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TARIBAN1, TARIBAN2, TARIBAN3, and TARIBAN4 'Matooke' Cooking Banana Cultivars for the Great Lakes Region of Africa

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Bananas and plantains (*Musa* sp.) are important staple and income-generating fruit crops for millions of people worldwide (Robinson and Saúco 2010; Ssebuliba et al. 2005). They are edible and vegetatively propagated parthenocarpic species (Ortiz 1997; Simmonds 1962). East African highland bananas (EAHBs) are a distinct group of cultivars found only in the highland of African Great Lakes region, where the "greatest mass of bananas in the world" are found (Simmonds 1966). Bananas are important in the food economy of millions of people in this region, with annual per capita consumption estimated to be between 250 and 600 kg (Karamura et al. 2012). These triploid ($2n = 3x = 33$ chromosomes) cultivars are known locally as Matooke. When fully ripe, they can be eaten raw like dessert bananas; however, because their pulp is insipid, they are mostly eaten after cooking. Shepherd (1957) referred to them as the 'Lujugira-Mutika' subgroup of the AAA genome group. They are also known by its acronym (EAHBs) because they thrive on the East African plateau at altitudes ranging from 900 to 1800 m above sea level (Davies 1995). A small group of these EAHBs are processed into a beverage, and called beer or 'Mbidde' bananas.

The major threats to the future sustainability of EAHB production across the region are pests such as banana weevils *Cosmopolites sordidus*, burrowing nematode *Radopholus similis*, black leaf streak (BLS) pathogen *Pseudocercospora fijiensis*, *Fusarium* wilt *oxysporum* f. sp. cubense, and banana bacterial wilt *Xanthomonas campestris* pv. *musacearum* (Tushemereirwe et al. 2015). EAHBs are susceptible to the airborne fungal pathogen *P. fijiensis*, which causes BLS and was previously known as black Sigatoka. The pathogen causes necrotic leaf lesions on the photosynthetic area of the host plant, resulting in fruit yield losses (up to 50%) and poor fruit quality (Craenen and Ortiz 1998; Mobambo et al. 1993; Swennen and Vuylsteke 1991; Swennen et al. 1989; Vuylsteke et al. 1993). Long-term host plant resistance is thought to be the best option for BLS disease control because fungicide-based control is expensive and could be hazardous to human health and the environment (Churchill 2011). Furthermore, large banana plantations elsewhere spend up to US\$1000·ha^{-1} on disease control each year, accounting for up to 30% of total production costs (Alakonya et al. 2018; Churchill 2011).

In 1994, the International Institute of Tropical Agriculture (IITA) and Uganda's National Agricultural Research Organization (NARO) together began to breed EAHBs (Tushemereirwe et al. 2015). Several interploidy crosses between triploid 'Matooke' and the diploid ($2n = 2x = 22$) wild nonparthenocarpic banana 'Calcutta-4' (AA), a donor of BLS resistance, were used to produce primary tetraploid ($2n = 4x = 44$) hybrids; thereafter, they were included in crossing blocks with improved diploid bananas to obtain secondary triploid and tetraploid hybrids (Tushemereirwe et al. 2015). The best EAHB hybrids developed by NARO and IITA were called NARITAs; they were selected based on their bunch weight, host plant resistance to *P. fijiensis*, and fruit quality traits. These were evaluated at five sites over three cropping cycles (mother plant and at least two ratoons) in Tanzania and Uganda. The best four hybrids were released in Tanzania in 2021, as TARIBAN1 (‘NARITA 4’), TARIBAN2 (‘NARITA 7’), TARIBAN3 (‘NARITA 18’), and TARIBAN4 (‘NARITA 23’). They were registered on Tanzania’s national cultivar list, thus becoming available for farmer multiplication and distribution. In Tanzania, their mean yield potential could reach 20.3 $t{\cdot}ha^{-1}$ per year, with their bunches weighing up to 51.0 kg.

