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Agronomic Performances and Nutritional Assessment of Three Sweet Potato Varieties (*Ipomoea batatas* (L) Lam.) Introduced in an Agro-ecological Zone of Groundnut Basin in Senegal

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Authors' contributions

Author PMDDS conducted the data collection, statistical analysis, writing the first draft of the manuscript and participated in the design of the study. Authors FN, AB and NSC participated in data collection and statistical analyses. Authors AD, LT and ND provided follow-up and control of laboratory analyses. Authors MSM, GM, SW, PD and KN designed the study line. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To evaluate the agronomic and nutritional performances of three varieties of sweet potato (Kandee, Caromex and Gandiol1) cultivated for the first time in the agro-ecological zone of the groundnut basin in Senegal.
Study Design: The experiment was arranged in Randomized Completely Block Design.
Place and Duration of Study: The study was conducted during two growing seasons from April to August 2017 and from October 2018 to February 2019 in Sagna village (Kaffrine, Senegal).
Methodology: The planting of the cuttings was done with a density of 0.3 x 1 m or 3333.3 cuttings ha^{-1}. Drip irrigation was used and mineral fertilization with 15-15-15 was applied. In each elementary plot, 5 plants were checked monthly for growth and phytosanitary monitoring. The harvest took place at 145 days after planting. The yields and agro-morphological characteristics of the roots were determined as well as their nutritional value and the incidence of bio-aggressor attacks.
Results: The success percentage of cuttings was 90.1, 90.5 and 88% for Kandee, Caromex and Gandiol1, respectively. The length development of sweet potato stems was variable between the 3 varieties. The Gandiol1 variety with stems longer than 1.6 m was very spread out contrary to Caromex whose average stem length did not exceed 0.5 m. The marketable tuber yields obtained were comparable between the varieties and were 21.5, 22.5 and 13.4 t ha^{-1} respectively for Kandee, Caromex and Gandiol1. The morphology of the tubers was different in shape (diameter and length) but also in flesh color. Kandee had orange flesh, rich in carotenoids (101.1 mg/kg; $P<0.001$), Caromex a cream color with carotenes of 43.2 mg kg^{-1} and Gandiol1 a white flesh. Caromex had the best proportion of dry matter (40.6%; $P<0.001$) compared to the other varieties. This amount of dry matter was correlated with the marketable root yield ($r=0.54$; $P=0.04$) and the carbohydrates amount ($r = 0.52$; $P=0.05$). Bio-aggressor incidence on tubers was lower for the Kandee variety (10.3%; $P=0.01$).
Conclusion: Sweet potato varieties performed well in the agro-ecological conditions of the groundnut basin and showed comparable agronomic performance. The three varieties can be discriminated on the level of their nutritional quality, particularly on their β-carotene content.

