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Agronomic performance of provitamin A-rich banana cultivars in Burundi and the Democratic Republic of Congo

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Vitamin A deficiency (VAD) is a major global health issue, contributing to morbidity and mortality. East and Central Africa face VAD prevalence that exceeds the World Health Organization (WHO) threshold of 15%. In Burundi and the Democratic Republic of Congo (DRC), VAD prevalence is greater than 43% in rural communities. Promoting vitamin A-rich foods (including banana) is an effective and sustainable strategy to address VAD in poor rural communities. Supported principally by HarvestPlus over more than a decade, banana researchers have been evaluating the performance of high provitamin A banana cultivars to address this challenge. This study evaluated the agronomic performance of six provitamin A-rich banana cultivars originally from outside Burundi and Eastern DRC. Growth and yield parameters were collected for the first, second and third crop cycles. Results revealed that growth and yield parameters were significantly affected by the interaction between sites and cultivars ($P < 0.05$). Banana cultivar yield was also influenced by the combined effect of bunch weight and crop cycle duration. The most promising cultivars in terms of yield were 'Apantu-AAB', 'Lahi-AAB', 'Lai-AA', 'Bira-AAB' and 'Pelipita-ABB' across all sites and crop cycles. This indicates that although ecological factors could have influenced their performances over sites, genotype could be the most important influencing factor. These evaluations provide hard evidence of the high potential for adoption of the most promising cultivars by the local community members to boost (pro) vitamin A consumption and effectively eliminate VAD.

Key words: Agronomic performance, vitamin A rich banana, crop cycle, Burundi, Democratic Republic of Congo.

INTRODUCTION

Hidden hunger, caused by low intake and absorption of micronutrients especially iron, vitamin A, iodine and zinc,

is a form of under-nutrition affecting over 2 billion people worldwide (Ekhoulouenatale et al., 2020). It has far-

reaching effects such as poor health, mental and physical impairment, low human productivity and even death (Kennedy et al., 2003). Lack of diet diversification, diseases, and increased micronutrient needs during infancy, pregnancy, and lactation are some of the factors that contribute to hidden hunger in many developing countries (Frison et al., 2011; Thompson and Cohen, 2012). Among these, is vitamin A deficiency (VAD) which significantly affects children under five and women of reproductive age with a prevalence for children of 48% in sub-Saharan Africa, 43% in Burundi and 42% in the Democratic Republic of Congo (DRC) (Stevens et al., 2015).

To address this, supplementation, fortification, bio-fortification, dietary diversification and public health and disease-control measures have been implemented (Greiner, 2013; Kennedy et al., 2003; Ruel and Levin, 2001; Thompson and Amoroso, 2014). Food-based approaches that promote production and consumption of vitamin A-rich foods were noted to be sustainable particularly among rural poor communities (Greiner, 2013; Thompson and Amoroso, 2014). The common foods that have been promoted as good sources of vitamin A (pro-vitamin A carotenoids (pVACs)) have been dark green leafy vegetables, red palm oil, yellow and orange fruits, and orange-fleshed sweet potatoes (Greiner, 2013; Uusiku et al., 2010). There is currently an increasing interest in using potential staple foods like bananas, maize, cassava, rice, and potatoes that have higher than average levels of pVACs; (Greiner, 2013; Tang et al., 2009). Among the staple foods, bananas are exceptional because the carotenoids in bananas have higher bio-accessibility compared to roots, tubers and some vegetables (Ekesa et al., 2012; Failla et al., 2009).

Over 17 million tonnes of bananas are annually produced in East and Central Africa, mostly being East African Highland cooking bananas consumed as a staple (Mbwika, 2009; Ordonez et al., 2015; Tripathi et al., 2009). Regionally, bananas are a major source of livelihood for over 20 million people and play a significant role in households' and pre-school children's diets (Ekesa et al., 2013; Karamura and Gold, 2000). In addition, there are banana cultivars around the world that contain high pVACs levels (up to 61.10 µg) (Davey et al., 2009; Ekesa et al., 2013; Englberger et al., 2003; Fungo and Pillay, 2011). Some banana cultivars have been estimated to meet over 50% of the Vitamin A requirements of women when 3-5 fingers are consumed daily (Ekesa et al., 2015; Englberger et al., 2006). These banana cultivars with higher pVACs levels could help address and prevent VAD in East and Central Africa. However, acceptance and adoption of introduced banana cultivars do not rely solely on nutritional importance and familiarity with the

crop, but is also greatly influenced by the production characteristics like yield, bunch weight, finger size, disease and pest resistance and sensory attributes (Akankwasa et al., 2013; Barekye et al., 2013; Kikulwe et al., 2011). This study therefore evaluated the agronomic performance of selected pVAC-rich banana cultivars originally from outside the Eastern Africa region to establish their potential for inclusion in the farming systems of Burundi and Eastern DRC.

MATERIALS AND METHODS

Six sites, one in Burundi, and five in DRC, were purposively selected for the study based on different agroecological zoning with contrasting altitudes, rainfall and soil characteristics. These sites were Cibitoke (Burundi), Butembo, Maboya and Mavivi (North Kivu-DRC), Mulungu and Mushweshwe (South Kivu-DRC) (Table 1).

Six pVAC-rich banana cultivars namely 'Apantu'-AAB African plantain originally from Ghana, 'Bira'-AAB Pacific plantain from Papua New Guinea, 'Pelipita'-ABB plantain from the Philippines, 'Lahi'-AAB Pacific plantain from Hawaii, 'Lai'-AAA Dessert banana from Thailand and 'To'o'- AA Dessert banana from Papua New Guinea with Provitamin A carotenoids (pVAC) retinol activity equivalents >333µg/100gdw were selected for fast-tracking. The six cultivars were ordered from Bioversity International's International Transit Centre (ITC) in Leuven, Belgium and sent to Burundi's tissue culture (TC) laboratory, Phytolab for planting material multiplication. The hardening of TC plantlets was done in Phytolab for the Burundi site, at the Catholic University of Graben Butembo for the North Kivu sites, and at the National Institute of Agronomic Studies and Research (INERA) Mulungu for the South Kivu sites. At three months, fifteen plants of each cultivar (in three replicates of five plants) were planted at each experimental site for agronomic evaluation. Plants were spaced at 3x2 m, providing a density of 1,667 plants/ha. The size of the planting hole was 60 x 60 x 60 cm and 10 kg of rotted cow manure was applied to each planting hole during planting. Weeding was carried out at three-monthly intervals, while de-suckering and de-leaving of dead leaves were conducted as needed. Three stems were kept per mat (mother plant, first sucker and second sucker) except for the third cropping cycle of 'Lahi' in Burundi which was missing due to its genetic degeneration. Mulching was carried out at the beginning of each dry season (once a year). Where necessary, forked wooden sticks were used to support mature plants bearing heavy bunches to prevent toppling.

