	AAB plantain	74.3	25.7	43.3	18.3	9.7	3.0	0.0
	Aketi	414	AAB plantain	67.7	32.3	41.7	17.0	8.7	0.3	0.0
	Ango	611	AAB plantain	70.0	30.0	45.3	14.7	10.0	0.0	0.0
	Mean			70.7	29.3	43.4	16.7	9.4	1.1	0.0
	SE			5.9	5.9	3.2	3.2	1.2	2.8	0.0
	Overall mean			89.2	10.3	35.4	36.1	14.1	3.7	0.4
	SE			78.8	10.7	21.4	43.3	16.4	5.2	1.4

[#]: 0: no aphids; 1: a single simple colony; 2: several simple colonies; 3: a large colony with one or more winged individuals; 4: several colonies with one or more winged individuals and 5: generalized colonies at the level of the leaves and the pseudostem.

(Table 5). Disease severity was similar for both plot types, with about half of the symptomatic plants showing dark green streaks on the leaf lamina (severity score 1) (Table 5). Leaf margin chlorosis was the second most observed symptom and was recorded on 17% of symptomatic plants in the home gardens and on 15% of plants in the distant plots.

Aphid colonies were observed on 71% of mats in the home gardens compared with 65% of mats in the distant plots (Table 5). Single simple aphid colonies (score 1) clearly dominated in both plot types (46 and 41% for, respectively, home and distant plots), while multiple aphid colonies with one or more winged individuals (score 4) were rare and generalized aphid colonies at the level of the leaves and pseudostem (score 5) were totally absent (Table 5). A total of 12 and 11% of mats in, respectively, the home gardens and distant plots harbored winged aphids.

A very strong relationship was observed between BBTD incidence and aphid presence in Oriental province ($R = 0.93$, $p < 0.01$). The correlation coefficient between site altitude and percentage BBTD incidence was -0.65 ($p < 0.01$) when taking into account all the surveyed territories in Oriental province, while the correlation coefficient between altitude and aphid vector presence (%) was $R=-0.79$ ($p < 0.01$). The altitude across all the

Table 5. BBTD incidence and severity, and aphid presence according to the location of a plantain/banana plot in the districts of Ituri, Haut Uélé and Bas Uélé, Oriental province, north-eastern DR Congo.

Location	District	Territory	Altitude (masl)	Predominant genome group	Average BBTD incidence (% of assessed mats)	Average BBTD severity score (1-5)[#] (%)					Aphid presence (% of assessed mats)	Aphid colony typology* (%)				
						1	2	3	4	5		1	2	3	4	5
Plots adjacent to the house	Ituri	Mambasa	901	AAB plantain	75.3	64.0	6.0	4.7	0.7	0.0	62.0	37.3	15.3	8.7	0.7	0.0
		Djugu	1117	AAA-EA	100.0	39.3	5.3	32.0	14.7	8.7	77.3	34.7	23.3	14.7	4.7	0.0
		Mahagi	1703	AAA-EA	40.0	36.7	0.7	2.7	0.0	0.0	33.3	32.0	1.3	0.0	0.0	0.0
	Haut Uélé	Niangara	724	AAB plantain	88.0	45.3	2.7	25.3	10.7	4.0	78.0	53.3	13.3	8.7	2.7	0.0
		Wamba	779	AAB plantain	98.7	66.0	1.3	21.3	8.7	1.3	90.0	60.0	10.7	17.3	2.0	0.0
		Watsa	988	AAB plantain	-	-	-	-	-	-	-	-	-	-	-	-
	Bas Uélé	Buta	413	AAB plantain	88.7	60.0	3.3	19.3	2.7	3.3	78.7	46.0	14.0	12.7	6.0	0.0
		Aketi	414	AAB plantain	73.3	36.7	14.0	22.0	0.7	0.0	78.0	54.0	14.0	9.3	0.7	0.0
		Ango	611	AAB plantain	70.0	53.3	3.3	8.7	2.0	2.7	72.7	47.3	14.7	10.7	0.0	0.0
Mean					79.2	50.2	4.6	17.0	5.0	2.5	71.2	45.6	13.3	10.2	2.1	0.0
SE					10.3	6.5	2.2	5.6	2.9	1.6	9.1	5.4	3.2	2.7	1.2	0.0
Distant plots on cleared forest land	Ituri	Mambasa	901	AAB plantain	60.0	45.3	4.0	8.7	0.7	1.3	58.7	42.0	12.0	4.0	0.7	0.0
		Djugu	1117	AAA-EA	99.3	18.7	3.3	31.3	23.3	23.3	79.3	35.3	20.0	17.3	6.7	0.0
		Mahagi	1703	AAA-EA	46.7	44.7	0.7	1.3	0.0	0.0	39.3	38.7	0.7	0.0	0.0	0.0
	Haut Uélé	Niangara	724	AAB plantain	82.7	48.0	3.3	22.7	4.7	4.0	63.3	39.3	9.3	13.3	1.3	0.0
		Wamba	779	AAB plantain	93.3	52.0	4.0	25.3	8.7	3.3	85.3	49.3	13.3	21.3	1.3	0.0
		Watsa	988	AAB plantain	74.7	43.3	6.7	15.3	6.0	3.3	60.0	46.7	5.3	6.0	2.0	0.0
	Bas Uélé	Buta	413	AAB plantain	78.7	51.3	6.7	19.3	1.3	0.0	70.0	40.7	22.7	6.7	0.0	0.0
		Aketi	414	AAB plantain	66.0	56.7	3.3	5.3	0.7	0.0	57.3	29.3	20.0	8.0	0.0	0.0
		Ango	611	AAB plantain	66.7	46.7	10.0	8.0	1.3	0.7	67.3	43.3	14.7	9.3	0.0	0.0
Mean					74.2	45.2	4.7	15.3	5.2	4.0	64.5	40.5	13.1	9.5	1.3	0.0
SE					12.6	9.8	2.8	4.9	3.7	3.7	13.5	8.3	4.5	3.7	1.1	0.0

