New High-yield Cooking Banana Cultivars with Multiple Resistances to Pests and Diseases (‘NAROBan1’, ‘NAROBan2’, ‘NAROBan3’, and ‘NAROBan4’) Released in Uganda

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‘NAROBan1’, ‘NAROBan2’, ‘NAROBan3’, and ‘NAROBan4’ are secondary triploid cooking banana cultivars. They were bred by the National Agricultural Research Organisation (NARO) in Uganda, and officially released and added to the national cultivar list by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) in 2017. The cultivars are highly resistant to black Sigatoka, a fungal disease caused by *Mycosphaerella fijiensis* (Morelet), which was the main breeding target. In addition, they are resistant to the banana weevil *Cosmopolites sordidus* (Germar) and nematodes, the pests of most economic concern in banana production, especially in the lowland areas of central and eastern Uganda. Compared with the local cultivars, which have an average bunch yield of less than 30% of their potential of 60 to 70 t/ha/year, ‘NAROBan1’, ‘NAROBan2’, ‘NAROBan3’, and ‘NAROBan4’ produce average bunch yields of 54.9 t/ha/year, 60.4 t/ha/year, 64.7 t/ha/year, and 68.8 t/ha/year, respectively. Moreover, they have soft, tasty, aromatic, and near-yellow food color, which make them appreciated like the existing farmer-accustomed local cooking banana cultivars that have, however, a low yield and are susceptible to pests and diseases.

Origin

Banana (*Musa* spp.) is an important food and cash crop grown extensively in the tropical and subtropical regions of the world (FAOSTAT, 2016). In Uganda, the cooking type of banana commonly known as East African highland banana occupies the largest cultivated area among staple food crops and is grown by more than 75% of the farmers. The current productivity of cooking banana cultivars in the country is less than 30% of their potential of 60 to 70 t/ha/year (Tushemereirwe et al., 2001). Moreover, their plantation life in some areas of Uganda has reduced enormously to less than 5 years (Tushemereirwe et al., 2001). The reduced productivity and plantation life are largely attributed to susceptibility of the local cultivars to the banana weevil *Cosmopolites sordidus* (Germar), burrowing nematodes, and black Sigatoka (Brown et al., 2017). One of the key strategies for addressing these challenges in the country is by developing resistant cultivars through breeding. This article presents four new cooking banana cultivars (NAROBan1, NAROBan2, NAROBan3, and NAROBan4) bred and released in Uganda.

‘NAROBan1’, ‘NAROBan2’, ‘NAROBan3’, and ‘NAROBan4’ (Fig. 1) are secondary triploid banana hybrids derived from inter-specific interploidy crosses made by scientists of NARO in Uganda. ‘NAROBan1’ originated from a cross of ‘917K-1’ (‘Enzirabahima’ × ‘Calcutta4’) × ‘SH3217’, ‘NAROBan2’ from ‘365K-1’ (‘Kabucuragye’ × ‘Calcutta4’) × ‘SH3362’, ‘NAROBan3’ from ‘917K-2’ (‘Enzirabahima’ × ‘Calcutta4’) × ‘SH3217’ and ‘NAROBan4’ from ‘246K-1’ (‘Kabucuragye’ × *Musa balbisiana*) ×