Agronomic data were collected on banana growth at the flowering stage and yield at harvest over the three cropping cycles (C1: mother plant, C2: first sucker and C3: second sucker). Data collected on banana growth included the height of pseudostem (cm), girth of pseudostem at 1m from the base and the number of functional leaves. Banana height and girth are important traits that indicate the potential of resistance of the plant to strong wind (lodging-resistance), whereas functional leaves contribute to the photosynthesis process of the plant for optimal growth and productivity. Plant height was measured from soil level to the point where the leaf petioles of the youngest two leaves intersect, while the total number of functional leaves was determined by counting all the existing green leaves on a plant that had at least 50% green leaf lamina surface area. Data collected on banana yield at harvest were the weight of bunch (kg), number of hands in a bunch, number

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Table 1. Geographical Coordinates, annual rainfall and soil characteristics of the study sites.

Attribute		Burundi		North Kivu		South Kivu	
		Cibitoke	Butembo	Maboya	Mavivi	Mulungu	Mushweshwe
Geographical coordinates	Latitude	N 2.7714	N 0.11786	N 0.25019	N 0.56903	S 2.3345	S 2.31161
	Longitude	E 29.1172	E 29.25869	E 29.32986	E 29.47894	E 28.79197	E 28.89186
	Altitude(masl)*	925	1815	1412	1066	1707	1528
Rains	Annual rainfall (mm)	1245	1058	1275	1389	1043	1043
Soil characteristics	Om (%)	6.2	4.8	6	3.6	7.2	4.8
	pH	7.07	5.9	5	6.5	6.2	5.5
	N (%)	0.33	0.25	0.3	0.2	0.32	0.22
	P (mg/kg)	8.82	28.1	6.1	4.4	118.9	12.4
	Ca (cmolc/kg)	3.37	2.72	0.81	3.98	6.16	1.4
	Mg (cmolc/kg)	1.88	0.75	0.18	0.51	1.08	0.42
	K (cmolc/kg)	0.91	0.49	0.09	0.16	0.83	0.46
	Soil texture	Clay	Sandy clay	Clay	Sandy loam	Heavy clay	

*masl: meters above sea level; Om: organic matter; pH: potential Hydrogen; N: Nitrogen; P: Phosphorus; Ca: Calcium; Mg: Magnesium; K: Potassium.

of fruits in lower row of second lowest hand, and total number of fruits in the bunch. Mature bunches were harvested when the fingers of the second lowest hand had attained a round shape (Ndayitegeye et al., 2017). Bunch weight was measured with a spring balance.

Statistical analysis was carried out using Statistics Analysis System (SAS Institute Inc., 2008) (Shim et al., 2014). The General Linear Model procedure was used to analyze the data and Tukey's student range test was used for multiple comparisons. The average annual yield was calculated using the formula: "Bunch weight/number of days to harvest x 365 x plant density ha⁻¹" where 365 are the number of days in a year (Gaidashova et al., 2010). Averages for various growth and yield traits were computed across the three cropping cycles and compared between the three regions.

RESULTS

Overall cultivars' growth performance at flowering across sites

Within cultivars and across sites, the growth performance differed significantly ($P < 0.05$) (Table 2). The tallest cultivar was 'Pelipita' with a height of 346 cm recorded in the Burundi site which had the lowest altitude; followed by 'Lai' in Burundi and in South Kivu, with the heights of 342 cm and 341 cm, respectively. The most robust plant girths at 1 m level were generally recorded in the mid-altitude sites (1431 m.a.s.l) of North Kivu, with 71, 66, 65 and 64 cm, for Lai, 'Lahi', 'Pelipita' and 'Bira' respectively (Table 2). In addition, it was noticed that 'Lai' produced plants with bigger girth than other cultivars across sites with averages of between 60 and 71 cm across sites (Table 2).

The shortest plants were produced by 'Lahi' in Burundi (925 m.a.s.l), with height averaging 175 cm; whereas 'To'o' generally produced the shortest plants across sites, with 273, 242 and 237 cm in South Kivu, North Kivu and

Burundi sites respectively. Furthermore, 'To'o' recorded the least robust plant with a girth averaging 37 to 49 cm across sites (Table 2). The cultivar with the highest number of leaves at flowering stage was 'Lahi' in South Kivu, producing an average of 11 leaves, followed by 'Pelipita' in South Kivu and in Burundi. The lowest number of functional leaves was produced by 'To'o' and 'Apantu' in North Kivu (Table 2).

Cultivars' growth performance at flowering within cropping cycles

Within crop cycles, the height of the evaluated cultivars differed significantly ($P < 0.05$) (Table 3). In Burundi in cycle 1, the tallest cultivars were 'Bira' (291 cm), 'Lai' (289 cm) and 'Pelipita' (290 cm). 'Lai' was recorded as the tallest cultivar in each of the three crop cycles in Burundi. Pelipita was also identified as one of the tallest cultivars in the 2nd and 3rd cycles (364 - 386 cm), while the shortest cultivar was 'To'o' in all three cycles. In North Kivu, the tallest cultivars were 'Lai' in cycle 1, 'Bira' and 'Pelipita' in cycle 2 and cycle 3. In cycle 2, the height of 'Lai' was not significantly different from the heights of 'Bira' and 'Pelipita' while in cycle 3, 'Lahi' had almost the same height as 'Pelipita'. The shortest cultivar was 'To'o' in all cycles with the height ranging between 229 cm and 258 cm. In South Kivu, 'Lai' and 'To'o' were recorded to be the tallest and the shortest cultivars for all three crop cycles respectively. There was no significant difference between the height at flowering of 'Lai', 'Bira', 'Lahi', and 'Pelipita' in cycle 3; and between 'Apantu' and 'To'o' in cycle 2 in South Kivu (Table 3).

