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Combining ability for beta-carotene and important quantitative traits in a cassava f1 population

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Cassava is ideal for biofortification due to its popularity as a root staple among populations with high vitamin A malnutrition. The crop is vegetatively propagated and retains the enhanced trait across generations. The combining ability for beta-carotene content and important yield trait was evaluated in a cassava F1 generation. Ten high beta-carotene clones from International Institute of Tropical Agriculture (IITA) were hybridized with ten local clones in a North Carolina Design II mating design. The F1 population was evaluated at the Kenya Agricultural Research Institute (KARI). A total of 125 families were evaluated, including 35 reciprocal crosses. The IITA parents had highly significant (P ≤ 0.001) General Combining Ability (GCA) for pulp colour and plant height. The GCA of the local parents was significant (P≤ 0.05) for harvest index, number of lobes (P≤ 0.05) and for plant height (P≤ 0.001). The Specific Combining Ability (SCA) was significant for harvest index and plant height at P≤ 0.05 and P≤ 0.001 respectively. Root pulp colour was influenced by both additive and non-additive genetic effects. There were also maternal effects associated with the trait. Results indicated that local cassava varieties can be improved for beta-carotene content without a decline in agronomic performance.

Key words: Malnutrition, biofortification, phenotyping, Kenya.

INTRODUCTION

Cassava is an important source of calories with a daily contribution of more than 500 Kcal and 100 Kcal to about 70 million and 500 million people respectively (Kawano, 2003). The crop is well adapted to various environments and it is generally grown under low input conditions. The crop can withstand biotic and abiotic stress and the roots can be left in the ground as a famine reserve. However, the nutritional quality of the cassava root is not sufficient to meet all dietary needs. Though cassava roots are rich in calories, they are highly deficient in proteins, fat, and important micronutrients like pro-vitamin A, iron and zinc (Montagnac et al., 2009). Therefore, populations dependent on the crop as their main staple are deficient of important micronutrients. Majority of the population, especially children, in cassava producing areas in Sub-Saharan Africa is deficient in vitamin A (Aguayo and Baker, 2005). About 49% of children under the age of five suffer from clinical or subclinical Vitamin A deficiency

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(Kennedy et al., 2003). In the cassava growing regions in Kenya cassava serves as the main staple to about 60% of the population. Inadequate vitamin A intake is prevalent in 89% of the children in this population (Gegios et al., 2010). This is exacerbated by a low dietary diversity whose cost of intervention is beyond reach among most rural inhabitants.

Vitamin A deficiency can be controlled by using interventions like supplementation and food based approaches like fortification and plants with enhanced pro-vitamin A activity (Fraser and Bramley, 2004). Carotenoids serve as precursors for vitamin A. They are the most widespread pigments in nature. In plants they play various important roles like regulation of phyto-hormonones (Demming-Adams and Adams, 2002). They are also important for regulation of biosynthesis pathways for environmental adaptation. Most pro-vitamin A carotenoids are beta carotene, alpha carotene and beta cryptoxanthin. Beta-carotene is the most important carotenoid as half of its structure makes up the vitamin A molecule (Rodriguez-Amaya and Kimura, 2004).

Cassava can be bio-fortified for β-carotene since there exists genetic variation that can be utilized in improving the micronutrient value of cassava (Maziya-Dixon et al., 2000; Nassar et al., 2005). Cassava breeding can improve on its beta-carotene content by exploiting the diversity that exists in yellow-orange root cassava accessions (Gregorio, 2002; Welch and Graham, 2002). Beta carotene is the predominant carotenoid in yellow rooted accessions. Furthermore, efficacy of vitamin A from biofortified cassava marches that of supplements and can adequately maintain vitamin A status in consumers (Howe et al., 2009). Cassava with improved pro-vitamin A carotenoids has an added advantage due to synergistic effects of these carotenoids with zinc and iron bioavailability (Graham and Rosser, 2000; Hess et al., 2005).