Keywords: Orange fleshed sweet potato; agronomy; nutritional value; β-carotene; Senegal.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* (L) Lam.), a dicotyledonous plant belonging to the family Convolvulaceae, is cultivated for its edible tuberous roots but also its leaves consumed as a green vegetable in several regions of the world [1]. Regarding its morphological characteristics, the skin color, the shape and flesh of sweet potato roots vary between varieties [2]. In Senegal, white-fleshed sweet potatoes are the most varieties produced with around 42570.6 tons/year during the last 10 years [3]. This production is mainly carried out in the north and northwest of the country, respectively on the banks of the Senegal River and around the Lake Guiers where there is easy access to irrigation water. Although sweet potato production is located in these areas, it is widely consumed throughout the country as a vegetable. Sweet potato is a low-demanding plant that can adapt to different agro-climatic conditions and is even used as a welding crop in certain regions [4,5]. However, in most sub-Saharan African countries the yields obtained by producers are below expectations and this is mainly due to high parasite pressure, climatic factors but also the lack of high yielding varieties [5]. However, in Senegal, there has been renewed interest in the sweet potato sector during recent years. This is due, on the one hand, to the introduction of new varieties, more resistant to increase production yield and, on the other hand, to the introduction and promotion of biofortified varieties such as yellow or orange varieties rich in β-carotene used to fight against vitamin A (VA) deficiency. Indeed in Senegal, vitamin A deficiency is a health problem in rural areas where it affects 18.2% of children [6]. Regular consumption of Orange-Fleshed Sweet Potatoes (OFSP) can be an alternative and a way to prevent VA deficiency because of its high concentrations of β-carotene. Badiane et al. [7] showed that consumption between 23.4 and 131.2 g and from 46.8 to 262.5 g OFSP per day would cover the recommended daily intake in VA in children aged from 7 to 24 months and in lactating women, respectively. Besides, the OFSP is very well accepted by mothers and young children in the groundnut basin area [7] which may be favorable to consider the consumption of OFSP as a dietary approach to prevent VA deficiency. The objective of this study is to evaluate the agronomic and nutritional performances of three varieties of orange-fleshed sweet potato cultivated for the first time in the agro-ecological zone of the groundnut basin.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiments were conducted during two growing seasons from April to August 2017 and from October 2018 to February 2019. They were conducted in the modern agricultural farm installed in the village of Sagna (14°05'12.5"N 15°23'00.0"W) in Kaffrine by the National Agency for Insertion and of Agricultural Development (ANIDA) of the Ministry of Agriculture. It's 5 hectares farm fully fenced equipped with a drilling and drip irrigation system allowing agricultural production throughout the year (both in the dry and rainy season). The operation on the farm was carried out by an Economic Interest Group (EIG) mainly composed of women. In this agro-ecological zone, agriculture was generally practiced during the rainy season from July to August and related to the production of peanuts or cereals. The annual rainfall data recorded in this region between 2013 and 2017 varies from 400 to 860 mm/year. The region is prey to strong temperature peaks in the dry season. They can usually vary between 26 and 39°C during the day. A sunshine average duration of 11 hours per day was noted [8].

Before the experiments, physicochemical characteristics of the soil were evaluated at the LAMA (Laboratoire des Moyens Analytiques, IRD: Institut de Recherche pour le Developpement, Dakar, Senegal). Soil samples were collected from the field using soil auger at 0-20 cm depth and physical analyzes were focused on particle size. Analyzes reported the proportions of clays, fine silts, large silts, fine sands and coarse sands of local soils. The finest elements are obtained by sedimentation according to Stockes' law and the others by sieving. Based on these data, the texture of soil samples was determined using Henin's triangle [9]. The chemical analyzes were focused on pH (water pH), total nitrogen, mineral nitrogen, total carbon, assimilable phosphorus and exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+).

2.2 Planting Materials and Experimental Design

Three (3) varieties of sweet potato, 2 orange-fleshed (Kandee, Caromex) and a white-fleshed local variety (Gandiol1) were selected for the agronomic evaluation. The sweet potato cuttings included 3 to 4 nodes with an estimated average length of 13 to 15 cm. These healthy cuttings were from the National Research Laboratory on Plant Production of the Senegalese Institute for Agronomic Research (LNRPV-ISRA, Senegal). The experiment was arranged in Randomized Completely Block Design (RCBD) with 4 replications/variety. In each block, there were 3 plots and the spacing between blocks was 3 m. Each plot size has 24 m^2 with 6 m length and 4 m width. The soil was plowed by animal traction and ridges spaced 1 m with 80 cm wide and 70 cm high was made. The planting of the cuttings was done with a density of 0.3 x 1 m or 3333.3 cuttings ha^{-1}. Mineral fertilization with N: P: K, 15: 15: 15 was carried out in 3 spreadings either in bottom fertilizer due to 200 g/24 m^2, and 2 cover contributions spaces of 1 month in a localized way on the ridges. Manual weeding was practiced at 4 and 8 weeks after planting to keep the plots clean and free of weeds. Watering was uniformed throughout the experimental field by using a drip irrigation system according to a daily schedule. The harvesting was done manually 145 days after planting (DAP).

2.3 Data Collection

2.3.1 The agronomic performance

Data collection was done on the central part of the plot after removing one meter on each side to avoid the effects of curbs. Five (5) randomly selected plants were monitored each month to determine the number and length of creepers. The fresh tuberous roots were harvested 145 days after planting (DAP) with a hand hoe. The weight and number of the roots per plant for each variety were determined. Tuberous roots are considered unmarketable if they were too small in size (diameter < 10 cm) or had suffered damage to their physical integrity. The yield of fresh roots was measured in kilograms using a yield square of 1 m^2. Combining the roots harvested on each plot with a balance and the recorded weight per plot unit was extrapolated to the base in tons per hectare (t ha^{-1}). The weight of fresh biomass (white paper) was measured in kilograms as root harvested with freshly cut vines per plot and was extrapolated to tones per hectare.

