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Full Length Research Paper

β-Carotene content of selected banana genotypes from Uganda

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Health related problems due to vitamin A deficiency affect a large part of the world's population. Enhancing the levels of vitamin A in staple foods is regarded as a sustainable food-based approach that can have a significant long term beneficial impact on optimising vitamin A intake. Banana and plantain (*Musa* spp.) is the staple food crop for millions of people in Africa and other parts of the world. Increasing the nutritional qualities of *Musa* spp. will translate into improved diets. This study used high-performance liquid chromatography (HPLC) to determine the β-carotene content of 47 banana genotypes from the International Institute of Tropical Agriculture (IITA) germplam collection in Uganda and used a color meter to assess the correlation between pulp color intensity and β-carotene levels. There was wide variability in β-carotene levels within and among the different groups of banana studied. Banana genotypes from Papua New Guinea (PNG) had the highest levels of β-carotene with values as high as 2594.0 µg/100 g edible pulp. A positive correlation existed between pulp color intensity and β-carotene concentration. Accessions with relatively high levels of β-carotene, especially the PNG genotypes, could be deployed to regions with high vitamin A deficiency and/or be used as parents for development of vitamin dense varieties. The PNG genotypes could be useful in genetic studies related to vitamin A in banana.

Key words: Banana, plantain, cultivars, vitamin A deficiency, β-carotene.

INTRODUCTION

Banana and plantain (*Musa* spp.) is a major staple food crop and source of income and employment for millions of people in the tropical and subtropical regions of Africa and other parts of the world. Although many types of bananas including those traditionally classified as dessert, roasting, cooking and juice producing varieties are grown, certain varieties predominate in some geographical regions. For example, the East African Highland banana (EAHB) is the dominant cooking banana in the highlands of Eastern Africa where it is used in the preparation of 'matooke' and other local dishes. Bananas are considered to make a useful contribution in vitamin A, C and B_6 in the diet (Robinson, 1996). Yet, unacceptably high vitamin A deficiency (VAD) rates were reported in the banana growing regions in Uganda especially where children were being weaned primarily on EAHB (Kikafunda et al*.,* 1996).

Vitamin A deficiency is also a major health problem in many low income countries within sub-Saharan Africa (Aguayo et al., 2005) South East Asia and some Pacific Islands (UNICEF 1990; Setiawan et al., 2001). The health benefits of vitamin A have been explained adequately by many authors (Bouis, 2003; Arora et al., 2008). Essentially, vitamin A is considered to have protective effects in the prevention of cancer, cardio-vascular disease, cataracts and macular diseases as well as neurologic, inflammatory and immune disorders (Arora et al., 2008).

Majority of people in low income countries derive over

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Abbreviations: EAHB, East African highland banana; **VAD, v**itamin A deficiency; **PNG,** Papua New Guinea; **HPLC,** high **pe**rformance liquid chromatography; **BHT,** butylated hydroxyanisole; **ABB,** roasting bananas; **RAE,** retinol activity equivalents; **RE,** retinol equivalents.

80% of their vitamin A from the provitamin A carotenoids present in plant foods (Van de Berg et al., 2000). Provitamin carotenoids are referred to as vitamin A precursors since they are absorbed and converted into vitamin A in the human body (Kidmose et al., 2007). Carotenoids are responsible for the red, orange and yellow colors of some flowers and fruits. The most predominant and active carotenoids in plants is β-carotene (Bhaskarachary et al., 1995) and most studies have concentrated their efforts on this micronutrient. Thus provitamin A carotenoids, especially β-carotene, from plant foods are very important in alleviating vitamin A deficiency in developing countries (Kidmose et al., 2007).

Several strategies, including breeding crops for better nutrition, have been proposed to reduce the level of vitamin A deficiency (Welch and Graham, 2004). Biofortification provides a means of delivering naturally fortified foods to malnourished populations in relatively remote areas where commercially marketed fortified foods are not readily available or are unaffordable (Bouis, 2003). Food sources containing natural carotenoids are considered to be more beneficial than synthetic β-carotene supplements since studies have shown that high doses of the latter increases the risk of susceptibility to some diseases (Van den Berg et al., 2000).

