

*Full Length Research Paper*

# **Development of two high-yielding, consumer-acceptable apple banana hybrids (*Musa* species, AAB genome group) with resistance to *Fusarium oxysporum* f. sp. *cabense* race 1**

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Received 9 January, 2018; Accepted 5 March, 2018

***Fusarium* wilt of bananas (*Musa* species) is caused by *Fusarium oxysporum* f. sp. *cabense* (Foc). Foc race 1 in particular affects dessert bananas in Uganda, causing >60% yield loss. This study was conducted to assess the performance of two new apple banana genotypes for bunch yield, resistance to Foc race 1 and consumer acceptability. The new apple banana genotypes (NAMU1 and NAMU2), along with two check cultivars, one susceptible but preferred by consumers (Sukali ndiizi) and the other resistant (Yangambi-KM5), were evaluated at the National Agricultural Research Laboratories in Uganda. Bunch yields of the two new apple bananas were higher than those of check cultivars by >50%. NAMU1 and Yangambi-KM5 showed no symptoms of Foc race 1, whereas NAMU2 showed mild symptoms on its corms. Sukali ndiizi showed severe pseudostem splitting and corm discoloration as the key symptoms of Foc race 1. The consumer acceptability of NAMU1 and NAMU2 was as high as that of Sukali ndiizi, implying that they can be perfect substitutes for the Foc race 1 susceptible Sukali ndiizi.**

**Key words:** Dessert banana hybrids, host plant resistance, Panama disease, sensory attributes.

## **INTRODUCTION**

Apple banana (*Musa* species, AAB genome group), is one of the more than 300 varieties of banana grown worldwide. It is the most widely distributed dessert banana cultivar in Uganda (Gold et al., 2002). Apple

banana is locally known as Sukali ndiizi and Kabaragara in the Central and Western regions of Uganda, respectively (Nsabimana and Van Staden, 2006); in Rwanda, it is known as Kamaramasenge (Nsabimana

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and Van Staden, 2006). The cultivar is known for its small fruits with a thin peel and a slightly acidic apple-like taste of the pulp, which is its unique characteristic (Van Asten et al., 2010). It makes a major contribution to Uganda's economy, as its production is mainly by small-scale farmers who sell it for improved incomes and also eat it for nutrition. Apple banana has been commonly sold and consumed fresh, but of late, it is being processed by a number of private sector and development partners to improve shelf life and value addition (Van Asten et al., 2010). This makes it fit well in the Uganda government policy of value addition of agricultural products.

*Fusarium* wilt, also known as Panama disease, is the most important lethal disease of dessert bananas (Butler, 2013; Dale et al., 2017). It is a fungal disease caused by *Fusarium oxysporum* f. sp. *cubense* (Foc) (Ploetz and Evans, 2015). Foc race 1 is the primary cause of *Fusarium* wilt disease of dessert bananas in Uganda (Karangwa et al., 2016). The disease severely affects important exotic banana cultivars, such as Gross Michel, Kayinja, Kisubi and apple banana, which are major dessert and juice-producing bananas in the country (Bettina et al., 2012). It causes an estimated yield loss of >60% in dessert bananas (Tushemereirwe et al., 2000).

The first internal symptom in diseased plants is a reddish brown discoloration of the xylem that develops in feeder roots, the initial sites of infection (Butler, 2013; Ploetz, 2015). Vascular discoloration progresses to the rhizome, where the stele joins the cortex, and ultimately proceeds up to the pseudostem. On plants that are more than four months old, the oldest leaves yellow or split longitudinally at the base. Eventually, younger leaves wilt and collapse until the entire plant canopy consists of dead or dying leaves (Ploetz, 2015). Infected rhizomes are often symptomless and effectively spread the pathogen when used as planting material (Stover, 1962). The pathogen spreads in soil, running water and farm implements, and survives for up to 30 years in the absence of banana (Stover, 1962). Because of the persistent nature of Foc in the soil and the lack of effective chemical control strategies, the development of Foc-resistant cultivars has been a priority in banana genetic improvement programs (Daniells, 2011).