‘TMB2X7197-2’. Four hundred botanical seeds of each cross were harvested and their embryos germinated in vitro as described by Vuylsteke et al. (1990). A total of 500 hardened seedlings pooled from all the crosses were established in a single-site, nonreplicated, on-station early-evaluation trial at the National Agricultural Research Laboratories-Kawanda, Uganda, from 2005 to 2008. Fifteen cooking-type triploid hybrid bananas identified by flow cytometry (Karamura et al., 2016), with pendent bunches, resistance to black Sigatoka, and a bunch weight of ≥10 kg/plant were selected and multiplied in vitro for further evaluation in replicated randomized complete block design (RCBD) preliminary yield trials (PYTs) at three locations. The PYTs were established in 2009 and the hybrids were evaluated for bunch yield; response to black Sigatoka, weevils, and nematodes; and consumer acceptability for three cycles. Four promising hybrids combining high bunch yield; resistance to black Sigatoka, weevils, and nematodes; and high-quality fruit attributes were selected from PYTs of the 15 hybrids evaluated. The four hybrids selected, together with four other closely similar and already adopted cultivars (Kisansa, Enjagata, Mbawazirume, and Kabana 6H), were further evaluated in six regional on-farm trials in Nakabango, Nakaseke, Mukono, Ntungamo, Hoima, and Kawanda for two ratoon crop cycles from 2014 to 2017. The average rainfall received in Nakabango was 1150 mm; Nakaseke, 1240 mm; Mukono, 1390; Ntungamo, 900 mm; Hoima, 1371 mm; and Kawanda, 1280 mm. The trial at each site was laid out in an RCBD, with three replications using 2-month-old tissue culture plants that were planted in deep holes (0.4 m deep and 0.6 m wide) spaced at 3 × 3 m, giving a plant population density of 1111 plants/ha. Line plots of eight plants per genotype per block were used. At planting, 5 kg of well-decomposed organic manure were applied to each hole. Blocks were surrounded by ‘Mbawazirume’, a check cultivar susceptible to black Sigatoka, weevils, and nematodes. The trials were conducted without supplemental irrigation and the areas were weeded regularly. The new hybrids were evaluated under codes M19, M20, M25, and M27, and later released by MAAIF in 2017 as ‘NAROBan1’, ‘NAROBan2’, ‘NAROBan3’, and ‘NAROBan4’, respectively. ‘NAROBan’ denotes the institution NARO, which developed these hybrids. Genotypic response to black Sigatoka infection as the main target constraint was assessed using the index of nonspotted leaf (INSL) as described by Orjeda (1998). Their response to weevil damage was assessed according to Gold et al. (1998), and that of nematode damage according to Speijer and De Waele (2001). Growth and yield parameters were evaluated at flowering and at harvest according to Swennen and De Langhe (1985). Consumer acceptability tests of the genotypes’ cooked food were completed by a panel of 60 trained banana farmers (35 women and 25 men)

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Fig. 1. Bunches of the four new cooking banana cultivars released in Uganda in 2017: (A) NAROBan1, (B) NAROBan2, (C) NAROBan3, and (D) NAROBan4.

Table 1. Mean performance of eight banana cultivars, including new hybrids, evaluated for bunch yield, number of hands, plant height, plant girth, number of functional leaves, and index of nonspotted leaf across two ratoon crop cycles and six sites in Uganda from 2014 to 2017.

Genotype	Bunch yield (t/ha/yr)	No. of hands	Plant ht (cm)	Plant girth (cm)	No. of functional leaves	Index of nonspotted leaf
NAROBan1 (M19)	54.9	10.5	281.1	48.0	12.8	76.1
NAROBan2 (M20)	60.4	10.1	320.0	55.4	11.6	77.9
NAROBan3 (M25)	64.7	10.3	339.9	53.8	11.4	82.9
NAROBan4 (M27)	68.8	11.0	341.8	56.3	11.0	78.4
Kabana 6H (M9)	60.0	9.7	341.0	54.6	11.9	76.2
Mbwazirume	24.3	8.5	255.1	51.4	8.2	48.2
Enjagata	23.4	7.4	281.3	46.2	7.0	46.3
Kisansa	34.4	8.0	280.6	45.1	9.0	41.9
Mean	48.9	9.4	305.1	51.4	10.4	66.0
LSD _{0.05}	2.9	0.3	14.2	1.8	0.53	4.0
F-probability	<0.001	0.001	<0.001	<0.001	<0.001	<0.001

LSD = least significant difference.