2.3.2 Nutritional quality of sweet potato tuberous roots

For each variety of sweet potato, roots were randomly sampled, wrapped with aluminum foil labeled and dated. These samples were transported to the LARNAH (Laboratoire de Recherche en Nutrition et Alimentation Humaine) for β-carotene analysis and to the expertise laboratory of the ESP (Ecole Supérieure Polytechnique) in Cheikh Anta Diop University (Dakar, Senegal). The amount of dry matter in sweet potato roots was determined according to the method described by [1]. Three (3) tuberous roots of each variety were cut by hand into thin strips (<1 mm), and mixed. Four 50 g samples were weighed on a precision scale (balance iBalance 2500, My Weigh, AZ, USA) and oven-dried at 60°C until their weight became constant. The percentage of dry matter is calculated using the following formal: Dry matter = (Dry matter)/(Fresh weight)x100.

The total carotenoids were determined by a colorimetric method using the iCheck (iCheckTM carotene BioAnalyt GmbH, Allemagne). This method was previously described by Djinadou et al. [10] to determine the level of β-carotene in cassava tubers. Only one-tenth dilutions were carried out on the samples because that sweet potato contains more carotenes than cassava. The β-carotene content was estimated based on the results of Vimala et al. [11] which showed that 90% of the carotenoids in sweet potato are β-carotene.

Fatty acids, proteins, carbohydrates, ashes and moisture were measured following the AFNOR methodology (AFNOR, 1982). The amount of dry matter was obtained according to the method described by [1]. The samples were dried in an oven at 105°C for 2 h, cooled and then weighed. Total lipids were obtained using a Soxhlet extractor with diethyl ether as solvent (NFV 03-905 standard). The nitrogen determination was carried out by the Kjeldhal method (standard NF 03-050) and the proteins were calculated using 5.7 as a coefficient.

2.4 Statistical Analyzes

Data analysis was performed with the open-source statistical software R version 4.0.0. The results are expressed on average ± standard deviation (SD) and or percentage (effective). All parameters measured between the 3 sweet potato varieties were subjected to an analysis of variance (ANOVA). If the ANOVA was significant, the differences between the means were determined using the least significant difference (LSD) post-hoc test. Correlation analysis among yield and the nutritional value was done using Pearson's correlation test and ggcorr function of the package GGally. The evolution of growth along the length of the vines has been represented in figure format using the ggplot2 package. The principal component analysis (PCA) was performed to identify the mains characteristics of sweet potato varieties. It was accomplished using the PCA functions of the FactoMineR package and its visualization was done using the Factoextra package. For all these analyzes a significance level of 5% was retained.

3. RESULTS

3.1 Soil Characteristics of the Experimental Field

The soil was sandy-loam with 72.3% of sand, 23.1% of silt and 4.5% clay (Table 1). A slight acidity (pH = 6.4) was noted as well as a low organic matter content (0.68%). The Total N and assimilable P contents of the soil were 0.3 g kg^{-1} and 4.4 mg kg^{-1}, respectively. The results showed also a cation exchange capacity (CEC) of 13.3 cmol kg^{-1} with a dominant presence of Ca^{2+} and K^+ ions.

Table 1. Physicochemical properties of the experimental site soil (0-20 cm)

Particle size distribution	**%**
Sand	72.3
Silt	23.1
Clay	4.5
Textural class	Sandy loam
Chemical properties	
pH (H_2O)	6.4
Organic matter (g/kg)	6.8
N total (g/kg)	0.3
Aviable P (mg/kg)	4,4
CEC (cmol/kg)	1.3
Exchangeable bases (cmol/kg)	
- K^+	4.5
- Na^+	1.3
- Mg^{2+}	3.9
- Ca^{2+}	21.1

3.2 Recovery and Success Percentage of Cuttings

During the first year of the experiment, the success percentage of cuttings was in Gandiol1 90%, Kandee 87.7% and Caromex 81%. Furthermore, in at the second year of the experiment, no replacement of cuttings was made on Caromex variety plots which recorded a recovery percentage of 100%. The average percentage of cuttings from Kandee and Gandiol1 was 92.5% and 86%, respectively. The greatest variability in recovery between the two growing seasons was noted in Gandiol1 variety (12.1%).