[#]: 0: no symptoms, 1: dark green streaks on the leaf lamina, 2: dark green streaks on the leaf petiole, 3: chlorosis of the leaf margins, 4: reduction in leaf size and 5: bunchy top appearance. *: 0: no aphids; 1: a single simple colony; 2: several simple colonies; 3: a large colony with one or more winged individuals; 4: several colonies with one or more winged individuals and 5: generalized colonies at the level of the leaves and the pseudostem.

territories in the province ranges from 390 to 1,703 masl. The lowest average disease incidence and severity level was observed at Mahagi, Ituri district (1,703 masl) which is by far the highest altitude location (Table 2).

All samples collected in Tshopo district on plants showing dark green streaks on the leaf midribs and leaf petioles (that is, severity score 2), and leaf dwarfing and a typical bunchy top appearance (scores 4 and 5) had positive TAS-ELISA results (Table 2). However, only 48% of plants with dark green streaks on the leaf lamina veins (severity score 1) and 33% of plants with chlorosis of the leaf margins (score 3) gave positive TAS-ELISA results. In addition, 40% of symptomless plants tested positive. The samples collected in Ituri and Haut-Uélé, from plants having a typical bunchy top appearance (severity score 5) all gave positive

TAS-ELISA results, while only 50% of samples collected from stage 5 plants in Bas Uélé tested positive (Table 2).

Surveys in Bandundu, Equateur, Eastern and Western Kasai, Katanga and Maniema provinces

Plantains are predominantly cultivated in Bandundu, Eastern Kasai, Equateur and Maniema, while east African highland cultivars dominate the production landscape in Katanga (Table 6). The cultivation of AAA dessert bananas is widespread in Kwilu district, Bandundu and in Lulua district in Western Kasai. All the *Musa* cultivars grown in farmers' fields across these six provinces are susceptible to BBTD. The average BBTD incidences in Bandundu, Equateur, Kasai, Katanga and Maniema were lower than the incidence levels observed in Oriental province (Tables 2 and 6). The lowest incidence levels were observed in Equateur (43%) and Katanga (35%). Disease severity level 1 was most commonly observed across these provinces (Table 6). However, just as in Djugu territory (35%) in Oriental province, relatively high disease severity levels (scores 4 plus 5) were also recorded in most territories of Maniema (ranging from 20 to 53%), Bandundu (ranging from 10 to 20%) and Katanga (13%). All suckers/lateral shoots with stage 4 or 5 symptoms collected across Bandundu, Equateur, Katanga, Maniema and in Butembo, North Kivu gave positive TAS-ELISA results, while only 50% of samples from suckers collected in Eastern and Western Kasai tested positive (Table 6). The aphid vector was present in all districts and surveyed territories of Bandundu, Equateur, Kasai, Katanga and Maniema (Table 7). Single simple aphid colonies without winged insects and multiple simple colonies without winged insects were most frequently observed across these provinces. However, 20% of mats in Maniema contained winged aphids (colony types 4 and 5) (Table 7). This corresponds with the high disease incidence and especially severity levels which were observed in this same province (Table 6).