Major and minor genes play a role in inheritance of beta-carotene in cassava. There are major genes involved in transport and accumulation of carotenoids in the roots (Akinwale et al., 2010; Chavez et al., 2005; Iglesias et al., 1997). There is a wide variability observed within the root pulp colour classes due to the minor effect of the few genes involved in the accumulation process (Iglesias et al., 1997). The beta-carotene content trait is also associated with a reduction in post-harvest physiological deterioration of the harvested roots due to the oxidative nature of carotenoids (Morante et al., 2010; Sanchez et al., 2006).

Cassava clones with high levels of pro-vitamin A carotenoids, iron, and zinc have been developed at International Institute of Tropical Agriculture (IITA) and International Centre for Tropical Agriculture (CIAT) (Chavez et al., 2005). Roots of high carotenoid clones have low dry matter and poor culinary properties (Moorthy et al., 1990). However, conventional breeding can be used to introgress the trait in already adapted varieties. Improvement for beta carotene does not reduce the agronomic performance of such varieties (Chavez et al., 2005). Therefore, a conventional breeding approach was adopted to improve locally adopted cassava varieties for carotenoid content. The objective of the study was to evaluate combining ability for beta-carotene content and important yield traits in a cassava F1 generation. Ten high beta carotene clones from International Institute of Tropical Agriculture were hybridized with 10 local parents in North Carolina Design II. The resultant genotypes were evaluated over a nine month period for agronomic performance and root pulp colour.

MATERIALS AND METHODS

Ten high beta-carotene parents from IITA were planted in a crossing block together with ten local parents at KARI- Katumani Kiboko sub-centre. The root pulp colour of the IITA parents was within the yellow range. All the local parents used had white root pulp colour. Crosses were carried out by hand pollination among the twenty parents in a North Carolina Design II (NCD II) mating design with local parents as females. Reciprocal crosses were also carried out for IITA parents with adequate female flowers. Normal agronomical practices were carried out to maintain the crossing block. Harvesting of F1 seeds was carried out every 90 days after making a particular cross. The seeds were then cleaned and stored in labeled paper bags ready for planting. The F1 population was evaluated at KARI-Katumani Kiboko sub-centre in the year 2009/2010. The experimental design was 12 × 12 simple lattice in three replications whereby only the families were replicated but not the individual genotypes. A total of 125 families were evaluated, 90 derivatives of local female parents and 35 reciprocal crosses (Table 1). The missing families were largely due to lack of synchronization of flowering among the parents. The seedlings were established in ten row-plots of ten plants per row. The number of rows per family was dependent on the number of successful seedlings. The family size range was 39 to 74 and with an average of 52 genotypes per family. A plant spacing of 1 m between rows and 0.5 within rows was adopted to favor competition among plants from the same family. Normal agronomic requirements for cassava were applied during the entire growth period.

Phenotypic characterization of the genotypes was carried out at 3 months after planting (MAP), 6 MAP and at 9 MAP. Data was collected on all the genotypes within the family at all the three stages of evaluation. At 3 MAP data was collected on number of leaf lobes, lobe width (cm) and lobe length (cm). The lobe length and width ratio was also calculated for each genotype. The quantitative descriptors evaluated at 6 MAP included plant height (cm) and height (cm) to first branching for each genotype. The plant height was taken as the perpendicular height (m) from the ground to the top most canopy while branching height (m) was measured from the ground to the level of the first branch. The trial was harvested after 9 MAP. The plants were harvested by hand and data collected on individual plants. The data collected at harvest included shoot weight (kg), number of storage roots, total weight of roots (kg) and root pulp colour. The root pulp colour was rated on a scale of 1-4 where, 1- white, 2 – cream, 3-yellow and 4- pink adopted from IITA. The harvest index was calculated as a ratio of root weight and total biomass (shoot weight+ total weight of roots). Data at 3 and 6MAP was collected from 2998 genotypes. Harvest data was collected from 2821 genotypes that produced sufficient roots for evaluation.

