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Levels of host plant resistance to banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), in Ugandan *Musa* germplasm

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Summary

Forty-five *Musa* clones, including endemic and introduced cultivars plus hybrids, were evaluated for resistance against the banana weevil, *Cosmopolites sordidus*, in a field trial in Uganda. The predominant groups of staple crops, East African highland bananas (*Musa* spp. AAA) and plantains (*Musa* spp. AAB), as well as plantain-derived hybrids (AAB × AA), showed the highest levels of susceptibility to this pest. These were followed by dessert bananas (*Musa* spp. AAA), exotic bananas (*Musa* spp. ABB) and finally diploids of *M. acuminata* (AA). Hybrids of banana origin were highly resistant. Some East African highland cultivars, especially brewing types (e.g., Kabula, Bagandeseza, Ediirira), showed intermediate levels of resistance. Among the non-highland bananas, high levels of resistance were observed in Yangambi-Km5 (AAA), Cavendish (AAA), Gros Michel (AAA), Kayinja (ABB, Pisang Awak subgroup), Ndiizi (AB, Ney Poovan subgroup) and Kisubi (Ney Poovan subgroup). The highest resistance was observed in banana hybrids TMB2×7197-2, TMB2×8075-7 and the wild banana Calcutta-4 (AA). These were considered the best sources of resistance for a weevil resistance-breeding programme with the two hybrids commonly used as improved male parents.

Introduction

The banana weevil *Cosmopolites sordidus* (Germar) is the most destructive insect pest of *Musa* in Africa where banana and plantain are produced as subsistence staples. The East African highland banana (EAHB) (*Musa* sp., AAA, 'Mutika Lujugira' subgroup) is the primary food crop in the East African Great Lakes region, while plantain (*Musa* spp. AAB) is an important staple in much of West and Central Africa. Both groups are widely considered susceptible to the banana weevil (Kiggundu et al., 1999; Gold et al., 2002). In East Africa, the weevil is a serious production constraint and a principal factor contributing to the decline and disappearance of highland banana in central Uganda and western Tanzania (Gold et al., 1999; Mbwana & Rukazambuga, 1999).

The female weevil lays its eggs in the corm and pseudostem base of the banana plant. The emerging larvae bore through the corm. The resulting larval damage impedes water and nutrient uptake and reduces the stability of the plant. Weevil attack can interfere with crop establishment, reduce bunch size, and lead to plant loss, mat die-out and shortened plantation life (Rukazambuga et al., 1998; Gold et al., 1999, 2002).

Integrated pest management for banana weevil has been reviewed by Gold et al. (2002). Currently, there are few cost-effective control methods available for resource-poor African banana and plantain growers. Host plant resistance to banana weevil offers the potential to provide long-term and sustainable crop protection to subsistence farmers at little cost. In Uganda, *Musa* production includes a highly diversified local germplasm, containing mainly the EAHB. About 80 distinct, locally evolved (endemic) cultivars, including cooking ('matooke') and brewing ('mbiire') types, have been identified by morphological characterisation (Karamura, 1998). It is believed that the real genetic diversity of this group, which is yet to be investigated by molecular techniques, is much smaller.

In addition to the EAHB cultivars, Ugandan banana growers use a wide range of other genotypes including dessert (*Musa* spp. AB, AAA), cooking (*Musa* spp. ABB), roasting (= plantain) (AAB) and brewing (*Musa* spp. AB, ABB) types (Gold et al., 2002). Moreover, in the last five years hybrids from two breeding programmes (The International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria and the Fundación Hondureña de Investigación Agrícola (FHIA) in Honduras), targeting black Sigatoka disease, have been introduced into Uganda for evaluation on-station and in selected farmers' fields.

In recent years, there has been increased interest in the development of host plant resistance to banana weevil (INIBAP, 2001). However, very little work has been done on screening for banana weevil resistance. Available reports (reviewed by Pavis & Lemaire, 1997; Kiggundu et al., 1999; Gold et al., 2002) were inconclusive defining resistant clones. Much of the information on weevil damage levels on different cultivars had been collected in surveys (e.g. Gold et al., 1994) and therefore, confounded by site differences. Fogain & Price (1994), Ortiz et al. (1995b), Rajamony et al. (1993, 1994, 1995) and Anitha et al. (1996) conducted screening trials to identify existing clones displaying resistance to weevil. Most other studies on host plant response to banana weevil employed few clones, producing highly variable and often contradictory findings (Kiggundu et al., 1999). Limited information on susceptibility of highland banana clones.

The objectives of this study were (1) to screen a representative sample of the endemic EAHB cultivars and a series of *Musa* accessions that have been introduced into East Africa for response to banana weevil; (2) to identify important sources of resistance for use in breeding for resistance to banana weevil.