A high correlation was observed between disease incidence and aphid occurrence when analyzing data from all the 7 surveyed provinces ($R = 0.63$, $p < 0.001$). A significant negative correlation was observed between altitude and aphid presence ($R = -0.44$, $p = 0.002$), while no significant correlation was observed between BBTD incidence and altitude ($R = -0.08$, $p = 0.57$).

TAS-ELISA results confirmed the presence of BBTV in all stage 5 suckers collected in Butembo town. In contrast, no BBTV infected plants were observed in the countryside around Butembo (Charles Sivirihauma, personal communication, 2013).

DISCUSSION

BBTD and the aphid vector were observed in all surveyed provinces, districts and territories. It is no surprise to have observed the BBTV aphid vector across the whole of north-eastern DR Congo as this aphid has been reported to be present in all banana-growing regions of the tropical world (Hill, 1983; Robson et al., 2007). Highest disease incidence levels were observed in Oriental, Eastern and Western Kasai and Maniema provinces. The lowest average disease incidence and severity level, in Oriental province, was observed at Mahagi, Ituri district (1,703 masl) which is the highest altitude location that was surveyed. Very low disease incidence levels are currently also observed in the highland regions of North and South Kivu provinces (FAO, 2010; Charles Sivirihauma and Célestin Niyongere, personal communication, 2013). An increase in altitude and corresponding lower temperatures negatively influences vector presence and disease incidence; *P. nigronervosa* is known to have a preference for warmer climates. A negative correlation has, for instance, been found between aphid presence and altitude (cooler temperatures) in the Great Lakes region of Africa (Niyongere et al., 2012). Moreover, a high temperature is more favorable for aphid transmission of the BBTV than a low temperature (Wu and Su, 1990).

The altitude across all the territories of the 7 provinces ranges from 320 to 1,117 masl, with one outlier of 1,703 masl for Mahagi territory in Ituri district, Oriental province. The weak altitude effect, when analyzing the data from all 7 provinces together, may have arisen from the fact that most territories are located at altitudes below 1,000 masl.

Highest disease severity levels were observed in Djugu, Kisangani and Yahuma territories in Oriental province, and in the majority of territories in Maniema province. However, disease severity in the majority of surveyed districts is predominantly limited to streaks on the leaf veins and petioles, which has not been reported as having an influence on bunch weight or yield. In addition, infected mats can produce numerous healthy looking and productive plants over prolonged periods of time (Benoit Dhed'a and Bonaventure Ibanda, personal communication, 2013).

Home garden plantations or backyards are generally older than those found on cleared forest land. However, high values of disease incidence and aphid presence were observed in most plots on cleared land, which most likely resulted from the use of infected planting material when establishing a new distant plot. In addition, the surveys revealed that famers do not remove any aphids when preparing planting material, as they are simply unaware of the presence and role of these aphids.

The positive results from the TAS-ELISA analysis of samples from Butembo, North Kivu confirm the presence of BBTD in this Eastern province. A *Musa* diseases survey that was carried out by the International Institute of Tropical Agriculture (IITA) in 2009 in North Kivu reported a BBTD incidence of 29% across backyards of Butembo town (1,600 to 1,800 masl), while surveys carried out by FAO in 2010 (FAO, 2010) in the Beni and

Table 6. BBTD incidence and severity across Maniema, northern Katanga, Eastern and Western Kasai, Bandundu and Equateur provinces. TAS-ELISA results are presented for samples collected from plants exhibiting severity levels 4 or 5.

