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Evaluation Of Promising Orange Fleshed Sweetpotato Genotypes In Different Agroecological Zones Of Uganda

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ABSTRACT: Vitamin A deficiency (VAD) is a major public health problem affecting 127 million children under age five and more than 7 million pregnant women in developing countries. In Uganda, VAD affects 20% of women of child-bearing age and 18% of children below five years. VAD can lead to disorders such as xerophthalmia, the leading cause of preventable childhood blindness, anemia, weakened host resistance to infection and premature death. The orange-fleshed sweetpotato (OFSP), with its high beta-carotene (provitamin A) levels, is regarded as the most affordable and sustainable food-based strategy for combating VAD. The objectives of the study were to assess the adaptability and acceptability of promising OFSP genotypes in varied agroecologies of Uganda. Data were collected on sweetpotato virus and *Alternaria* disease infection, root yield, weevil infestation, and taste attributes; analysis was done using regression and AMMI model in GenStat. Genotypes and environments accounted for 38.84% and 21.51%, respectively, while genotype x environment interactions accounted for 0.01% of the total variation for root yield. Genotypes Dimbuka, SPK004/1/1, SPK004/6/6 and SPK004/6 had above average root yield under high yielding environments of Nakasongola, Kabale and Busia, whereas NASPOT 5/63, SPK004/1, SPK004 (check), NASPOT 5/22 and NASPOT 5/50 had below average root yield and fell under low yielding environments of Mpigi and Wakiso districts. Dimbuka, SPK004/1/1 and SPK004/6/6 were better adapted at Kabale. Genotypes NASPOT 5/22 and SPK004/6 were the most stable while SPK004 and SPK004/6/6 were the least stable. SPK004/6 was the most preferred while NASPOT 5/50 was the least preferred genotype based on taste attributes. Genotypes SPK004/6, SPK004/6/6, SPK004/1/1, SPK004/1 and Dimbuka are recommended for release; SPK004/6 and SPK004/6/6 need to be promoted specifically to combat vitamin A deficiency, whereas SPK004/1/1, SPK004/1 and Dimbuka are mainly for reducing food insecurity in Uganda. (Word count: 291 words)

Key Words**:** Vitamin A deficiency; GEI; stability; AMMI; regression analysis; acceptance

Abbreviations*:* AMMI=Additive Main effects and Multiplicative Interaction; BS=Busia; GEI=Genotype x Environment Interaction; KB=Kabale; MP=Mpigi; NK=Nakasongola; OFSP=Orange Fleshed Sweet Potato; WK=Wakiso; SPVD=Sweet Potato Virus Disease; VAD=Vitamin A Deficiency

INTRODUCTION

Vitamin A deficiency (VAD) is a major health challenge in developing countries, affecting 127 million children under age 5 and more than 7 million pregnant women, particularly in Asia and Sub-Saharan Africa (CIP 2010). According to Uganda Demographic and Health Survey (UDHS 2006) results, VAD affects 19 % of women of child-bearing age and 20% of children below five years. The Micronutrient Initiative (MNI 2004) estimated that 66% of children under 6 had sub-clinical VAD which contributed up to 25% of child mortality due to related diseases such as malaria, diarrhoea, acute respiratory infections and vaccine preventable diseases.

The main underlying cause of VAD is having a diet that is chronically insufficient in vitamin A (VA) which can lead to lower body stores and failure to meet physiological needs (e.g. support tissue growth, normal metabolism, resistance to infection). According to World Health Organization (WHO) deficiency of sufficient duration or severity can lead to disorders that are common in vitamin A deficient populations, such as xerophthalmia (“dry eye”) the leading cause of preventable childhood blindness, anemia, and weakened host resistance to infection, which can increase the severity of infectious diseases and risk of death. Low VA intake during nutritionally demanding periods in life, such as infancy, childhood, pregnancy and lactation, greatly raises the risk of health consequences, or VAD disorders. It was estimated that between 2004 and 2014, VAD would cost Uganda US $ 2.5 billion due to untreated illnesses associated with VAD and a further US $ 382 million due to lost productivity amongst women with anaemia (MoH *et al*. 2004, cited in Potts and Nagujja 2007).