3.3 Vegetative Development of Sweet Potato Varieties

The plant development of sweet potato varieties was appreciated by the growth in length of the vines. Fig. 1(A) presented the situation in 2017 and Fig. 1(B) presented the situation in 2019. The three (3) sweet potato varieties had a fairly varied pattern of land use development (Fig. 1). As illustrated in Fig. 1, Gandiol1 variety had a greater spread out tendency, with the average length of the stems being around 90 cm from the first month (30 DAP). Thereafter (between 60 and 120 DAP), the stem length of Gandiol1 increased exponentially. At Harvest time, the average length of its stems was over 1.70 m. Exponential development was also observed for Kandee stems with lengths that ranged from 40 cm to 30 DAP to 1.40 m at 120 DAP. The development of Kandee stems was between 30 and 60 DAP (< 50 cm). The most important development was noted between 90 and 120 DAP. At harvest, the Kandee stems had already attained a length of over 1.20 m. In contrast to the Gandiol1 and Kandee varieties, Caromex did not tend to spread and looked denser with an average stem length not exceeding 50 throughout the experiment.

3.4 Sweet Potato Fresh Tuberous Roots and Leaves Yield

A combined analysis between root/leaf yields, variety types and treatment blocks allowed the comparison of yields (Table 3). During the 2 years of experiment, the average yields of fresh sweet potato tuberous roots were comparable (*P* = 0.108) between Kandee (25.5 t ha^{-1}), Caromex (25.1 t ha^{-1}) and Gandiol1 (15.1 t ha^{-1}) varieties. The marketable yield of this performance was 21.5, 22.6 and 13.4 t ha^{-1} for Kandee, Caromex and Gandiol1 respectively without any significant difference (*P* = 0.184). Similarly, the yields of above-ground biomass (leaf and stem) were also comparable between the three varieties regardless of the growing season (*P* = 0.421) even if a variation in mean yield was noted between the two growing seasons. The overall biomass yield was 12.1 t ha^{-1} for Kandee, 8.5 t ha^{-1} for Caromex and 9.9 t ha^{-1} for Gandiol1,

Table 2. Mean percentage recovery of sweet potato cuttings

Cuttings success	Kandee	Caromex	Gandiol1	*P*
(%) 2017	87.7 ± 5.4	81 ± 0.7	90 ± 4.6	0.257
(%) 2019	92.5 ± 8.8	100 ± 0.0	86 ± 19.0	0.326
Overall	**90.1 ± 7.1**	**90.5 ± 0.7**	**88 ± 11.1**	**0.140**
CV%	**7.9**	**0.8**	**12.1**	

