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Fusarium oxysporum Race 1 resistance and quality traits variations in apple banana germplasm

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***Musa* species, AAB genome group, commonly known as Sukali Ndizi (SND) in Uganda, has attained a substantial commercial value in the recent past owing to its superior fruit quality attributes and better prices. However, its sustainable production and productivity are highly threatened by *Fusarium* wilt. To facilitate large scale area expansion of this important dessert banana, the present study was carried out to identify the near-ideotypic lines of best quality fruit traits that are also resistant to *Fusarium wilt*. Nineteen SND ecotypes were subsequently collected from nine key SND growing districts of Uganda and evaluated in the field and laboratory for different fruit quality attributes and response to *Fusarium* wilt. Results showed a wide diversity among SND ecotypes for fruit-quality traits (fruit pulp texture, flavor and taste). The ecotypes were, however, not significantly different ($p > 0.05$) for susceptibility to FOC race 1. Cluster analysis based on organoleptic and physio-chemical properties grouped the 19 ecotypes into two major-clusters, each of which was also split into two sub-clusters. Individual sub-clusters summarize levels of similarity amongst the different ecotypes. The study confirmed the presence of diversity in SND germplasm that could be exploited for SND genetic improvement of the crop through hybridization and selection.**

Key words: Sukali Ndizi, fruit-quality traits, *Fusarium* wilt, ecotypes, desert banana, diversity.

INTRODUCTION

Apple banana is the most widely distributed dessert banana cultivar in Uganda (Gold et al., 2002). It is locally known as Sukali Ndizi (SND) in central Uganda, Kabaragara in the Western region of Uganda and Kamaramasenge in Rwanda (Nsabimana and van Staden, 2006).

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The banana is most popular due to its sensorial and nutritional characteristics. It has a small fruit with a thin peel and a slightly acidic apple like taste of the pulp, which is its unique character (Van Asten et al., 2010). It is commonly sold and consumed fresh, but can also be processed for shelf-life improvement and value addition (Van Asten et al., 2010). This makes it fit well in the Uganda government policy of value addition of agricultural products (MAAIF and MFPED, 2000). Owing to its superior characters, SND has big potential regional and export markets (Akankwasa, 2007).

Although SND is important to the farmers in the East African region, it is susceptible to most banana pests and diseases, especially weevils, nematodes, black Sigatoka, yellow Sigatoka, banana bacterial wilt and *Fusarium* wilt. *Fusarium* wilt, also known as Panama disease, is the most important lethal disease of dissert bananas (Butler, 2013; Dale et al., 2017). It is a fungal disease caused by *Fusarium oxysporum f*. sp. *cubense* (FOC) (Ploetz, 2015). Foc race 1 is the primary cause of Fusarium wilt disease of SND in Uganda (Karangwa et al., 2016). It causes an estimated yield loss of >60% to this type of bananas (Tushemereirwe et al., 2000). In addition, the low yield of about 7.9 kg/bunch weight (Onyango, 2007) and non-uniformity in physio-chemical attributes among the cultivars make it difficult for the variety to sustainably penetrate the export market.

A sustainable and user-friendly strategy to control pests and diseases is by use of resistant cultivars, either by selection within existing germplasm or by introgressing resistance into the population ecotypes (Amorim et al., 2011). Diversity in any germplasm could arise as a result of occurrence of genetic variations or be induced artificially under *in vitro* conditions through use of mutagens (Bhagwat and Duncan, 1998). In bananas, production of somaclonal variants is common naturally due to meiotic instability (Withers, 1992). Whereas rates are very low, discovery of a single variant can be of great interest.

Surveys of traditional plant growing areas have been of great importance in the discovery of desirable variants which otherwise would have gone unnoticed in nature. For example, variants have been discovered in banana that exhibit desirable characters such as dwarfness (Tang and Hwang, 1998), resistance to *Fusarium* wilt disease (Ploetz, 1994) and banana cultivars of good fruit size and shape suitable for export in Brazil (Ferreira and Silver, 2002). A good understanding of genetic diversity within SND germplasm would be a useful tool in the genetic improvement of SND as it would boost the discovery and use of genes of commercial value in its improvement program.

Banana breeders have improved yield, host plant resistance to diseases and other agronomic aspects but have not targeted improvement of sensory fruit quality. To respond to consumers' needs, crop breeders must know the potential genetic variability and influence of environment on the quality traits. In this context, emphasis has shifted towards choice of parents with high performance from diverse groups. Selecting parents based on performance and genetic diversity to obtain better recombinants can provide a great opportunity to the breeder. Therefore, the present study was aimed at assessing the diversity within the SND germplasm for organoleptic, physio-chemical and Fusarium wilt race 1 resistance traits. The information generated will guide breeders to develop desirable and market preferred SND cultivars.

MATERIALS AND METHODS

Plant germplasm collection

Indigenous germplasm of SND ecotypes were collected from the major SND growing areas, representing diverse germplasm from the different eco-geographic parts in Uganda based on promising performances with regard to consumer preferences for the fruit as well as yield performance and evaluated for the traits.