Province	District	Territory	Altitude (masl)	Predominant genome group	Average BBTD incidence (% of assessed mats)	Average BBTD severity score (0-5)# (%)						TAS-ELISA (severity level 4 and 5) (%)
						0	1	2	3	4	5	
												(n = 3)
Bandundu	Kwilu	Masi-manimba	413	AAB plantain	60.0	40.0	20.0	3.3	20.0	3.3	13.3	100
		Bulungu	445	AAA dessert	70.0	30.0	26.7	3.3	20.0	16.7	3.3	100
	Plateau	Bolobo	336	AAB plantain	50.0	50.0	26.7	0.0	13.3	3.3	6.7	100
	Mean				60.0	40.0	24.4	2.2	17.8	7.8	7.8	100
	SE				1.7	1.7	0.7	0.3	0.7	1.3	0.9	
												(n = 2*)
Eastern Kasai	Kabinda	Ngandajika	766	AAB plantain	66.7	33.3	33.3	26.7	6.7	0.0	0.0	50
		Luilu	832	AAB plantain	73.3	26.7	30.0	30.0	10.0	3.3	0.0	50
	Mean				70.0	30.0	31.7	28.3	8.3	1.7	0.0	50
	SE				1.0	1.0	0.5	0.5	0.5	0.5	0.0	
												(n = 3)
Equateur		Bikoro	320	AAB plantain	46.7	53.3	23.3	0.0	23.3	0.0	0.0	100
	Equateur	Ingende	332	AAB plantain	36.7	63.3	20.0	0.0	16.7	0.0	0.0	100
		Bolomba	343	AAB plantain	33.3	66.7	26.7	0.0	6.7	0.0	0.0	100
		Basankusu	366	AAB plantain	73.3	26.7	23.3	0.0	16.7	16.7	16.7	100
	Tshuapa	Monkoto	375	AAB plantain	26.7	73.3	10.0	0.0	16.7	0.0	0.0	100
	Mean				43.3	56.7	20.7	0.0	16.0	3.3	3.3	100
	SE				2.4	2.4	0.9	0.0	0.8	1.0	1.0	
												(n = 3)
Katanga	Tanganyika	Nyunzu	641	AAA-EA	40.0	60.0	20.0	6.7	0.0	6.7	6.7	100
		Kalemie	1011	AAA-EA	30.0	70.0	3.3	10.0	3.3	10.0	3.3	100
	Mean				35.0	65.0	11.7	8.3	1.7	8.3	5.0	100
	SE				1.5	1.5	2.5	0.5	0.5	0.5	0.5	
												(n = 3)
Maniema		Lubutu	512	AAB plantain	76.7	23.3	13.3	0.0	40.0	10.0	13.3	100
		Kailo	517	AAB plantain	60.0	40.0	10.0	3.3	13.3	26.7	6.7	100
		Kibombo	534	AAB plantain	66.7	33.3	0.0	0.0	26.7	30.0	10.0	100
		Punia	547	AAB plantain	50.0	50.0	13.3	13.3	3.3	16.7	3.3	100
		Pangi	548	AAB plantain	76.7	23.3	13.3	0.0	40.0	10.0	13.3	100
		Kasongo	554	AAB plantain	86.7	13.3	6.7	0.0	26.7	26.7	26.7	100
	Mean				69.4	30.6	9.4	2.8	25.0	20.0	12.2	100
	SE				1.6	1.6	0.7	0.7	1.8	1.1	1.0	

Table 6. Contd.

													(n = 2*)
Western Kasai	Lulua	Dimbelenge	624	AAB plantain	80.0	20.0	36.7	26.7	10.0	6.7	0.0		50
		Kazumba	705	AAA dessert	73.3	26.7	40.0	23.3	10.0	0.0	0.0		50
		Luiza	831	AAA dessert	76.7	23.3	26.7	36.7	13.3	0.0	0.0		50
	Mean				76.7	23.3	34.4	28.9	11.1	2.2	0.0		50
	SE				0.6	0.6	1.2	1.2	0.3	0.7	0.0		
	Overall mean				59.7	40.3	20.2	8.7	16.0	8.9	5.9		91.4
	SE				1.2	1.2	0.7	0.8	0.7	0.6	0.5		

#: 0: no symptoms, 1: dark green streaks on the leaf lamina, 2: dark green streaks on the leaf petiole, 3: chlorosis of the leaf margins, 4: reduction in leaf size and 5: bunchy top appearance. *: although three suckers were collected, some suckers did not survive the long journey back to Kisangani.