Data was subjected to a REML analysis procedure using GENSTAT version 14. A combined analysis of variance was then

Table 1. Summary of the number of families derived from local parents and reciprocal crosses.

Local parents		IITA parents	
Parent	**Number of families**	**Parent**	**Number of families**
05/0045	10	06/1539	8
05/0047	8	07/0520	6
05/0055	7	07/0751	6
05/0059	10	07/0752	7
05/0078	9	01/1412	8
820001	7		
820058	10		
990132	10		
990183	10		
PYT	9		

Table 2. Phenotypic correlation of the vegetative growth and yield attributes for the evaluated families.

Variables	PLP	HI	L:W	L	RCT	RTW	RYD	STW
PLP	-							
HI	-0.075	-						
L:W	0.666***	-0.019	-					
L	0.089	0.233**	0.201*	-				
RCT	0.725***	0.014	0.508***	0.271*	-			
RTW	0.960***	-0.039	0.661***	0.133	0.773***	-		
RYD	0.041	0.595***	-0.011	0.334***	0.274**	0.149	-	
STW	0.864***	-0.235**	0.622***	0.224**	0.806***	0.895***	0.196*	-
TBM	0.789***	-0.089	0.542***	0.293***	0.811***	0.828***	0.374***	0.958

PLP-root pulp colour; HI-harvest index (%); L: lobe length L: W- lobe length and width ratio; RCT- root count; RTW-Root weight (kg/plant), RYD-root yield (tons/ha); STW-Shoot weight (kg/plant); * significant at $P \leq 0.05$; **significant at $P \leq 0.01$ and *** significant at $P \leq 0.001$.

carried out using the General Linear Model (GLM) on GENSTAT 14. The between-family variation was partitioned into variation due to general combining ability (GCA) effects of the IITA and local parents, the specific combing ability (SCA) of the two groups of parents (IITA x Local) and the female parents variation. The families and genotypes were considered fixed; therefore the results only apply to the parents used in the study.

RESULTS

The variation between families was significant (P ≤ 0.001) for root count, harvest index, root pulp colour, root yield, height to first branching, plant height and number of lobes (P≤ 0.05). The average root count per family was 4.51. Families 06/1539 × 990132 and 01/1412 × 0045 had the highest and lowest number of roots at 8 and 2.28 respectively. The average number of lobes per family was 7.58. The maximum number of lobes was 7.58 for the family 0520 × 820001. Family 820058 × 06/1698 had the lowest number of lobes at 3.87. The coefficient of variations (CV) for the evaluated variables ranged from 5.94 to 29.11. The root pulp colour was positively correlated with most of the traits evaluated except HI. The correlation was significant (P≤ 0.001) for lobe length and width ratio, root count, root weight, shoot weight and total biomass (Table 2).

The IITA parents had highly significant (P ≤ 0.001) GCA for pulp colour and plant height (Table 3). The GCA for the local parents was significant at P≤ 0.05 for harvest index and number of lobes and P≤ 0.001 for plant height. The female parents had significant GCA for pulp colour, harvest index and lobe length and width ratio and plant height. The SCA was significant for harvest index and plant height at P≤ 0.05 and P≤ 0.001 respectively. The local parents contributed more GCA effects for all the traits except root pulp colour and plant height. The IITA parents contributed 28.88 and 15.71% of the GCA effects for root pulp colour and plant height respectively (Table 4). The SCA effects were important for all the traits evaluated.

The IITA parents had significant GCA effects (P≤ 0.01) for most of the quantitative traits evaluated (Table 5). Positive GCA was desirable for all pulp and yield components evaluated. Parents 2005/1658 and 2007/0534 had positive and significant GCA (P≤ 0.01) for pulp colour. Parents with significant (P≤ 0.01) GCA effects for HI

Table 3. Mean square values for pulp colour and quantitative traits from the ANOVA for the combining abilities for local and IITA parents.