Mature green SND fruits and banana plant suckers were collected from Mbarara, Masaka, Lira, Hoima, Singo, Dokolo and Mbale representing the major SND growing areas of Uganda.

Field screening of Sukali Ndizi ecotypes for resistance to *Fusarium oxysporum* f. sp. *Cubense (FOC)*

Experimental fields were established in a randomized complete-block design with four replicates at National Agricultural Research Laboratories (NARL), Kawanda between the periods of 10/09/2016 to 8/08/2017. Kawanda is located in Central Uganda at 32°36'E and 0°25'N, 1210 m above sea level (Tumuhimbise et al., 2016). During the Foc screening period, the mean annual rainfall was 1322.7 mm and temperatures ranged from 17.8 to 29°C. Kawanda is a hotspot for many pathogens and pests, including FOC race 1, weevils and nematodes. To produce enough planting materials for the experiment, the various banana suckers collected from different sources were multiplied *in vitro* (Faturoti et al., 2002). Tissue culture-derived plantlets of each ecotype, Yangambi (Km5), 1026 hybrid and Pisanglilan from International Musa Germplasm Transit Centre (ITC) (resistance to FOC) and "Kawanda-local " (susceptible to FOC) were planted in lines of seven plants per ecotype. Manuring, spacing and inoculation was done as described in Buregyeya et al. (2018). The data collected from the trials included pseudostem splitting on a scale of 1-3 and corm discoloration on a scale of 0-6 as described by Smith et al. (2008), but with some modifications, where 0= no discoloration of tissue of stellar region of corm or surrounding tissue, 1 = no discoloration of stellar region of corm; discoloration at junction of root and corm, 2 = trace to 5% of stellar region discolored, 3 = 6-20% of stellar region discolored, 4 = 21-50 of stellar region discolored, 5 = more than 50% of stellar region discolored and 6 = discoloration of the entire corm stele. Disease severity assessment based on pseudostem splitting was done using a scale of 1-3, where 1 = no cracking of the pseudostem, 2 =slight cracking of the pseudostem and 3 = advanced cracking of the pseudostem.

Physio-chemical assays on extracted juice

Juice samples from the ripe banana fruits were extracted using a commercial fruit blender (8011E Model 38BL41 Made USA). Fifty

Table 1. Severity scores for pseudostem splitting and corm discoloration due to Foc race 1 in the Uganda Sukali Ndizi ecotypes.

Zone	District	Code	Site	Pseudostem splitting scale 1-3	Corm discoloration index scale 0-6
Central	Lwengo	A	Kyazanga-Luyembe	2.19±0.8[a]	4.89± 0.33[a]
Central	Lwengo	KYA-I	Kyazanga–Kyakanyenya	2.07 ± 0.20[a]	4.57 ± 0.32[a]
Central	Lwengo	B	Kyazanga- Rwebigali	1.83 ± 0.19[a]	4.60 ± 0.32[a]
Central	Lwengo	KYA-II	Kyazanga–Mukapochi	1.69 ± 0.18[a]	4.72 ± 0.31[a]
Central	Masaka	K	Kinoni	1.93 ± 0.19[a]	4.69 ± 0.32[a]
Central	Masaka	M	Kyasonko	1.89 ± 0.19[a]	4.52 ± 0.35[a]
Central	Masaka	MSK-TN	Nzizi	2.35 ± 0.15[a]	5.11 ± 0.25[a]
South-western	Mbarara	C	Nyakayojo	2.07 ± 0.19[a]	4.76 ± 0.31[a]
South-western	Mbarara	O	Kashaka	2.04 ± 0.18[a]	4.71 ± 0.37[a]
South-western	Mbarara	F	Nyaihanga	2.00 ± 0.19[a]	5.00 ± 0.27[a]
South-western	Mbarara	Mmb-Bw	Biharwe	1.93 ± 0.21[a]	4.28 ± 0.35[a]
South-western	Mbarara	RT-mb	Mwizi	2.21 ± 0.18[a]	4.77 ± 0.32[a]
South-western	Mbarara	D	Rubaya	2.07 ± 0.19[a]	4.69 ± 0.31[a]
Western	Kiboga	N	Lwamatta	1.93± 0.18[a]	4.69 ± 0.42[a]
Western	Hoima	L	Bukwili	2.12 ± 0.18[a]	5.04 ± 0.22[a]
Eastern	Mbale	G	Bufumbo	1.96 ± 0.18[a]	4.63 ± 0.34[a]
Northern	Lira	H	Akokoro	2.10 ± 0.17[a]	4.52 ± 0.37[a]
Northern	Dokolo	J	Lwala	2.07 ± 0.18[a]	4.53± 0.31[a]
Northern	Lira	I	Agwata	2.07 ± 0.17[a]	4.90 ± 0.30[a]
Northern	Lira	Lira'J'	Boroboro	1.86 ± 0.19[a]	4.86 ± 0.27[a]
ITC	Wakiso	Km5	NBRP-kawanda	1.00 ± 0.00[b]	0.00 ± 0.00[b]
ITC	Wakiso	Psanglilin	NBRP-kawanda	1.00± 0.19[b]	0.00 ± 0.00[b]
Central	Wakiso	E (1026-hybrid)	NBRP-kawanda	1.00 ± 0.20[b]	0.00 ± 0.29[b]
Central	Wakiso	L12-1	NBRP-kawanda	2.10 ± 0.20[a]	4.79 ± 0.28[a]

Means with different letters in the same column are significantly different at α = 5%.