Origin. The secondary triploid banana hybrids ‘TARIBAN1’, ‘TARIBAN2’, and ‘TARIBAN3’, and the primary triploid ‘TARIBAN4’, ensued. The parents of the primary tetraploid hybrids (female parents of secondary triploid hybrids) are EAHBs and ‘Calcutta 4’ (C4). C4 (*M. acuminata* ssp. *burmannica*) is an inedible wild diploid banana accession from Myanmar (De Langhe and Devreux 1960) with resistance to BLS (Tushemereirwe et al. 2015) and some nematode species, such as *R. similis* (burrowing nematode) and *P. coffeae* (banana root nematode) (Dochez et al. 2009; Viaene et al. 2000), whereas the EAHBs are farmer cultivars that dominate the African Great Lakes Region, where they are endemic (Karamura 1998; Pillay et al. 2001). TARIBAN1 is a secondary triploid derived from crossing the primary tetraploid ‘660K-1’ (‘Enzirabahima’ × ‘Calcutta 4’) and the IITA’s bred-diploid ‘TMB2 × 9128-3’ (Pillay et al. 2012; Tenkouano et al. 2003). ‘TARIBAN2’ is a secondary triploid that resulted from crossing the primary tetraploid ‘1201K-1’ (‘Nakawere’ × ‘Calcutta 4’) and an improved diploid ‘SH3217’, which was bred by the Fundación Hondureña de Investigación Agrícola in La Lima (Honduras). ‘TARIBAN3’ is a secondary triploid offspring derived from crossing the primary tetraploids ‘365K-1’ (‘Kabucuragye’ × ‘Calcutta 4’) and ‘660K-1’ (‘Enzirabahima’ × ‘Calcutta 4’). TARIBAN4 is a primary triploid derived from crossing the EAHB cultivar Kazirakwe and the IITA’s diploid male parent ‘TMB2 × 7197-2’ (Tushemereirwe et al. 2015).

Crossing and preliminary field trials were conducted at an IITA breeding site in central Uganda (Sendusu 0°31′N, 32°36′E, 1140 m above sea level). This site soil is an isoperthemic Rhodic Kandiudalf/Rhodic Nitisol (United States Department of Agriculture taxonomy/World Referennce Base) with a 4% slope and pH ranging from 5.4 to 6.4 in the upper 20 cm. Sendusu receives 1200 mm of rain each year, which is distributed bimodally. The crossbreeding effort began with the identification of seed-producing ‘Matooke cultivars in NARO and IITA banana germplasm collections in Kawanda and Sendusu, respectively (Batte 2019). Twelve triploid Matooke cultivars were selected, propagated in vitro, planted in the field, and pollinated by hand with C4; primary tetraploid hybrids were produced. These primary tetraploids had residual seed fertility, thus causing low fruit quality because of seed set; therefore, it is unsuitable for eating. This problem was resolved by crossing the primary tetraploids with improved diploids, resulting in seed-sterile secondary triploid hybrids that were selected for their productivity and host plant resistance to BLS (Tushemereirwe et al. 2015). Planting materials from the selected triploid hybrids were multiplied, and the superiority of each hybrid in terms of bunch yield, fruit taste, and response to BLS was evaluated in a series of field trials (Tushemereirwe et al. 2015). The promising secondary and primary triploid hybrids were evaluated and selected for their performance in unreplicated early evaluation trials, then in replicated preliminary yield trials, and finally in advanced yield trials over three cropping cycles in Sendusu and Kawanda. Kawanda lies at an altitude of 1210 m above sea level and at 00°25′N, 00°32′E. It has a bimodal type of rainfall, with the “short” rains beginning in March/April to June, and the “long” rains beginning in August to November/December (Barekye 2009).

The aim of the different stages of evaluation was to identify promising hybrids that could be advanced for cultivar release. From more than 1000 hybrid seeds, 28 hybrid clones were selected and tested during preliminary yield trials, and 18 were selected and tested during advanced yield trials. The 18 crossbred hybrids selected during the advanced yield trials were advanced to multisite testing and on-farm trials for further evaluation and selection in comparison with a local ‘Matooke’ EAHB check known as ‘Mbwazirume’. After several years of intensive testing, 27 superior ‘Matooke’ hybrids were chosen for testing by farmers in a variety of target end-user environments.