Intervention approaches aimed at alleviating VAD are: (a) diet diversification through use of foods rich in VA; (b) food fortification; and (c) supplementation with VA capsules. There are two forms of VA, namely: preformed VA esters found in liver, milk, cheese, eggs or food products fortified with VA; and carotenoid precursors - mainly beta-carotene - that are found in green leaves, carrots, ripe mangoes and pawpaws, and other yellow-orange vegetables and fruits. Promotion of VA-rich foods and food fortification are likely to be solutions that can address one of the underlying causes of VAD, because VA of animal origin is relatively expensive compared to that of plant origin. Therefore, VAD can be addressed through use of crop varieties with high beta-carotene concentration such as the orange fleshed sweetpotato (OFSP) (Jaarsveld *et al*. 2005; Low *et al*. 2007). The OFSP varieties are regarded as the most affordable and sustainable food-based strategy for combating VAD compared to VA supplementation with VA capsules (Low *et al*. 2007). It was estimated that just 125g of fresh sweetpotato roots from most orange-fleshed sweetpotato varieties contain enough of it to provide the daily provitamin A needs of a pre-schooler (CIP 2010).

Unfortunately, most of the varieties grown and consumed in Uganda are white- and cream- fleshed, a sign of very low levels of ß-carotene. White-fleshed varieties’ ß-carotene content may be as low as 70 µg/100 g compared to the yellow- and orange-fleshed types whose ß-carotene concentration may be up to 4000 µg/100 g (fresh weight basis) (Woolfe 1992). Therefore, the main thrust of the Uganda National Sweetpotato Program (UNSP) is to develop sweetpotato varieties with multiple desirable traits of high yield, high dry matter content (≥ 30%), orange-flesh (high β-carotene content), and resistance to viruses and weevils, that meet consumer and market demands.

The success of any newly introduced variety will depend not only on production characteristics, but also on its acceptability to consumers in terms of both sensory and utilisation characteristics (Tomlins *et al.* 2001). Consumer preferences appear to differ greatly between regions; for example, in East Africa, high dry matter and good taste are important criteria (Kapinga *et al*. 1997). Other attributes include cooking quality (referring to the time needed for cooking) and the colour of the flesh and skin, low fibre content, good storability after purchase and root size (Tomlins *et al*. 2001). The criteria used by traders fit closely to those of the consumers, except that appearance is relatively more important, ranking equally with good taste. Sensory taste panels can be used to produce sensory profiles of varieties (Tomlins *et al*. 2001). The objectives of the study were, therefore, to assess adaptability and acceptability of promising orange- fleshed sweetpotato genotypes in varied agro-ecological zones of the country.

MATERIALS AND METHODS

Eight promising orange-fleshed sweetpotato genotypes were tested against one standard check, Kakamega, plus one local check (farmer’s variety) at five locations for four seasons between April 2005 and May 2007. The genotypes were: SPK004/1, SPK004/1/1, NASPOT 5/22, NASPOT 5/50, NASPOT 5/63, SPK004/6, SPK004/6/6 and Dimbuka (Table 1). The four seasons of trialing were 2005b, 2006a, 2006b and 2007a, where ‘a’ and ‘b’ denote short and long rains, respectively. During each season, the genotypes were evaluated on 15 farms each in Busia, Kabale, Wakiso, Mpigi and Nakasongola districts. According to Wortmann and Eledu (1999), Busia district represents the short grassland (warm, humid) agroe-cological zone (AEZ) in the east; Kabale represents cool, highland AEZ in the southwest; Wakiso and Mpigi represent the tall grassland (warm, humid) AEZ in the south; while Nakasongola falls in the semi-arid (part of ‘cattle corridor’) AEZ in the central region.