Given the role that banana plays as a staple food in many countries, increasing its nutritional value through breeding or genetic engineering ought to have positive effects on the health and well-being of millions of people. By nutritionally enhancing bananas and plantains, severe vitamin A deficiencies can be reduced considerably especially in countries where diets are banana-based. In addition, there is increasing evidence to show that bananas are an important source of health promoting phytochemicals (Wang et al., 1997; Setiawan et al., 2001; Someya et al., 2002; Rabbani et al., 2004; Davey et al., 2007; Arora et al., 2008; Yin et al., 2008; Amorim et al., 2009). Biofortification of bananas can be achieved by conventional breeding or via the transgenic approach if suitable genes for micronutrients are identified. Assessing the available genetic variation for micronutrients, especially vitamin A, present in the banana germplasm may be useful for both approaches by (i) providing information on suitable parents for a breeding program and (ii) identifying and cloning of genes for traits of interest. The objectives of this study were to (i) determine the contents of β-carotene in a sample of bananas from Uganda with different pulp colour grown under similar conditions and (ii) assess the correlation between pulp colour intensity and β-carotene levels.

MATERIALS AND METHODS

Identification and sampling of samples

The forty seven banana genotypes used in this study are listed in Table 1. The plant fruits were obtained from the International Institute of Tropical Agriculture (IITA) germplasm collection in Uganda. The sample represented a range of different banana genotypes that were selected on the basis of their pulp color and included 9 EAHB varieties, 11 varieties from Papua New Guinea (PNG), 7 dessert (sweet) varieties, 4 juice producing types, 9 roasting varieties, 6 artificially produced hybrids and one diploid species. The hybrid 'TMBx5610' is from the cross between the EAHB 'Kabucuragye' and the hybrid 'TMB2x7197-2' while TMB2x 446S-1 resulted from the cross 'Sukali ndizi' x *M.acuminata* "Calcutta 4". The accessions from PNG were obtained form the *Musa* germplasm collection at the International Transit Center in Belgium and were established in the fields in Uganda. The fruits were obtained from healthy, non diseased individual plants of the same age cultivated under standard field conditions. Three fruits were harvested when the fingers of the first hand on the bunch showed signs of ripening or yellowing. Each of the three fingers were harvested from the first, middle and last hand, respectively. The sampling and analysis were repeated three times over a period of 5 months to cater for seasonal variation.

Extraction

The fruits were hand delivered to the Government Analyst and Chemist Laboratories in Kampala-Uganda within 24 h. They were weighed, sliced lengthwise, photographed, frozen at -20°C and stored in sealed plastic bags in the chamber of the freezer. A multi-purpose household food processor (Magic Line, Model MFP 000, Nu World Ind. {Pty} Ltd, Johannesburg, South Africa) with stainless steel blades was used to grate and blend the cubes to a fine pulp.

β-Carotene analysis

The protocol for β-carotene analysis reported by Rodriguez-Amaya and Kimura (2004) was and modified according to observations reported by Fraser et al. (2000). The high performance liquid chromatography (HPLC) was used for β-carotene analysis. We analysed for β-carotene only because standards for alpha carotene and other carotenoids were not readily available from the supplier during the period of the study.

β-Carotene extraction procedure

β-Carotene extracts were prepared by adding 5 ml of the extracting solvent (chloroform) plus 0.25% butylated hydroxyanisole (BHT) to about 0.25 g to 1.5 g of the sample in the 10 ml extraction tube (Fraser et al., 2000). Tubes were incubated at 85°C for 10 min, cooled on ice and homogenised for 30 s using a Polytron homogeniser (Kinematica, type PT 10 to 35, Switzerland). The homogenate was filtered using a sintered glass funnel with filter pad lined with a glass microfibre filter disk (GF/A, Whatman, England) into a 10 ml volumetric flask. Samples were then centrifuged for 15 min at 14,000 rpm and the supernatant was transferred to a fresh 2 ml reaction tube on ice. The pellet was extracted twice with 5 ml extraction solvent and the final combined supernatants were centrifuged at 14,000 rpm for 30 min and filtered through a disposable 0.45 µL filter prior to HPLC analysis. The Polytron shaft and blender tube was rinsed with another 5 ml of the extracting solvent, which was also used to rinse the funnel and filter.