Source of variation	df	PLP	HI	L	L:W	PHT	RCT	RYD
GCA IITA	9	0.384***	29.71	0.265	0.079	839.5***	0.643	36.61
GCA Local	9	0.103	66.12*	0.339*	0.535	452.5*	0.955	85.1
SCA (Local x IITA)	65	0.117	46.12*	0.189	0.257	560.9***	0.862	77.54
Female parent	15	0.151*	54.29*	0.184	0.627*	662.3***	1.707**	63.75
Error	26	0.07	24.86	0.13	0.27	135.9	0.56	74.17
CV (%)		17.36	18.36	0.13	10.93	5.94	16.56	29.11
SE		0.26	4.97	0.36	0.52	11.66	0.75	8.61

PLP-root pulp colour; HI-harvest index (%); L-number of lobes; L: W- lobe length and width ratio; PHT- plant height (m); RCT- root count; RYD-root yield (tons/ha); *Significant at $P \leq 0.05$; **significant at $P \leq 0.01$ and *** significant at $P \leq 0.001$.

Table 4. Proportion of GCA and SCA for the local and IITA parents.

Variables	IITA	Local	IITA x Local
Pulp	28.88	7.75	63.37
Harvest index (%)	6.93	15.42	77.66
No of lobes	13.58	17.39	69.03
Branching height (m)	11.80	14.52	73.67
Lobe and width ratio	3.24	21.88	74.88
Lobe length (cm)	4.18	10.23	85.60
Lobe width (cm)	12.96	18.66	68.38
Plant height (m)	15.71	8.47	75.82
Root count	8.22	12.21	79.57
Root weight (kg)	3.34	10.31	86.35
Root Yield (tones/ha)	5.37	12.48	82.15
Shoot weight (kg)	10.38	12.14	77.48
Total Biomass (kg)	8.28	14.23	77.50

Table 5. GCA effects for the IITA parents for pulp colour and quantitative traits.

Parent	PLP	HI	L	BHT	L:W	PHT	RCT	RYD
2001/1412	-0.03	-6.90***	-0.35*	-0.85	-0.42*	-15.85***	-0.4	-4.83
2005/1553	0.16	15.50***	0.23	-44.35***	0.45*	26.05***	-0.57*	13.57***
2005/1658	0.67***	-11.28***	-0.26***	25.85***	0.89***	-1.75***	1.65***	-3.43***
2006/1539	-0.46***	13.47***	0.86***	0.35***	0.13***	6.75***	-1.01***	-4.43***
2007/0751	-0.55***	-0.21***	0.14***	18.55***	-0.68***	-4.65***	0.52***	8.17***
2006/1698	-0.06	-10.82***	-0.15	20.85*	-0.62*	-22.25***	0.96***	-3.05
2007/0520	-0.09	5.22*	0.24*	-23.05***	0.61*	24.65***	-1.67***	0.32
2007/0534	1.05***	-11.14***	-0.94***	10.35***	-0.32***	-36.55***	0.26***	-3.93***
2007/0620	-0.55***	-11.55***	-0.35***	33.15***	0.10***	19.25***	0.11***	-11.73***
2007/0752	0.04	11.19***	0.23	-28.85***	-0.16	1.25	0.64*	8.59*

PLP-root pulp colour; HI-harvest index (%); L-number of lobes; BHT-branching height (m); L: W- lobe length and width ratio; PHT-plant height; RCT-root count; RYD-root yield (tons/ha*)*; * significant at $P \leq 0.05$; **significant at $P \leq 0.01$ and *** significant at $P \leq 0.001$.

included 2005/1553, 2006/1539 and 2007/0520. The GCA effects for number of lobes were positive and significant for 2006/1539. Positive GCA effects for branching height were significant (P≤ 0.01) for 2005/1658, 2006/1539, 2006/1698, 2007/0534 and 2007/0620. Parents 2005/1553, 2005/1658, 2006/1539, 2007/0620 and 2007/0520 had desirable GCA effects for lobe length and width ratio. The GCA effects for plant height were positive and significant for parents 2005/1553, 2006/1539, 2007/0520 and 2007/0620. For root count the GCA effects were significant and desirable for 2005/1658, 2007/0751, 2006/1698, 2007/0534 and 2007/0620. The

Table 6. GCA effects for pulp colour and quantitative traits for IITA genotypes when they were used as the females in the crosses.