(50) grams of fresh banana sample were diluted in 50 mL of distilled water and blended for 1 min until homogenized and turned juicy. The mixture was centrifuged (6000 rpm, 6 min) using the Hitachi centrifuge (Hitachi Germany).

The physio-chemical assays involved the determination of the titratable acidity (% malic acid) using 0.1 M NaOH (AOAC, 2016), total soluble solutes (%Brix) using a refractometer (WZS 50 brix meter YANHE Shangai Chain) and pH using handheld pH meter (Model TDS Made China), fruit texture (pulp firmness) in kgf (Soltani et al., 2010), and the sugar/acid ratio, which was calculated using Equations 1 and 2, and 0.0067, a factor for malic acid multiplied since malic acid is the dominant acid in dessert bananas (AOAC, 2016).

$$Percentage\ Acid = \frac{\text{Titre X Acid Factor X 100}}{\text{10 (ml Juice)}} \quad (1)$$

$$Sugar\ acid\ ratio = \frac{\text{°Brix Value}}{\text{Percentage Acid}} \quad (2)$$

Organoleptic assay

Sensorial acceptance test for fruits was conducted with a panel of untrained assessors selected from staff of the National Agricultural Research Laboratories, Food Bioscience Research Department, staff from companies involved in the SND export, and SND consumers in urban markets of Kampala. The test involved individual assessment in isolated testing conditions and panelists were not permitted to discuss outcomes. The panelists were asked to assess pulp flavor, sweetness, pulp texture, pulp color and overall acceptance on a six-point scale following the method described in Micham et al. (2003).

Statistical analysis

One-way analysis of variance (ANOVA) was applied with XLSTAT 2018 to determine whether there were any statistical significant differences between the studied quality attributes and host plant resistance to FOC. Complete linkage cluster and heat –map analyses were performed in R-version 3.3.1(2016) to assess similarities in the different SND ecotypes based on their taste and physio-chemistry characteristics. Multivariate analysis of variance (MANOVA) was also performed in (R-version 3.3.1(2016) to measure the strength of the relationships among the quality determining traits.

RESULTS AND DISCUSSION

Response of ecotypes to Fusarium oxysporum *f. sp.* cubense race 1

There were no significant differences (P > 0.05) in mean scores of the all ecotypes for corm discoloration and pseudostem splitting as measures of Foc race 1 severity (Table 1). Yangambi-Km5, the highly resistant check,

showed the lowest mean scores for both pseudostem splitting and corm discoloration.

There were no significant variations among the ecotypes in their reaction to Fusarium wilt (Table 1). The only observed variation in Table 1 was as a result of genotypes Km5, Pisang lilin and E which are the known Fusarium wilt race 1 resistant genotypes. The results suggest that all ecotypes used in the study lack host plant resistance to FOC Race 1, and such resistance would have to be introgressed in from a resistant parent.

Variability of Sukali Ndizi ecotypes for chemical attributes and pulp texture

Differences between ecotypes were significant (p < 0.0001) for five physio-chemical quality traits that were studied (Figure 1A-E). The traits were total soluble sugar (TSS), texture, sugar/acid ratio, titratable acidity (TA) and pH. Highly significant differences (F_r=2020.055, p<0.0001) existed for TSS levels which ranged from 14% Brix in RT-MB ecotype to 29.1% Brix in F ecotype (Figure 1A). The results from this study indicated significant variability that could be used in a breeding program to develop improved SND varieties with varying sugar levels to target different consumer groups. For example, ecotypes with high TSS content are desirable for fruit processing.

The fruit pulp texture is an important quality trait, as the markets prefer SND fruits within a certain range (0.6 to 1.5 kgf Figure 1B) of pulp texture that is not very soft and neither very hard texture. The trait showed significant differences (F_r=22.576, p<0.0001) for which pulp texture was low (0.610 kgf) in ecotype A and high (2.089 kgf) in Km5 (Figure 1B). In Figure 1C, significant difference (F_r=14,236, p<0.0001) was observed in sugar/acid ratios from low 69.847 in C ecotype to high 160.158 in N ecotype. Since the flavor of any fruit is also contributed by the sugar/acid ratio, then the variability in this may cause the variations flavor which causes the variability in the general acceptability of the fruit.