Table 1. Sweetpotato genotypes evaluated at five locations for four seasons during 2005-2007

Genotype	Category	Skin colour	Flesh colour	Beta-carotene concentration (µg/g (dwb*)
Dimbuka	Local landrace	Cream	Cream	4.3 - 14.3
NASPOT 5/22	Improved	Purple red	Pale orange (orange with yellow)	NA
NASPOT 5/50	Improved	Purple red	Cream	NA
NASPOT 5/63	Improved	Cream	Pale orange (orange with yellow)	NA
SPK004	Improved	Pink	Pale orange (orange with yellow)	92.4 - 105.2
SPK004/1	Improved	Purple red	Pale orange (orange with yellow)	46.7- 93.8
SPK004/1/1	Improved	Purple red	Pale orange (orange with yellow)	40.7 - 76.5
SPK004/6	Improved	Purple red	Dark orange	155.6 - 183.7
SPK004/6/6	Improved	Purple red	Dark orange	163.9 - 168.6

dwb* = dry weight basis; NA = Not available

Each farm was considered as a replicate and received a subset of 3 new genotypes. New participating farmers were selected each season. Gross plot size was 5 m wide x 6 m long (30 mounds) or 4 ridges x 7.5 m long spaced 1 metre apart. Vine tip cuttings (30 cm long) were planted in a single row at intervals of 30 cm along the ridge and 3 cuttings per mound (1 m^2) in a triangular pattern. The trials were researcher-designed but farmer-managed. Planting was done in April/May (2006a, 2007a) and September/October (2005b, 2006b) under rain-fed conditions. Readily available rainfall data for one site (Wakiso) is presented in Figure 1 below.

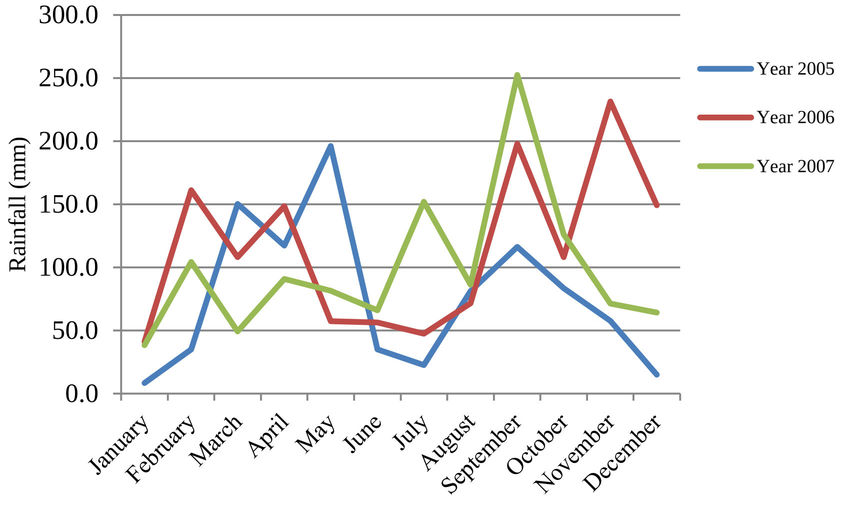

Figure 1. Annual rainfall (mm) distribution at Namulonge Weather Station (40 km north of Wakiso) during 2005-2007

Pre-harvest data on virus and *Alternaria* disease infections were collected at 45 days after planting (DAP) using the scale of 1 – 9 where 1 = no visible, 9 = severe symptoms. Harvesting took place at 4.5 - 5.5 MAP depending on altitude of the location. Net plot (harvest) area was 12 m^2, that is, 12 inner mounds or 2 central ridges each 6 m long. Data were recorded on number and weight of storage roots (marketable and unmarketable), vine weight, and weevil damage using the scale of 1-9, where 1 = no visible and 9 = severe damage. Individual post-harvest taste panelists (Figure 2) assessed the palatability attributes, namely; appearance, taste, flavour, mealiness, fibers and general appreciation using a scale of 1-5, where 1 = very bad; 2 = bad; 3 = moderate; 4 = good; 5 = very good (Rees *et al*. 2003) then made pair-wise comparisons and overall ranking of genotypes.