Multisite trials involving the Matooke and other banana cultivars were performed in Tanzania from 2016 to 2019, with the aim of selecting breeding clones that combine BLS resistance with steady high production and other desirable traits and that have the potential for adoption by farmers and consumers. The sites were Mitalula, Maruku, and Lyamungo in the northeastern and southern highlands of Tanzania, and the trials were performed by the Tanzania Agriculture Research Institute in collaboration with Bioversity International and IITA. ‘TARIBAN2’, one of the 24 hybrids included in the multisite testing as a hybrid check, was already released by NARO in Uganda under the name ‘Kiwangaazi’ (syn. ‘KABANA 6H’) (Nowakunda et al. 2015). It was released as a new banana cultivar for Tanzania in June 2021, after 3 years of testing.

Four replications of 2 to 3-month-old tissue culture plants were planted in deep holes (≈100 cm deep and 100 cm wide) spaced 3 m apart, resulting in a plant population density of 1152 plants/ha. There were 12 plants per testing clone in each plot, thus having a total of 48 plants for each clone per site. Each hole received 10 kg of well-decomposed organic manure at the time of planting. The design that was used was a randomized complete block design. The testing breeding clones were planted alongside Mbwazirume (EAHB subgroup, AAA genome), a local Matooke cultivar, to compare performance. During the dry season, irrigation was used in Lyamungo and Mitalula, and mulching was used at the Maruku site every year to keep the soil moist. Other management practices aligned with effective crop husbandry practices used by farmers. No chemical or biological pesticides were used.

The youngest leaf spotted (YLS) described by Viljoen et al. (2017) was used to determine host plant resistance to *P. fijiensis* in the field. ‘Williams’, a BLS-susceptible Cavendish dessert banana cultivar, served as the control. Increased YLS readings indicated that the plant had more healthy leaves and, thus, was more resistant to BLS. During flowering, the number of standing leaves and the YLS were recorded. The severity of BLS was determined visually by estimating the leaf area with symptoms for each standing leaf, with 0 indicating no visible symptoms, 1 indicating less than 1% of the leaf area infected, 2 indicating 1% to 5% of the leaf area infected, 3 indicating 6% to 15% of the leaf area infected, 4 indicating 16% to 33% of the leaf area infected, 5 indicating 34% to 50% of the leaf area infected, and 6 indicating 51% to 100% of the leaf area infected (Fig. 1) (Gauhl 1994). To account for genetic differences in the number of standing leaves, the index of nonspotted leaves (INSL) was calculated as follows:

$$\mathrm{INSL} = \left[(\mathrm{YLS} - 1)/\mathrm{NSL}\right] \times 100$$

where YLS and NSL indicate the youngest leaf spotted and the number of standing leaves, respectively. YLS=NSL+1 when the YLS was 0. The INSL represents the proportion of standing leaves that do not exhibit severe BLS symptoms (Craenen and Ortiz 1998).

We used the protocols of Swennen and De Langhe (1985) to evaluate growth and yield characteristics throughout the crop cycle. The yield potential (tonnes/hectare per year) was calculated using data from the first two crop cycles as follows:

$$\mathrm{YLD} = \mathrm{BW} \times 365 \times \mathrm{PD}/(\mathrm{DH} \times 1000)$$

where BW and DH are bunch weight per plant and days to harvest, respectively, and 365 and PD are days per year and plant density per hectare, respectively (Ortiz 1997; Swennen and De Langhe 1985; Tenkouano et al. 2019). The weight of the bunch was determined using a hanging spring scale with a