Parent	PLP	HI	L	BHT	L :W	PHT	RCT	RYD
2001/1412	0.21*	2.67	-0.12	6.02	-0.92***	-8.02*	1.01***	6.43*
2006/1539	-0.02	-8.77***	-0.02	2.22	0.50**	7.54***	1.01***	0.87
2006/1698	-0.17	11.15***	0.29*	4.72	-0.18	6.88***	-0.46	-3.27
2007/0520	0.57***	2.44***	-0.04***	-15.09***	-0.24***	-15.47***	-0.05***	5.91***
2007/0534	-0.42***	0.31***	0.19***	-24.39***	0.60***	-15.12***	0.59***	-4.99***
2007/0751	-0.44***	1.96***	-0.14***	13.62***	0.27***	12.94***	-1.29***	0.83***
2007/0752	0.09	-7.53***	-0.08	8.62	0.15	10.14***	-1.10***	-7.97**

PLP-root pulp colour; HI-harvest index (%); L-number of lobes; BHT-branching height (m); L: W- lobe length and width ratio; PHT-plant height; RCT- root count; RYD-root yield (tons/ha*);* * significant at $P \le 0.05$; **significant at $P \le 0.01$ and *** significant at $P \le 0.001$.

Table 7. GCA effects for the local parents for pulp colour and quantitative traits.

Parent	PLP	HI	L	BHT	L:W	PHT	RCT	RYD
820001	-0.12	-4.61**	-0.34**	-12.66*	0.07	-23.69***	-0.56*	-5.81*
820058	-0.01	-0.58	-0.34	-0.76	1.14***	-16.57***	-0.43	2
990132	-0.05	0.18	-0.1	-3.36	0.21	-12.21**	-0.59*	-1.22
990183	-0.19	-3.08	-0.13	6.94	0.04	13.73**	0.06	6.03*
2005/0078	-0.07	2.49	-0.13	-6.26	0.12	-8.54*	-0.46	-5.67
2005/0045	0.44***	1.85***	0.40***	-10.26***	-1.23***	-15.67***	-0.61***	3.34***
2005/0047	-0.1	2.43	-0.06	-1.06	-0.3	-5.81	-0.41	3.82
2005/0055	0.19*	2.98	0.04	8.64	-0.81***	1.63	1.23***	6.47*
2005/0059	0.03	-2.14	-0.28	5.04	-0.01	5.94	0.09	-5.55
PYT	0.11	-2.8	-0.35*	-5.06	-0.06	-5.37	0.2	-5.02

PLP-root pulp colour; HI-harvest index (%); L-number of lobes; BHT-branching height (m); L: W- lobe length and width ratio; PHT-plant height; RCT-root count; RYD-root yield (tons/ha*);* * significant at $P \le 0.05$; **significant at $P \le 0.01$ and *** significant at $P \le 0.001$.

GCA effects for root yield were positive and significant (P≤ 0.01) for 2005/1553, 2007/0751 and 2007/0752. Parent 2001/1412 had negative GCA effects for all the yield traits evaluated.

Where IITA parents had been used as females, 2001/1412 and 2007/0520 had positive and significant GCA effects for root pulp colour at P≤ 0.05 and P≤ 0.01 significantly (Table 6). Two female parents, 2006/1539 and 2007/0752 had negative GCA effects for HI. All the female parents from IITA had positive GCA effects for number of lobes. The GCA effects for branching height were positive and significant (P≤ 0.01) for 2007/0751 while those for lobe length and width ratio were desirable for 2006/1539, 2007/0534 and 2007/0752. All the IITA females had desirable GCA effects for plant height except 2007/0520 and 2007/0534. The best general combiner for root yield was 2007/0520.