Table 7. Aphid presence and aphid colony type across Maniema, northern Katanga, Eastern and Western Kasai, Bandundu and Equateur provinces.

Province	District	Territory	Altitude (masl)	Predominant genome group	Aphid presence (% of assessed mats)	Aphid colony typology# (%)					
						0	1	2	3	4	5
Bandundu	Kwilu	Masi-manimba	413	AAB plantain	76.7	23.3	-	-	-	-	-
		Bulungu	445	AAA dessert	60.0	40.0	-	-	-	-	-
	Plateau	Bolobo	336	AAB plantain	73.3	26.7	-	-	-	-	-
	Mean				70.0	30.0	-	-	-	-	-
	SE				1.5	1.5					
Eastern Kasai	Kabinda	Ngandajika	766	AAB plantain	66.7	33.3	40.0	26.7	0.0	0.0	0.0
		Luilu	832	AAB plantain	66.7	33.3	50.0	16.7	0.0	0.0	0.0
	Sankuru	Lodja	374	AAB plantain	63.3	36.7	43.3	10.0	3.3	3.3	3.3
		Katako-kombe	475	AAB plantain	73.3	26.7	70.0	0.0	3.3	0.0	0.0
		Lomela	571	AAB plantain	73.3	26.7	56.7	3.3	3.3	6.7	3.3
		Kole	575	AAB plantain	80.0	20.0	56.7	0.0	3.3	10.0	10.0
	Mean				70.6	29.4	52.8	9.4	2.2	3.3	2.8
	SE				0.7	0.7	1.3	1.3	0.2	0.5	0.5
Equateur	Equateur	Bikoro	320	AAB plantain	80.0	20.0	63.3	16.7	0.0	0.0	0.0
		Ingende	332	AAB plantain	80.0	20.0	33.3	43.3	3.3	0.0	0.0
		Bolomba	343	AAB plantain	76.7	23.3	56.7	20.0	0.0	0.0	0.0
		Basankusu	366	AAB plantain	56.7	43.3	36.7	16.7	3.3	0.0	0.0
	Tshuapa	Monkoto	375	AAB plantain	73.3	26.7	53.3	20.0	0.0	0.0	0.0
	Mean				73.3	26.7	48.7	23.3	1.3	0.0	0.0
	SE				1.3	1.3	1.7	1.5	0.2	0.0	0.0

Table 7. Contd.

Katanga	Tanganyika	Nyunzu	641	AAA-EA	50.0	50.0	30.0	10.0	10.0	0.0	0.0
		Kalemie	1011	AAA-EA	16.7	83.3	10.0	6.7	0.0	0.0	0.0
	Mean				33.3	66.7	20.0	8.3	5.0	0.0	0.0
	SE				5.0	5.0	3.0	0.5	1.5	0.0	0.0
Maniema	-	Lubutu	512	AAB plantain	20.0	80.0	3.3	13.3	0.0	0.0	3.3
		Kailo	517	AAB plantain	53.3	46.7	10.0	6.7	13.3	16.7	6.7
		Kibombo	534	AAB plantain	63.3	36.7	6.7	6.7	13.3	26.7	10.0
		Punia	547	AAB plantain	46.7	53.3	26.7	16.7	3.3	0.0	0.0
		Pangi	548	AAB plantain	66.7	33.3	26.7	13.3	16.7	10.0	0.0
		Kasongo	554	AAB plantain	86.7	13.3	10.0	20.0	10.0	13.3	33.3
	Mean				56.1	43.9	13.9	12.8	9.4	11.1	8.9
	SE				2.7	2.7	1.2	0.7	0.8	1.3	1.5
Western Kasai	Lulua	Dimbelenge	624	AAB plantain	73.3	26.7	56.7	13.3	3.3	0.0	0.0
		Kazumba	705	AAA dessert	66.7	33.3	43.3	20.0	3.3	0.0	0.0
		Luiza	831	AAA dessert	70.0	30.0	46.7	23.3	0.0	0.0	0.0
	Mean				70.0	30.0	48.9	18.9	2.2	0.0	0.0
	SE				0.6	0.6	1.2	0.9	0.3	0.0	0.0
	Overall mean				64.5	35.5	37.7	14.7	4.2	3.9	3.2
	SE				1.0	1.0	1.3	0.6	0.3	0.5	0.5