In Burundi, the cultivars with the largest girth (56-69 cm) were 'Lai' in all cycles and 'Pelipita' in cycle 1. In North Kivu, the cultivars with the largest girth (68-75 cm)

Table 2. Performance traits of pVAC-rich banana cultivars at flowering across sites.

Sites	Cultivars	Plant performance traits at flowering		
		Height (cm)	Girth at 1 m base (cm)	Functional leaves at bunch emergence
South Kivu	'Apantu'	296 ^{ed}	53 ^{gih}	9 ^{feg}
	'Bira'	315 ^{bdc}	55 ^{gfh}	10 ^{bdec}
	'Lahi'	314 ^{bdc}	58 ^{gfedh}	11 ^a
	'Lai'	341 ^{ba}	60 ^{fedc}	11 ^{bac}
	'Pelipita'	301 ^{dc}	55 ^{gfh}	11 ^{ac}
	'To'o'	273 ^{ef}	42 ^k	9 ^{fde}
North Kivu	'Apantu'	260 ^{gf}	58 ^{gfeh}	8 ^{hg}
	'Bira'	302 ^{dc}	64 ^{bdc}	9 ^{fhcg}
	'Lahi'	301 ^{dc}	66 ^{ba}	9 ^{feg}
	'Lai'	318 ^{bdc}	71 ^a	9 ^{fhcg}
	'Pelipita'	326 ^{bac}	65 ^{bac}	9 ^{feg}
	'To'o'	242 ^g	49 ^{ji}	8 ^h
Burundi	'Apantu'	257 ^{gf}	45 ^{jk}	9 ^{fhg}
	'Bira'	307 ^{dc}	53 ^{ih}	11 ^{ba}
	'Lahi'	175 ^h	48 ^{ji}	9 ^{fhg}
	'Lai'	342 ^{ba}	62 ^{bcedc}	10 ^{fdec}
	'Pelipita'	346 ^a	59 ^{gfedc}	11 ^{ba}
	'To'o'	237 ^g	371	10 ^{bdac}

Values are averages of 45 plants per cultivar per site. Means followed by the same letter within a column are not significantly different at $P < 0.05$.

were 'Lai' in cycle 1 and cycle 2 and 'Lahi' in cycle 3. There were no significant differences between 'Apantu', 'Bira', 'Lahi', 'Lai' and 'Pelipita' in cycle 2; between 'Bira', 'Lai', 'Lahi' and 'Pelipita' in cycle 3. In South Kivu, the cultivars with the largest girth (60-68 cm) were 'Lai' in cycle 1 and cycle 3 and 'Pelipita' in cycle 2. 'To'o' had the thinnest girth in all three cycles in all sites. No significant variations were observed in terms of the number of functional leaves amongst cultivars within crop cycles (at $P < 0.05$) (Table 3).

Overall cultivars' yield performance at harvesting across sites

Yield performance of cultivars was assessed in terms of number of hands, number of fingers on the second hand, length of finger, total number of fingers on a bunch, bunch weight and production (tons. ha⁻¹ per year) and showed significant differences (at $P < 0.05$) (Table 4). Sites and cycles combined, the highest average number of hands (7) was recorded for 'Lahi'. Other cultivars had 6 hands ('Apantu', 'Bira' and 'Pelipita'), 5 hands ('Lai') and 4 hands ('To'o'). The average number of fingers on a hand ranged between 12 for 'Apantu', 'Bira' and 'Lai', and 11 for 'Lahi', 'Pelipita' and 'To'o'. 'Apantu' (22cm) had the longest fingers while the shortest (17-18 cm) were for

'Bira', 'Lai' and 'Lahi' (Table 4). Fingers of 'Pelipita' and 'To'o' had a medium length (19 cm). The highest average total number of fingers on a bunch was recorded for 'Lahi' (81) followed by 'Lai' (66), 'Bira' (63), 'Apantu' (60) and 'Pelipita' (50). The highest average bunch weight was recorded for 'Apantu' and 'Lahi' (16kg) followed by 'Lai' and 'Pelipita' (14 kg) and 'Bira' (12 kg) while 'To'o' produced the smallest bunches (4 kg). The production expressed in tons per hectare and per year was highest for 'Apantu' and 'Lahi' (12 t.ha⁻¹) followed by 'Pelipita' (10 t.ha⁻¹), 'Lai' and 'Bira' (9 t. ha⁻¹). The lowest yield was recorded on 'To'o' (412 t.ha⁻¹) (Table 4).

Yield performance of cultivars within crop cycles and sites

Across cultivars and sites, yield performance differed significantly with cropping cycles ($P < 0.05$) (Table 5). Cultivars with the highest yield performance over crop cycles were 'Lahi', 'Apantu', 'Lai' and 'Bira'. 'Lahi' had the highest number of hands (6-9) on the bunch in all sites. The same cultivar 'Lahi' had the highest total number of fingers (111-113), bunch weight (17-20 kg) and yield (15-23 t/ha/year) in South Kivu and Burundi sites only. 'Apantu' recorded the longest fingers averaging 22 cm in all sites whereas the highest number of fingers on the

Table 3. Performance traits of pVAC-rich banana cultivars at flowering stage across cropping cycles and sites.