Figure 2. Taste panelists assessing sweetpotato genotypes at one of the trial sites

Yield data were subjected to log transformation first before doing regression analysis (takes care of missing data) using the General Model in GenStat (2011) statistical package to predict storage root and vine yield. The fitted terms were clone, location and season. Taste data from individual taste panelists, pest infestation and disease infections were also analysed using GenStat. The additive main effect and multiplicative interaction (AMMI) model was used to analyze the genotype x environment interactions. Palatability scores for the genotypes were summarised using pair-wise comparisons and ranking.

RESULTS

Agronomic performance of genotypes

Regression analysis of root yield showed that effects of genotype, location and season were highly ($P < 0.001$) significant (Table 2).

Table 2. Accumulated Analysis of Variance of Regression Analysis of Root Yield

Source of Variation	D.F.	Sum of Squares	Mean of Squares	Variance Ratio	F pr.
Genotype	8	4.13309	0.51664	8.38	<.001
Location	4	3.28498	0.8214	13.32	<.001
Season	3	2.41646	0.80549	13.07	<.001
Residual	543	33.4697	0.06164		
Total	558	43.3042	0.07761		

The combined analysis of variance using the AMMI model showed that there were highly significant ($p < 0.001$) differences among genotypes, environments (location and season) and G x E interactions for root yield (Table 3). The main effects of genotypes and environments accounted for 38.84% and 21.51% respectively, while the G x E interaction accounted for 0.01% of the total variation for root yield. In this study, genotype contributed higher variation than the environment on the root yield, as indicated by the large sum of squares. The IPCA 1 was found to be highly significant in explaining G x E interaction for root yield as it captured 100% of the interaction sum of squares.

Table 3. Analysis of variance for the AMMI model for storage root yield of 9 orange-fleshed sweetpotato genotypes grown at five locations for four seasons (2005b-2007a)

Source of Variation	D.F.	Sum of Squares	Mean of Squares	Total variation explained (%)	G x E explained (%)
Total	179	2944.5	16.45		
Treatments	44	1801.3	40.94		
Genotypes	8	1143.8	142.98***	38.84	
Environments	4	633.4	158.36*	21.51	
Block	15	1101.4	73.42		
GxE	32	24.1	0.75***	0.008	
IPCA1	11	24.1	2.19***		100.00
Error	120	41.8	0.35		

Table 4. Mean storage root yield, IPCA1 and IPCA2 for 9 orange-fleshed sweetpotato genotypes grown at 5 locations for 4 seasons 2005b-2007a

Code	Genotype	Root yield (t ha^{-1})	Rank	IPCAg[1]	IPCAg[2]
1	Dimbuka	16.0	1	-0.83061	-0.00453
2	NASPOT 5/22	8.8	8	0.64806	0.00624
3	NASPOT 5/50	8.2	9	0.77497	0.04053
4	NASPOT 5/63	11.7	5	0.04367	-0.02073
5	SPK004	10.6	7	0.27288	-0.04864
6	SPK004/1	10.9	6	0.2073	-0.0287
7	SPK004/1/1	15.4	2	-0.71328	0.00723
8	SPK004/6	12.3	4	-0.07165	0.00838
9	SPK004/6/6	13.5	3	-0.33134	0.04022
Location means:					
Busia		12.9	3	-0.36734	0.03814
Kabale		13.4	2	-0.56012	0.02058
Mpigi		9.7	4	0.81638	0.03219
Nakasongola		14.0	1	-0.76061	-0.0481
Wakiso		9.6	5	0.87168	-0.04282

Genotypes Dimbuka, SPK004/1/1, SPK004/6 and SPK004/6/6 had above average storage root yield (Table 4). The highest root yield was recorded for genotype Dimbuka at 16.0 t ha^{-1}, while NASPOT 5/50 registered the lowest yield of 8.2 t ha^{-1}. All genotypes except NASPOT 5/22 and NASPOT 5/50 performed better than the standard check SPK004. The highest yielding location was Nakasongola at 14.0 t ha^{-1} while the lowest yielding locations were Wakiso and Mpigi with 9.6 t ha^{-1} and 9.7 t ha^{-1}, respectively.