In Figure 1D, significant variation (F_r =11.830, p<0.0001) was observed in titratable acid levels which ranged from 1.49611 g/l in the RT-MB ecotype to a maximum of 3.216 g/l in the C ecotype (Figure 1D). SND has a slightly acidic apple like taste of the pulp which is its unique characteristic, and titratable acidity may contribute towards this trait. This is mainly observed in ecotypes with high levels 3.216 g/l highly acceptable than ecotype with low levels 1.49611 g/l and this variation can be exploited by selecting and promoting the highly preferred SND ecotypes from the present germplasm.

In Figure 1E, pH lowest value 3.1 was recorded for KYA 1 ecotype while the highest was 5.3 in Km5 genotype which portrayed statistically significant difference (F_r.=5172.157, p<0.0001). The pH of the pulp may be contributing towards the overall acceptability as it is observed that Km5 genotype with very high pH is not liked by the market. These significant differences among ecotypes for the quality attributes indicated that existence of variability to have an effective selection, thus producing market friendly ecotypes.

Organoleptic analysis of the ecotypes

In Figure 1F, a significant difference (F_r=5.835, p<0.0001) in opinion regarding mouth feel was recorded. On a scale of 1-6, the panelists rated ecotype RT-MB highest at 5.421 and ecotype D lowest at 3,000. Regarding mouth feel, > 75% of the ecotypes had averages above 4, and less than 25% had less than 3.9, which meant that the ecotypes were very good apart from the 4 (D, J, E and H) as far as mouth feel was concerned. These wide phenotypic variations in mouth feel (pulp texture) is of great importance to the breeder, for example, breeding with the best preferred pulp texture varieties would be preferable to choosing RT-MB and A as putative parents.

Results for taste showed significant variation (F_r=6.327, p<0.0001) in opinion regarding the different ecotypes. The highest score on a scale of 1 – 6 was 5.625 for ecotype A and lowest (2.875) for ecotype D (Figure 1G). According to the results, all the ecotypes tasted very well as they had averages above 4 apart from the 3 ecotypes, which had averages less than 3.9. The present results confirm the long time claim by traders and consumers of the presence of different SND clones that differ in terms of fruit quality.

Aroma (odor) is one of the unique traits responsible for the popularity of SND dissert bananas. There was a statistically significant difference (F_r=2.981, p<2.981) in opinion regarding aroma Figure 1H. On a scale of 1-6, the panelists rated ecotype K highest at 5.385 and ecotype J the lowest at 3.615. Up to 16 ecotypes were above 4 implying that most of the ecotypes had the unique flavor characteristic of SND. On the contrary, the 3 ecotypes were below average 4 thus not liked by the panelists.

Of the group of panelists, Figure 1I recorded a highly significant differences (F_r=4.413, p<0.0001) views in the likeability of the color of the fruit pulp for the different ecotypes. On a scale of 1 – 6, they rated ecotype K highly at 5.385, while ecotype D was rated lowest at 3.675. The results show that 75% of the ecotypes' color was liked by the panelists and 25% of the ecotypes less appealing to the panelists.

Figure 1J overall organoleptic analysis revealed a wide diversity among SND ecotypes with most ecotypes having average general acceptability above 4, that is, 15 ecotypes and 4 ecotypes had less than 4 meaning that the largest percentage of ecotypes were more acceptable to the panelists. The results agrees with those reported by Reis et al. (2016) who reported a linear correlation between the sensorial attributes and the overall