Purification of the β-carotene standard

A β-carotene standard (synthetic, crystalline, Type II, product C-4582) and a stock solution (1 mg/10ml tetrahydrofuran) was prepared and stored at –20°C. The β-carotene standard was

Table 1. List of genotypes, ploidy, origin, pulp colour , β-carotene content and retinol equivalents of samples used in this study.

Category	Local accession name	[a]Ploidy	Origin	Color of pulp	[b]Intensity of color	[b]Average β-Carotene (µg/100 g)	Standard Error (µg/100 g)	Retinol Equivalent (RE) (µg/100 g)
Cooking	Nakitembe	AAA	Landrace	Deep yellow	5720.3	527.1	±3.57	88.03
	Entukura	AAA	Landrace	Deep yellow	5106.7	490.2	±0.74	81.86
	Nakhaki	AAA	Landrace	Light-yellow	4657.3	462.1	±3.073	77.17
	Kibuzi	AAA	Landrace	Deep yellow	5472.7	428.9	±7.89	71.62
	Enzirabahima	AAA	Landrace	Deep yellow	4929.3	319.2	±1.82	53.31
	Tereza	AAA	Landrace	Deep Yellow	5574	245.7	±6.80	41.03
	Mbwazirume	AAA	Landrace	Deep yellow	4731.7	191	±1.99	31.89
	Mpologoma	AAA	Landrace	Deep yellow	5198.7	146.4	±1.75	24.45
	Kabucuragye	AAA	Landrace	Deep yellow	5100	141.3	±14.77	23.59
Papua New Guinea	Dimaemamosi	AA	PNG	Orange	6188	2416.7	±142.64	403.59
	Wambo	AA	PNG	Orange	6206.67	1904.4	±123.53	318.03
	Yalim	AA	PNG	Orange	5561	1627.3	±21.62	271.76
	Gunih	AA	PNG	Orange	5840	1426.9	±27.75	238.29
	Galeo	AA	PNG	Deep yellow	5296.67	1254.9	±50.61	209.57
	Kokopo 1	AA	PNG	Orange	5820	1141.8	±95.70	190.68
	Pitu	AA	PNG	Creamy	5669.67	1127.3	±51.86	188.26
	Porapora	AA	PNG	Orange	5325.7	787.7	±114.43	131.55
	Duningi	AA	PNG	Creamy	5190	743.1	±40.79	124.09
	Pagatau	AA	PNG	Orange	5254.67	454.2	±11.57	75.85
	Pongani	AA	PNG	Light yellow	5012.7	213	±4.057	35.57
Dessert	Pisang Mas	AA	ITC-Belgium	Orange	5555	1138.7	±81.70	190.16
	Williams	AAA	ITC-Belgium	Creamy	5097	620.48	±7.88	103.62
	GCTV 215	AAA	ITC-Belgium	Creamy	5106.7	577.4	±7.06	96.42
	Dwarf Cavendish	AAA	ITC-Belgium	Creamy	5222	460	±1.76	76.82
	Grand Naine	AAA	ITC-Belgium	Creamy	5271	447.1	±7.79	74.66
	IC2	AAAA	ITC-Belgium	Creamy	4907.3	401.8	±1.88	67.10