Cycles	Cultivars	Burundi			North Kivu			South Kivu		
		Height (cm)	Girth at 1m base (cm)	Functional leaves at bunch emergence	Height (cm)	Girth at 1 m base (cm)	Functional leaves at bunch emergence	Height (cm)	Girth at 1 m base (cm)	Functional leaves at bunch emergence
C1	'Apantu'	248 ^b	44 ^{bc}	8 ^a	260 ^c	51 ^d	9 ^b	315 ^b	56 ^b	9 ^b
	'Bira'	291 ^a	50 ^{ba}	11 ^a	261 ^c	58 ^c	10 ^{ba}	319 ^b	55 ^b	10 ^a
	'Lahi'	177 ^c	54 ^a	9 ^a	282 ^{cb}	64 ^b	10 ^a	315 ^b	56 ^{ba}	11 ^a
	'Lai'	289 ^a	56 ^a	9 ^a	339 ^a	75 ^a	9 ^{ba}	357 ^a	60 ^a	11 ^a
	'Pelipita'	290 ^a	56 ^a	9 ^a	296 ^b	62 ^{cb}	10 ^a	300 ^c	53 ^b	11 ^a
	'To'o'	227 ^b	38 ^c	8 ^a	234 ^d	40 ^e	9 ^{ba}	278 ^d	41 ^c	9 ^b
C2	'Apantu'	262 ^c	45 ^b	9 ^a	269 ^c	66 ^a	9 ^a	293 ^c	53 ^b	9 ^c
	'Bira'	338 ^b	55 ^{ba}	10 ^a	324 ^a	66 ^a	9 ^a	318 ^b	54 ^b	10 ^{bc}
	'Lahi'	170 ^d	25 ^c	9 ^a	284 ^{bc}	62 ^a	9 ^a	316 ^b	57 ^{ba}	11 ^a
	'Lai'	386 ^a	65 ^a	9 ^a	304 ^{ba}	68 ^a	9 ^a	338 ^a	56 ^{ba}	11 ^{ba}
	'Pelipita'	364 ^{ba}	61 ^a	12 ^a	336 ^a	65 ^a	9 ^a	300 ^{cb}	58 ^a	10 ^{ba}
	'To'o'	250 ^c	32 ^c	10 ^a	258 ^c	55 ^b	8 ^b	293 ^c	45 ^c	9 ^c
C3	'Apantu'	280 ^{cb}	47 ^c	11 ^a	251 ^c	55 ^b	7 ^b	266 ^b	50 ^c	9 ^d
	'Bira'	303 ^b	57 ^b	12 ^a	317 ^b	67 ^a	9 ^a	300 ^a	60 ^b	10 ^{cb}
	'Lahi'	-	-	-	331 ^{ba}	71 ^a	9 ^a	305 ^a	72 ^a	13 ^a
	'Lai'	377 ^a	69 ^a	10 ^a	303 ^b	66 ^a	8 ^{ba}	315 ^a	67 ^a	9 ^{cd}
	'Pelipita'	384 ^a	60 ^b	12 ^a	356 ^a	68 ^a	8 ^a	307 ^a	53 ^c	11 ^b
	'To'o'	246 ^c	38 ^d	11 ^a	229 ^c	48 ^c	7 ^b	217 ^c	39 ^d	10 ^{cb}

Values are averages of 15 plants per cultivar per crop cycle. Means followed by the same letter within a column are not significantly different at $P < 0.05$.

second hand (12), the highest bunch weight (15 kg) and the highest yield (11t/ha/ year) were only recorded in North Kivu site. 'Lai' produced the highest number of fingers on a hand (13-14) in Burundi and South Kivu whereas 'Bira' recorded the highest total number of fingers (60) in North Kivu.

Agronomic results across the three cropping cycles showed that the highest yield of 23.5 t/ha/year was for 'Lahi' and recorded in the lowest

altitude in Burundi (cycles 1 and 2). The yield of the same cultivar in the highest altitude was acceptable but 11.5 t/ha/year less compared with that recorded in the lowest altitude. The other cultivars with an acceptable yield of more than 10 t/ha/year were 'Apantu' (14-19 kg) in all sites (cycle 1); 'Pelipita' in Burundi (all cycles) and in DRC (cycle 1); 'Bira' in Burundi (cycle 1), North Kivu (cycles 1 and 2) and Lai in all sites (cycle 1) (Table 5).

The highest average number of fingers on a bunch (55-58) in North Kivu was recorded from 'Bira' (cycles 1 and 3) and 'Lahi' (cycle 2) and was almost half of the number recorded from the other sites. The least number of fingers on a bunch (22-28) were recorded from 'To'o' in the highest altitude sites of South Kivu (cycles 1 and 2) and mid-altitude sites of North Kivu (cycles 2 and 3). The cultivar with the heaviest bunch (15-20 kg) was 'Apantu' in DRC sites (all cycles) and in

Table 4. Performance traits of pVAC-rich banana cultivars at harvest across sites.

Sites	Cultivars	Number of hands	Number of fingers on hand	Length of Finger	Total number of fingers on a bunch	Bunch weight (Kg)	Production (Tons/ha/ year)
South Kivu	'Apantu'	8 ^b	11 ^{gef}	22a	75 ^b	18 ^b	13 ^{cd}
	'Bira'	6 ^{dc}	13 ^{cbd}	15 ^{gf}	64 ^c	9 ⁱ	7 ^g
	'Lahi'	9 ^a	12 ^{cebd}	15 ^{egf}	111 ^a	20 ^a	15 ^b
	'Lai'	6 ^{dc}	13 ^b	15 ^{egf}	84 ^b	17 ^{cb}	11 ^{ed}
	'Pelipita'	5 ^{fe}	12 ^{cebd}	17 ^d	46 ^{fe}	14 ^{deg}	10 ^{ef}
	'To'o'	4 ^{hg}	13 ^b	17 ^d	31 ^g	4 ^j	3 ^h
North Kivu	'Apantu'	5 ^{fe}	12 ^{efd}	22 ^a	47 ^{fe}	15 ^{ed}	11 ^{ed}
	'Bira'	6 ^{de}	11 ^{gef}	19 ^c	60 ^{dc}	13 ^{hg}	10 ^{ef}
	'Lahi'	6 ^e	11 ^g	20 ^{bc}	56 ^{dce}	14 ^{fhg}	9 ^{ef}
	'Lai'	5 ^{fg}	11 ^{gf}	21 ^{ba}	51 ^{dfe}	13 ^{fhg}	8 ^{gf}
	'Pelipita'	5 ^{fe}	10 ^{gh}	22 ^a	46 ^{fe}	13 ^{hg}	10 ^{ef}
	'To'o'	4 ^h	10 ^h	20 ^{bc}	30 ^g	4 ^j	3 ^h
Burundi	'Apantu'	7 ^c	13 ^{cb}	22 ^a	82 ^b	15 ^{fed}	15 ^b
	'Bira'	7 ^c	12 ^{cebd}	14 ^g	75 ^b	9 ⁱ	10 ^{ef}
	'Lahi'	9 ^a	13 ^b	16 ^{edf}	113 ^a	17 ^{cbd}	23 ^a
	'Lai'	5 ^{fe}	14 ^a	14 ^{gf}	76 ^b	12 ^h	9 ^{ef}
	'Pelipita'	7 ^c	12 ^{cefd}	17 ^{ed}	80 ^b	15 ^{ced}	14 ^{cb}
	'To'o'	4 ^{hg}	12 ^{cebd}	16 ^{egdf}	44 ^f	4 ^j	4 ^h

Values are averages of 45 plants per cultivar per site. Means followed by the same letter within a row are not significantly different at P<0.05.

