Comparative Morphophysiological and Yield Characteristics of *Musa* Genomes in Nigeria

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Abstract

Thirty-six *Musa* genotypes comprising tetraploid hybrids and triploid land-races belonging to AAA, AAB and ABB *Musa* genomes were evaluated in three agro-ecologies following a South-North rainfall and vegetation gradients in Nigeria. Plants were grown as sole crop at Onne (High rainforest zone), Ibadan (Forest-Savanna transition zone) and Abuja (Southern guinea savanna zone) plus an additional experiment grown in alley cropping system at Onne. Phenological and yield traits were measured for two crop cycles. The results revealed that crop cycle did not significantly influenced height of the tallest sucker at harvest of the plant crop, black sigatoka disease response and the fruit weight. All phenological and yield traits were significantly ($P < 0.05$) influenced by the environment of evaluation. Similarly, genotype, genome groups and their ploidy levels significantly affected all traits measured. First order interactions involving genome/ploidy levels, crop cycle and environment were significant ($P < 0.05$) for most traits. Triploid AAB had the longest duration for completing two crop cycles in most of the locations except at Ibadan where AAA had the longest duration. Yield was highest in Abuja for all genomes and ploidy levels whereas sole crop at Onne supported the poorest crop yield. Tetraploid hybrid AAA x AA yielded highest at Abuja and in alley cropping at Onne. The ABB land-races were the most productive under the Forest-Savanna transition zone of Ibadan, and were more adapted to the three ecological zones. Plantain hybrids demonstrated higher adaptation to alley cropping environment of the high rainfall zone where they were originally selected. However, plantain land-race had stable low yields across the locations. The resource base of each environment dictated genotypes performance and consequently genome/ploidy adaptation patterns. Abuja was the best for yield and most yield components but had the longest duration to harvest. Alley cropping was adjudged a better and sustainable *Musa* production management option because it combined early crop maturity with high yield.

Keywords: *Musa* species, Growth, Yield variations, Adaptation pattern, Agro-ecology

Introduction

The most widely cultivated edible bananas (*Musa* species) are triploid (2n = 3x = 33) (Lebot *et al.*, 1993). They are broadly classified as dessert bananas (AAA), plantains (AAB) and cooking bananas (ABB) (Stover and Simmonds, 1987; Robinson, 1996). Their genetic origin derived from the interspecific hybridization of *Musa acuminata* (A) and *Musa balbisiana* (B). Thus, the classification of edible *Musa* species is based on the relative contributions of the two ancestral parents (Simmonds and Shepherd, 1955).
There is a strong ecoregional distribution of the cultivated *Musa* species in sub-Saharan Africa (Swennen and Vuylsteke, 1991) where they have assumed a prestigious status as staple foods that are critical to the nutritional and economic wellbeing of millions of people (INIBAP, 1992). The plantains are predominant in the humid lowlands of West and Central Africa, beer and cooking bananas prevail in East Africa highlands (Vuylsteke, 2001) while, dessert bananas are cultivated throughout the humid and sub-humid tropics of Africa.

The concerns over declining yields of *Musa* species due to spread of black sigatoka disease, fusarium wilt and banana bunchy top virus have resulted in increasing efforts to genetically improve the crop (Persley and De Langhe, 1987). These efforts have resulted into selection of some