[#]: 0: no aphids; 1: a single simple colony; 2: several simple colonies; 3: a large colony with one or more winged individuals; 4: several colonies with one or more winged individuals and 5: generalized colonies at the level of the leaves and the pseudostem.

Lubero territories of North Kivu province reported a 19% disease incidence in the town of Butembo. A survey carried out by the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) in 2011 recorded the disease on 36% of assessed mats, mainly in the Kitulu neighborhood of Butembo town **(**Charles Sivirihauma, personal communication, 2012). This may indicate that town residents brought diseased planting material into Butembo town upon their return from the Congo basin region where the disease is omnipresent. More and more farmers from Butembo town and surrounding villages have started buying large farms in the Mambasa and Irumu territories of Ituri district (960 masl) for the cultivation of cacao, coffee, banana, palm oil and cassava (Charles Sivirihauma, personal communication, 2013). This trend could indeed increase the likelihood of *Musa* seed movements and could lead to further BBTD spread into the highland regions around Butembo town. Surveys carried out initially by Walangululu et al. (2010) and subsequently by Niyongere et al. (2013) confirmed the presence of BBTD and its aphid vector in predominantly mid-altitude regions of South Kivu province bordering the Rusizi valley. An average disease incidence of 23 and 29% was observed in Kamanyola (895 to 972 masl) and Nyangezi (1,254 to 1,937 masl) districts, respectively (Niyongere et al., 2012). Mats with severe disease symptoms (scores 4 and 5) attained a 15 and 17% frequency in Kamanyola and Nyangezi and aphid vectors were observed on 40 and 41% of mats, respectively (Niyongere et al., 2012). Aphid populations containing winged aphids (colony type 3 to 5) were observed on 15 and 17% of mats in Kamanyola and Nyangezi districts.

An effective quarantine service needs to be established to prevent the movement of planting materials into areas where the disease is currently non-existent or rare (e.g. in the largest parts of

North Kivu and South Kivu, which are predominantly high elevation sites). In addition, there is an urgent need to carry out serological tests (TAS-ELISA) in order to identify BBTD-free plants for multiplication and distribution of disease-free planting materials, while information on disease epidemiology and control needs to be disseminated on a large scale.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Burns TM, Harding RM, Dale JL (1995). The genome organization of banana bunchy top virus: analysis of six ssDNA components. J. Gen. Virol. 76:1471-1482. http://dx.doi.org/10.1099/0022-1317-76-6-1471 PMid:7782775

CTAHR (1997). Banana Bunchy Top Virus. Plant Disease. College of Tropical Agriculture and Human Resources (CTAHR), University of Hawaii, PD-12. 4p.

Dale JL (1987). Banana bunchy top: An economically important tropical plant virus disease. Adv. Virus Res. 33:301-325. http://dx.doi.org/10.1016/S0065-3527(08)60321-8

De Langhe E, Swennen R, Vuylsteke D (1994). Plantain in the early Bantu world. Azania. J. Br. Inst. in East. Afr. (GBR) 29-30:147-160.

Fahmy T (1924). A banana disease caused by a species of heterodera. Min. Agric. Eg. Bulletin 30.

FAO (2010). Enquête sur les maladies des bananiers: BBTD et BXW en Province du Nord Kivu. Rapport interne. FAO Goma office. North Kivu. 26 pp.

Fouré E, Manser PD (1982). Note sur l'apparition au Gabon d'une grave maladie virale des bananiers et plantains: le bunchy top. Fruits 37(6):409-414.