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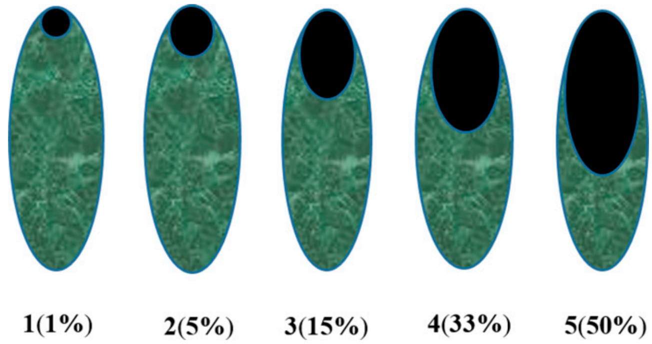

Fig. 1. Black leaf streak (BLS) severity scoring to estimate the infection caused by *P. fijiensis* on a single banana plant (Viljoen et al. 2017). The percentage of banana leaf area infected by BLS is shown in black. The remaining uninfected leaf area is shown in green.

genotypes, as determined by the percentage of INSL (Table 1). The INSL of TARIBAN3 was lower than that of Mbwazirume, but it exceeded the 70% threshold required for a banana cultivar to be considered resistant. Furthermore, when compared with 'Mbwazirume', 'TARIBAN' hybrids may gain at least one extra leaf without BLS spotting (Table 1). The host response to BLS in the selected germplasm is characterized by slow or delayed disease development, which entails a long incubation period (time between infection and symptom emergence), as well as effective suppression of symptom progression and spread.

The 'TARIBAN' hybrids resemble their female parents in terms of phenotype, with a

Table 1. Mean performance of the four 'Matooke' cooking banana cultivars 'TARIBAN' released in Tanzania averaged over the first two crop cycles.

Cultivar	Parents	Bunch wt (kg/plant)	Yield potential (tonnes/hectare per yr)	Plant ht (cm)	Plant girth (at 100 cm)	Functional leaves at flowering	Youngest leaf spotted (YLS) at flowering	Index of nonspotted leaf (INSL) at flowering
'TARIBAN1'	660K-1 × 9128-3	26.9	15.7	277.0	51.1	9.6	10.8	99.7
'TARIBAN2'	1201K-1 × SH3217	34.2	16.5	382.0	54.0	11.0	10.7	86.8
'TARIBAN3'	365K-1 × 660K-1	26.5	16.0	259.0	51.7	10.0	9.7	73.2
'TARIBAN4'	'Kazirakwe' × 7197-2	32.7	20.3	277.0	57.5	9.9	11.1	89.1
'Mbwazirume'	East African cultivar	15.8	10.6	243.0	51.2	8.8	8.9	75.6
Multisite mean		27.2	15.8	287.6	53.1	9.9	10.2	84.9
SE of differences[i]		6.5	5.2	20.6	7.5	0.7	0.8	3.6
ANOVA F probability[ii]		0.001	0.01	<0.001	0.01	0.001	<0.001	<0.001
Coefficient of variation		43.0	54.1	16.1	21.3	35.1	39.5	22.6

[i] *SE* of differences as estimated using the mean square error of the analysis of variance (ANOVA).

[ii] Probability of the F-test from the ANOVA.

capacity of 300 kg suspended on a tripod stand.

A panel of more than 300 banana farmers from three Tanzanian sites completed the consumer acceptability tests of the cooked hybrid by scoring it using a scale of 1 to 5, with 1 indicating extreme dislike (i.e., very bad) and 5 indicating extreme liking (i.e., very good) based on the sensory attributes of taste, aroma, mouth feel (or texture in the mouth), color, texture in hand, and overall acceptability (Marimo et al. 2020; Nowakunda and Tushemereirwe 2004). Tanzanian farmers evaluated boiled fruit as the main product. Farmers at Lyamungo also evaluated the fruit as machalari (i.e., chopped bananas boiled with meat and other ingredients) and mtori (i.e., boiled banana mixed with meat and smashed after cooking to make a thick porridge). The final selection of prospective 'Matooke' hybrids was guided by a product profile that includes host plant resistance to BLS, culinary acceptability, and bunch weight significantly higher than the standard local check 'Mbwazirume'.