The highest and lowest yielding environments were 2006b in Nakasongola (17.4 t ha^{-1}) and 2005b in Wakiso (6.8 t ha^{-1}), respectively (Table 5).

Table 5. Mean storage root yield, IPCAg[1], IPCAg[2] for 9 orange-fleshed sweetpotato genotypes grown in twenty environments

Code	Genotype	Root yield (t ha^{-1})	IPCAg[1]	IPCAg[2]
1	Dimbuka	16.0	-1.51316	0.01981
2	NASPOT 5/22	8.8	1.18019	0.0707
3	NASPOT 5/50	8.2	1.40965	0.08376
4	NASPOT 5/63	11.7	0.07741	-0.15841
5	SPK004	10.6	0.49512	-0.03828
6	SPK004/1	10.9	0.37786	-0.14202
7	SPK004/1/1	15.4	-1.29481	0.03145
8	SPK004/6	12.3	-0.13284	0.07243
9	SPK004/6/6	13.5	-0.59941	0.06057
Environment means:				
1	5B*BS	9.2	0.56279	0.01916
2	6A*BS	14.6	-0.54601	0.07324
3	6B*BS	16.1	-0.84556	-0.09933
4	7A*BS	11.8	0.02095	0.07269
5	5B*KB	9.6	0.48176	-0.0456
6	6A*KB	15.2	-0.655	-0.02911
7	6B*KB	16.7	-0.98916	0.0917
8	7A*KB	12.3	-0.06938	-0.01364
9	5B*MP	6.9	1.04589	-0.01061
10	6A*MP	11.0	0.17905	0.05994
11	6B*MP	12.2	-0.04964	-0.07512
12	7A*MP	8.9	0.62005	0.03818
13	5B*NK	10.0	0.39805	0.04249
14	6A*NK	15.8	-0.78855	-0.09959
15	6B*NK	17.4	-1.10344	-0.02167
16	7A*NK	12.8	-0.17878	0.04508
17	5B*WK	6.8	1.05791	-0.06092
18	6A*WK	10.9	0.22302	-0.00364
19	6B*WK	12.0	-0.02002	0.07058
20	7A*WK	8.8	0.65605	-0.05382

BS = Busia, KB = Kabale, MP = Mpigi, K = Nakasongola, WK = Wakiso

The biplot generated by AMMI model for G x E interaction permits visualization of differences in the interaction main effects (Figure 3). Displacement along the abscissa reflected differences in main effects, whereas displacement along the ordinate exhibited differences in interaction effects. Genotypes or environments on the same parallel line, relative to the ordinate have similar root yields, and a genotype or environment on the right side of the mid-point of this axis has higher yield than that on the left hand side. The favourable environments were 2006b in Nakasongola, 2006b in Kabale, 2006b in Busia, 2006a in Nakasongola, 2006a in Kabale, 2006a in Busia, 2007a in Nakasongola, 2006b in Mpigi and 2006b in Wakiso. The unfavourable environments were 2005b in Mpigi, 2006a in Mpigi, 2007a in Mpigi, 2005b in Nakasongola, 2005a in Wakiso, 2006a in Wakiso and 2007a in Wakiso. Genotypes with IPCA2 scores near zero had little interaction across environments and, vice versa for environments. Genotypes SPK004 was the most stable while NASPOT 5/50 and NASPOT 5/22 were the least stable of the low yielding genotypes. Dimbuka and SPK004/1/1 were the most stable whereas SPK004/6 and SPK004/6/6 were the least stable under the category of high yielding genotypes.