purchased from Sigma Chemical (Dorset, Poole, UK). Four 100 µl aliquots of the stock solution were purified via the HPLC (Class-VP, LC -10ATVP, Kyoto, Japan) column from which only the β-carotene fraction was collected. The four combined β-carotene fractions were dried by evaporation of the mobile phase in a water bath at a maximum temperature of 35°C, under a stream of nitrogen. The dried residue was dissolved in chloroform and quantitatively brought to volume in a 10 ml volumetric flask. The purity of this solution was confirmed by both the visible absorption spectrum between 350 and 600 nm using a Beckman DU-62 spectrophotometer (Beckman Instruments, Inc., Fullerton, CA, USA) and the HPLC chromatogram. The concentration of the purified standard solution was calculated by using the absorbance measured at 490 nm (*A*490nm) against chloroform (Fraser et al., 2000) as blank and the absorption coefficient of 2592 (*A*1%), as follows:

$$\frac{(10\ \text{mg/ml})}{A1\%} = \frac{C_x \text{ X } 1000}{A\,490\text{nm}}$$

Where, C_x is the concentration of β-carotene in µg/ml.

β-Carotene determination

An aliquot of 250 µl was dried by evaporating the extracting solvent in a water bath at a maximum temperature of 35°C, under a stream of nitrogen. The residue was dissolved in 700 µl of the mobile phase, of methanol-acetonitrile-water 490:40:20, v/v/v. all HPLC grade) and transferred to a sample vial from which an aliquot of 100 µl was injected into the liquid chromatograph. As with the sample, an aliquot of 250 µl of the purified standard solution with known concentration was dried and the residue dissolved in 700 µl of the mobile phase, transferred to a sample vial from which an aliquot of 100 µl was injected into the liquid chromatograph. Separation on the HPLC was achieved using a 5 u C-18 steel column (Waters Associates, Milford, MA).

The β-carotene content of the banana samples was calculated as follows:

$C_x = (C_s \text{ X } A_x / A_s) \text{ X } 10 / m$

Where, C_s is the concentration of the β-carotene standard (µg/ml), A_x is the area under the β-carotene peak of the sample, A_s is the area under the β-carotene peak of the standard, 10 is the total

Table 1. Contd.

Category	Local accession name	[a]Ploidy	Origin	Color of pulp	[b]Intensity of color	[b]Average β-carotene (µg/100 g)	Standard error (µg/100 g)	Retinol equivalent (RE) (µg/100 g)
	Sukali Ndizi	AAB	landrace	Creamy	5190	50.6	±5.94	8.45
Juice/beer	Yangambi Km5	AAA	ITC-Belgium	Creamy	4842.7	251.1	±2.75	41.93
	Pisang Awak	ABB	ITC-Belgium	Creamy	4211.3	135.8	±1.72	22.68
	Kikundi	AAA	Tanzania	Deep yellow	4870	99.8	±5.09	16.67
	Kisubi	AB	Uganda	Creamy	3927.3	89	±2.71	14.86
Roasting	Kidhozi	ABB	Uganda	Creamy	4642	499.3	±40.17	83.38
	Saba	ABB	ITC-Belgium	Creamy	4335.3	430	±13.26	71.81
	Fugamou	ABB	ITC-Belgium	Creamy	4734	369.3	±11.72	61.67
	Cachaco	ABB	ITC-Belgium	Creamy	5149.7	192.6	±31.65	32.16
	Burro Cemesa	ABB	ITC-Belgium	Creamy	4322.33	283.7	±3.77	47.37
	Bluggoe	ABB	Uganda	Creamy	4366.7	240.2	±5.05	40.11
	Kivuvu	ABB	Uganda	Creamy	4596	260.1	±5.95	43.44
	Gonja Nakatasese	AAB	Uganda	Creamy-orange	5649.7	466.6	±2.31	77.92
	Mshale	AA	Tanzania	Creamy	5290.3	316.9	±5.93	52.92
FHIA hybrids	FHIA 02	AAAA	Honduras	Creamy	4337	304.6	±4.86	50.86
	FHIA 25	AAAA	Honduras	Creamy-white	4606.3	157.4	±3.22	26.28
	FHIA 17	AAAA	Honduras	Creamy	4930.7	143.2	±5.75	23.91
	FHIA 03	AABB	Honduras	Creamy	3266.7	98	±5.75	16.37
	M.acuminata ssp. Malacensis	AA	PNG	Deep yellow	5353.33	1114.2	±61.66	186.07
Hybrids	TMB2x5610	AA	Uganda	Creamy white	4090.33	193.3	±5.72	32.28
	TMBx466S-1	AAAA	Uganda	Creamy	4332.7	304.5	±7.64	50.85
Wild banana	M.acuminata ssp. Malaccensis	AA	PNG	Deep yellow	5353.33	1114.2	±61.66	186.07
LSD					124.7	116		