Materials and methods

Site description

A field screening trial was established in November 1996 at the International Institute of Tropical Agriculture Sendusu Farm (00.53 °N, 32.58 °E, 1260 masl, 12 hours day length throughout the year), situated in Namulonge, 25 km NE of Kampala. The site has two rainy seasons (March-June and September-December) and a mean annual rainfall of 1200 mm (Yost & Eswaran, 1990). Average daily temperatures are 17.5 °C minimum and 27 °C maximum. Soils are dark reddish-brown loams with pH ranging from 5.4–6.4. The experimental plot had been in grass fallow for 2 years and was more than 100 m from the nearest banana stand. Whereas the banana weevil has limited dispersal capability (Gold et al., 2002), a naturally occurring infestation was expected to be low.

Experimental design

Forty-five cultivars, including representatives of all five EAHB clonal groups (Karamura, 1998), plantains (AAB), exotic ABB cooking (Bluggoe) and brewing (Kayinja (Pisang awak subgroup)) cultivars, dessert banana cultivars (AAA), diploids (AA and AB) and selected hybrids were screened for resistance to banana weevil (Table 1). The clones selected for this study were highly diverse in both genomic origin and end uses. Planting material was collected from the Uganda National Banana Research Programme (NBRP) germplasm collection at the Kawanda Agricultural Research Institute, farmers' fields in surrounding villages, and IITA's germplasm collection at Sendusu Farm. Tested hybrids included plantain-derived selections and banana-derived selections from IITA's breeding programme (See Table 1 for parentage and ploidy), and FHIA-03 which had been previously imported from the FHIA breeding program in San Pedro Sula, Honduras.

The experimental field was 146 × 33 m. The 45 treatments (clones) were arranged in a randomised complete block design (5 rows of 9 plants) with 12 replicates (1 plant/clone/block). Borderlines of the known susceptible EAHB cultivar Atwalira (Gold et al., 1994; Rukazambuga et al., 1998) was planted around the field and between blocks in order to increase and more evenly distribute weevil infestation levels. Plant spacing was 2 × 3 m.

Planting was in November 1996. Sword suckers were used for planting material. Before planting, suckers were pared (i.e., all roots and outer cortical tissue were removed) and then immersed for 20 minutes in hot water baths (55–60 °C) to eliminate most weevil eggs and larvae and to reduce nematode infection (Gold et al., 1998). Planting holes were 60 cm wide and 60 cm deep. At planting, 250 g of single super phosphate (SSP) fertiliser was mixed with topsoil

Table 1. Information on *Musa* accessions used in screening study for resistance to banana weevil at IITA Sendusu Farm, Namulonge, Uganda

Cultivar	Genome group or parents[1]	Sub-group	Local use
Atwalira	AAA	EAHB-Matooke	Cooking
Bagandeseza	AAA	EAHB-Matooke	Cooking
Bluggoe	ABB	Bluggoe	Cooking
Bogoya	AAA	Gros Michel	Dessert
Bukumu	AAA	EAHB-Matooke	Cooking
Cavendish	AAA	Cavendish	Dessert
Calcutta-4	AA	Wild banana	None
Endiirira	AAA	EAHB-Matooke	Brewing
Enshenyi	AAA	EAHB-Matooke	Cooking
FHIA03	AABB	Banana hybrid	Brewing and dessert
Gonja	AAB	Plantain	Roasting and cooking
Kabula	AAA	EAHB-Mbiire	Brewing
Kayinja	ABB	Pisang awak	Brewing and juice
Kibuzi	AAA	EAHB-Matooke	Cooking
Kisansa	AAA	EAHB-Matooke	Cooking
Kisubi	AB	Nay Poovan	Brewing and juice
Mbwazirume	AAA	EAHB-Matooke	Cooking
Musakala	AAA	EAHB-Matooke	Cooking
Mutangendo	AAA	EAHB-Matooke	Cooking
Nakabululu	AAA	EAHB-Matooke	Cooking
Nakamali	AAA	EAHB-Matooke	Cooking
Nakawere	AAA	EAHB-Matooke	Cooking
Nakitembe	AAA	EAHB-Matooke	Cooking
Nakyetenbe	AAA	EAHB-Matooke	Cooking
Nalukira	AAA	EAHB-Mbiire	Brewing
Namafura	AAA	EAHB-Matooke	Cooking
Naminwe	AAA	EAHB-Matooke	Cooking
Namwezi	AAA	EAHB-Matooke	Cooking
Nandigobe	AAA	EAHB-Matooke	Cooking
Ndibwabalangira	AAA	EAHB-Matooke	Cooking
Ndiizi	AB	Ney Poovan	Dessert
Nsowe	AAA	EAHB-Mbiire	Brewing
Obino l'Ewai	AAB	Plantain	Roasting and cooking
Shombobuku	AAA	EAHB-Mbiire	Brewing
Siira	AAA	EAHB-Matooke	Cooking
Tereza	AAA	EAHB-Matooke	Cooking
TMB2×6142-1	Nyamwihongora × Long Tavoy	EAHB-Hybrid (2X)	–
TMB2×7197-2	SH 3362 × Long Tavoy	Banana hybrid (2X)	–
TMB2×8075-7	SH 3362 × Calcutta-4	Banana hybrid (2X)	–
TMB×612-74	Bluggoe × Calcutta-4	Banana hybrid (4X)	–
TMP×15108-6	TMP× 4479-1 × SH 3362	Plantain hybrid (3X)	–
TMP×5511-2	Obino l'Ewai × Calcutta 4	Plantain hybrid (4X)	–
TMP×7002-1	Obino l'Ewai × Calcutta 4	Plantain hybrid (4X)	–
TMP×7152-2	Mbi Egome 1 × Calcutta 4	Plantain hybrid (4X)	–
Yangambi-Km5	AAA		Dessert