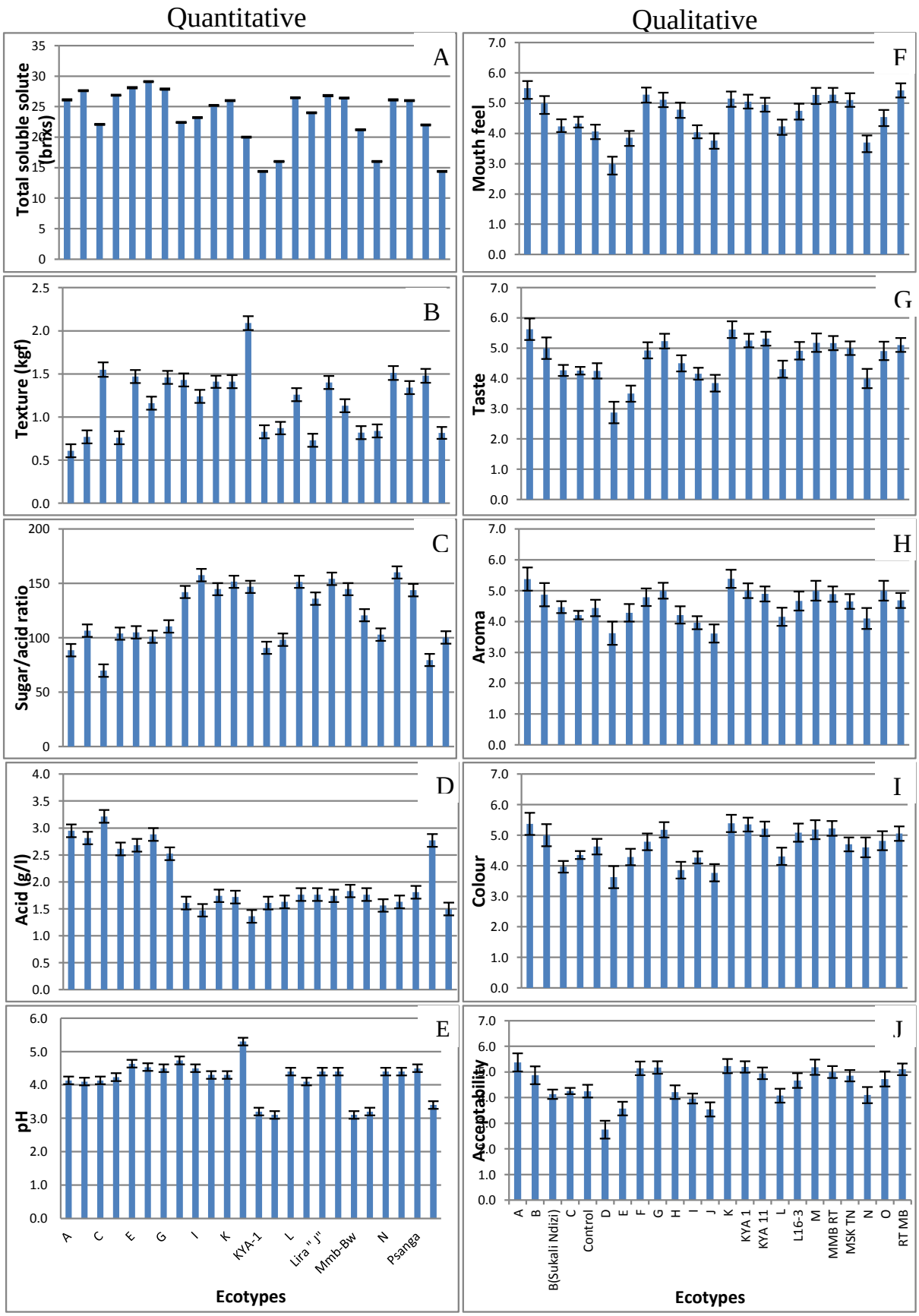

Figure 1. Variability in organoleptic and physio-chemical attributes of the ecotypes at 5% significance level.

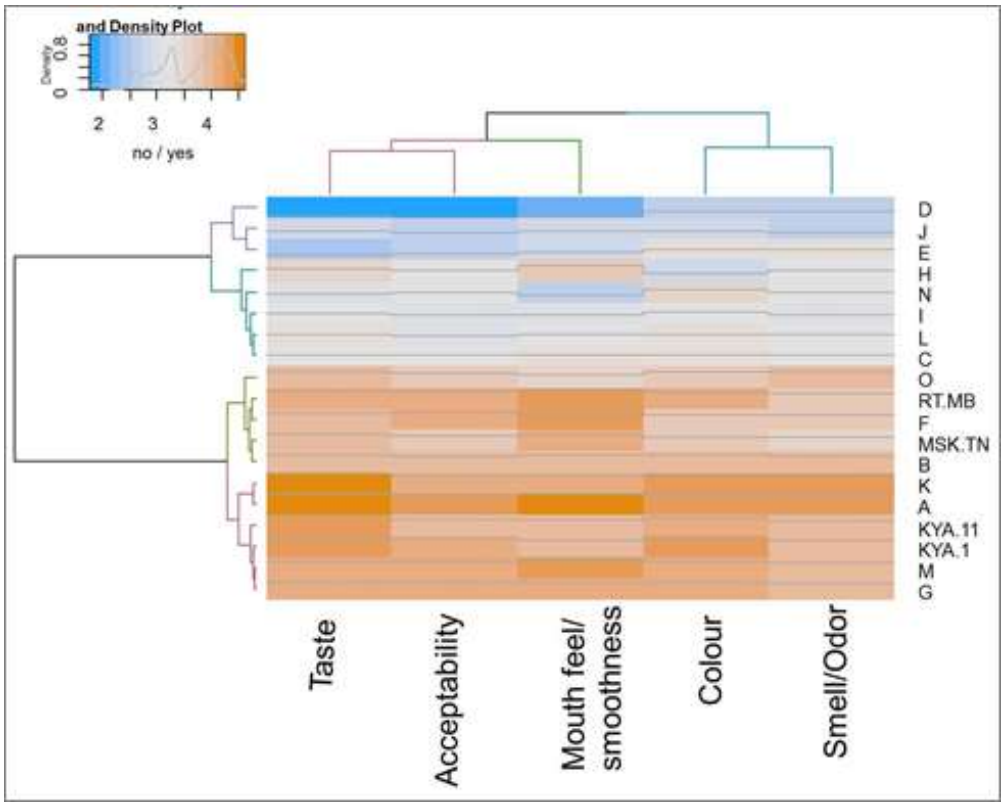

Figure 2. Comparative clustering with heat-map of Sukali Ndizi ecotypes for organoleptic fruit quality attributes.

acceptance of the bananas. Basing on this, it was observed that ecotypes K and A rated highest on almost all the attributes consistently and ecotype D scored the least on almost all the attributes and was the least liked. The wide range observed in all the characters of interest is a clear sign of variability amongst the ecotypes irrespective of origin. Donors for different SND quality characters can be selected from this germplasm but it would require an understanding of the amount of environmental variance.