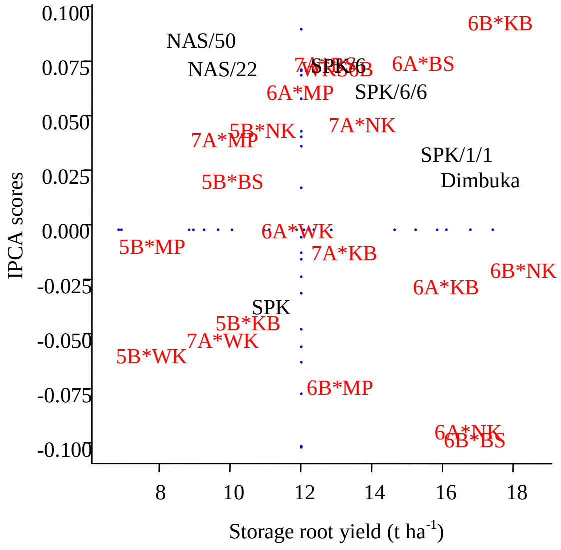

Figure 3. Biplot of interaction principal component axis 2 (IPCA2) score versus mean storage root yield of 9 sweetpotato genotypes

All genotypes except SPK004/1 were slightly more susceptible to sweetpotato virus disease (SPVD) than SPK004, the standard check (Table 6). Dimbuka was the only genotype which was slightly more susceptible to Alternaria disease than SPK004. Genotypes NASPOT 5/63 and SPK004/6 were slightly more susceptible to weevil damage while the rest of the genotypes were less susceptible compared to SPK004. The most favourable environments for development of disease were Kabale and Mpigi for Alternaria blight, Mpigi and Wakiso for SPVD, while Wakiso and Mpigi were the most favourable environments for weevils. The most favourable seasons for disease development were 2006b for Alternaria blight and SPVD, and 2007a for SPVD and weevils.

Table 6. Overall mean scores on pests and diseases for 9 genotypes tested at 5 sites for 4 seasons during 2005b - 2007a

	Scores		
Genotype	Alternaria	SPVD*	Weevil
Dimbuka	1.8	2.8	1.5
NASPOT 5/22	1.9	2.7	1.3
NASPOT 5/50	2.2	2.6	1.5
NASPOT 5/63	1.9	2.5	1.7
SPK004	1.7	2.7	1.6
SPK004/1	2.2	2.6	1.5
SPK004/1/1	1.6	2.3	1.3
SPK004/6	1.8	2.5	1.7
SPK004/6/6	1.7	2.5	1.5
Mean	1.9	2.6	1.5
SEM	0.09	0.08	0.10
Location			
Busia	1.9	2.4	1.6
Kabale	2.1	2.6	0.9
Mpigi	2.1	2.8	1.7
Nakasongola	1.5	2.4	1.6
Wakiso	1.9	2.7	1.8
Mean	1.9	2.6	1.5
SEM	0.07	0.06	0.09
Season			
2005B	1.6	2.3	1.1
2006A	1.4	2.3	1.5
2006B	2.5	2.9	1.6
2007A	2.1	2.9	1.9
Mean	1.9	2.6	1.5
SEM	0.07	0.06	0.09

*SPVD = Sweet potato virus disease. SPVD, Alternaria and weevil damage scored on a scale of 1-9: 1 = no symptoms, 9 = very severe

SENSORY RESULTS

SPK004/6 was the most preferred genotype with taste attributes having mean scores ranging from 3.4 – 4.2 (i.e., moderate to good), while NASPOT 5/50 was the least preferred genotype with mean scores ranging from 2.8 – 3.5 (i.e., poor to moderate) (Table 7). The reasons for ranking SPK004/6 highest were that it had attractive colour, no fibres, good flavor (smell) and was mealy and sweet. NASPOT 5/50 was ranked lowest (least liked) because it had fibres, bad flavor, was soft and not sweet.