Two local parents, 820001 and 2005/0045 had positive GCA effects for root pulp colour significant at (P≤ 0.01) and (P≤ 0.05) respectively (Table 7). The GCA effects for HI were positive and significant (P≤ 0.01) for 990183 and 2005/0059. Parents 2005/0045, 2005/0047 and 2005/0055 had desirable GCA effects for root count. The GCA effects for root yield were positive and significant (P≤ 0.01) for parent 2005/0055 only.

When local parents were used as females, 2005/0047 and 2005/0059 had positive GCA effects for pulp colour significant at (P≤ 0.01) and (P≤ 0.05) respectively (Table 8). Parent 2005/0047 was the only one with positive and significant (P≤ 0.01) GCA effects for HI and number of lobes. The GCA effects for root yield were desirable for 990183, 2005/0047 and 2005/0059.

DISCUSSION

The highly significant (P≤ 0.001) mean square for pulp colour among the crosses shows the genetic variation among the parents and families derived from them. Some of the crosses outperformed their parents a phenomenon attributed to transgressive segregation. Of the 125 families evaluated for root pulp colour, 51 performed as expected while 36 had a higher colour rating than the parents. Among the genotypes that outperformed the parents, 61% arose from reciprocal crosses. Majority of these reciprocal crosses (81%) were from three parents; 2001/1412, 2007/0520 and 2007/0752. Transgressive segregation is desirable in breeding for pulp colour and

Table 8. GCA effects for pulp colour and quantitative traits for local genotypes when they were used as the male progenitor in the crosses.

Parent	PLP	HI	L	BHT	L:W	PHT	RCT	RYD
820001	-0.14	-4.38**	-0.40*	-10.76	0.16	-16.69***	-0.41*	-5.78*
820058	-0.02	-0.35	-0.40*	1.14	1.23***	-9.57***	-0.28	2.03
990132	-0.06	0.41	-0.16	-1.46	0.29	-5.21**	-0.44*	-1.19
990183	-0.21	-2.85	-0.19	8.84	0.12	20.74**	0.22	6.06*
2005/0045	-0.09	2.72	-0.19	-4.36	0.21	-1.54*	-0.31	-5.64*
2005/0047	0.43***	2.08***	0.34***	-8.36***	-1.15***	-8.67***	-0.46***	3.37***
2005/0055	-0.12	2.66	-0.12	0.84	-0.22	1.2	-0.26	3.85
2005/0059	0.17*	3.21*	-0.02	10.54	-0.73***	8.64*	1.38***	6.50*
2005/0078	0.02	-1.91	-0.34*	6.94	0.07	12.95**	0.24	-5.52
PYT	0.09	-2.57	-0.41*	-3.16	0.02	1.64	0.36	-4.99

PLP-root pulp colour; HI-harvest index (%); L-number of lobes; BHT-branching height (m); L: W- lobe length and width ratio; PHT-plant height; RCT-root count; RYD-root yield (tons/ha*);* * significant at $P \leq 0.05$; **significant at $P \leq 0.01$ and *** significant at $P \leq 0.001$.

yield components in cassava. Its occurrence in breeding for root pulp colour has been reported in cassava (Akinwale et al., 2010) and sweet potato (Chiona, 2009). The highly significant general combining ability for root pulp colour from the IITA parents indicates the importance of additive effects in inheritance of the trait. Root pulp colour is directly correlated to beta-carotene content in cassava (Chavez et al., 2005). The GCA effects for root pulp colour were positive and significant for parents, 2005/1658 and 2007/0534 from IITA at P≤ 0.001 and local parents 2005/0055 and 2005/0045 at P ≤ 0.001 and P≤ 0.05 respectively. This is indicative of the positive contribution of additive gene action to the expression of root pulp colour in cassava. The best cross overall was PYT x 0534 with a mean root pulp colour score of 2.989 and it was the only derivative of parents with positive GCA effects for the trait in the best ten families. Six of the best ten were combinations of parents with positive and negative GCA effects. The GCA and SCA effects of these families shows that the performance of a cross cannot be solely predicted on the basis of the general combining GCA of the parents.