[1]Parents of hybrids are female × male.

placed in the planting hole and the sucker was placed inside the hole and covered with additional topsoil.

Gap filling (replanting where plants failed to establish) was in January and April 1997. The bananas were periodically de-suckered to maintain plant density at 3 per mat. A grass mulch was maintained throughout the trial. Deleafing (removal of old leaves) and manual weeding were undertaken as necessary.

Weevil infestation

To supplement the low level of natural weevil infestation of the experimental field, 5 female and 5 male adult banana weevils (collected in farmers' fields) were released at the base of each mat (including borderlines) in July 1997 and December 1997. Releases were made between 1800 and 2000 hours.

Weevil damage assessment

Banana weevil damage was assessed on recently harvested, toppled, snapped or dead plants using destructive sampling techniques. Thus, weevil damage was scored only once for each plant. Fruits were harvested when the first finger ripened. The clones employed in this trial displayed different maturation rates. Data were collected from the time of first harvest (October 1997) through February 2000. At the time the trial was terminated, the plantains had completed three cycles, while all other clones had passed through at least four cycles.

Weevil damage was estimated using the percentage coefficient of infestation (PCI) scoring method of Mitchell (1978) and the peripheral damage and cross-section methods of Gold et al. (1994). Damage assessment was conducted twice a week. As such, evaluations precluded scoring any post-harvest weevil attack that might occur on crop residues (c.f. Gold et al., 1997). Corms were uprooted to facilitate scoring.

The PCI was determined by paring the upper 10 cm of the outer half of the corm (i.e., distal to the follower of the next crop cycle) to expose the weevil tunnels. This area was then divided into a grid of ten 18° sectors, using a metal template. Each sector was divided in half, i.e., 0 to 5 cm from collar (rhizome/pseudostem junction) and 5 to 10 cm below the collar. Presence or absence of weevil damage was recorded for both upper sections (PCI-U) and lower sections (PCI-L). Peripheral damage (PD) was determined by estimating the percentage of surface area consumed by weevil larvae in the same area being used for PCI determinations.

Table 2. Banana weevil damage parameters, total cross-section damage (XT) and percentage coefficient of infestation (PCI), for the plant crop and three ratoon cycles in a screening trial at IITA Sendusu Farm, Namulonge, Uganda

Cycle	XT		PCI	
Plant crop	5.1	a	7.2	a
1	5.4	ab	6.8	b
2	6.5	c	6.2	c
3	5.6	ab	4.9	d
LSD at 0.05	*1.27*		*0.47*	

Means followed by same letters within columns indicate not significantly different ($p > 0.05$) by LSD.

Two cross-sections were made through the corm at 5 and 10 cm below the collar (upper and lower positions, respectively). For each cross section, weevil damage was assessed independently for the central cylinder and the cortex by estimating the percentage of corm tissue consumed by weevil larvae in each area. The mean of the four scores was calculated to generate a total cross-section damage estimate (XT).

Data analysis

Pearson correlation coefficients were carried out on all damage parameters to determine linear relationships among them. Principal component analysis (PCA) determined that XT and PCI were the most important damage parameters. These were selected for comparison of clones, genome groups and crop cycles. XT and PCI were used as response variables in the analysis of variance in the PROC GLM procedure in Statistical Analysis System (SAS) software (SAS Institute, 1991). Data for the plant crop and three ratoon cycles were used in the analyses, although no data were available for the third ratoon cycle for the plantains. Means for cycle and genome comparisons were separated using the least significant difference (LSD) test.