The values presented as mean ± standard deviation

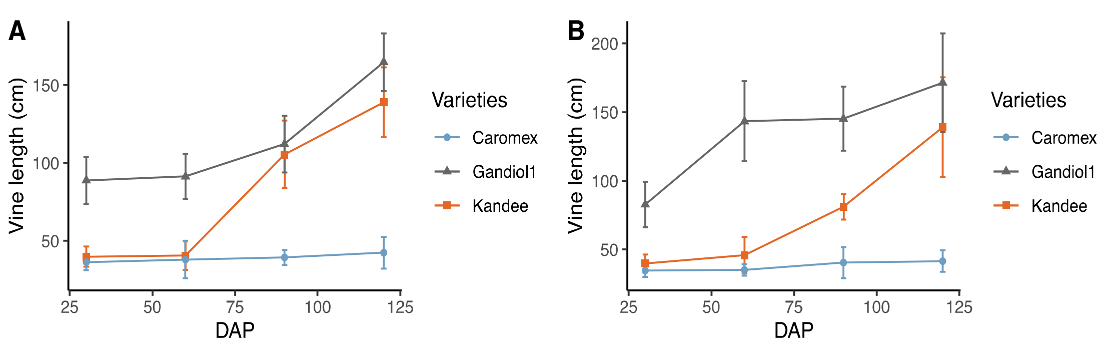

Fig. 1. Growth in length of sweet potato vines during the 2 growing periods

Table 3. Sweet potato fresh root yields and leaves yield

	Kandee (n = 4)	Caromex (n = 4)	Gandiol1 (n = 4)	P	*LSD*
Total tuberous root yield (t ha^{-1})					
TTRY 2017	27.4 ± 3.7	29.3 ± 12.2	21.7 ± 8.8	0.585	**-**
TTRY 2019	23.6 ± 15.4	20.9 ± 5.2	8.5 ± 9.2	0.112	**-**
Overall TRY	**25.5 ± 10.4**	**25.1 ± 9.7**	**15.1 ± 9.1**	**0.108**	**-**
Marketable tuberous yield (t ha^{-1})					
MTRY 2017	23.3 ± 2.9	25.9 ± 12.3	20.0 ± 8.1	0.706	-
MTRY 2019	19.7 ± 15.4	18.7 ± 4.1	6.8 ± 1.7	0.177	-
Overall	**21.5 ± 10.4**	**22.6 ± 9.3**	**13.4 ± 8.9**	**0.184**	**-**
CV %	**48.4**	**41.2**	**66.4**		
Unmarketable tuberous root yield (t ha^{-1})					
UTRY 2017	4.1 ± 1.0^{a}	3.3 ± 0.7^{a}	1.7 ± 0.8^{b}	0.024	1.562
UTRY 2019	3.9 ± 1.7^{a}	2.2 ± 1.8^{ab}	1.7 ± 0.3^{b}	0.080	2.040
Overall	**4.0 ± 1.3^{a}**	**2.8 ± 1.4^{b}**	**1.7 ± 0.5^{c}**	**<0.001**	**1.061**
CV %	**32.6**	**49.7**	**33.9**		
Leaves yield (t ha^{-1})					
LY 2017	12.4 ± 5.4	9.7 ± 5.5	9.7 ± 6.9	0.805	-
LY 2019	11.8 ± 6.5	7.3 ± 1.7	10.1 ± 4.8	0.561	-
Overall	**12.1 ± 5.6**	**8.5 ± 4.0**	**9.9 ± 5.5**	**0.421**	**-**
CV %	**46.3**	**47,1**	**55.5**		

The values presented as mean ± standard deviation, Means followed by the same letters within the row indicate no differences at p< 0.05, TTRY: Total tuberous root yield; MTRY: Marketable tuberous root yield; UTRY: Unmarketable tuberous root yield; LY: Leaves yield

without any difference between the three varieties. Kandee variety recorded the highest amount unmarketable tuberous root yield 4 t ha-1 followed by the Caromex variety and at the end by the variety Gandiol1 1.7 t ha^{-1} (P<0.001).

3.5 Agro-morphological Characteristics of Sweet Potato Varieties

The number of sweet potato tuberous roots per plant was more than 2 roots in all varieties whose agro-morphological characteristics are presented in Table 4. The sizes of the roots were comparable with average diameters ranging from 16 to 20 cm. However, the roots of the Kandee were the longest with an average length of 21.9 cm, and that of Caromex roots were shortest with 13.2 cm of length (P <0.001). One root of the Kandee and Gandiol1 varieties weighed between 551.3 and 567.9 g, respectively, and were significantly heavier than those of the Caromex variety (318.6 g, P = 0.023). Similarly, the average weight of the sweet potato root per plant was lower for Caromex (P = 0.023). However, there was a very high variability for this parameter (Table 4). Sweet potato plant produced an amount of above-ground biomass equal to 648.3, 1014.4 and 1019 g for the Caromex, Gandiol1 and Kandee varieties respectively. The amount of above-ground biomass produced by the plant was comparable (P = 0.197) between these varieties, but a high variability was noted especially in Kandee plants with a standard deviation more than the mean value itself (1019.6 ± 1042.1 g).

Phenotypic evaluation of freshly harvested sweet potato roots revealed that those of Caromex and Gandiol1 varieties had a purplish-pink skin with the skin of Kandee roots being orange to brown. The three varieties were very distinct regarding flesh color. The Kandee was orange-fleshed, the Caromex was cream-colored and the Gandiol1 white-fleshed.