The female parent was also significant for pulp colour indicating possible maternal effects in inheritance of these traits in cassava. Two female parents from IITA; 2001/1412 and 2007/0520 had positive and significant GCA effects for the trait at P≤ 0.05 and P≤ 0.001 respectively. Three of the best performing crosses were reciprocals of 2007/0520. Not all parental combinations showed the maternal effects, an observation that was also reported from two yellow-fleshed parents (Akinwale et al., 2010). However, maternal effects in the inheritance of the trait have been reported in sweet potato (Chiona, 2009). The link between maternal effects can be explained by the role of chloroplasts and plastids in carotenoid synthesis and storage and the fact that the genomes of these organelles are inherited from the female parents in most angiosperms with complete loss of the genome from the male parent.

To improve on the adoption of cassava varieties improved for beta –carotene among the growers, the varieties have to meet the farmer-preferred attributes key of which is yield. The parents differed in their GCA for the different agronomic yield attribute traits determined in the study. Parent 2007/0534, the best parent for root pulp colour among the IITA parents had positive and significant (P ≤ 0.001) GCA effects for root count. Among the local parents; 2005/0045 had good GCA for root pulp colour and HI and 2005/0055 had good GCA effects for root count and root yield. Most of the crosses with high SCA for root pulp colour also had positive SCA for the yield attributes with family 2007/0520 × 820001 being among the best ten crosses in root count and root yield. Improvement of local varieties for beta carotene will therefore not lead to a reduction in quantitative yield attributes.

Conclusion

Results from this study show that it is possible to biofortify existing cassava varieties for beta-carotene without loss of important agronomic attributes. Breeding for the trait will require careful selection of parents. The female parent should be considered in view of the existence of maternal effects. The GCA and SCA of the selected parents should also be considered due to the additive and non-additive gene effects involved in the inheritance of the trait. Most of the qualitative characteristics in cassava are fixed in the early stage. Therefore, it is possible for promising progenies to be selected early in the selection process. Potential for biofortification of local varieties for beta-carotene will help reduce malnutrition status of the targeted population. Yellow cassava roots have also been associated with an increase in high value proteins in the leaves. Therefore, improving cassava for beta-carotene will also improve the overall nutritional benefit of the crop.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Aguayo VM, Baker SK (2005). Vitamin A deficiency and child survival in sub-Saharan Africa: A reappraisal of challenges and opportunities. Food Nutr. Bul. 26:348-355. PMid:16465981

Akinwale MG, Aladesanwa RD, Akinyele BO, Dixon AGO, Odiyi AC (2010). Inheritance of ß-carotene in cassava (Manihot esculenta crantz). Int. J. Genet. Mole. Biol. 2:198-201.

Chavez AL, Sanchez T, Jaramillo G, Bedoya JM, Echeverry J, Bolanos EA, Ceballos H, Iglesias CA (2005). Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica 143:125-133. http://dx.doi.org/10.1007/s10681-005-3057-2

Chiona M (2009). Towards enhancement of b-carotene content of high dry mass sweet potato genotypes in Zambia. KwaZulu-Natal. P. 200.