Considering the regions, most of the ecotypes in Central region (Greater Masaka) were consistently rated best on all the organoleptic attributes. This could be due to selection pressure whereby farmers have resorted into planting location specific ecotype in central region. Ecotypes that were least rated on organoleptic attributes were from Northern and South-Western. Notably, no single region contributed 100% of ecotypes in the same class of rating, thus presence of variability within each region. Multivariate analysis of variance on characters of various ecotypes (both organoleptic and physio-chemical) showed very significant difference (F_r=1168.5, p<2.2 e-16) confirming the presence of wide variations in the studied traits of the ecotypes. This trait diversity evident among the Uganda SND germplasm suggests presence of opportunities for genetic improvement through selection directly from the germplasm and or selection of diverse parents for hybridization programs.

Clustering of ecotypes and diversity

Considering cluster classification for SND organoleptic quality attributes, grouped 19 SND ecotypes into four distinct clusters (Figure 2), whereby the whole group was first divided into two sub-groups as indicated by the brown and bluish colors which were finally divided into four clusters. That is brown color is divided into two smaller sub-clusters, the lower brown with 6 ecotypes and the upper one light-brown with 5 ecotypes. The lower brown contains ecotypes with average rating of all organoleptic attributes of 5 and above while the upper light-brown has most of ecotypes with average rating of all organoleptic attributes of ≤5. The bluish sub-cluster is also further divided into two groups: the very light bluish which is lower one with 5 ecotypes and the upper one bluish which has 3 ecotypes. The lower very light-bluish has most of ecotypes with average rating of all organoleptic attributes >4 and bluish upper group with ecotypes of average rating of all organoleptic attributes of <4. The brown sub-cluster is made up of the highly preferred ecotypes and the preference diminishes

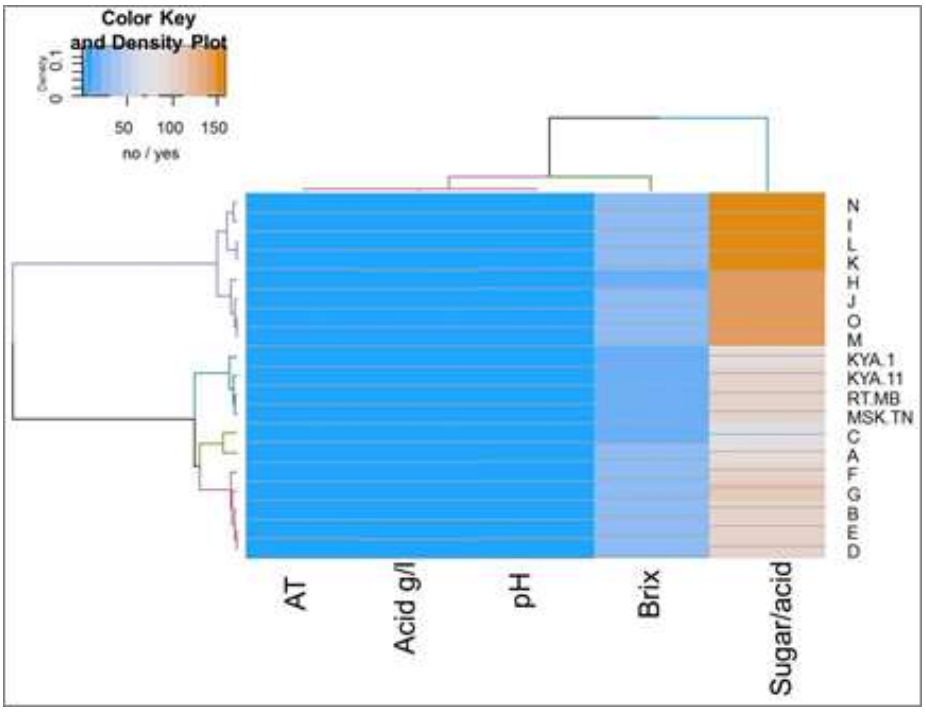

Figure 3. Comparative clustering with heat-map of Sukali Ndizi ecotypes for physio–chemical fruit quality attributes.

upwards until the bluish cluster of 3 which were not preferred by the taste panelists. With regard to the proportionate contribution of geographical origins, our clusters for organoleptic quality attributes, and the 19 ecotypes from the 5 regions were grouped into four clusters (Figure 2).

The contribution per cluster varied from 83.3 to16.7%. In this regard, large (83.3%) amounts of ecotypes were contributed to cluster I by central region, cluster II (60%) by South-western region, cluster III by (40%) South-western and cluster IV (33.3%) by Northern region. In most cases, it was difficult to see the ecotypes that were collected from one geographical origin in the same cluster, implying that they were clustered in mixture of geographical origin, which could be attributed to the free movement of planting materials among geographical origins. This might be explained as gene flow in SND attributed to human interference (since most bananas are sterile) but could only be confirmed based on molecular markers analysis clustering.