Control of Foc through the deployment of dessert banana varieties similar to Sukali ndiizi but are resistant to the locally prevalent Foc race 1 has not been successful in Uganda until the present time. In this paper, the performance of two consumer-acceptable apple banana genotypes possessing resistance to Foc race 1, which were developed at the National Banana Research Programme (NBRP) in Uganda was presented and discussed. In the early 1990s, scientists at the NBRP in Uganda evaluated a wide range of banana cultivars and recommended FHIA 17, FHIA 23, Cavendish and Yangabi-KM5 as resistant dessert banana cultivars to Foc race 1 (Tushemereirwe et al., 2000). Although these varieties were high-yielding and resistant to Foc race 1,

their sensory/organoleptic traits were not appealing to consumers accustomed to the taste of apple bananas (Tushemereirwe et al., 2000; Van Asten et al., 2010). Against this background, there was a need to develop new varieties of apple banana that combine resistance to Foc race 1 and desired fruit quality traits to sustainably exploit the potential of local and export markets for the apple banana. The objective of this study was to compare two newly developed consumer-acceptable apple banana genotypes with the existing commercial cultivar (Sukali ndiizi) for bunch yield, resistance to Foc race 1 and consumer acceptability.

## MATERIALS AND METHODS

### Experimental site

The experiments were conducted at the National Agricultural Research Laboratories (NARL), Kawanda, from March 2013 to April 2017. Kawanda is located in Central Uganda at 32°36'E and 0°25'N, 1210 m above sea level (Tumuhimbise et al., 2016). During the experimental period, the mean annual rainfall was 1372 mm and temperatures ranged from 12.8 to 29.5°C. Kawanda is a hotspot for many pathogens and pests, including *Mycosphaerella fijiensis* Morelet, Foc race 1, weevils and nematodes.

### Plant germplasm

Three genetically diverse parents sourced from the farmers' fields and NBRP (Table 1) were used to develop the two dessert banana genotypes that were evaluated for this study. Selection of the parents was based on their better performance for bunch yield, flowering-ability and relative degrees of field resistance to Foc race 1.

### Genotype development

Targeted controlled crosses between male and female parental lines (Table 1) were made between 6:00 and 8:30 a.m. by dusting pollen on the stigmas of Sukali ndiizi. Before pollination, female and male flowers that had just flowered were bagged to avoid contamination by stray pollen. Seeds from mature ripe pollinated bunches were extracted, as described by Vuylsteke et al., (1995). *In vitro* germination of the extracted seeds was carried out according to the protocol described by Vuylsteke et al. (1990). The resulting seedlings were planted in the early evaluation trial at NARL in April 2011. Based on visibly high bunch yield, fruit size, fruit pulp smoothness, taste, color and smell, and resistance to black Sigatoka and Foc race 1 of the genotypes at the early evaluation trial stage (results not presented), two Sukali ndiizi hybrids (NAMU1 and NAMU2) were selected for further evaluation in a replicated preliminary yield trial. NAMU1 resulted from the cross Sukali ndiizi x Cultivar Rose, whereas NAMU2 resulted from the cross Sukali ndiizi x TMB2 x 8075-7. It is the results of these two new apple banana hybrids (NAMU1 and NAMU2) (Figure 1) and the two local check cultivars (Sukali ndiizi and Yangambi-KM5) that are presented and discussed in this paper.