Burundi (cycles 1 and 3). Another cultivar producing the heaviest bunches was 'Lahi' recorded from Burundi (cycles 1 and 2), South Kivu (all cycles) and North Kivu sites (cycle 1). 'Pelipita' also produced the largest bunches at each crop cycle in Burundi, in North Kivu (cycle 2) and South Kivu (cycles 2 and 3) (Table 5).

Within sites, yields of cultivars differed significantly (P<0.05) (Table 5). In Burundi, 'Lahi' recorded the highest number of hands (9), the highest total number of fingers (112-119), the highest bunch weight (17-18 kg) and the highest

yield (23-24 t/ha/year) in comparison to other cultivars. 'Apantu' produced the longest fingers (20-24 cm) in all three cycles and the highest bunch weight (15 kg) in cycle 3; 'Lai' was recorded with the highest number of fingers on a hand (14-15) in all the three cycles and highest total number of fingers recorded in cycle 3 (86). 'Bira' showed the highest number of hands (7) in cycle 3 whereas in the same cycle 'Pelipita' also recorded the highest number of hands (7), as well as the highest yield (11 t/ha/year).

In North Kivu, 'Bira' recorded the highest

number of hands (6-7) and the highest total number of fingers (53-72) in all cycles while it produced a higher yield in cycle 2 (11t/ha/year). 'Apantu' recorded the highest number of fingers on a hand (12), the highest bunch weight (14-16 kg) and the highest yield (9-14t/ha/year) in the three cycles. 'Lahi' had the equal-highest number of fingers on a hand (12) in cycle1. In South Kivu, 'Lahi' had the highest number of fingers on a hand (8-10), the highest total number of fingers (101-129), the highest bunch weight (17-23 kg) and the highest yield (11-17 t/ha/year) in the three cycles.

Table 5. Performance traits of pVAC-rich banana cultivars at harvest across cropping cycles and sites.

Cycles	Cultivars	Burundi					North Kivu					South Kivu							
		Number of Hands	Number of Fingers on Hand	Length Finger	Number of Fingers on bunch	Bunch weight (Kg)	Production (Tons.ha ⁻¹ per year)	Number of Hands	Number of Fingers on Hand	Length Finger	Number of Fingers on bunch	Bunch weight (Kg)	Production (Tons.ha ⁻¹ per year)	Number of Hands	Number of Fingers on Hand	Length Finger	Number of Fingers on bunch	Bunch weight (Kg)	Production (Tons.ha ⁻¹ per year)
C1	'Apantu'	7 ^b	14 ^{ba}	24 ^a	84 ^b	16 ^a	19 ^{ba}	6 ^a	12 ^a	23 ^a	50 ^a	14 ^a	14 ^a	8 ^a	12 ^b	22 ^a	72 ^b	16 ^a	16 ^a
	'Bira'	7 ^b	12 ^b	14 ^c	81 ^b	9 ^b	12 ^c	6 ^a	11 ^{ba}	19 ^c	55 ^a	11 ^b	12 ^b	6 ^b	13 ^{ba}	15 ^c	50 ^c	7 ^c	6 ^c
	'Lahi'	9 ^a	13 ^{ba}	16 ^{cb}	112 ^a	17 ^a	23 ^a	5 ^a	12 ^a	18 ^c	53 ^a	14 ^a	13 ^{ba}	8 ^a	12 ^b	14 ^c	101 ^a	17 ^a	17 ^a
	'Lai'	5 ^c	15 ^a	15 ^c	72 ^b	11 ^b	11 ^c	5 ^b	11 ^{ba}	21 ^b	49 ^a	13 ^a	10 ^c	5 ^{cbd}	13 ^{ba}	14 ^c	70 ^b	16 ^{ba}	13 ^b
	'Pelipita'	7 ^b	12 ^b	18 ^b	82 ^b	16 ^a	18 ^b	5 ^a	10 ^b	24 ^a	48 ^a	12 ^a	13 ^{ba}	5 ^b	13 ^{ba}	17 ^b	39 ^{dc}	14 ^b	12 ^b
	'To'o'	4 ^c	12 ^b	16 ^{cb}	43 ^c	4 ^c	5 ^d	4 ^c	11 ^{ba}	18 ^c	40 ^b	4 ^c	5 ^d	4 ^c	14 ^a	16 ^b	28 ^d	4 ^{fe}	4 ^d
C2	'Apantu'	7 ^{ba}	12 ^{ba}	20 ^a	80 ^b	11 ^{bc}	8 ^b	5 ^a	12 ^a	20 ^b	45 ^b	16 ^a	9 ^b	8 ^a	10 ^b	21 ^a	82 ^c	18 ^b	10 ^c
	'Bira'	7 ^b	12 ^b	15 ^b	68 ^{cb}	9 ^{dc}	8 ^{cb}	6 ^a	11 ^{ba}	20 ^{ba}	49 ^{ba}	16 ^{ba}	11 ^a	6 ^c	13 ^a	13 ^d	78 ^c	11 ^d	8 ^d
	'Lahi'	9 ^a	14 ^{ba}	16 ^b	119 ^a	18 ^a	24 ^a	5 ^a	10 ^{dc}	22 ^a	53 ^a	14 ^b	9 ^b	9 ^a	13 ^a	15 ^c	115 ^a	23 ^a	14 ^a
	'Lai'	5 ^{bc}	14 ^a	14 ^b	75 ^b	11 ^{bc}	7 ^{cb}	5 ^b	11 ^{bc}	22 ^a	48 ^{ba}	14 ^b	8 ^c	7 ^b	12 ^a	15 ^c	97 ^b	20 ^b	12 ^b
	'Pelipita'	7 ^{ba}	12 ^{ba}	16 ^b	83 ^b	15 ^{ba}	12 ^b	5 ^b	11 ^{bc}	22 ^{ba}	44 ^b	15 ^{ba}	9 ^b	5 ^c	11 ^b	17 ^{cb}	51 ^d	15 ^c	9 ^c
	'To'o'	4 ^c	12 ^{ba}	16 ^b	38 ^c	4 ^d	3 ^c	4 ^c	10 ^d	22 ^a	26 ^c	5 ^c	4 ^d	4 ^d	13 ^a	17 ^b	22 ^e	4 ^e	2 ^g
C3	'Apantu'	6 ^{ba}	12 ^a	21 ^a	77 ^a	15 ^a	9 ^a	6 ^c	12 ^a	23 ^a	47 ^c	16 ^a	9 ^a	8 ^{bc}	13 ^{ba}	24 ^a	68 ^{cd}	19 ^a	9 ^b
	'Bira'	7 ^a	13 ^a	15 ^b	73 ^a	10 ^b	8 ^a	7 ^a	11 ^{ba}	18 ^b	72 ^a	13 ^b	7 ^b	9 ^{ba}	12 ^b	18 ^{cb}	74 ^{cb}	13 ^c	7 ^c
	'Lahi'							6 ^{ba}	10 ^c	19 ^b	61 ^b	13 ^b	6 ^{cb}	10 ^a	13 ^{ba}	17 ^c	129 ^a	22 ^a	11 ^a
	'Lai'	6 ^{bc}	14 ^a	14 ^b	86 ^a	13 ^{ba}	8 ^a	5 ^d	11 ^{ba}	19 ^b	58 ^b	13 ^b	6 ^{cb}	8 ^{bc}	15 ^a	18 ^{cb}	88 ^b	17 ^b	8 ^b
	'Pelipita'	7 ^{ba}	12 ^a	16 ^b	76 ^a	15 ^{ba}	11 ^a	6 ^{bc}	10 ^{bc}	20 ^b	46 ^c	12 ^b	6 ^c	6 ^d	13 ^{ba}	19 ^{cb}	55 ^{ed}	15 ^{cb}	8 ^{cb}
	'To'o'	5 ^c	13 ^a	15 ^b	49 ^b	5 ^c	4 ^b	4 ^e	8 ^d	20 ^b	25 ^d	4 ^c	2 ^d	7 ^{dc}	13 ^b	20 ^b	51 ^e	6 ^d	4 ^d