Retinol equivalents (conversion factor 6:1 from b-carotene equivalents to RE).

volume (ml) of the extract, m is the mass (g) of the analytical sample, C_x is the β-carotene concentration of the sample (µg/g).

Pulp color analysis

A cross section of each of the sampled banana accessions was sliced in such a way that it fitted the sensor of the color meter (Colour Tech. PCM_{TM} Pittsford, New York) firmly and flatly before and during the measurement of pulp color. As a result of different samples having different pulp coloration, the color meter was programmed to measure the yellow reflectance of the samples under investigation. This was to avoid bias and mix up of sample color reflectances. Consequently, the displayed measurement result was a specific calculation made using sample yellowness reflectance. The value of pulp intensity was displayed as yellowness (E313).

Statistical analysis

All data obtained were subjected to analysis of variance (ANOVA) and significant differences were observed, means were separated using Fishers Protected Least Significant Difference (LSD) test at the 5% probability level. Correlation analysis and level of significance (P = 0.05) were done to determine the relationship between the β-carotene content and color intensity. In correlation analysis, β-carotene and color intensity data were transformed to Log (10), to bring normality within the data set. Also correlations were done for the two categories of bananas that is, PNG and the East African highland cooking types.

RESULTS AND DISCUSSION

β-Carotene content

This study showed a wide variation in pulp β-carotene levels within and among the different groups of bananas (Table 1). This is in agreement with other studies (Englberger et al., 2003 a, b; Wall, 2006; Arora et al., 2008; Amorim et al., 2009) that have also reported wide variability in β-carotene content in bananas. As expected, variability for micronutrient content has also been

reported for many other crops such as maize (Bunziger and Long, 2000), cassava (Iglesias et al., 1997), and bean (Graham et al., 1999). In this study, the accessions from PNG had the highest levels of β-carotene with values ranging from 204.9 µg/100g in the cultivar 'Pongani' to 2594.0 µg/100g in 'Dimaemamosi'. These levels are within the range of values reported for Micronesian bananas that have the highest levels of carotenoids in the world with values as high as 6360 ug/100g (Engelberger et al., 2003a, b). Similarly, a study conducted in Brazil showed that three banana genotypes from New Guinea had the highest levels of carotenoids among the 42 samples investigated (Amorim et al., 2009). In that study, the two diploid (AA) genotypes, Modok Gier and NBA-14, had total carotenoid contents of 1605 and 1304 ug/100 g, respectively, while the AAB triploid genotype, Saney, had 1924 ug/100 g.

In the EAHB sampled, β-carotene levels ranged from 141.3 ug/100 g in 'Kaburucayge' to 527.1 ug/100g in 'Nakitembe', both with deep yellow pulp. This is the first report of β-carotene content in the EAHB. Our study shows that the EAHB have at least one-twelfth of the β-carotene content of the bananas from PNG. Although the EAHB and the dessert bananas are classified as AAA, the two types of banana have different characteristics and are also eaten in different ways.