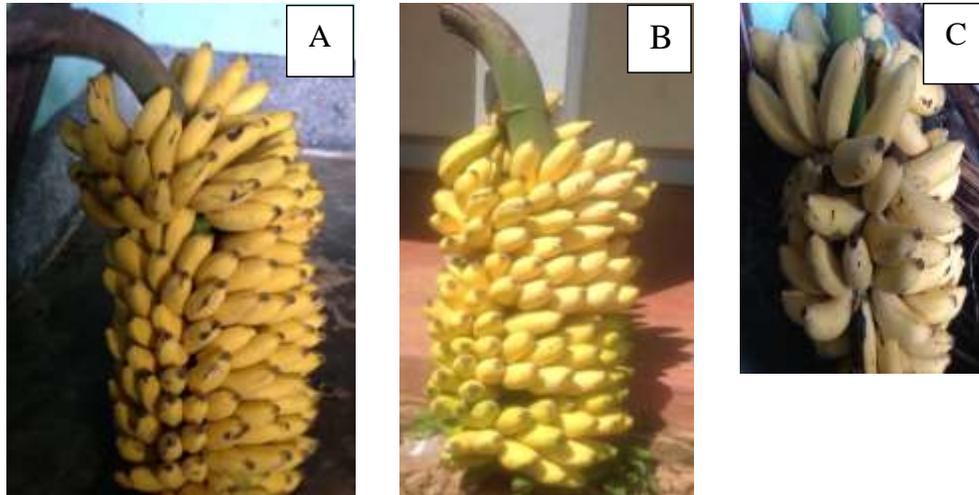
### Experimental design

Experiments were planted in a randomized complete-block design with three replications. Because of low multiplication rate of

**Table 1.** Three banana parental lines that were hybridized and their special attributes

Parent	Ploidy	Use	Source	Special attribute
TMB2x8075-7	2x	Male parent	NBRP	Resistant to Foc race 1, long bunch
Cultivar Rose	2x	Male parent	NBRP	Resistant to Foc race 1, firm fruit pulp and sweet
Apple banana (Sukali ndiizi)	3x	Female parent	Farmers' fields	Apple flavored, sweet, firm pulp, susceptible to Foc race1

NBRP: National Banana Research Program.



**Figure 1.** New apple banana genotypes: A= NAMU1, B=NAMU2, and their female parent: C=Sukali ndiizi.

bananas by suckers, NAMU1, NAMU2, Sukali ndiizi and Yangambi-KM5 were multiplied *in vitro* to generate sufficient planting materials for replicated preliminary yield trial. The tissue culture-derived plantlets of each genotype were planted in lines of 10 plants genotype<sup>-1</sup> replication<sup>-1</sup>. Spacing between plants intra- and inter-lines was 3 × 3 m<sup>2</sup>. At planting, 10 kg of Kraal manure was applied in 0.5 m deep and 0.6 m wide planting holes. The trial field had a history of severe Foc race 1 infestation, thus, considered a hot spot. Nevertheless, to avoid field escape of some plants to the pathogen because of uneven pathogen distribution, Foc race 1 inoculum at a concentration of 5 × 10<sup>6</sup> spores/ml was distributed around the banana stools. Also, Sukali ndiizi, a banana cultivar susceptible to both Foc race 1 and black Sigatoka, was planted around the trial to act as a guard row, as well as a spreader for Foc race 1 and black Sigatoka.

#### Data collection

Data collection was done during the plant growth and at harvest on: plant height (cm), number of functional leaves at flowering, youngest leaf spotted at flowering as a measure of the genotypes' response to black Sigatoka, pseudostem splitting and corm discoloration. Harvesting of bunches was done when at least one fruit finger of the first hand on a bunch began to ripen and data were recorded on bunch weight (kg plant<sup>-1</sup>), number of hands, fruit finger length (cm), and fruit finger circumference (cm). Bunch weight was obtained by weighing the harvested bunch using a weighing scale, whereas the number of hands on a bunch was