Table 1: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria

Genotypes	DTF	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
					Plantain Hybrids						
PITA 1	496.5	115.9	314.8	250.1	9.2	16.4	13.8	74.8	140.5	11.0	18.3
PITA 2	458.7	115.7	329.2	241.0	9.5	16.9	13.0	81.3	154.0	13.0	21.4
PITA 3	552.4	109.0	306.9	159.0	7.6	17.9	12.3	69.3	144.7	10.5	17.0
PITA 5	473.8	114.3	320.2	259.9	8.1	17.1	12.3	76.1	131.9	10.8	18.0
PITA 7	535.1	112.6	345.3	214.7	7.4	16.8	12.2	96.8	132.4	12.6	21.0
PITA 8	485.1	112.8	288.4	221.5	9.1	15.3	11.3	82.5	108.3	8.8	14.6
PITA 9	5423	117.3	299.0	241.1	7.2	13.4	9.7	85.1	72.3	6.5	10.6
PITA 11	527.6	127.0	306.6	262.0	7.5	16.1	11.5	63.0	116.3	7.3	12.2
PITA 12	534.0	140.8	290.4	246.1	8.5	14.2	10.6	93.3	90.4	8.7	14.5
PITA 14	477.2	116.9	287.4	245.0	7.5	17.0	10.7	75.1	105.8	8.1	13.5
PITA 16	499.8	128.2	263.9	227.3	7.4	17.7	11.6	118.3	105.3	13.1	21.9
FHIA 21	566.5	97.9	287.1	171.8	7.8	25.9	11.7	74.7	127.1	10.0	16.7
FHIA 22	545.8	105.8	298.7	138.1	6.5	16.7	11.4	104.1	113.3	12.1	20.1
					Plantain Landraces						
AGBAGBA	583.0	89.4	323.6	158.4	6.5	20.9	13.5	34.8	216.8	7.5	12.4
UNN.DB	608.7	86.5	323.7	145.2	6.3	21.4	13.0	43.8	172.0	8.1	13.5
OBINO L'EWAI	607.1	91.1	322.4	117.0	6.1	15.5	11.3	67.7	99.5	7.2	12.1
					Cooking Banana Hybrids						
BITA 1	506.6	140.5	306.8	246.0	8.3	15.9	14.0	51.9	143.0	8.4	14.0
BITA 2	565.7	140.6	378.8	344.3	8.1	11.2	12.8	124.0	89.7	11.6	19.3
BITA 3	497.1	102.9	313.4	206.6	6.9	18.6	11.2	81.5	120.0	9.8	16.3
FHIA 3	509.6	109.5	280.4	188.3	8.9	16.0	17.8	118.4	135.7	17.7	29.5
					Cooking Banana Landraces						
BLUGGOE	521.5	124.0	368.8	304.3	6.7	16.8	15.0	61.5	177.6	11.6	19.3
CARDABA	466.5	129.5	356.8	298.9	8.8	16.5	15.1	83.1	169.3	15.2	25.3
FOUGAMOU	534.8	141.9	377.0	347.2	9.4	12.2	13.1	149.9	83.7	13.5	22.4
PELIPITA	499.8	130.5	375.9	355.7	9.8	11.6	11.4	138.3	81.6	11.6	19.3
SABA	520.5	127.0	360.9	290.4	8.5	16.1	14.5	90.7	155.7	14.9	24.9
					Dessert Banana Hybrids						
FHIA 1	492.7	129.6	261.1	193.6	10.1	17.7	12.3	116.8	141.8	16.9	28.2
FHIA 2	470.1	131.5	241.0	162.0	8.7	14.6	11.1	116.8	97.8	12.2	20.3
FHIA 23	625.1	110.5	318.4	218.9	6.6	16.0	11.7	151.9	103.6	17.0	28.3
SH 3640	514.6	110.0	285.6	177.9	9.4	18.6	13.1	99.3	164.3	17.5	29.2
SH3436-9	558.5	109.9	272.8	195.0	7.7	15.9	11.6	139.6	123.9	17.4	28.9
EMB 402	389.1	141.9	322.4	303.7	8.5	11.9	10.3	83.4	68.7	6.8	11.3
EMB 403	368.9	141.3	228.6	209.3	7.8	11.1	9.9	84.4	65.0	6.0	10.0
EMC 602	586.2	110.1	378.0	275.6	6.8	10.7	11.1	90.0	72.7	7.3	12.2
					Dessert Banana Landraces						
KM 5	475.6	124.1	290.3	280.3	7.7	10.6	9.8	109.1	62.2	7.0	11.6
Pisang ceylan	518.1	101.3	355.4	313.6	8.4	11.2	10.2	176.7	61.3	10.9	18.2
VALERY	532.5	106.9	229.4	169.9	6.4	16.3	10.2	109.1	84.6	9.4	15.6
LSD(0.05)	40.5	8.8	17.6	30.5	1.0	1.9	2.5	11.6	23.4	2.2	3.6

See materials and methods for interpretation of abbreviations

tetraploid hybrids by breeding stations around the world.

The hybrids are currently undergoing international testing (Orjeda, 1998) before final releases and adoption as cultivars.

As a short-term intervention to the scourge of black sigatoka disease (*Mycosphaerella fijiensis*) on plantain, amounting to 30 – 50% yield reduction (Mobambo *et al.*, 1993), the International Institute of Tropical Agriculture (IITA) introduced cooking banana cultivars from Asia into Nigeria. These new introductions and hybrids, selected at *Musa* breeding stations around the world, should be evaluated for adaptation, agronomic and horticultural qualities along side existing

Table 2: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria: The main effects of genome group and ploidy levels