Cluster analysis based on fruit chemical quality traits grouped 19 SND ecotypes into four distinct clusters (Figure 3), whereby the whole group was first divided into two sub-groups that were finally divided into four clusters. The respective first, second, third and fourth clusters consisted of 7 ecotypes (37%), 4 ecotypes (21%), 4 ecotypes (21%) and 4 ecotypes (21%) of total ecotypes. This indicates that SND ecotypes of the same cluster group were at least with similar quality chemical attributes. The ecotypes' distribution pattern in four clusters confirmed the existence of diversity among the SND germplasm. Looking at cluster classification for SND physio-chemical quality attributes, the ecotypes were clustered into 4 groups (Figure 3). Clusters I, II, III and IV (Figure 3) were characterized by relatively high mean values of average titratable acidity and total soluble solutes, low average titratable acidity, pH and total soluble solutes, very high pH and high sugar/acid ratio respectively. For contribution of geographical origins over clusters for physio-chemical quality attributes, the results of the 19 ecotypes showed the presence of variation within the same location of collection (Figure 3). Accordingly, the ecotypes from central region were distributed into 4 clusters (I, II III and IV). It can be understood that these ecotypes are quite different for physio-chemical quality attributes though they were from the same geographic origins, suggesting a high diversity within each geographical location. Therefore, there is no need to go for geographic origins to collect genetically diverse plants in breeding for such quality traits. The possible explanation for this could be the wide divergence in the features created within each geographic origin through selection. Conversely, Western region contributed 50% of all ecotypes into cluster IV for physio-chemical quality attributes. Based on these results, Central region has wider genetic variability as compared to Western region. By the fact that Western region's ecotypes fall in the same cluster IV, implying they were similar for physio-

Table 2. Cluster means for chemical attributes.

Trait	Cluster				SD
	I	II	III	IV	
Titratable acidity	4.23	2.35	2.6	2.45	0.73
Alkalinity / acidity of pulp	4.33	3.22	4.55	4.4	1.34
Total soluble solute	26.81	15.1	25	25.44	4.84
Sugar/acid ration	97.94	98.09	143.9	155.2	32.32

chemical quality attributes, ecotypes within the cluster are similar. There are no ecotypes from the same region that occupied up to 100% of the cluster without shearing with other regions. These findings indicate that the SND germplasm from same region were diverse in physio-chemical quality attributes. Our results showed that several ecotypes were clustered together despite being collected from different geographical location, as shown in the clusters I, II, III and IV. For example, ecotypes collected from different places such as South-western, Central and Eastern regions were grouped in cluster I. Likewise, ecotypes collected from Northern, South-Western and Central regions were also clustered together in cluster III. Cluster II included ecotypes from Central and Western regions. Finally, ecotypes collected from Western, Northern and Central regions were grouped in cluster IV. The observed mix-up could be explained by the unrestricted movement of the SND planting materials from one region to another by farmers.

There were SND ecotypes with different physio-chemical quality attributes spread over the clusters, and crossing of clusters would give positive response to quality improvement. This is great opportunity in selection and breeding program to improve location-specific varieties and promote production of known SND sugar/acid ration quality profile, plus selection of appropriate parents for future breeding programs. These phenotypic analysis data are of great importance for SND breeders as they could assist in selection of appropriate ecotypes as putative parents in future breeding programs. For example, for breeding Foc race 1 resistant with consumer preferred attributes Ndizi hybrid, it would be preferable to choose female parents in cluster II (Figure 3) and cross them with diploid Foc race 1 resistant male parent.

The diverse mean values of different characters (in respect to quality chemical attributes) for different clusters (Table 2) shows that there exists a substantial level of divergence among ecotypes investigated. In fact, as regards most of the evaluated characters, the diversity amongst all the clusters is big because the mean values do differ very much. The exhibiting of difference in cluster means for various characters indicates that there is option available for identification of donors for different traits to be proposed for inclusion in hybridization program.

Conclusion

The findings of the study demonstrate the existence of diversity within SND germplasm in Uganda for quality attributes of physio-chemical and organoleptic traits. No variability was observed within SND germplasm for resistance to FOC race 1. Characterization of germplasm ecotypes based on quality traits using the hierarchical cluster analysis resulted in grouping of the germplasm ecotypes into four clusters. Most of the cluster means were significantly different, indicating the presence of variability which can be exploited through selection and hybridization. Ecotypes belonging to cluster I bear desired values for various quality traits. These ecotypes could be promoted for export.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Akankwasa K (2007). Consumer acceptability and willingness to pay for introduced dessert bananas. In. Makerere University, MSc Thesis. Available at: http://makir.mak.ac.ug/handle/10570/427

Amorim EP, Pillay M, Tenkouano A (2011). Quality improvement of cultivated musa. Banana breeding: Progress and challenges New York: CRC Press, pp. 252-280.