obtained by counting the hands on a bunch. Finger length was obtained by measuring the length of one middle finger from each hand on a bunch and the average length per bunch was calculated. Finger circumference was obtained by measuring the length around the middle finger of each hand on a bunch and the average circumference per bunch was calculated. Plant height was measured from the ground level to the point where the last leaf emerged from the pseudostem. Number of functional leaves was determined by direct counting of green leaves on a plant. Youngest leaf spotted at flowering was determined by recording the leaf number with the first black Sigatoka symptoms, counting from the youngest leaf to the oldest leaf. Resistance to Foc race 1, as determined by disease severity, was assessed based on internal corm symptoms and pseudostem splitting at harvest, as described by Smith et al. (2008) but with some modifications. Disease severity assessment based on corm symptoms was done using a scale of 0-6, where 0= no discoloration of tissue of stellar region of corm or surrounding tissue, 1 = no discoloration of stellar region of corm; discoloration at junction of root and corm, 2 = trace to 5% of stellar region discolored, 3 = 6-20% of stellar region discolored, 4 = 21-50% of stellar region discolored, 5 = more than 50% of stellar region discolored and 6 = discoloration of the entire corm stele. Disease severity assessment based on pseudostem splitting was done using a scale of 1-3, where 1 = no cracking of the pseudostem, 2 = slight cracking of the pseudostem and 3 = advanced cracking of the pseudostem.

For sensory traits evaluation, mature harvested bunches were stored in one of the laboratory rooms at NARL to ripen. The room temperature ranged from 23 to 29°C and relative humidity from 71

**Table 2.** Mean severity scores for pseudostem splitting and corm discoloration due to Foc race 1.

Genotype	Plant traits assessed <sup>§</sup>	
	Pseudostem splitting (1-3)	Corm discoloration (0-6)
Sukali ndiizi	2.06±0.1 <sup>a</sup>	4.76±0.2 <sup>a</sup>
Yangambi-Km 5	1.00±0.0 <sup>c</sup>	0.00±0.0 <sup>c</sup>
NAMU2	1.50±0.2 <sup>b</sup>	1.50±0.5 <sup>b</sup>
NAMU1	1.00±0.0 <sup>c</sup>	0.00±0.0 <sup>c</sup>
F prob.	≤0.0001	≤0.0001

<sup>§</sup>Means with different letters in the same column are significantly different by Fisher's protected least significant test at  $\alpha = 5\%$  while those with the same letters are not significantly different.

**Table 3.** Mean performance of the genotypes for plant height, number of functional leaves and response to black Sigatoka.

Genotype	Plants traits assessed <sup>§</sup>			
	Plant height (cm)	Plant girth (cm)	NFLF	YLSF
Sukali ndiizi	263.57±3.8 <sup>c</sup>	42.70±0.6 <sup>c</sup>	9.56±0.2 <sup>b</sup>	7.95±0.2 <sup>b</sup>
Yangambi-Km 5	268.01±3.6 <sup>c</sup>	43.60±0.6 <sup>c</sup>	12.1±0.2 <sup>d</sup>	9.10±0.4 <sup>a</sup>
NAMU2	294.85±9.2 <sup>b</sup>	52.15±2.0 <sup>b</sup>	10.53±0.3 <sup>a</sup>	9.06±0.4 <sup>a</sup>
NAMU1	328.95±3.8 <sup>a</sup>	48.79±0.5 <sup>a</sup>	8.81±0.1 <sup>c</sup>	7.73±0.2 <sup>b</sup>
F prob.	<0.0001	<0.0001	<0.0001	0.013

NFLF: Number of functional leaves at flowering; YLSF: youngest leaf spotted at flowering. <sup>§</sup>Means with different letters in the same column are significantly different by Fisher's protected least significant test at  $\alpha = 5\%$  while those with the same letters are not significantly different

to 81%. Fully ripened bunches were taken for sensory evaluation by a trained group of 20 apple banana farmers/consumers. Genotype assessments (NAMU 1, NAMU 2 and Sukali ndiizi) based on taste, color, smell and general acceptability were done on as a scale of 1 to 5, where 1 = dislike very much, 2 = dislike, 3 = like fairly, 4 = like, and 5 = like very much.