Values are averages of 15 plants per cultivar per crop cycle. Means followed by the same letter within a column are not significantly different at P<0.05.

'Apantu' had the longest fingers (21-24 cm) in all cycles and the highest number of hands (8) in cycle 1. The highest number of fingers on a hand (13-15) was observed for 'To'o' (cycle 1 and 3) and 'Bira' and 'Lahi' (cycle 2).

Cultivars' crop-cycle duration

Cultivars' crop cycle duration was assessed in terms of the number of days from planting to flowering and from planting to harvest. Significant

variations (P<0.05) were observed amongst cultivars across sites and within crop cycles (Table 6). In Burundi, the cultivars that took the longest time from planting to flowering and from planting to harvest were 'Lai' in cycle1 (474 and

Table 6. Crop cycle duration of pVAC-rich banana cultivars from planting to flowering and harvest across cropping cycles and sites.

Cycles	Cultivars	Burundi		North Kivu		South Kivu	
		Planting to flower (days)	Planting to harvest (days)	Planting to flower (days)	Planting to harvest (days)	Planting to flowering (days)	Planting to harvest (days)
C1	'Apantu'	409 ^{ba}	528 ^{ba}	475 ^b	601 ^b	485 ^{bc}	616 ^{bdc}
	'Bira'	339 ^b	410 ^c	403 ^c	511 ^c	550 ^{ba}	646 ^{bac}
	'Lahi'	346 ^b	449 ^{bc}	487 ^b	587 ^b	495 ^{bc}	606 ^{dc}
	'Lai'	474 ^a	608 ^a	660 ^a	780 ^a	569 ^a	676 ^{ba}
	'Pelipita'	411 ^{ba}	545 ^a	494 ^b	607 ^b	575 ^a	701 ^a
	'To'o'	465 ^a	534 ^a	402 ^c	485 ^c	459 ^c	562 ^d
C2	'Apantu'	766 ^{ba}	878 ^{ba}	934 ^a	1049 ^{ba}	942 ^a	1063 ^a
	'Bira'	675 ^a	736 ^b	789 ^c	894 ^c	818 ^c	889 ^b
	'Lahi'	351 ^b	449 ^c	785 ^c	916 ^c	924 ^{ba}	1076 ^a
	'Lai'	860 ^a	970 ^a	961 ^a	1093 ^a	948 ^a	1078 ^a
	'Pelipita'	658 ^a	786 ^{ba}	873 ^b	994 ^b	869 ^{bc}	948 ^b
	'To'o'	646 ^a	707 ^b	765 ^c	874 ^c	922 ^{ba}	1049 ^a
C3	'Apantu'	913 ^a	1026 ^a	1048 ^c	1155 ^c	1115 ^{ba}	1218 ^{bc}
	'Bira'	706 ^b	814 ^b	1013 ^d	1086 ^d	1068 ^{bc}	1186 ^c
	'Lahi'	-	-	1101 ^b	1207 ^b	1171 ^a	1259 ^a
	'Lai'	885 ^a	1002 ^a	1142 ^a	1252 ^a	1149 ^a	1259 ^a
	'Pelipita'	721 ^b	842 ^{ba}	1061 ^c	1172 ^c	1132 ^a	1239 ^{ba}
	'To'o'	788 ^{ba}	853 ^{ba}	1064 ^c	1142 ^c	1040 ^c	1136 ^d

*: the third cycle for "Lahi" in Burundi was not recorded. Values are averages of 15 plants per cultivar per crop cycle. Means followed by the same letter within a column are not significantly different at $P < 0.05$.