Table 2. Mean performance of seven cultivars evaluated for cross-sectional corm damage by weevils, and percentage of root necrosis by nematodes for two ratoon crop cycles at the National Agricultural Research Laboratories-Kawanda in Uganda from 2014 to 2017.

Cultivar	Total cross-sectional damage to corm by weevils (%)	Root necrosis by nematodes (%)
NAROBan1 (M19)	3.85	7.3
NAROBan2 (M20)	2.01	2.9
NAROBan3 (M25)	4.07	5.6
NAROBan4 (M27)	5.61	4.4
Kabana 6H (M9) (Hybrid check)	4.13	6.3
Mbwazirume (Susceptible local check)	10.32	16.9
Yangambi-KM5 (Resistant local check)	0.28	4.1
Mean	4.32	6.8
LSD _{0.05}	2.91	8.9
F-probability	<0.001	0.03

LSD = least significant difference.

Table 3. Mean performance of the four new cooking banana cultivars, local check cultivar 'Mbwazirume', and hybrid check cultivar 'Kabana 6H' evaluated for fruit sensory attributes across two ratoon crop cycles and six sites in Uganda from 2014 to 2017.

Cultivar	Fruit sensory attributes ^a				Overall acceptability
	Taste	Aroma	Mouth feel	Color	
NAROBan1 (M19)	5.17	4.87	4.83	4.87	5.03
NAROBan2 (M20)	5.24	4.83	4.87	4.53	4.87
NAROBan3 (M25)	4.22	4.33	4.53	3.27	4.13
NAROBan4 (M27)	4.87	5.33	5.23	5.53	5.13
Kabana 6H (M9)	4.13	4.23	4.43	3.33	4.03
Mbwazirume	5.73	5.52	5.63	5.63	5.63
Mean	4.89	4.86	4.92	4.53	4.81
LSD _{0.05}	0.11	0.09	0.09	0.10	0.09
F-probability	<0.001	<0.001	<0.001	<0.001	<0.001

^aHedonic scale of 1 to 6, where 1 = dislike extremely, 2 = dislike, 3 = like fairly, 4 = like, 5 = like very much, and 6 = like extremely.

LSD = least significant difference.

based on five sensory attributes—taste, aroma, mouth feel, color, and overall acceptability—using a scale of 1 to 6, where 1 = dislike extremely, 2 = dislike, 3 = like fairly, 4 = like, 5 = like very much, and 6 = like extremely. Data collected across six

sites and two ratoon crop cycles were averaged and analyzed using GenStat, version 14 (Payne et al., 2011). Trait means were separated using least significance differences at $P < 0.05$ (Payne et al., 2011).

Description

The field trial performance results (Table 1) show that 'NAROBan1', 'NAROBan2', 'NAROBan3', and 'NAROBan4' are medium to tall cultivars with wide pseudostem

Table 4. Key descriptive features of four new cooking banana cultivars released in Uganda in 2017.

Character	Cultivar			
	NAROBan1 (M19)	NAROBan2 (M20)	NAROBan3 (M25)	NAROBan4 (M27)
Leaf habit	Drooping	Spreading	Drooping	Spreading
Pseudostem color (with sheath)	Green	Green-yellow	Green	Red-purple
Predominant underlying color of the pseudostem	Pink-purple	Pink-purple	Pink-purple	Red-purple
Blotches at the petiole base	Large blotches	Large blotches	Large blotches	Large blotches
Male bud peduncle color	Green	Dark green	Dark green	Dark green
Bunch position	Hanging at an angle	Hanging at an angle	Hanging at an angle	Hanging at an angle
Bunch shape	Conical	Cylindrical	Cylindrical	Conical
Bunch compactness	Medium	Lax	Lax	Compact
Rachis orientation of male phase	Hanging vertically	Inclined at an angle	Hanging vertically	Horizontal with inclined end
Male bud shape	Ovoid	Triangular	Lanceolate	Ovoid
Bract apex shape	Slightly pointed	Pointed	Pointed	Pointed
Fruit shape	Straight in the distal part	Straight in the distal part	Slightly curved	Slightly curved
Fruit apex	Bottle-necked	Blunt tipped	Pointed	Bottle-necked
Persistence of floral organs	Absent	Absent	Absent	Absent