Hill DS (1983). Agricultural insects and pests of the tropics and their control. 2nd edition, Cambridge, UK: Cambridge University Press. 749 pp.

Kumar PL, Hanna R, Alabi COJ, Soko MM, Oben TT, Vangu GHP, Naiduc RA (2011). Banana bunchy top virus in sub-Saharan Africa: investigations on virus distribution and diversity. Virus Res. 159(2):171-182. http://dx.doi.org/10.1016/j.virusres.2011.04.021 PMid:21549775

Magee CJP (1927). Investigation on the bunchy top disease of the banana. Melbourne, Australia: Counc. Sci. Ind. Res. Bull. 30:1–64.

Magee CJP (1953). Some aspects of the bunchy top disease of banana and other Musa spp. J. Proc. Royal Soc. New South Wales 87:3-18.

Mobambo KN (2010). S.O.S: la banane congolaise atteinte d'un virus. Quotidien indépendant, Kinshasa. RDC. 1 Page.

Mobambo KN, Naku M (1993). Situation de la cercosporiose noire des bananiers et plantains (Musa spp.) sous différents systèmes de culture à Yangambi, Haut-Zaïre. Tropicultura 11:7-10.

Ndungo V, Eden-Green S, Blomme G, Crozier J, Smith J (2006). Presence of banana xanthomonas wilt (*Xanthomonas campestris* pv. musacearum) in the Democratic Republic of Congo (DRC). Plant Pathol. 55:294. http://dx.doi.org/10.1111/j.1365-3059.2005.01258.x

Niyongere C, Ateka E, Losenge T, Blomme G, Lepoint P (2011). Screening Musa genotypes for banana bunchy top disease resistance in Burundi. Acta Hortic. (ISHS) 897:439-447.

Niyongere C, Losenge T, Ateka EM, Nkezabahizi D, Blomme G, Lepoint P (2012). Occurrence and distribution of banana bunchy top disease in the Great Lakes region of Africa. Tree For. Sci. Biotechnol. 6(1):102-107.

Niyongere C, Losenge T, Ateka EM, Ntukamazina N, Ndayiragije P, Simbare A, Cimpaye P, Nintije P, Lepoint P, Blomme G (2013). Understanding banana bunchy top disease (BBTD) epidemiology in Burundi for an enhanced and integrated management approach. Plant Pathol. 62(3):562-570. http://dx.doi.org/10.1111/j.1365-3059.2012.02676.x

R Development Core Team (2010). R: A Language and Environment for Statistical Computing. Reference Index, Version 2.11.1 (2010-05-31). R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.lsw.uni-heidelberg.de/users/christlieb/teaching/UKStaSS10/R-refman.pdf (accessed 23 November 2013). Information also at: http://www.R-project.org/ (accessed 23 November, 2013)

Robson JD, Wright MG, Almeida RPP (2007). Biology of Pentalonia nigronervosa (Hemiptera, Aphididae) on banana using different rearing methods. Environ. Entomol. 36(1):46:52.

Saverio B (1964). Banana cultivation in Eritrea and its problems. Edizioni Agricole, P. 56.

Sebasigari K, Stover RH (1988). Banana diseases and pests in East Africa: report of a survey made in November 1987. Montpellier, France: International Network for the Improvement of Banana and Plantain.

Walangululu MJ, Matara MR, Bahati L, Niyongere C, Lepoint P, Blomme G (2010). Assessing the spread and seasonal influence of fruit peel disease and banana bunchy top disease in South Kivu, eastern DR Congo. Tree For. Sci. Biotechnol. 4(2):98-104.

Wardlaw CW (1961). The virus diseases: bunchy top. In: Banana Diseases, including Plantains and Abaca. London, UK: Longman, Green pp. 68-115.

Wu R-Y, Su H-J (1990). Transmission of banana bunchy top virus by aphids to banana plantlets from tissue culture. Bot. Bull. Acad. Sin. 31:7-10.

Yasmin T, Khalid S, Soomro MH, Malik SA, Shah H, Ahmad I (2001). Specificity of host-pathogen interaction of banana bunchy top disease. Asian Network for Scientific Information. J. Biol. Sci. 1(4):212-213. http://dx.doi.org/10.3923/jbs.2001.212.213