Demming-Adams B, Adams WW (2002). Antioxidants in photosynthesis and human nutrition. Science 298:2149-2153. http://dx.doi.org/10.1126/science.1078002; PMid:12481128

Fraser PD, Bramley PM (2004). The biosynthesis and nutritional uses of carotenoids. Progr. Lipid Res. 43:228-265. http://dx.doi.org/10.1016/j.plipres.2003.10.002; PMid:15003396

Gegios A, Amthor R, Maziya-Dixon B, Egesi C, Mallowa S, Nungo R, Gichuki S, Mbanaso A, Manary M (2010). Children Consuming Cassava as a Staple Food are at risk for Inadequate Zinc, Iron, and Vitamin A Intake. Plant Foods Hum. Nutr. 65:64-70. http://dx.doi.org/10.1007/s11130-010-0157-5; PMid:20165984 PMCid:PMC2840668

Graham RD, Rosser JM (2000). Carotenoids in staple foods: Their potential to improve human nutrition. Food Nutr. Bul. 21:404-409.

Gregorio GB (2002). Symposium: Plant Breeding: A new tool for fighting micronutrient malnutrition. Progress in breeding for trace minerals in staple crops. J. Nutr. 132:500-502.

Hess SY, Thurnham DI, Hurrell RF (2005). Influence of Provitamin A Carotenoids on Iron, Zinc, and Vitamin A Status. In: HarvestPlus Technical Monograph 6. : Washington, DC and Cali: International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture (CIAT).

Howe JA, Maziya-Dixon B, Tanumihardjo S (2009). Cassava with enhanced b-carotene maintains adequate vitamin A status in Mongolian gerbils (Meriones unguiculatus) despite substantial cis-isomer content. British J. Nutr. 102:342-349. http://dx.doi.org/10.1017/S0007114508184720; PMid:19138445

Iglesias CA, Mayer J, Chavez F, Calle F (1997) Genetic potential and stability of carotene content in cassava roots. Euphytica 94: 367-373. http://dx.doi.org/10.1023/A:1002962108315

Kawano K (2003). Thirty Years of Cassava Breeding for Productivity – Biological and Social Factors for Success. Crop Sci. 43:1325-1335. http://dx.doi.org/10.2135/cropsci2003.1325

Kennedy G, Nantel G, Shetty P (2003). The scourge of "hidden hunger": global dimensions of micronutrient deficiencies. Food Nutr. Agric. 32:8-16.

Maziya-Dixon B, Kling JG, Menkir A, Dixon A (2000). Genetic variation in total carotene, iron, and zinc contents of maize and cassava genotypes. Food Nutr. Bul. 21:419-422.

Montagnac JA, Davis CR, Tanumihardjo SA (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. Comprehensive Rev. Food Sci. Food Safety 8:181-194. http://dx.doi.org/10.1111/j.1541-4337.2009.00077.x

Moorthy SN, Jos JS, Nair RB, Sreekumari MT (1990). Variability of b-carotene content in cassava germplasm. Food Chem. 36:223–236. http://dx.doi.org/10.1016/0308-8146(90)90058-C

Morante T, Sánchez N, Ceballos H, Calle F, Pérez JC, Egesi C, Cuambe CE (2010). Tolerance to postharvest physiological deterioration in cassava roots. Crop Sci. 50:1333–1338. http://dx.doi.org/10.2135/cropsci2009.11.0666

Nassar N, Vizzotto CS, Lima da Silva H, Schwartz CA, Pires OR (2005). Potentiality of Cassava Cultivars as a Source of Carotenoids. Gene Conserve 4:267-283.

Rodriguez-Amaya DB, Kimura M (2004). HarvestPlus handbook for carotenoid analysis. HarvestPlus Technical Monograph Series 2. Washington, DC: International Food Policy Research Institute (IFPRI). Harvest plus: Washington DC and Cali.

Sanchez T, Chavez AL, Ceballos H, Rodriguez-Amaya D.B., Nestel P, M Ishitani M (2006). Reduction or delay of post-harvest physiological deterioration in cassava roots with higher carotenoid content. J. Sci. Food Agric. 86:634-639. http://dx.doi.org/10.1002/jsfa.2371

Welch RM, Graham RD (2002). Breeding crops for enhanced micronutrient content. Plant Soil 345:205-214. http://dx.doi.org/10.1023/A:1020668100330