girths, high bunch yields and a resistance to black Sigatoka. The average bunch yield of 'NAROBan1' is 54.9 t/ha/year; 'NAROBan2', 60.4 t/ha/year; 'NAROBan3', 64.7 t/ha/year; and 'NAROBan4', 68.8 t/ha/year. These yields are much greater than those of the local check cooking banana cultivars (Mbawazirume, Enjagata, and Kisansa), which range from 23.4 t/ha/year for 'Enjagata' to 34.4 t/ha/year for 'Kisansa' (Table 1). Production of high bunch yield is one of the most important selection criteria considered by farmers when deciding on cultivars for cultivation (Akankwasa et al., 2013). Of the four new cultivars, 'NAROBan4' is the tallest, with an average pseudostem height of 341.8 cm, followed by 'NAROBan3' with 339.9 cm and 'NAROBan2' with 320.0 cm. 'NAROBan1', on the other hand, is the shortest cultivar, with a desirable average pseudostem height of 281.1 cm. Although tall banana plants (>300 cm) are not desirable because of their vulnerability to wind breaks, 'NAROBan4', 'NAROBan3', and 'NAROBan2' have correspondingly wide, robust pseudostem girths of more than 53 cm, which are able to support their heavy bunches. All of the four new cultivars have greater levels of black Sigatoka resistance than their counterpart local cooking cultivars already widely grown by farmers (Table 1). The resistance of new cultivars to black Sigatoka was determined by an INSL value of more than 70% compared with that of local check cultivars, which was less than 50% (Table 1). Orjeda (1998) revealed that bananas require more than 70% of active leaf foliage at flowering for proper development of the banana fruit. Black Sigatoka, a wind-borne fungal disease, attacks the banana leaves, causing a decrease in functional leaf area, which results in a decline in the quality and quantity of the fruit because the fruit of infected plants ripen prematurely before proper filling (Daniells, 2009). Resistance to black Sigatoka results from the interaction between a major recessive gene and two modifiers with additive effects (Vuylsteke et al., 1993). Furthermore, the performances of 'NAROBan1', 'NAROBan2', 'NAROBan3', and 'NAROBan4' for resistance to banana weevils and nematodes are close to that of 'Yangambi-KM5', a check

cultivar resistant to banana weevils and nematodes, implying they are resistant to weevils and nematodes (Table 2). The new cultivars also have high consumer acceptable fruit sensory attributes—namely, yellow, aromatic, tasty, and soft upon cooking (Table 3). During the sensory assessments, their overall acceptance was closest to that of 'Mbawazirume', the most acceptable local cooking banana cultivar for sensory attributes (Table 3). Akankwasa et al. (2013) revealed that, for a new banana cultivar to satisfy end user needs, it must be balanced in terms of bunch yield, resistance to pests and diseases, and sensory attributes. Certainly, the new cultivars combine high bunch yield with multiple resistances to black Sigatoka, weevils, and nematodes (especially *Radopholus similis*), and good sensory attributes. Banana weevils and nematodes have been underlined as the most economically concerning pests of banana production, reducing its plantation life and productivity, especially in the lowland areas of east and central Uganda (Tushemereirwe et al., 2001). The key descriptors of 'NAROBan1', 'NAROBan2', 'NAROBan3', and 'NAROBan4' that make them distinct from other close cooking banana cultivars are presented in Table 4.

Availability

'NAROBan1', 'NAROBan2', 'NAROBan3', and 'NAROBan4' are officially released banana cultivars being maintained in on-station fields and in vitro by the National Banana Research Program of NARO in Kawanda, Uganda. They can be accessed through NARO and designated private tissue culture laboratories in the country.

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