In the sweet bananas, β-carotene levels ranged from 50.6 ug/100 in 'Sukali Ndizi' (AAB) to 1138.7ug/100 g in 'Pisang mas' (AA). This group consisted of a mixture of genomes and ploidy levels and comparisons within the group were not attempted. 'Pisang mas' had almost twice the β-carotene content of the Cavendish varieties (Williams, GCTV 215, Dwarf Cavendish and Grande Naine). 'Pisang mas' also known as 'lady finger' and 'baby banana' because of its size is widely eaten in South East Asia and has been cultivated in Costa Rica and exported to Britain on a trial basis. Reports for other AAB cultivars that are used primarily as dessert bananas showed that 'Poovan' (AAB) and 'Rasthali' (AAB) had 300 and 29.61ug/100 g, respectively, (Arora et al., 2008) while the Dwarf Brazilian banana had 96.9 ug /100 g β-carotene (Wall, 2006). Previous studies have reported different values for β-carotene levels in dessert bananas. This ranges from 21 ug/100 g (Holland et al., 1991; Holden et al., 1999) for an unknown cultivar (probably Cavendish) to Williams 55.7 ug/100 g (Wall, 2006) and 117.20 ug/100 g for Red banana (AAA) in India (Arora et al., 2008). In another study, three Cavendish cultivars 'Nanica', 'Lacatan' and 'Valery" were reported to have 106, 318 and 232 ug/100 g total carotenoids, respectively (Amorim et al., 2009). However, it must be pointed out that the study by Amorim et al. (2009) looked at total carotenoids of bananas. Our study found a much higher value for β-carotene in the dessert bananas. This may be due to a number of factors including differences in methodology and the fact that β-carotene was not separated from other provitamin A carotenoids as explained by Wall (2006). It is also reported that the nutritional composition of a banana and other fruit at harvest can vary widely due to cultivar, maturity, climate, soil type and fertility (Shewfelt, 1990; Mozafar, 1994; Lee and Kader, 2000; Emaga et al., 2007).

In the roasting bananas (ABB), β-carotene levels ranged from 192.2 ug/100 g in 'Cachaco' to 499.3 ug/100 g in 'Kidhozi'. These values are much higher than that reported for the ABB Indian cultivar 'Karpuravalli' (27.99 ug/100 g) but is closer to the value reported for ABB 'Figo Cinza' from Brazil (220 ug/100 g) (Amorim et al., 2009). The plantain 'Gonja Nakatasese' (AAB) was included in this group since it is used primarily for roasting in Eastern Africa while it is usually fried in West Africa.

In the juice producing bananas, levels of β-carotene ranged from 89.0 ug/100 g in 'Kisubi' (AB) to 251.1 ug/100 g in 'Yangambi Km 5' (AAA). It must be noted that 'Yangambi Km 5' is also consumed as a dessert banana in some regions in Africa.

Among the tetraploid FHIA hybrids, β-carotene levels ranged from 98.0 ug/100 g in FHIA 3 (AABB) to 304.6 ug/100 g in FHIA 2 (AAAA). Different genome compositions have been proposed for FHIA 02 and FHIA 03 in the literature and without pedigree data it has not been possible to ascertain what is correct. In other studies, the tetraploids 'Oura da Mata' (AAAB) and 'Porp' (AAAB) had a mean carotenoid content of 352 ug/100 g (Amorin et al., 2009). The wild diploid (AA) banana genotype *M. acuminata* ssp. *malaccensis* had a β-carotene of 1114.2 ug/100 g. This value is higher than those reported for the diploid AA bananas in the Brazilian study that had carotenoid values ranging from 150 to 902 ug/100 g, with the exception of the 3 New Guinea genotypes.

In this study, the three genotypes with the lowest β-carotene content included 'Sukali ndizi' (AAB), 'Kisubi' (AB) and 'FHIA 3' (AAAB). Unlike a previous study (Amorim et al., 2009), which showed that AAB triploids had higher total carotenoids than AAA triploids, we are not able to infer any relationship between genome composition and/or ploidy and β-carotene levels in the samples that were assessed. Rather, our study is in agreement with that of Amorin et al. (2009) which showed that there is a relationship between geographical origin of the genotypes and β-carotene levels.