Genome group	Ploidy level	DTF	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
Land-races												
Dessert banana												
[AAA]	3x	508.2	116.9	293.0	257.0	7.5	12.6	10.0	131.6	68.8	9.0	15.0
Plantain												
[AAB]	3x	599.4	88.9	323.3	140.9	6.3	19.5	12.7	48.5	163.2	7.6	12.7
Cooking banana												
[ABB]	3x	508.5	130.6	367.9	319.6	8.6	14.6	13.8	104.7	132.7	13.3	22.2
Hybrids												
Dessert banana												
[AAA x AA]	4x	499.3	123.4	287.1	215.6	8.2	14.7	11.4	110.8	105.3	12.8	21.3
Plantain												
[AAB x AA]	4x	514.9	116.9	303.4	222.5	8.0	17.1	11.8	84.2	119.9	10.3	17.1
Cooking banana												
[ABB x AA]	4x	520.5	125.1	320.2	249.1	8.1	15.2	14.1	94.6	122.6	11.9	19.9
LSD(0.05)		**21.5**	**4.7**	**9.4**	**15.6**	**0.5**	**2.2**	**1.0**	**6.3**	**11.1**	**1.2**	**2.0**

See materials and methods for interpretation of abbreviations

land-races. It is thereafter that specific and reliable recommendation of genotype could be made for cultivation.

The major *Musa* production zone in Nigeria had hitherto been the humid rainforest (Keay, 1963) while the sub-humid area is an emergent production zone (Baiyeri and Mbah, 1994). There is a possibility that cooking bananas known for tolerance to abiotic and biotic stresses and the new hybrids could adapt to the growth conditions in the sub-humid and southern guinea environments of Nigeria. Variations in adaptation pattern of *Musa* based on genomic group have also been reported (Turner and Hunt, 1984; Daniells and O'Farrell, 1988).

This study therefore, reports the performance of 36 *Musa* genotypes (belonging to the three *Musa* genomic groups) grown under four contrasting environments during two cropping seasons in Nigeria.

Materials and Methods

The three *Musa* genomes, AAA, AAB and ABB, comprising landrace (3x) and hybrid (4x) genotypes were grown under four contrasting environments in Nigeria for two cropping seasons. Plants were grown as sole crop at Onne (High rainforest zone), Ibadan (Forest-Savanna transition zone) and Abuja (Southern guinea savanna zone) plus an additional experiment grown in alley crop at Onne. The experiments were all set up in the research farms of the International Institute of Tropical Agriculture (IITA). Details of genomes and sites characteristics are reported in Baiyeri *et al.* (1999 and 2000).

The study was conducted between June, 1995 and June, 1998 with 36 *Musa* genotypes, comprising 11 land-races and 26 hybrids (see Table 1). Each genotype was grown in a single-row plot of five plants. The experimental design was a 6 x 6 simple lattice, replicated twice, with a planting distance of 3 m between rows and 2 m within rows. Cultural practices were as recommended by Swennen (1990). Phenological and yield data were collected for the plant crop and the first ratoon crop. Fruits were harvested at round-full stage (disappearance of fruit angularity) or at the onset of ripening of one fruit from the proximal end of the bunch. Bunch weight per plant (BWT, kg) was also measured. Other measurements included days to flowering (DTF), days for fruit filling (DFF), plant height at flowering (PHF, cm), height of the tallest sucker at harvest of the plant crop (HTSH, cm), black sigatoka disease resistance status, measured as the number of youngest leaf spotted at flowering (YLSF), fruit length (FLT, cm) and circumference (FCR, cm), fruit weight (FWT, g), and the number of fruits per bunch. Yield per hectare (YLDHA, tons) was estimated from yield per plant and the plant population.

Data collected over the two crop cycles were analyzed based on plot means due to unequal number of observations per plot (Piepho, 1997). Due to missing values the statistical model fitted for the analyses was that of factorial in randomized complete block design instead of lattice design. Data were subjected to analysis of variance and

Table 3: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria: The main effects of environments

Environments	DTF	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
Abuja sole crop	547.8	135.5	322.1	260.2	9.2	16.1	14.3	103.2	152.5	15.3	25.5
Ibadan sole crop	535.4	117.8	283.1	200.6	8.3	17.4	12.1	80.8	108.4	9.2	15.4
Onne sole crop	519.2	110.4	273.1	191.5	6.9	14.3	11.1	77.9	99.2	7.5	12.4
Onne alley crop	466.6	111.8	369.1	288.0	7.6	15.4	11.3	121.5	111.3	12.8	21.3
LSD(0.05)	13.5	2.9	5.9	10.1	0.3	0.6	0.8	3.9	7.7	0.7	1.2

See materials and methods for interpretation of abbreviations

separation of means using the GLM procedure in SAS (SAS, 1992).