Principal component analysis helped to reduce and summarise variables into two meaningful dimensions that can help to visualise the data graphically. PCA was performed on five damage variables PCI, XT, PD, PCI-U and PCI-L. These were selected through an iterative process to determine which combination provided the best and most meaningful principal components (i.e., with at least two principal components taking care of more than 90% of the total variation)

Table 3. Banana weevil cross section damage (XT) and percentage coefficient of infestation (PCI) for *Musa* genome groups over four crop cycles in a screening trial at IITA Sendusu Farm, Namulonge, Uganda

Genome	XT*	PCI
AAA-EA (East African highland bananas)	8.0 (24.5±0.29a)	8.8 ±0.08a
AAB (Plantains)	6.0 (21.3±1.12b)	7.2±0.32b
Plantain derived hybrids	5.5 (19.3±0.70b)	6.2±0.20cd
AABB (FHIA03)	3.3 (16.5 ±1.52c)	6.3±0.43c
ABB	2.6 (14.6±1.13c)	5.3±0.32d
AB	1.5 (11.2±1.13d)	3.2±0.32e
AAA (Cavendish, Gross Michel, Yangambi km5)	1.0 (9.7±0.79de)	2.3±0.22f
Banana derived hybrids	1.0 (8.9±0.62de)	1.5±0.17g
AA (Calcutta-4)	0.7 (8.4±1.12e)	0.8±0.32g
CV (%)	43.9	37.1

* Data in brackets was derived from arcsine transformation using the following formulae: XT* = 100* arcsin((sqrt (xt+0.5)) /100*22/28).
Means followed by same letters within columns indicate not significantly different ($p > 0.05$) by LSD.

and, therefore, a graphical spread representing resistance response. The first and second principal component (PC1 and PC2) axis values were plotted to enhance dispersion of the host response to banana weevil damage of the *Musa* accessions.

Cluster analysis was also employed, using the FASTCLUS procedure in SAS software, to allow grouping of damage variables and partitioning of cultivars into susceptible, intermediate and resistant groups. This analysis also reduced redundancy in data, due to the highly correlated damage variables. This procedure, which is non-hierarchical, produces a pre-set number of clusters (in this case three) with the highest possible distinction, while minimising the variance within each cluster. It uses repeated analysis of variance and iteration (Aldenderfer & Blasfield, 1984; Smith, 1990).

Results

For the four crop cycles studied, weevil damage ranged from 5.1 to 6.5% for XT and 4.9 to 7.2% for PCI at the field level (Table 2). While XT remained stable across cycles, PCI displayed a gradual decline over time from its initial levels in the plant crop.

The EAHB displayed the highest levels of banana weevil damage (Table 3), suggesting that this group contains many susceptible clones. The plantains also had high levels of damage. The EAHB had more surface damage (PCI) than plantains, while the two groups had similar levels of internal damage (XT). The diploids (AB, AA) and AAA dessert bananas all appeared relatively resistant. The mean internal damage levels (XT) for the plantain derived hybrids were similar to those of their plantain female parents while banana derived hybrids were as resistant as their wild male parent, Calcutta-4.

During the course of the trial, internal damage increased for the most susceptible clonal groups (i.e., EAHB, plantain, plantain-derived hybrids and FHIA03). In contrast, for other banana genome groups, internal damage either decreased over time (AAA, AB, ABB bananas) or showed no change (AA, banana-derived hybrids). PCI for the EAHB and AA diploids remained constant across over time, while that of FHIA03 seemed to increase after the second ratoon. Surface damage to all other groups decreased across crop cycles. Plantains showed a rather peculiar response with high weevil damage in the plant crop, much lower damage in the first ratoon and then increased damage in the second ratoon. The observed decrease in surface damage may have been due to increasing death of susceptible plants thus bringing down the overall mean.

There were significant differences among the cultivars studied in their response to banana weevil damage (Table 4). Total cross section damage, compiled across four crop cycles, ranged from 0.2 for the diploid banana hybrids TMB2×7197-2 and TMB2×8075-7 to 10.7 for the plantain hybrid TMP×5511-2. Yangambi-Km5 (AAA), Calcutta 4 (AA), Cavendish (AAA), Gros Michel (AAA), Kisubi (Ney Poovan subgroup)

Table 4. Mean (± SE) values of two banana weevil damage indices, total cross-section damage (XT) and percentage coefficient of infestation (PCI) across four crop cycles in a *Musa* screening trial, IITA Sendusu Farm, Namulonge, Uganda