608 days respectively) and in cycle 2 and 'Apantu' (cycle 3), while 'Bira' took the shortest one in cycle 1 (339 days and 410 days) and cycle 3) and 'Lahi' (cycle 2). This indicated that Lai took 135 days and 198 days more compared to Bira in cycle 1. In North Kivu, 'Lai' took the longest time in all cycles with 660 days (flowering) and 780 days (harvest) in cycle 1 whereas 'To'o' (cycle 1 and cycle 2) and Lahi (cycle 3) took the shortest time from planting to flowering and from planting to harvest with 402 days and 485 days for To'oin cycle 1. In South Kivu, the cultivars that took the longest time from planting to harvest were 'Pelipita' in the number of days from planting to flowering and from planting to harvest. Significant variations ($P < 0.05$) were observed amongst cultivars across sites and within crop cycles (Table 6). In Burundi, the cultivars that took the longest time from planting to flowering and from planting to harvest were 'Lai' in cycle 1 (474 and 608 days respectively) and in cycle 2 and 'Apantu' (cycle 3), while 'Bira' took the shortest one in cycle 1 (339 days and 410 days) and cycle 3) and 'Lahi' (cycle 2). This indicated that Lai took 135 days and 198 days more compared to Bira in cycle 1. In North Kivu, 'Lai' took the longest time in all cycles with 660 days (flowering) and 780 days (harvest) in cycle 1 whereas 'To'o' (cycle 1 and cycle 2) and Lahi (cycle 3) took the shortest time from planting to flowering and from planting to harvest with 402 days and 485 days for To'oin cycle 1. In South Kivu, the cultivars that took the longest

time from planting to harvest were 'Pelipita' in cycle 1 with 575 days and 701 days, Lai (cycle 2 and cycle 3) and 'Lahi' (cycle 3). Similar to other sites, To'o (cycle 1 and cycle 3) and 'Bira' (cycles 1 and 2) took the shortest time. The assessment on crop cycle duration indicated that the average time taken by cultivars to flower and to yield bunch over the three cycles was generally lower in Burundi (the lowest altitude site) than in DRC sites (medium- and highest altitude sites) (Table 6).

Correlation between altitude and different cultivars' growth and yield attributes

A significant relationship was observed between altitude and different growth and yield attributes ($P < 0.05$) (Table 7). It was observed that plant height generally increased with increasing altitude across all the cultivars evaluated except for 'Pelipita' ($R^2 = -0.15$) which showed a significant decrease of plant height with increasing altitude. Generally, cultivar crop-cycle duration also significantly increased with altitude. Cultivars took significantly longer to mature at the high-altitude sites. It was also noted that production ($\text{Ton} \cdot \text{ha}^{-1}$ per year) declined with increasing altitude. In addition, the bunch weight of 'Lai' ($R^2 = 0.33$) was most strongly correlated with altitude while 'Bira' ($R^2 = -0.17$), 'Pelipita' ($R^2 = -0.24$) and 'To'o' ($R^2 = -0.13$) were negatively correlated with

Table 7. Correlation coefficients between altitude and different banana cultivars growth and yield attributes over cropping cycles.

Characteristic	'Apantu'	'Bira'	'Lahi'	'Pelipita'	'Lai'	'Too'
Height (Cm)	0.22**	0.27**	0.48***	-0.15*	0.23**	0.16*
Girth at 1m base (Cm)	0.04	0.26**	0.33***	-0.30***	0.20**	-0.09
Functional leaves at bunch emergence	0	0.06	0.20*	0.08	0.21**	-0.12
Planting to Flowering (Days)	0.13	0.22*	0.23*	0.23*	0.33***	0.07
Planting to Harvesting (Days)	0.15	0.23*	0.24*	0.21*	0.35***	0.11
# Hands	0.17*	0.16*	0.25*	-0.28**	0.18*	0.02
#Fingers on Hand	-0.03	-0.07	0.01	-0.14	-0.35***	0.11
#fingers on bunch	0.01	0.05	0.26**	-0.54***	0.01	-0.07
Bunch weight (Kg)	0.03	-0.17*	0.06	-0.24**	0.33***	-0.13
Production (Tons.ha ⁻¹ per year)	-0.09	-0.35***	-0.18	-0.34***	-0.01	-0.11

*, **, ***: F-value significant at (P < 0.05), (P < 0.01), (P < 0.001), respectively.

altitude; whereas the other cultivars showed no linear association with altitude (Table 7).

DISCUSSION

All cultivars except To'o had promising agronomic results. Growth characteristics and crop cycle duration were correlated with altitude. Based on the growth performance, the evaluated cultivars could be categorized in groups of i) tallest and robust cultivars ('Lai' and 'Pelipita'), ii) cultivars with medium height and girth ('Apantu', 'Bira' and 'Lahi'), and iii) smallest and thinnest cultivars ('To'o'). However, the growth of these cultivars differed across sites and cycles. Some cultivars grew very well with consistent height and girth in all sites ('Bira' and 'Lai'), at higher altitudes ('Lahi', 'Apantu', and 'To'o') and lower altitude ('Pelipita'). In addition, it was observed that some cultivars could degenerate rapidly in unsuitable altitudes. The examples are "Lahi" that had only 2 cycles in the lower altitude while it had all 3 cycles in the higher altitude; 'Lai' that decreased in growth at higher altitudes just after the first cycle while it continued growing in the lower altitude. These findings on the growth performance of these cultivars in different agroecological zones could orient researchers or extension-agents to disseminate these cultivars in their favorable areas.

The height and girth of some of the assessed banana cultivars such as 'Pelipita' and 'Lai' could be of concern, given the existing crop management and farming systems. Very tall cultivars such as 'Pelipita' (346 cm of height) could be challenging for removing the male bud, a practice recommended to prevent insect vector transmission of Banana Xanthomonas Wilt (BXW) disease in typical regions according to the observed incidence of BXW.

Furthermore, taller bananas may be less resistant to strong winds which may cause their toppling. In addition, very robust plants such as 'Lai' (71cm of girth), may

occupy a large area, reducing space for other crops. This is a concern because it is common for smallholders in the East African region to intercrop bananas with different crops (Ouma, 2009).

To address these issues, farmers could install shelter-belts such as agroforestry tree species around the banana fields to alleviate the impact of strong winds and use appropriate banana plants spacing to maximize the use of land while intercropping bananas with other crops like legumes, cereals and multipurpose trees (Ouma, 2009). Over the study areas, bananas are generally intercropped with annual crops and there has been an increase in the grower interest in using intercropping, growing two or more crops simultaneously on the same land. For male-bud removal, farmers can use forked sticks long enough to reach the male bud (Ocimati et al., 2013). In the areas where this may not apply, areas that experience strong winds, the alternative could be to promote only short or medium-high cultivars such as 'Bira' and 'Apantu' and promote thinner cultivars in areas where farmers have less land. These alternatives could increase the rate of adoption of the different pVAC-rich cultivars by farmers in the study areas.