Description and performance. The average bunch weight of four triploid hybrids across sites ranged from 26.5 to 34.2 kg, with potential yields ranging from 16.0 to 20.3 $t{\cdot}ha^{-1}$ per year. 'TARIBAN2' had the largest bunch weight (34.2 kg) of the four hybrids, followed by 'TARIBAN4', 'TARIBAN1', and 'TARIBAN3' (Table 1). The bunch weight of the check cultivar, Mbwazirume, was 15.8 kg, thereby demonstrating that the 'TARIBAN' hybrids have a heavier bunch weight. Cultivars with a huge bunch are preferred by banana growers, traders, and domestic users because they command a high market price and, hence, boost family income (Dadzie and Orchard 1997; Ssemwanga et al. 2000). The four hybrids have a pendulous compact bunch with more fruit per bunch, as well as heavy and large fruit. With the exception of 'TARIBAN3', which produces few suckers and takes a long time to sprout, all four hybrids have good suckering potential.

The assessment of the YLS at flowering in the three Tanzanian sites revealed that three of the four 'TARIBAN' hybrids had higher levels of BLS resistance than their susceptible EAHB parents and their reference medium to tall plant size, rapid cycling (with the exception of 'TARIBAN3', which has a longer growth cycle), and higher fruit productivity, all of which are highly desirable traits for banana production by farmers. Additionally, they produce parthenocapic fruit with an erect curved fruit orientation (Fig. 2). Three of the four 'TARIBAN' hybrids have a height shorter than 350 cm (Table 1), which is the maximum indicated in 'Matooke' product profiles. 'TARIBAN1' and 'TARIBAN4' have the shortest plant height (277 cm) of the four triploid hybrids, whereas 'TARIBAN2' is the tallest, surpassing the product profile threshold by 32 cm. 'TARIBAN2' is also

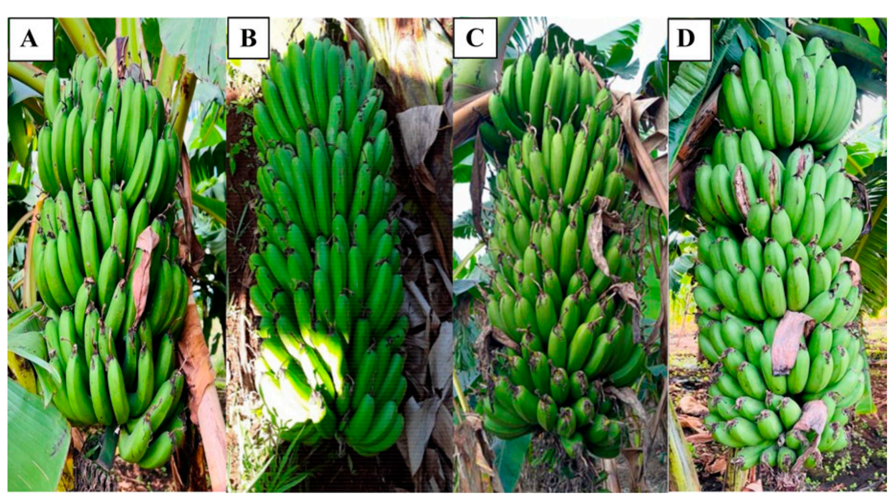

Fig. 2. Bunches of the four new Matooke cooking banana cultivars released by the Tanzania Agriculture Research Institute (TARI) in June 2021: (**A**) 'TARIBAN1'; (**B**) 'TARIBAN2'; (**C**) 'TARIBAN3'; and (**D**) 'TARIBAN4'.

Table 2. Morphological characteristics distinguishing four Matooke cooking banana cultivars (TARIBAN) released in Tanzania.