Name	Genome group	XT*	PCI
TMP×5511-2	Plantain hybrid	10.7(27.8±1.4 a)	7.8±0.4 e-h
Atwalira	AAA-EA	10.3(27.9±1.4 a)	8.9±0.4 a-d
Nakawere	AAA-EA	10.2(27.6±1.4 ab)	9.5±0.4 a
Kibuzi	AAA-EA	10.1(27.9±1.7 a)	9.0±0.4 a-d
Nakabululu	AAA-EA	9.5(27.3±1.3 abc)	9.3±0.3 a-c
Musakala	AAA-EA	9.4(27.7±1.9 ab)	9.3±0.4 ab
Namwezi	AAA-EA	9.4(26.1±1.4 a-d)	9.2±0.4 a-c
Siira	AAA-EA	9.2(26.8±1.4 a-d)	9.5±0.4 a
Mbwazirume	AAA-EA	8.8(26.4±1.3 a-d)	9.6±0.3 a
Nandigobe	AAA-EA	8.8(25.5±1.3 a-d)	9.3±0.4 a-c
Mutangendo	AAA-EA	8.8(26.0±1.5 a-d)	8.9±0.4 a-e
Bukumu	AAA-EA	8.7(25.8±1.3 a-d)	9.2±0.3 a-c
Nakyetengu	AAA-EA	8.5(24.9±1.6 a-f)	8.9±0.4 a-d
Ndiibwabalangira	AAA-EA	8.6(25.3±1.5 a-e)	8.4±0.4 b-g
Namafura	AAA-EA	8.3(24.8±1.4 a-g)	9.0±0.4 a-d
Naminwe	AAA-EA	8.1(25.1±1.3 a-f)	9.2±0.4 a-c
Shombobureku	AAA-EA	7.4(23.9±1.3 b-h)	8.7±0.3 a-f
Gonja	AAB	7.4(23.3±1.6 d-i)	7.6±0.4 g-i
Nakitembe	AAA-EA	7.4(24.1±1.2 a-f)	9.2±0.3 a-c
Nakamali	AAA-EA	7.2(23.3±1.3 d-i)	9.2±0.3 a-c
Kisansa	AAA-EA	7.1(23.4±1.5 c-i)	8.6±0.4 a-g
Nsowe	AAA-EA	7.1(23.5±1.6 c-i)	8.1±0.4 d-h
Enshenyi	AAA-EA	7.1(23.6±1.4 c-i)	9.1±0.4 a-d
Tereza	AAA-EA	6.8(22.9±1.4 d-i)	9.0±0.4 a-d
Nalukira	AAA-EA	6.4(21.7±1.6 g-j)	8.1±0.4 d-h
TMP×7002-1	Plantain hybrid	6.3(21.2±1.3 h-j)	7.3±0.3 h-j
Endiirira	AAA-EA	6.1(21.7±2.0 e-j)	8.6±0.5 a-g
Obino l'Ewai	AAB	5.7(20.9±1.5 h-j)	6.8±0.4 ji
TMP×7152-2	Plantain hybrid	5.1(19.6±1.4 i-k)	7.2±0.4 h-i
Bagandeseza	AAA-EA	5.0(20.0±1.5 h-k)	8.3±0.4 c-h
Kabula	AAA-EA	4.2(18.5±1.5 j-k)	7.8±0.4 f-i
FHIA03	Banana hybrid	3.3(16.5±1.4 k-m)	6.3±0.4 jk
Bluggoe	ABB	3.0(15.5±1.3 l-n)	5.7±0.3 kl
TMBx612-74	Banana hybrid	3.0(14.3±1.3 m-o)	4.3±0.3 mn
Ndiizi	AB	1.6(11.7±1.2 n-p)	3.5±0.3 on
Kayinja	ABB	1.7(12.9±1.6 m-o)	4.7±0.4 lm
Kisubi	AB	1.5(10.9±1.6 o-q)	2.4±0.4 p
TMP×15108-6	Plantain hybrid	1.4(11.2±1.2 o-q)	2.9±0.3 op
Bogoya	AAA	1.5(11.6±1.5op)	3.8±0.4 m-o
Cavendish	AAA	1.2(11.1±1.5 o-q)	3.7±0.4 m-o
TMB2×6142-1	Banana hybrid	0.8(8.3±1.2 pq)	0.9±0.3 q
Calcutta-4	AA	0.6(8.4±1.1 pq)	0.8±0.3 q
Yangambi-Km5	AAA	0.4(8.0±1.1 pq)	0.9±0.3 q
TMB2×8075-7	Banana hybrid	0.2(7.3±1.0 q)	0.6±0.3 q
TMB2×7197-2	Banana hybrid	0.2(7.3±1.2 q)	0.9±0.8 q
CV (%)		41.5	32.8

* Data in brackets was derived from arcsine transformation using the following formulae: XT* = 100* arcsin((sqrt (xt+0.5)) /100*22/28).
Means followed by same letters within columns indicate not significantly different ($p > 0.05$) by Lsd.

Table 5a. Correlation coefficient between five banana weevil damage indices for data collected during a Musa screening trial, IITA Sendusu Farm, Namulonge, Uganda

Damage index	1	2	3	4	5
1. PD		0.945	0.955	0.957	0.922
2. PCI (Upper)			0.996	0.982	0.853
3. PCI (Total)				0.995	0.853
4. PCI (Lower)					0.845
5. XT					

All coefficients are significant at $p < 0.05$).