Yield differed with cultivars and growth performance. All cultivars except 'To'o' produced big bunches (15-20kg) and had good yields (10-23 t/ha/year) with differences in performance most likely due to altitude, in conformity with Turner et al., (2016) who observed altitude having a negative association with bunch weight, particularly when nitrogen, phosphate, potassium (NPK) and organic matter (OM) concentrations are low. 'Apantu', 'Lahi' and 'Pelipita' produced good bunch sizes in all sites while 'Bira' and 'Lai' got bunches of similar sizes only in the medium and highest altitude sites in DRC.

Higher yields were observed in the lower altitude sites of Burundi compared to the medium and highest altitude sites. For example, 'Lahi' in the lowest altitude produced almost twice the yield compared to when it was grown at the highest altitude. In addition, a decrease in yield across cycles was been observed within sites with a

higher yield in the first cycle compared to the 2 other cycles. The influence of plant growth on yield was observed also by Woomer et al., (1999) who noticed a highly significant relationship between plant mass and production expressed in terms of bunch weight across a range of management practices. In addition to plant growth, altitude significantly affected plant production. The yield of all cultivars except 'Lai' was higher at lower altitudes (Burundi) compared to medium altitudes. This association was also observed in previous findings (Sikyolo et al., 2013; Sivirihauma et al., 2016; Soares, 2012) which concluded that most assimilates could go towards sucker development at high altitude, where a higher frequency of sucker production is observed for most cultivars.

Cultivars with the highest and medium growth also produced big bunches and had higher yields compared to the shortest ones. This has been observed for 'Lai', 'Lahi' and 'Pelipita' which had an average of 65cm height, 18 cm girth and each producing 10kg bunches. The yield of these cultivars in different sites was significantly higher than the yield of existing local cultivars. In Burundi, the average annual yield of the 5 cultivars (9 to 23 t/ha) was much higher than the estimated national annual banana yield (7.9t/ha) (FAOSTAT, 2018).

This can be further illustrated by the dessert cultivar 'Lai' which produced a 12kg bunch and an average yield of 9 t/ha in comparison with the common local dessert cultivars 'Ikigurube' and 'Kamaramasenge' grown in Burundi which produce bunches of 9.5 kg and 8.0 kg and a yield of 8.1 t/ha and 8.0 t/ha, respectively (Kamira et al., 2013). A similar observation was made in DRC, where the cultivars 'Bira', 'Lahi', 'Lai' and 'Pelipita' generated annual yields (7-15 t/ha) higher than the overall national annual yield of bananas (4.6 t/ha) (Dowiya et al., 2009). In addition, the pVAC-rich dessert cultivar "Lai" with an average bunch weight of 17kg in South Kivu, though lower than local cultivar 'Gros Michel' with 32kg, has the potential to increase as seen by the maximum bunch weight of 22kg that was noted in a banana germplasm evaluation study (Kamira et al., 2016).

The observed yields and high to medium growth confirmed the previous findings stipulating that larger girths and greater pseudostem strength are important characteristics that could positively influence banana bunch weight (Donato et al., 2006; Nyombi et al., 2009). A significant positive relationship between bunch weight and number of fruits per bunch has been previously reported (Soares, 2012). It has been confirmed in this study with 'Lahi' which had the highest bunch weight and yield at the same the highest overall number of hands and fingers on a bunch; likewise, this was observed for Apantu and Pelipita which ranked amongst the high performing cultivars in terms of bunch weight and yield. However, even though bunch weight and number of fingers, can be used to directly express banana productivity, they cannot be considered in isolation when

choosing a cultivar (Silva et al., 2002). Therefore, it is vital that the best/ recommended agronomic practices are used in the management of the cultivars to enable them to achieve their optimal production potential.

'To'o', the cultivar with the lowest growth performance also produced the smallest bunch among the studied cultivars and when compared to the local cultivars. This could negatively impact the acceptance of that cultivar within the local communities. However, given the high pVAC level (Ekesa et al., 2015), that cultivar could be used in the improvement of pVACs of existing banana varieties.

In addition, across cultivars, it was generally noted that crop cycle duration increased with altitude in conformity with the observation of Sivirihauma et al., (2016) that high altitude and corresponding low temperatures significantly increased crop-cycle duration of banana cultivars. The increase in crop-cycle duration with increasing altitude could be explained by lower temperature characterizing the higher altitude that contributed to lengthen the crop cycle. This conforms with Sikyolo et al. (2013) who assessed an increase in banana crop cycles with altitude. Farmers can be sensitized to adopt the banana cultivars with short and long cycles to enhance food security as reported for rice (Sall et al., 2000). Growing cultivars with both short and long cycles will increase and sustain the availability of pVAC-rich bananas.

In addition to good agronomic performance and high pVAC content, the cultivars selected for promotion should be acceptable to the target communities (Dowiya et al., 2009; Nowakunda and Tushemereirwe, 2004). A series of sensory evaluation exercises conducted within the project sites in Burundi, North Kivu and South Kivu showed that 'Apantu', 'Bira' and 'Lahi' were acceptable especially when boiled, roasted without peel or pan-fried in Burundi and North Kivu, and when roasted with or without peel or pan-fried in South Kivu (Ekesa et al., 2017). Recipes that incorporate the pVAC-rich banana cultivars such as those developed for South Kivu (Nabuuma et al., 2020) and value-added products also have the potential to increase adoption and create demand for these cultivars.

Conclusion

We conclude that 'Apantu', 'Lahi', 'Bira', 'Lai', and 'Pelipita' are the most promising pVAC-rich banana cultivars with agronomic performance that shows good potential for adoption by farmers in the study areas. Promotion of these cultivars through multiplication, dissemination of planting material in banana-dependent communities across Burundi and Eastern DRC should consider the influence of altitude as shown by the results of the study. They should also be accompanied by promoting recommended agronomic practices to achieve good yield, and by supplying information on appropriate

storage and cooking methods to maintain the pVAC content and improve nutrient quality. Further investigations on the susceptibility of these cultivars to the prevailing banana diseases within the study areas and evaluation of cultivar performance in farmers' fields are recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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