	Cultivar			
Descriptor	'TARIBAN1'	'TARIBAN2'	'TARIBAN3'	'TARIBAN4'
Fruit shape	Straight (or slightly curved)	Straight (slightly curved)	Straight (slightly curved)	Straight (or slightly curved)
Fruit apex	Pointed	Blunt-tipped	Blunt-tipped and remains of flower relicts	Blunt-tipped
Rachis position	Falling vertically	With a curve	With a curve	Falling vertically
Rachis appearance	Male flowers/bracts above the male bud	Neutral/flowers and presence of withered bracts	Male flowers/ bracts above the male bud	Neutral
Pseudostem color (with sheath)	Medium green	Green	Dark green	Black green
Pigmentation of the underlying pseudostem	Pink-purple	Purple	Red-purple	purple-brown
Blotches at the petiole base	Large blotches	Large blotches	Large blotches	Extensive pigmentation
Male bud peduncle color	Dark green	Green	Green	Dark green
Male bud shape	Intermediate	Ovoid	Intermediate	Ovoid
Bract apex shape	Obtuse	Slightly pointed	Slightly pointed	Obtuse

Table 3. Sensory attributes and mean performance of Matooke cooking banana cultivars (TARIBAN) released in Tanzania.

	Fruit sensory attributes[i]					
Cultivar	Color	Aroma	Taste	Mouthfeel	Texture	Overall acceptability
'TARIBAN1'	3.86	3.81	3.56	3.26	3.29	3.58
'TARIBAN2'	3.60	3.70	3.54	3.50	3.43	3.57
'TARIBAN3'	3.73	3.86	3.86	3.87	3.83	3.91
'TARIBAN4'	3.14	3.41	3.21	3.05	3.03	3.27
'Mbwazirume'	4.21	4.02	4.03	3.96	3.90	4.15
Multisite mean	3.71	3.76	3.64	3.53	3.49	3.70
SE of differences[ii]	0.19	0.11	0.19	0.23	0.23	0.19
ANOVA F probability[iii]	<0.001	<0.001	<0.01	<0.01	< 0.01	< 0.01
Coefficient of variation	11.20	6.34	9.50	12.00	11.60	9.85

[i] Hedonic scale of 1 to 5, where 1 = very bad, 2 = bad, 3 = fair, 4 = good, and 5 = very good.
[ii] *SE* of differences estimated from the mean square error of the analysis of variance (ANOVA).
[iii] Probability of the F-test from the ANOVA.

known for its larger girth (54 cm). Nowakunda et al. (2015) reported comparable results with the official release of Kiwangaazi in Uganda (TARIBAN2 in Tanzania), claiming it is a tall cultivar with a plant height of more than 3 m. Tall banana plants are normally vulnerable to windbreak, but 'TARIBAN2' is protected by its larger girth of more than 50 cm at a height of 1 m. The 'TARIBAN' cultivars have regulated suckering behavior, with only a few suckers escaping apical dominance and developing into the ratoon crop. Table 2 lists the key characteristics that distinguish them based on the International Plant Genetic Resources Institute (1996) standard descriptor list for bananas.

To meet end-user demand, hybrids must show a balance among high yield, host plant resistance to pests and pathogens, and desired culinary quality (Nowakunda and Tushemereirwe 2004). The sensory characteristics of the hybrids were closest to those of 'Mbwazirume' for color, aroma, taste, mouthfeel, texture, and overall acceptability (Table 3). Mbwazirume is one of the most popular consumer-preferred Matooke cooking banana cultivars because of the high-quality attributes of its cooked food.

Availability. 'TARIBAN1', 'TARIBAN2', 'TARIBAN3', and 'TARIBAN4' are available from TARI at its subcenters of Horti-Tengeru, Maruku, and Mitalula in Tanzania. Additionally, tissue culture plantlets are available from designated private tissue culture laboratories in Tanzania. The National Banana Research Program of NARO in Kawanda, Uganda, is responsible for maintaining the 'TARIBAN' (or 'KABANA') in Uganda at on-station fields and in vitro. They are accessible through NARO and specific domestic private tissue culture enterprises.

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