Table 5b. Eigen vectors of principal component analysis using five-weevil damage indices

Damage index	PC 1	PC 2
1. PD	**–0.65**	0.43
2. PCI (Upper)	–0.29	–0.29
3. PCI (Total)	–0.57	–0.53
4. PCI (lower)	–0.27	–0.24
5. XT	–0.28	**0.62**
Percentage of total variation:	***96.1%***	*2.9%*
Eigen Value:	***78.35***	*2.34*

PD: Peripheral damage to corm.
PCI: Percentage coefficient of infestation.
XT: Cross section damage.

(AB), Kayinja (Pisang awak subgroup) (ABB), Ndiizi (Ney Poovan subgroup) (AB), three banana-derived hybrids and one plantain-derived hybrid had damage scores less than 2.0 and appeared resistant. Two EAHB had damage scores between 4 and 5, while all other EAHB had damage scores exceeding 6.0 and three cultivars (Atwalira, Nakawere and Kibuzi) had damage scores > 10. The two plantains had damage scores of 5.7 and 7.4, respectively, while plantain-derived hybrids ranged in damage from 1.4 to 10.7.

PCI scores ranged from 0.6 for the hybrid TMB2×8075-7 to 9.6 for the EAHB cultivar Mbwazirume. Calcutta 4, Yangambi-Km5, Kisubi, Cavendish, Gros Michel, Ndiizi, three banana-derived hybrids and one plantain-derived hybrid had PCI scores less than 4.0. All EAHB had PCIs over 7.8 and many had scores over 9.

All cultivars showing low weevil damage levels were recent introductions into the region and grown for end uses other than cooking (see Table 1). The IITA hybrids TMB2×7197-2, TMB2×8075-7, Yangambi-Km 5 and the wild banana Calcutta-4 appeared to be the most resistant, displaying very low damage for both damage parameters.

Principle component analysis

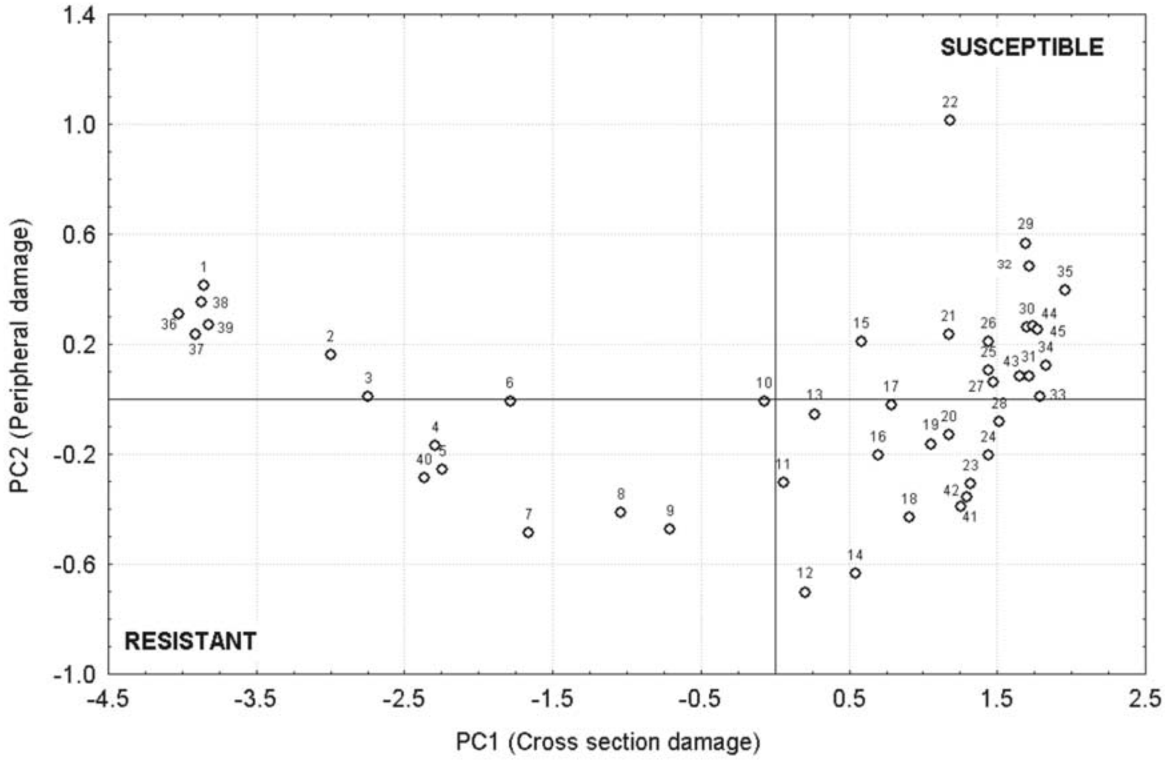
Two major variables were used, one measuring inner damage and the other peripheral damage. Of note is that some cultivars were high in one aspect and low in the other. For example, the EAHB cultivars Kabula, Endirira and Nsowe showed high PCI scores, but relatively low XT values.