Results

Genotype main effect plantains: Among the hybrids, PITA 2 was the most resistant to black sigatoka disease; it had the shortest days to flowering and harvest while FHIA 21 had the shortest days for fruit filling (Table 1). PITA 2 and PITA 16 produced the biggest bunch whereas PITA 9 produced the poorest yield and fruit traits among the plantain hybrids. Plantain land-races were similar in most phenological traits except that Agbagba produced taller suckers than Obino L'Ewai. Similarly, yield and fruit traits were in most cases statistically the same, except that Obino L'Ewai was different in terms of number of fruits per bunch and fruit size (Table 1).

Cooking bananas: Days to flowering and harvest were longest in BITA 2; it had the highest number of fruits per bunch (which were the smallest in size). BITA 3 had the shortest fruit filling period but lower YLSF. FHIA 3 produced the highest yield, and comparatively high quality fruit traits. FHIA 3 had about 53% yield advantage over BITA 1. Fougmou had the longest number of days to flowering, harvest and for fruit filling among the landrace genotypes (Table 1). It produced taller plants and also had high YLSF. Cardaba produced the highest yield, which was similar to that produced by Saba. Bluggoe had the fewest fruits per bunch and invariably the best fruit traits.

Dessert bananas: FHIA 23 took the longest duration to flowering and harvest whereas EMB 402 and EMB 403 had the shortest (Table 1). Days for fruit filling, however, was longest (about 142 days) for the EMB's and shortest (110 days) for SH 3640 and SH 3436-9. EMB 402 was the tallest at flowering and also produced the tallest suckers at harvest. In contrast, FHIA 2 had the smallest stature. FHIA 1 had the highest YLSF, which was similar to SH 3640. Bunch yields of FHIA 1, FHIA 23, SH3640 and SH3436 were similar, but they differed significantly in fruit traits (Table 1). The land-races had similar days to flowering and harvest but differed significantly in number of days for fruit filling. Pisang Ceylan had the highest YLSF. KM 5 produced the lowest yield and poorest fruits traits. However, it produced the same number of fruit per bunch as Valery.

Genome/ploidy level main effect: Days to flowering and harvest were similar among the hybrids. But among the land-races plantain had significantly longer days to flowering but shorter duration for fruit filling (Table 2). Also, fruit filling period was shortest in plantain hybrids than the other hybrid genomes. Generally, hybrids had longer days for fruit filling but shorter plant stature. Bunch yield of cooking banana land-races and dessert banana hybrids was similar and higher than other genome/ploidy level. Plantain land-races had heavier and longer fruits whereas the dessert bananas (3x and 4x) produced the highest number of fruits per bunch.

Environments main effect: Days to flowering and harvest were significantly ($P < 0.05$) longer in Abuja and Ibadan than Onne. Under alley cropping at Onne, plants were taller but flowered earlier and took shorter days for fruit filling (Table 3). On average, fruit filling took 4.5 months in Abuja as against 3.7 months in Onne. There were more leaves free of black sigatoka disease in Abuja and Ibadan than Onne. Heavier bunches and consequently, higher yield per hectare were obtained in Abuja than other environments.

Table 4: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria: The main effects of crop cycles.

Crop cycles	DTF	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
Plant crop	378.9	120.0	285.5	234.9	8.1	15.4	11.8	86.8	120.3	10.0	16.6
Ratoon crop	659.5	117.3	338.0	235.3	7.9	16.1	12.6	105.6	114.9	12.5	20.8
LSD(0.05)	9.5	2.1	4.2	ns	ns	0.5	0.6	2.7	ns	0.5	0.8

See materials and methods for interpretation of abbreviations

At Onne, alley cropping supported 42% more bunch yield than the sole cropping. Similarly, Abuja enhanced 40% more bunch yield per hectare than Ibadan. Heavier fruits were produced in Abuja, but Onne alley cropping supported more fruits per bunch. Fruits produced in Ibadan were longer than those produced in other environments.

Crop cycle main effect: Crop cycle significantly influenced most phenological traits except HTSH and YLSF (Table 4). There was a 10-month difference between the flowering of plant crop and the ratoon crop. Fruits of ratoon crop matured earlier. Ratoon crop plants were taller than the plant crop at flowering, and had 20% yield increase over the plant crop. Yield traits of the ratoon crop, except fruit weight, were significantly better than those of the plant crop. Higher yield of the ratoon crop plants was associated with 18% more fruits per bunch over the plant crop.

Environment by genome/ploidy level interaction: Days to flowering (DTF) were similar in Abuja and Ibadan for most genomes. Under sole and alley cropping systems at Onne DTF was also similar across genomes (Table 5). Generally, plants flowered earlier at Onne than at Abuja and Ibadan. Earliness to completion of two harvest cycles varied with genomes in each environment. At Abuja, plantains (3x and 4x) and dessert banana land-races (3x) took the longest duration (about 24 months) as against 21 months by cooking banana land-races (3x). Days for fruit filling (DFF) were longer at Abuja for all genomic groups than other environments. For example, DFF of plantain land-races was 80.8 days under sole cropping at Onne but was 104 days in Abuja. Cooking banana land-races had the longest DFF in all environments except in Abuja. Plants were taller in Abuja and under alley cropping in Onne than other environments. In all cases, cooking banana land-races had the tallest plants. There was a progressive South to North increase in YLSF.