Table 7. Overall mean scores of palatability assessment and preference ranking of different genotypes during 2005b-2007a

	Scores						
Genotype	Appearance	Taste	Flavor	Fibres	Starch	General appreciation	Pair-wise Rank
Dimbuka	3.6	4.0	3.9	4.3	3.6	4.0	3
NASPOT 5/22	3.4	3.5	3.5	3.5	2.9	3.4	6
NASPOT 5/50	3.5	3.2	3.1	3.4	2.8	3.2	8
NASPOT 5/63	3.2	3.3	3.1	3.8	2.9	3.2	7
SPK004/1	3.4	3.7	3.5	3.8	3.6	3.7	5
SPK004/1/1	3.4	3.4	3.2	3.7	3.4	3.5	4
SPK004/6	4.0	4.2	3.9	4.0	3.5	3.9	1
SPK004/6/6	4.1	3.9	3.8	4.0	3.6	4.0	2
Mean	3.6	3.6	3.5	3.8	3.2	3.6	NA
$LSD_{0.05}$	0.35	0.33	0.34	0.35	0.38	0.32	NA
CV (%)	31.27	28.78	30.97	29.2	36.83	27.97	NA

Taste attributes were rated on a scale of 1-5; where 1 = very bad; 2 = bad; 3 = moderate; 4 = good; 5 = very good

DISCUSSION

The main effects of genotype were highly significant and contributed higher variation than the environment to the total variation in storage root yield. A large sum of squares for genotypes indicated that the genotypes were diverse, with large differences among genotype means causing variation in root yield. The most favourable season was 2006b followed closely by 2006a; 2007a was moderate, while 2005b was the least favourable, suggesting climatic variability. For example, the amount of seasonal rainfall recorded at the nearest weather station to Wakiso site was highest in 2006b and lowest in 2005b. For best performance, sweetpotato requires an annual rainfall range of 750-1000 mm that is well distributed; below 500 mm rainfall, growth and yield are greatly reduced (citation needed). Genotype-by-environment effects were highly significant for storage root yield, implying variable genotypic responses for yield across environments. Although rainfall data was not readily accessible for 4 out 5 sites, information available on the internet (http://wwww.weatherspark.com), though not indicating the amount of rainfall, showed that rainfall amount and distribution may have negatively affected crop growth and root yields. A similar view was held by Moussa *et al*. (2011). Earlier work by Gong *et al*. (1990) showed that drought stress lasting for more than 20 days during any part of the growing period decreased storage root yield of sweetpotato by 15-39 %. Similar results were reported by Turyagenda *et al*. (2013) for cassava with 37% reduction in fresh root yield due to drought stress. Van de Fliert and Braun (1999) reported that favorable conditions during the first month after planting (MAP) are of vital importance for storage root initiation and will determine the number of roots on a plant. Pest and disease pressure was quite low suggesting that these biotic factors had little influence on genotype performance.

Genotype SPK004/6 which had moderate root yield was the most preferred by taste panelists whereas the highest yielding Dimbuka was ranked third best preferred genotype. This implies that taste attributes may be as important as agronomic traits when farmers are making decisions on which varieties to adopt or reject. This is in agreement with Tomlins *et al*. (2001, unpublished) who reported that the success of any newly introduced variety will depend not only on production characteristics, but also on its acceptability to consumers in terms of both sensory and utilisation characteristics. Farmers' main criteria are high yield, early maturity, disease and pest tolerance, sweetness, low fiber content, root firmness and extended in-ground storability (Kapinga *et al*. 1997).

CONCLUSIONS

Genotype SPK004/6 had superior organoleptic traits compared to Dimbuka, though the former's root yield was lower. It is, therefore, not enough for a variety to possess good agronomic traits; it must also have desirable sensory and utilisation characteristics. Genotype SPK004/6, SPK004/6/6, SPK004/1/1, SPK004/1 and Dimbuka are recommended for release in all agro-ecologies of Uganda. SPK004/6 and SPK004/6/6 have dark orange-flesh and are to be promoted specifically for combating vitamin A deficiency, while SPK004/1/1, SPK004/1 and Dimbuka are mainly for reducing food insecurity.

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