The correlation matrix between damage observations revealed highly significant coefficients (Table 5a). PCA reduced the damage observations to two major components that together accounted for 99% of the original variation. The first and most important component, principle component one (PC1) accounted for 96.1% of the total variability in the original data. PD and PCI-total were the most important variables contributing to this component (eigen vectors –0.65 and –0.57, respectively) (Table 5b). Therefore, PC1 was taken as a new measure for peripheral damage. It was then plotted with principle component two (PC2) which had a high positive correlation (0.62) with XT, and contributed 2.9% of the total variation. The plot of PC1 against PC2 (Figure 1) revealed that TMP×5511-2 was the most susceptible cultivar followed by the range of cultivars in the top-right quarter of Figure 2. Most of the EAHBs, however, were intermediate, showing higher peripheral damage than inner damage (bottom left corner of Figure 1), further confirming the results from the cluster analysis.

Kabula (a brewing type) was the most resistant EAHB positioned in the bottom left quarter of Figure 2. Overall TMB2×6142-1, TMB2×8075-7 TMB2×7197-2, Yangambi-Km5 and Calcutta-4, displayed the greatest resistance. Kisubi, Cavendish, Kayinja and Ndiizi were the only cultivars showing high resistance in terms of less peripheral and less inner damage.

Cluster analyses

A non-hierarchical clustering method was used to cluster all the cultivars into three response groups, i.e., resistant, intermediate and susceptible for composite response across the four cycles (Table 6). Most of the EAHB tested were grouped in the susceptible range while the plantains (Obino l'Ewai and Gonja) were intermediate in their response to weevil attack. Apart from Kisansa, Tereza and Nakamali all the other EAHB in the intermediate range were brewing types.



Key		
1. TMB2X6142-6	16. Nalukira	31.Bukumu
2. Kisubi	17. Nsowe	32. Kibuzi
3. TMPX1508-6	18. Endiira	33. Mbwazirume
4. Ndiizi	19. Kisansa	34. Siira
5. Bogoya	20. Shombobu	35. Nakawere
6. TMBX612-74	21. Ndiibwabalagira	36. TMB2X8075-7
7. Kayinja	22. TMPX5511-2	37. TMB2X7197-2
8. Blugoe	23. Ensenyi	38. Km5
9. FHIA03	24. Nakitembe	39. Calcutta-4
10. Obino l'ewai	25. Nakyetengu	40. Cavendish
11. TMPX7152	26. Mutangendo	41. Tereza
12. Kabula	27. Namafura	42. Nakamali
13. TMPX7002-1	28. Naminwe	43. Nandigobe
14. Bagandeseza	29. Atwalira	44. Musakala
15. Gonja	30. Namwezi	45. Nakabululu

Figure 1. Plot of first (PC1) and second (PC2) principle components from a principal component analysis of five banana weevil damage variables of selected *Musa* germplasm in screening trial at IITA Sendusu Farm, Namulonge Uganda.

Table 6. Response groups derived from cluster analysis using estimates of banana weevil cross section damage and percentage coefficient of infestation across four crop cycles in *Musa* screening trial at IITA Sendusu Farm, Namulonge, Uganda

Resistant	Intermediate	Susceptible
TMB×612-74	Obino L'ewai	Nandigobe*
TMB2×6142-1	TMP×7002-1	Mutangendo*
Ndiizi	Gonja	Atwalira*
Bluggoe	Enshenyi*	Naminwe*
Bogoya	Kabula**	Nakabululu*
Kisubi	Kisansa*	Kibuzi*
Cavendish	Nakamali*	Mbwazirume*
Kayinja	Nalukira**	TMP×5511-2
Yangambi-Km5	Nsowe**	Namafura*
Calcutta	Shombobureku**	Bukumu*
TMP×15108-6	Tereza*	Siira*
TMB2×7197-2	Bagandeseza**	Musakala*
TMB2×8075-7	Endiirira**	Ndiibwabalangira*
	FHIA03	Namwezi*
	TMP×7152-2	Nakawere*
		Nakitembe*
		Nakyetengu*

* EAHB cooking type.
** EAHB brewing types

Discussion

The banana weevil has been considered to be one of the most important production constraints on highland cooking banana in East Africa (Rukazambuga et al., 1998; Gold et al., 1999). Although host plant resistance is an important component of an integrated pest management strategy for the control of banana weevil (INIBAP, 2001; Gold et al., 2002), little information has been available on levels of resistance already present within the highland banana group.

Elsewhere, the pest status of the banana weevil (reviewed by Gold et al., 2002) has been controversial. Plantains in Africa and Latin America have generally been considered highly susceptible to the weevil (Mesquita et al., 1984, Fogain & Price, 1994; Ortiz et al., 1995b). However, reports on AAA dessert bananas have ranged from resistant to susceptible. For example, on the large commercial Cavendish plantations in Central America and the Caribbean, the weevil has been considered a minor or insignificant constraint (Ostmark, 1974; Anonymous, 1989; Sponagel et al., 1995), while Viljoen (pers. comm.) reports that the weevil has become a serious pest in commercial Cavendish stands in South Africa.