Bunch yield ranged from 20.4 t/ha (dessert banana land-races) to 32.9 t/ha (dessert banana hybrids) in Abuja in contrast to 8.6 t/ha (dessert banana land-races) and 19.9 t/ha (cooking banana land-races) at Ibadan. At Onne, plantain land-races yielded 9.8 t/ha under sole crop as against 13.4 t/ha under alley cropping (Table 5). The highest bunch yield (32.9 t/ha) was produced by dessert banana hybrids in Abuja and the lowest yield (8.6 t/ha) by dessert banana land-races at Ibadan. The highest number of fruits per bunch and the smallest fruit size were produced by dessert banana land-races in all the environments. In contrast, the fewest number but biggest fruits were produced by plantain land-races in most of the environments (cooking banana landrace produced the biggest fruits in Abuja). The best fruit grade (19.4 cm) was produced by cooking banana hybrids in Abuja but the longest fruits were plantain land-races at Ibadan.

Crop cycle by genome/ploidy level interaction: For both plant and ratoon crops, plantain land-races took longer days to flowering and harvest but had the fewest number of days for fruit filling (Table 6). Flowering to flowering and/or harvest to harvest period took seven months in dessert banana land-races (AAA) whereas, the hybrids (AAA x AA) took about 10 months. Plant height was similar for the two crop cycles for plantain land-races only. YLSF was similar across crop cycles for each genome.

Bunch yield of ratoon crop increased in most genomes except plantain land-races. The yield advantage of the ratoon crop over the plant crop ranged between 20 – 28% except plantain hybrids that had only 6% yield increase (Table 6).

Table 5: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria: Environment by genome/ploidy level interaction

Environments	Genome/ploidy level	DT	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
Abuja sole crop	AAA [3x]	587.8	23 6	317.0	280.9	8.6	13.4	11.6	134.9	91.7	12.2	20.4
	AAB [3x]	631.6	101.0	320.0	189.1	6.2	16.3	13.3	59.5	169.9	10.0	16.6
	ABB [3x]	488.1	142.3	391.2	335.6	11.0	14.4	16.9	115.4	181.6	19.1	31.8
	AAA xAA [4x]	528.2	143.2	311.4	253.3	9.8	15.0	13.4	127.1	154.8	19.7	32.9
	AAB x AA [4x]	585.0	131.6	298.6	227.8	9.0	19.2	13.0	84.9	148.4	12.4	20.6
	ABB x AA [4x]	522.5	141.6	339.0	303.3	9.5	14.7	19.4	93.2	147.9	14.1	23.5
Ibadan sole crop	AAA [3x]	583.9	99.9	249.1	183.4	8.0	12.7	9.6	98.3	64.4	5.1	8.6
	AAB [3x]	558.6	88.5	290.3	128.4	7.9	22.2	13.0	43.3	148.4	7.3	12.2
	ABB [3x]	487.3	132.9	328.3	270.7	9.1	17.1	13.5	95.3	126.3	12.0	19.9
	AAA xAA [4x]	524.4	127.0	266.3	193.8	8.0	15.1	11.3	88.8	85.7	8.8	14.7
	AAB x AA [4x]	579.4	112.2	276.4	176.7	8.5	18.7	12.1	66.8	106.8	8.2	13.7
	ABB x AA [4x]	509.1	119.0	290.4	203.1	7.3	17.6	13.4	75.1	119.5	10.0	16.7
Onne sole crop	AAA [3x]	437.6	112.0	245.7	212.0	6.8	12.0	9.7	115.5	62.6	7.4	12.2
	AAB [3x]	630.9	80.8	290.7	95.7	5.5	17.4	12.1	38.8	164.6	5.9	9.8
	ABB [3x]	554.3	125.3	320.4	261.5	6.9	13.3	12.5	81.3	107.5	8.5	14.2
	AAA xAA [4x]	507.7	106.2	244.2	169.9	7.0	12.8	9.9	87.2	71.9	7.0	11.6
	AAB x AA [4x]	498.2	110.6	271.7	195.0	7.0	15.2	11.1	70.1	107.5	7.5	12.4
	ABB x AA [4x]	596.1	116.3	285.7	188.7	7.6	14.5	12.1	77.1	111.0	8.8	14.7
Onne alley crop	AAA [3x]	431.7	106.6	346.6	320.7	6.7	12.6	9.4	168.0	61.0	10.7	17.8
	AAB [3x]	615.0	82.8	399.3	162.3	5.7	19.8	12.1	55.2	177.7	8.1	13.4
	ABB [3x]	519.6	121.6	431.7	406.8	7.8	13.7	12.6	126.7	118.5	13.7	22.8
	AAA xAA [4x]	443.2	115.4	331.4	250.2	8.1	15.3	11.0	136.3	103.6	14.6	24.4
	AAB x AA [4x]	430.8	110.9	362.3	280.1	7.6	15.9	10.8	110.5	110.1	12.1	20.0
	ABB x AA [4x]	445.1	115.7	370.1	287.7	8.2	15.0	12.2	123.4	113.9	13.9	23.1
LSD(0.05)		**37.3**	**8.0**	**16.4**	**26.2**	**0.9**	**3.7**	**1.8**	**5.4**	**18.7**	**2.1**	**3.4**