### Statistical analysis

Data analysis was performed using SAS version 8.2 for windows (2001). To compare the trait means, Fisher's protected least significant test at  $\alpha = 5\%$  was performed.

## RESULTS

### Genotypic response to Foc race 1

There were highly significant differences in mean scores of the experimental genotypes for corm discoloration and pseudostem splitting, as measures of Foc race 1 severity (Table 2). NAMU1 showed the highest resistance to Foc race 1, as it exhibited the lowest mean scores for pseudostem splitting and corm discoloration. Sukali ndiizi, the susceptible check cultivar, showed the highest mean scores for pseudostem splitting and corm discoloration.

Yangambi-KM5, the highly resistant check, showed the lowest mean scores for pseudostem splitting.

### Genotypic performance relative to plant height, number of functional leaves and response to black Sigatoka

Highly significant differences were observed among the test genotypes for plant height, plant girth, number of functional leaves at flowering, and response to black Sigatoka (Table 3). NAMU1 showed the highest mean performances for plant height, followed by NAMU2; whereas Sukali ndiizi had the lowest plant height. NAMU2, on the other hand, had the highest mean performance for plant girth, followed by NAMU1. Sukali ndiizi had the lowest mean plant girth. Yangambi-KM5 and NAMU2 had the highest mean performance for the youngest leaf spotted.

### Genotypic performance for bunch yield and yield-related traits

Highly significant differences were observed among the

**Table 4.** Mean performance of the genotypes for bunch yield, number hands, fruit finger circumference and fruit finger length.

Genotype	Plants traits assessed <sup>§</sup>			
	Bunch weight (kg plant <sup>-1</sup> )	Number of hands	Fruit finger circumference (cm)	Fruit finger length (cm)
Sukali ndiizi	6.22±0.3 <sup>a</sup>	6.12±0.1 <sup>a</sup>	10.06±0.1 <sup>a</sup>	11.17±0.2 <sup>a</sup>
Yangambi-KM5	6.55±0.3 <sup>a</sup>	6.41±0.1 <sup>a</sup>	10.21±0.1 <sup>a</sup>	11.37±0.2 <sup>a</sup>
NAMU1	9.85±0.3 <sup>b</sup>	7.45±0.2 <sup>b</sup>	13.60±0.2 <sup>b</sup>	14.30±0.1 <sup>b</sup>
NAMU2	10.38±0.7 <sup>b</sup>	8.57±0.4 <sup>c</sup>	12.13±0.5 <sup>c</sup>	12.88±0.3 <sup>c</sup>
F prob.	<0.0001	<0.0001	<0.0001	<0.0001

<sup>§</sup>Means with different letters in the same column are significantly different by Fisher's protected least significant test at  $\alpha = 5\%$  while those with the same letters are not significantly different.

**Table 5.** Mean performance of the new hybrids and check cultivar for pulp smoothness, taste, color, smell and acceptability as assessed by farmer/consumers.

Genotype	Sensory attributes <sup>§</sup>				
	Smoothness	Taste	Colour	Smell	Acceptability
Sukali ndiizi	4.29±0.2 <sup>a</sup>	4.29±0.2 <sup>a</sup>	4.00±0.2 <sup>a</sup>	4.39±0.2 <sup>a</sup>	4.13±0.2 <sup>a</sup>
NAMU1	4.69±0.2 <sup>a</sup>	4.69±0.2 <sup>a</sup>	4.56±0.2 <sup>ab</sup>	4.63±0.2 <sup>a</sup>	4.38±0.2 <sup>a</sup>
NAMU2	5.00±0.3 <sup>a</sup>	4.69±0.3 <sup>a</sup>	4.94±0.2 <sup>b</sup>	4.50±0.3 <sup>a</sup>	4.60±0.2 <sup>a</sup>
F prob.	NS	NS	0.01	NS	NS