Vitamin A activity in foods is expressed as ug retinol activity equivalents (ug RAE) or simply retinol equivalents (ug RE). One RAE is estimated to be equal to 6 ug β-carotene or 12 ug of other provitamin a carotenoids (National Research council 1989). The estimated mean requirements of vitamin A for children from 1 to 4 years are 200 ug RE/ day (FAO/WHO, 1988). Consequently a child of 2 to 4 years consuming 250 g of banana daily would obtain his/her total daily retinol requirement of 200 µg RE from any one of the following cultivars: 'Dimaemamosi', 'Wambo', 'Yalim', 'Gunih', 'Galeo', 'Kokopo 1', 'Pitu' 'Pisang Mas', and 'Nakitembe'. It is estimated that banana consumption is relatively high in Uganda averaging about 1 kg per capita. A lactating mother consuming 500 g of banana daily would also

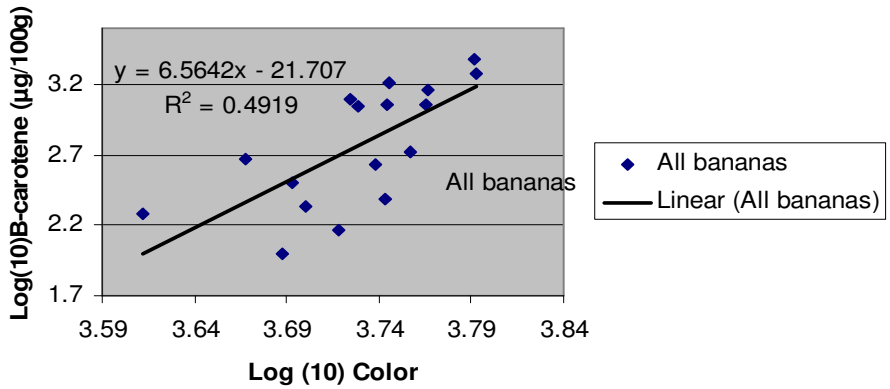

Figure 1. Relationship between **β**-Carotene and pulp color in banana accessions.

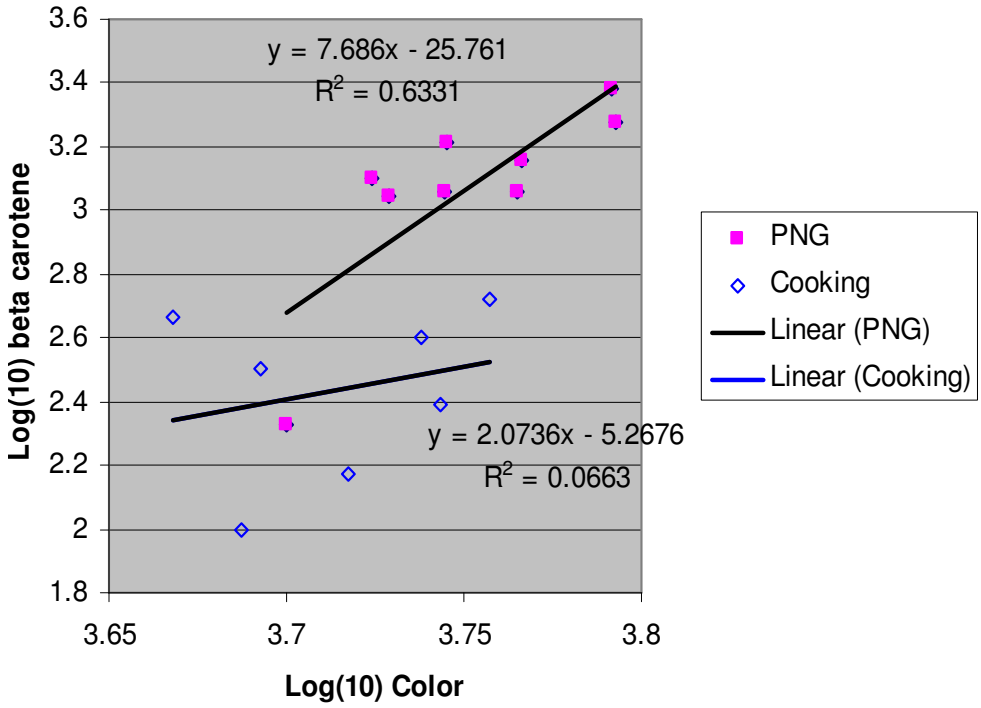

Figure 2. Relationship between **β**-carotene and pulp color of Papua New Guinea and cooking banana accessions.

obtain her total daily retinol requirements of 450 µg RE from the following genotypes: 'Dimaemamosi', 'Gunih', 'Galeo', 'Kokopo 1', 'Wambo', 'Pisang Mas', 'Yalim'. Currently it appears that 'Nakitembe' is the only EAHB cultivar that meets the Vitamin A requirements for children aged 2 to 5 years in Uganda.