See materials and methods for interpretation of abbreviations

Fruit weight and length of plantain land-races were better than others in both crop cycles. Dessert banana land-races produced the highest number of fruits per bunch in both crop cycles.

Main effect of genome/ploidy level (G), environment (E) and GE interaction on bunch weight per mat: Bunch weight per mat (i.e. sum of bunch weight of plant and ratoon crops) varied significantly ($P < 0.01$) among the genomes (Table 7). Tetraploid genomes produced bunches that were heavier than their respective triploids, except for the cooking bananas, in which the reverse was the case.

Plants grown in alley cropping produced bunches that were 42% heavier than those produced under sole cropping at Onne. Similarly, bunch weight at Abuja was 40% and 50% heavier than bunch weight obtained at Ibadan and under sole cropping at Onne, respectively.

Interaction pattern was a cross-order type. Dessert banana hybrids produced the highest bunch weight at Abuja and under alley cropping at Onne, but at Ibadan and under sole cropping at Onne, the highest bunch weight was produced by cooking banana land-races and their hybrids, respectively. Bunch weight of each genome was highest in Abuja. Among the triploid, cooking banana consistently produced the heaviest bunch weight while its plantain counter parts the smallest (Table 7). The tetraploids had similar yield except at Abuja where dessert banana hybrid had higher yield than in other environments.

Discussion

The significant first-order interaction involving the genomes, crop cycle and environments justifies the study. Multi-environment evaluation trials of crop genotypes have often been used to measure crop performance or adaptability and stability (Pritts and Luby, 1990). Phenotypic variation for specific genotype is usually attributable to the environments (Kang, 1998). Thus, to exploit fully

Table 6: Phenological and yield traits of 36 *Musa* genotypes grown in four environments for two cropping cycles in Nigeria: Crop cycle by genome/ploidy level interaction

Crop cycles	Genome/ploidy level	DTF	DFF	PHF	HTSH	YLSF	FLT	FCR	FRUITS	FWT	BWT	YLDHA
Plant crop	AAA [3x]	404.4	114.2	280.3	256.8	7.5	11.8	9.8	110.8	66.4	7.4	12.4
	AAB [3x]	461.2	90.8	324.5	129.6	6.1	19.9	12.9	50.0	181.9	8.2	13.6
	ABB [3x]	382.0	132.3	331.4	335.9	8.7	14.5	13.2	94.5	128.9	11.4	19.1
	AAA xAA [4x]	354.9	124.2	258.5	220.9	8.5	14.1	10.9	100.2	100.0	10.7	17.9
	AAB x AA [4x]	370.1	117.0	280.3	222.9	8.4	16.6	11.6	79.0	126.1	9.7	16.2
	ABB x AA [4x]	374.5	125.5	290.9	236.1	8.1	15.2	12.5	83.7	118.3	10.0	16.6
Ratoon crop	AAA [3x]	616.0	106.8	317.1	241.7	7.6	13.5	10.3	147.6	73.5	10.3	17.1
	AAB [3x]	756.8	87.3	325.7	158.2	6.6	18.0	12.4	48.4	148.3	7.4	12.4
	ABB [3x]	661.8	128.7	404.4	301.4	8.8	14.8	14.5	114.9	138.1	15.2	25.3
	AAA xAA [4x]	646.9	121.7	318.1	212.7	8.0	15.1	11.9	119.5	108.0	14.4	23.9
	AAB x AA [4x]	676.6	115.6	324.2	216.8	7.7	17.9	12.0	87.2	110.3	10.4	17.2
	ABB x AA [4x]	661.8	120.8	351.7	255.3	8.2	15.8	16.0	100.8	127.8	13.4	22.4
LSD(0.05)		**26.4**	**ns**	**11.6**	**18.5**	**ns**	**ns**	**1.2**	**7.6**	**13.2**	**1.5**	**2.4**

See materials and methods for interpretation of abbreviations

information contained in multi-environment trials of genotypes, it is necessary to understand the resources/challenges controlling crop growth/yield in individual environments; and the reasons for the differential genotype performance across environments as a response to the varying resources/challenges in those environments (Bidinger *et al.*, 1996).