NS: Non-significant at 5%. <sup>§</sup>Means with different letters in the same column are significantly different by Fisher's protected least significant test at  $\alpha = 5\%$  while those with the same letters are not significantly different.

test genotypes for the yield and yield-related traits (Table 4). The mean performances for bunch weight, number of hands, finger circumference and length were higher for the new apple banana genotypes than those of the check cultivars. For instance, the bunch weight was the highest for NAMU2, followed by NAMU1 and least for Sukali ndiizi. The number of hands was the highest for NAMU2, followed by NAMU1 and least for Sukali ndiizi. Fruit finger circumference, however, was the highest for NAMU1, followed by NAMU 2, and least for Sukali ndiizi. Fruit finger length was the highest for NAMU1, followed by NAMU 2 and the least for Sukali ndiizi.

### Genotypes performance for fruit sensory traits

The new apple banana genotypes and check cultivar were only different for pulp color with NAMU1 having the highest score for consumer acceptability (Table 5). Genotypes was not different significantly for the pulp smoothness, taste, smell and general acceptability

## DISCUSSION

The development of high-yielding and disease-resistant

bananas is essential for increased food security, improved human nutrition, and incomes for the farmers. Bananas are being improved for resistance to prevalent stresses, yield and quality by selecting for useful traits, and accumulating desirable genes from genetic resources.

In this research, the hybridisation of Sukali ndiizi with cultivar Rose and TMB2×8075-7 resulted in high-yielding, consumer-acceptable apple banana hybrids with resistance to Foc race 1. Hybridization introduced these agriculturally valuable traits into the progeny of Sukali ndiizi. Cultivar Rose and TMB2×8075-7 used in this breeding program are being used by other dessert banana breeding programs for *Fusarium* wilt resistance breeding.

Resistance of NAMU1 and NAMU2 to Foc race 1 gives assurance to farmers of sustained apple banana production and productivity. In addition, NAMU1 and NAMU2 showed partial and full resistances to black Sigatoka, respectively and good sensory attributes. Black Sigatoka, a leaf spot disease causes reduction in functional leaf area results in a decline in the quality and quantity of the fruit since the fruits of infected plants ripen prematurely before proper filling. The higher performance of NAMU1 and NAMU2 for the number of hands and fruits per bunch, as well as the fruit circumference and

length are of great economic importance to the producers and the market, as the bunch is the commercial unit of apple bananas. Moreover, fruit length and circumference are important criteria for selection of a commercial banana. In addition, of the four banana genotypes evaluated, NAMU1 and NAMU2 were characterized by the highest pseudostem girth, which is associated with plant vigor and cracking resistance of the pseudostem; thus, reflecting the support capacity for the plant and bunch. Genotypes with strong pseudostems are less susceptible to lodging by wind.

The ripe fruits' pulp smoothness, taste and smell of NAMU1 and NAMU2 were acceptable to the consumers and not significantly different from those of Sukali ndiizi. This implied that the new apple banana genotypes were as good as the local commercial Sukali ndiizi. Sensory attributes of crop plants are pertinent to their acceptability and adoption (Barrett et al., 2010). Therefore, since NAMU1 and NAMU2 are more yielding and resistant to Foc race 1 and black Sigatoka compared to Sukali ndiizi, they can be its perfect substitutes.

## Conclusion

The results of this study show prospects for the use of hybrids that can substitute for Sukali ndiizi while increasing productivity not only in Uganda but also in other Sukali ndiizi-growing areas in the Great Lakes region of East Africa with similar production constraints, especially Foc race 1. As NAMU1 and NAMU2 combine resistance to Foc race 1 and black Sigatoka with improved yield and consumer-desired fruit characteristics, they can replace Sukali ndiizi that is adversely affected by Foc race 1. It is recommended that NAMU1 and NAMU2 can be evaluated in multi-location field trials to confirm their stability for yield and Foc race 1.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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