Correlation between pulp color intensity and βcarotene levels

This study showed a significant ($P < 0001$) positive correlation ($R = 0.5089$) between pulp color intensity of banana with β-carotene concentration (Figure 1). It was also found that among PNG bananas, a significant positive ($P < 0.01$) correlation ($R = 0.7654$), between β-carotene and pulp color levels existed. On the other hand, among the East African highland cooking bananas, although the correlation was positive ($R = 0.1253$), it was not significant at $P = 0.05$ (Figure 2). Further studies, investigating more color parameters and more pro-vitamin A carotenoids are essential, to explain in detail the nature of the relationship between vitamin A and pulp coloration in bananas. However, these findings concur with earlier observations reported for Micronesian and Brazilian bananas (Engelberger et al., 2003a, b; Amorim

Figure 3. Photograph showing banana pulp with low (FHIA 25) and high Vitamin A (Kokopo).

et al., 2009), which showed that content of β-carotene is higher in yellow to orange bananas than in those with white or beige pulp (Figure 3). Krinsky (1998) and Russell (1998) also reported of significant positive correlation between intensity of coloration for fruits and β-carotene content.

Processing techniques such as exposure to heat and light are known to degrade provitamin A carotenoids (Bengtsson et al., 2008). The EAHB is generally steamed for preparation of 'matooke', the most common dish in Uganda. Similarly, the cooking and roasting bananas are also subjected to intense heat before being eaten. This raises the question whether methods used in the preparation of banana will result in loss of β-carotenes. Although this study did not consider the effect of heat treatment on the content of βcarotene in banana, results from other studies (Engelberger et al., 2003ab) demonstrated that a higher carotenoid content was found in cooked banana samples than in uncooked samples. In the sweet potato, it was shown that boiling for 20 min resulted in a β-carotene loss of 9 to 16 % (Bengtsson et al., 2008).

Conclusion

The very high β-carotene content of some of the PNG bananas provides a good case for the introduction and dissemination of these genotypes in countries where vitamin A deficiency is high. Providing consumer acceptability, this could provide a quick solution to VAD. In a scenario where consumer acceptability of the PNG banana is problematic, biofortification using the plant breeding strategy can be considered. All the PNG bananas used in this study are AA diploids and could be used as potential parents for introgressing traits for high vitamin A. For example, breeding represents one of the ways in which the β-carotene content of EAHB and other bananas could be elevated. This will be of particular importance in the banana growing regions of East and Central Africa, where these bananas are easily grown, have highly consumer acceptability and are consumed in large quantities. The number of genes regulating vitamin A content in banana will determine methods used to develop varieties with superior concentrations of vitamin A. While two genes are responsible for inheritance of β-carotene root concentration in cassava (Iglesias et al., 1997), multiple genes control the biosynthesis of carotenoids in carrots (Santos and Simon, 2002) and maize (Wong et al., 2004). The PNG bananas should be considered as ideal candidates for the identification of genes for vitamin A. The β-carotene levels of two hybrids used in this study does provide evidence that banana breeding has the potential of altering the β-carotene levels of banana genotypes. The two hybrids TMB2x5610 and TMBx 466S-1 had higher levels of β-carotene than their female parents, 'Kabucuragye' and 'Sukali Ndizi', respectively. Previous studies showed that there is a large and continuous variation in fruit vitamin A contents across all cultivars in banana. This indicates multigenic inheritance (Davey et al. 2007; 2009).

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