Environment effects: According to Bidinger *et al.* (1996) crop performance is a direct product of the resources available in the environment. Abuja environment produced the best yield and yield components, the lowest black sigatoka disease incidence but longest duration from planting to harvest. High crop performance at Abuja might be related to rainfall averaged 1300 mm annually, which meets the minimum annual requirement for *Musa* species (Swennen, 1990). Besides, there was supplemental irrigation during the months of November to March (137 mm per months), sunshine hours averaged above six hour per day, thus no obvious solar radiation limitation to photosynthetic activity and yield (Turner, 1995). As a result of low relative humidity, black sigatoka disease (BSD) inoculum level in the air was probably low and so plants were healthier than in other environments. Soil fertility and water retention capacity were not limiting. Abuja represented a resource rich environment with little or no stressful conditions. Crop performances under alley crop were similar to performances under Abuja conditions. This is probably due to good soil characteristics under alley crop, since sole cropping in the same Onne gave the poorest crop performance. Resources available under alley cropping included: high organic matter buildup (throughout the cropping season) from pruning of hedgerows; organic matter buildup increases productivity via reduced root deterioration and conserves soil surface moisture (Robinson, 1996). Though high relative humidity under alley crop could predispose plants to BSD attack due to high inoculum level (Gauhl, 1994), other growth factors within the system seemed to have overcome the limitation. Plants in alley crop were taller than in other environments; they flowered and were harvested earlier probably due to the enhanced resource capacity. Shorter crop duration had no negative impact on yield which contrasts the general opinion that the longer the crop duration the higher the biomass production (Evans, 1993). Thus, earliness combined with high yield under alley crop would be due to growing conditions available under this cropping system.

The relatively poor crop performance at Ibadan was due to erratic rainfall in 1996, which had a carry over effect on the ratoon crop performance. Other growth factors seemed to have been about optimum for *Musa* species but the stress created by poor distribution of rain must have impaired potential growth and yield (Ezedinma, 1976) in this location. Turner (1995) reported that water deficit could reduce productivity by up to 30 - 50%. Crop yield and yield components under sole crop at Onne were

Table 7: The effects of environment (E), genome group (G) and G x E interaction on bunch weight (kg) per mat (plant and ratoon crops total)

Environments	Genome / ploidy level						Main effect of environments
	AAA	AAB	ABB	AAA x AA	AAB x AA	ABB x AA	
Abuja sole crop	25.2	19.[illegible]	38.2	39.4	25.6	27.6	30.1
Ibadan sole crop	11.1	14.0	23.9	18.7	17.3	19.8	18.1
Onne sole crop	14.8	10.8	16.0	14.0	14.9	16.7	14.7
Onne alley crop	21.4	15.8	27.4	29.4	24.6	28.2	25.5
Main effects of genome/ploidy level	**18.4**	**14.9**	**26.4**	**25.5**	**20.6**	**23.2**	**22.1**

LSD (0.05) comparing: any two genome groups = 2.4; any two environments = 1.7; G x E interaction = 4.3

the poorest due to soil factors (Ortiz *et al.*, 1997).

The soil is characterized by high acidity, which consequently affected nutrient availability (Delvaux, 1995). As a result of poor organic matter content, the soil was prone to nutrient leaching and surface runoff. High relative humidity predisposed plant to high BSD infection. Coupled with low sunshine hours (although rainfall was not limiting), the resource available under sole crop at Onne was the poorest among the tested environments. This resource status would explain the poor phenological and yield traits under this system.

Abuja and sole cropping at Onne contrasted in both resource potential and crop performance. Relative crop performance under alley cropping showed that, in a resource poor location like Onne (high acidity, low nutrient status, prolong cloud cover), cropping system could ameliorate poor crop performance. Shannon *et al.* (1994) reported that alley cropping combines the advantages of maintaining land in food production for long periods while improving soil productivity. They reiterated that, alley cropping with moderate fertilizer use may be the best means to stabilize yield. Such yield stabilization effect was obtained in this study.