This study has revealed a wide range of host plant responses to banana weevil, between genome groups and among cultivars within groups. The results confirm the susceptibility of both EAHB and plantains. Moreover, three of the four tested hybrids of plantain origin also showed high levels of banana weevil susceptibility. Ortiz et al. (1995b) found significant dosage effect of the susceptibility gene in plantain and this may be the reason why these plantain hybrids, all of which are tetraploid, are highly susceptible.

EAHB displayed the highest levels of both internal and external weevil damage. Although plantains have been widely reported to be the most susceptible *Musa* genome group (Gold et al., 2002), many EAHB clones supported greater levels of damage than the plantains employed in this study. All EAHB clones were considered either highly or moderately susceptible. Yet, considerable variation in susceptibility was found with the group with internal damage levels ranging from 4.2 to 10.6%. (External damage was more uniform EAHB among clones, ranging from 7.8 to 9.5). ABB (Bluggoe. Kayinja), and AB bananas (Kisubi, Ndiizi) showed limited damage and appeared relatively resistant. The AAA dessert bananas (Cavendish, Gross Michel, Yangambi-Km5) and the single wild type AA banana (Calcutta 4) showed high levels of resistance to the weevil.

The EAHB brewing cultivars (i.e. Kabula, Bagandeseza, Endiirira, Nalukira and Nsowe) all appeared among the most resistant clones within the group. This confirms observations of many farmers throughout Uganda. These farmers often reported that these cultivars produced greater quantities of and more bitter sap than cooking bananas (A. Kiggundu & D. Karamura, unpublished data). It is possible that these traits contribute to reduced weevil damage in these clones. Among the EAHB cooking clones, Kisansa and Tereza appeared to be the most resistant.

Kisansa has been selected by the NBRP as an important high yielding cultivar for recommendation to farmers in Uganda, while Tereza, having very good seed set qualities (R. Ssebuliba *unpublished data*), is an important highland banana female parent in current conventional banana breeding programs. Kisansa, and Tereza can be recommended by the National Banana programme as cultivars moderately resistant to weevil, although Tereza does not produce a very large bunch.

Moderate levels of resistance among cultivated genotypes can be exploited in an IPM strategy to control the banana weevil. The use of resistant cultivars in IPM acts by reducing the rates of a pest population build up and this could be effectively achieved with moderate levels of host resistance, especially if it is antibiotic in nature (de Ponti, 1982; Pathak, 1991).

Unfortunately, most resistant cultivars were introduced (exotic) and are not used as food in Uganda. Nevertheless, they might be included in crossing programmes to transfer resistance to cultivars that are more acceptable to Ugandan producers and consumers.

The wild diploid banana Calcutta-4, three diploid banana hybrids (TMB2×6142-1, TMB2×8075-7 and TMB2×7197-2), and cultivars Yangambi-Km5 and Cavendish showed very high levels of resistance to banana weevil and may be exploited as sources of resistance genes, while the EAHB Tereza can continue to be utilized in conventional crossing to maintain resistance in the derived hybrids. Currently, hybrids derived from Tereza × Calcutta-4 crosses are being tested and evaluated by the NBRP for use as improved male parents for future breeding. Calcutta-4 is also highly resistant to leaf spot decreases and has been successfully used in conventional breeding in Nigeria and Uganda (Ortiz et al. 1995a, Vuylsteke et al. 1997) and is, therefore, a good source of multiple resistance genes for banana improvement.

Yangambi-Km5 has also been reported as resistant to banana weevil by Fogain and Price (1994) and Lemaire, (1996). Yangambi-Km 5 is female fertile and could be used in breeding for banana weevil resistance through conventional crossing (M. Pillay, pers comm.). The fertility of other resistant clones and hybrids needs to be investigated before their role in a breeding program might be determined.

For all the several analyses performed, total cross section damage (XT) was used as the most important criteria for selecting resistance and for ranking cultivars. This is because it measured the extent to which weevil larvae could penetrate deep into the corm. Damage that occurs deep inside the corm is believed to translate more directly into yield loss and survival of the plant than damage occurring on the corm periphery (Gold et al., 1994; Rukazambuga et al., 1998). The percentage coefficient of infestation (PCI) assesses surface damage, which although not as important as internal attack, may have a negative effect on the root system and plant stability. However, the PCI showed instability from cycle to cycle and may not be a good parameter for quantifying banana weevil damage and host plant resistance levels in *Musa*.

There appears to be useful levels of banana weevil resistance genes in the *Musa* germplasm available. However, the extent of usability of these genes for a successful improvement programme is not clear. Their mechanisms of resistance and inheritance or genetic control are only faintly understood and these need to be elucidated further before they can meaningfully be used.

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