Association of official Analytical chemist (AOAC) (2016). Official methods of analysis of the Association of official Analytical chemist. 20th edition 2016.

Bhagwat B, Duncan EJ (1998). Mutation breeding of High gate (Musa acuminate, AAA) for tolerance to Fusarium oxysporum f.s.p. cubense using gamma irradiation. Euphytice 101:143-150

Buregyeya H, Tumuhimbise R, Kubiriba J, Talengera D, Nowankunda K, Arinaitwe G, Tushemereirwe WK, Karamura D, Karamura E, Rubaihayo PR (2018). Development of two high-yielding, consumer acceptable apple banana hybrids (Musa species, AAB genome group) with resistance to *Fusarium oxysporum f. sp. Cubense* race 1. International Journal of Plant Breeding and Crop Science 10:128-133.

Butler D (2013). Fungus threatens top banana. Nature 504:195-196

Faturoti B, Tenkouano A, Lemchi J, Nnaji N (2002). Rapid Multiplication of plantain and banana: Macropropagation techniques. IITA Report.

Ferreira FR, Silva SO (2002). Collecting banana germplasm from the AAA genomic group/ Cavendish sub group. Crop Breeding and Applied Biotechnology 2(3):485-488.

Gold CS, Kiggundu A, Abera AMK, Karamura D (2002). Diversity, distribution and farmer preference of Musa cultivars in Uganda. Experimental Agriculture 38:39-50.

Dale J, Anthony J, Jean-Yves P, Harjeet K, Mark S, Peraza-Echeverria S, Fernando G-B, Gert K, Waterhouse P, Mengersen RHK (2017). Transgenic Cavendish bananas with resistance to Fusarium wilt tropical race 4. Nature Communications 8(1):1-8.

Karangwa P, Blomme G, Beed F, Niyongere C, Viljoen A (2016). The distribution and incidence of banana Fusarium wilt in subsistence farming systems in east and central Africa. Crop Protection 84:132-140.

Ministry of Agriculture, Animal Industry and Fisheries and Ministry of Finance, Planning and Economic Development (2000). MAAIF and MFPED Plan for Modernization of Agriculture. MAAIF and MFPED, Kampala.

Micham B, Cantwell M, Kader A (2003). Methods for Determining Quality of Fresh Commodities. Perishable handling Newsletter 85p.

Nsabimana A, Van Staden J (2006). Ploidy investigation of bananas (Musa spp.) from the National Banana Germplasm Collection at Rubona–Rwanda by flow cytometry. South African Journal of Botany 72:302-305.

Onyango MA (2007). Characterization of East African accessions of *Musa* AAB “APPLE” and *Musa* AA “MURARU” dessert bananas. PhD Dissertation.

Ploetz RC (2015). Management of Fusarium wilt of banana: a review with special reference to Tropical race 4. Crop Protection 73:7-15.

Ploetz (1994). Panama disease: Return of the first banana menace. International Journal of Pest Management 40:326-336

Reis RC, Eliseth de SV, Lopes de JJ, Tâmara MS, Naiara A (2016). Physicochemical and sensorial quality of banana genotypes Pesq. Agropecific Tropical Goiânia 46 (1):89-95.

Smith LJ, Smith MK, Tree D, O’Keefe D, Galea VJ (2008). Development of a small plant bioassay to assess banana grown from tissue culture for consistent infection *by Fusariumoxysporum f. sp. cubense*. Australas. Plant Pathology 37:171-179.

Soltani M, Alimardani R, Omid M (2010). Prediction of banana quality during ripening stage using capacitance sensing system. Australian Journal of Crop Science 4(6):443-447.

Tang CY, Hwang SC (1998). Selection and asexual inheritance of a dwarf variant of Cavendish banana resistant to race 4 of *Fusarium oxysporum f. sp. Cubense.* Australian Journal of Experimental Agriculture 38:189-194.

The R- Foundation for statistical computing R-version 3.3.1 (2016-06-21)

Tumuhimbise R, Buregyeya H, Barekye A, Ssali RT, Talengera D, Kubiriba J, Muhangi S, Namagembe B, Namanya P, Arinaitwe G, Tushemereirwe WK, Karamura D, Karamura E (2016). Selection of cooking banana genotypes for yield and black Sigatoka resistance in different locations in Uganda. Journal of Plant Breeding and Crop Science 8(5):60-71.

Tushemereirwe WK, Kangire A, Kubiriba J, Nowakunda K (2000). Fusarium wilt resistant bananas considered appropriate replacements for cultivars susceptible to the disease in Uganda. Uganda Journal of Agricultural Sciences 5:62-64.

Van Asten PJA, Florent D, Apio MS (2010). Opportunities and constraints for dried dessert Banana (Musa sp). Available at: http://banana.Acta/897

Withers LA (1992). Early detection of somaclonal variation. In. INIBAP (Ed.), Proceedings of the workshop on Biotechnology Application for Banana and Plantain Improvement. San Jose, Costa Rica, pp. 200-208.