Genotype: The 36 genotypes evaluated consisted of hybrids of variable genetic background and land-races, which had not been improved. Thus, it was normal that genotypes displayed distinct phenological and yield differences. Extensive variability among germplasm offers the possibility of selection to fit different uses (Plucknett *et al.*, 1987) and also allow for selection based on traits. Relative performance increase at tetraploid level over the triploid is due to heterosis and BSD resistance (Ortiz, 1995). In an earlier trial at Onne, Mobambo *et al.* (1993) reported that the yield of PITA 2 was 43% higher than its fungicide treated plantain parent and twice the yield of non treated plot. Susceptibility to BSD of plantain land-races may not sufficiently account for their lower productivity since FHIA 22 (a plantain hybrid) was similarly susceptible but higher yielding. Long duration plus few fruits per bunch might be additional factors limiting yield per area per unit time of plantain land-races.

Genome group: Earlier cultivar trials (Turner and Hunt, 1984; Daniells and O'Farrell, 1988) reported significant differences due to genomic group and ploidy level effect, as obtained in this study. Better performances of the hybrid could be due to heterosis and higher disease resistance (Ortiz, 1995; Rowe and Rosales, 1996).

Landrace cooking bananas out yielded other genomes. According to Rowe and Rosales (1996), cooking banana land-races are robust, tolerant to marginal soil and rainfall conditions and resistant to BSD. However, poor yield of plantain land-races was explained by fewer fruits per bunch and their high susceptibility to BSD, which could cause up to 50% yield reduction (Mobambo *et al.*, 1993). Hybrid plantains out-yielded their land-races, essentially due to better disease resistance, several fruits per bunch and relatively heavy fruit weight. Similarly, higher yield of hybrid dessert bananas than their land-races was as a result of disease resistance and heavier fruit weight. Contrary to the trend in other *Musa* genomes, cooking banana land-races out yielded their hybrids due to many big fruits per bunch.

Yield per mat assessed by genomes across environments: Cumulative yield for the two crop cycles provided information on resource capture and conversion efficiency of the different genomes over a three-year cropping season. There was a high genomic plasticity for bunch weight per mat. Tolerance to biotic and abiotic stresses is influenced by the relative presence of 'A' and/or 'B' genetic compliment in the genome (Price, 1995). Stress factors varied in the evaluation environments thus, variable genome adaptation and yield patterns. High humidity throughout the year at Onne predisposed plants to BSD in contrast to Abuja, which was relatively drier, and thus lower BSD inoculum (Gauhl, 1994). General poor performances of plantain land-races could be a reflection of their genetic potential, as plantain hybrids were high yielding. The productive potential of alley crop was, in most cases, 40% higher than the sole crop substantiating earlier report by Shannon *et al* (1994) that alley cropping system stabilizes yield and increases productivity of farmer in land-tight condition. Crossover genome by environment interaction on cumulative yield implies that genomes should be recommended for where it was best suited. Hardy nature and relatively consistent performance of cooking banana land-races would make them candidate for further test in drier northern Nigeria.

Crop cycle (plant crop versus the ratoon crop) effect: Significant differences in crop cycle effects on growth and yield traits was expected since the two crop cycles were different in terms of resources captured. It would be realized that the plant crop had a shorter vegetative growth period (Stover and Simmonds, 1987) while the longer duration of the ratoon crop could be advantageous in terms of resource captured. The ratoon crop benefited from fertilizer applied to the plant crop while constituting a competitive sink during early growth stage (Swennen and De Langhe, 1985; Baiyeri and Ortiz, 1995). Organic matter turn over from the trash of the plant crop coupled with fertilizer applied to the ratoon was added advantage to ratoon crop performance. Earlier study of Lahav and Turner (1989) showed that nutrient available to the ratoon crop from the decomposition of the plant crop trash was enormous.

Harvest to harvest of about nine months was similar to earlier report of Irizarry *et al.* (1981). Taller ratoon plants was due to quest for light during heavy canopy cover of the plant crop (Robinson, 1996), but as a result of better growth conditions of the ratoon crop fruit filling days was shorter.

Conclusion: Resource base of each environment dictated genotype performances and genome adaptation pattern. Abuja was the best for yield and most yield components but had the longest duration to harvest. But, judging from yield per unit area per unit time, alley cropping at Onne had similar yield potential with Abuja, due to shorter crop duration. Alley cropping proved in all ramifications a better and sustainable *Musa* production management option. It combined early crop maturing with high yield. The significant positive effect of alley cropping on *Musa* productivity was associated with microclimatic change caused by this system, coupled with soil improvement effects via mulching from the pruning of the natural multi-species hedgerows. Alley cropping will be most suitable in a land-tight area and where soil resource is poor. This is exemplified by the relative out performance of crops under alley crop compared to sole crop, both at Onne.

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