3.6 Nutrient Contents of Sweet Potato Varieties

The mean values of protein, fat, ash carbohydrate, dry matter and β-carotene of the Gandiol1, Kandee and Caromex varieties were compared to each other In Table 5. Data showed that all varieties contained low amounts of lipids (from 0.61 to 0.76%) and protein (from 0.9 to 1.2%). Carbohydrate was one of the major constituents of the sweet potato roots, but was significantly higher in the Caromex variety (P<0.001). Significantly, the Caromex roots contained more dry matter (P<0.001). The highest amount of protein was found in Gandiol1 roots (P=0.02) as well as the lowest amount of ash (P=0.033). Out of all the varieties, Kandee has the highest concentration of β-carotene (101.1%), i.e. 2.5 times more than the quantity found in the two other varieties Caromex (*P*<0.001).

3.7 Incidence of Diseases and Insects on Sweet Potato Varieties

Potato leaves were very appreciated by insects (locusts, caterpillars etc.) from the first months of cultivation, particularly in the foliage. The leaves of the Kandee variety seemed to be more attractive during the first months of cultivation with an average incidence of attacks of 18.4%. With an increase in the number of leaves and branches, the incidence of attacks seemed to decrease at 60 DAP, however, they were more present in the Gandiol1 variety. However, at 90 DAP, attacks become significantly higher in the Caromex variety with an average incidence of 15%. At the end of the cycle, more than 5% of the leaves of all varieties was attacked and mostly in the Gandiol1 variety (*P* <0.001). The damage noted in the roots was caused by termites, millipedes, weevil larvae, gall nematodes and palm rats. The overall incidence of damage to roots was given in Table 6. Almost half of the roots (40.6%) of Gandiol1 suffered from attacks caused by one of the insects mentioned above. Roots of the Kandee variety were less affected by pest attacks with only 10.35% of roots concerned (*P*=0.010).

Table 4. Agro-morphological characteristics of sweet potato varieties

Parameters	Kandee	Caromex	Gandiol1	P
NTRP (n)	2.5 ± 1.7	2.7 ± 1.5	2.3 ± 1.3	0.574
TRD (cm)	17.0 ± 5.7	16.9 ± 4.5	19.9 ± 5.2	0.051
TRL (cm)	21.9 ± 8.1^{a}	13.2 ± 4.1^{b}	18.4 ± 5.8^{a}	< 0.001
TRW (g)	551.3 ± 481.9^{a}	318.6 ± 249.2^{b}	567.9 ± 441.0^{a}	0.023
TRWP (g)	534.9 ± 366.1^{ab}	400.8± 252.7^{b}	737.8 ± 692.3^{a}	0.023
LWP (g)	1019.6 ± 1042.1	648.3 ± 581.0	1014.4 ± 674.7	0.197
Skin color	Orange-brown	Pink-purple	Pink-purple	-
Flesh color	Orange	Cream	White	-

The values presented as mean ± standard deviation, Means followed by the same letters within the row indicate no differences at p< 0.05, NTRP: Number of Tuberous Roots per Plant; TRD: Tuberous Roots Diameter (cm); TRL: Tuberous Roots Length (cm); TRW: Tuberous Roots Weight; TRWP: Tuberous Roots fresh Weight per Plant (g plant^{-1}); LWP: Leaves Weight per Plant (g plant^{-1})

Table 5. Nutrients contents of sweet potato varieties

Nutrients (%)	Kandee (n = 4)	Caromex (n = 4)	Gandiol1 (n = 4)	P	*LSD*
Protein	1.0 ± 0.0^{ab}	1.2 ± 0.2^{a}	0.9 ± 0.1^{b}	0.074	0.255
Fat	0.8 ± 0.1	0.7 ± 0.19	0.6 ± 0.06	0.307	
Carbohydrate	24.4 ± 3.4^{a}	30.98 ± 1.38^{b}	25.13 ± 2.32^{a}	<0.001	2.68
Ash	0.9 ± 0.1^{a}	0.9 ± 0.2^{a}	0.6 ± 0.2^{b}	0.033	0.216
Dry matter	30.7 ± 1.4^{a}	40.6 ± 2.2^{b}	32.2 ± 2.1^{a}	<0.001	2.60
Total carotene (µg/g)	101.1 ± 9.6^{a}	43.2 ± 1.6^{b}	31.9 ± 2.9^{c}	<0.001	10.14
β-carotene (µg/100 g)	9100 ± 870^{a}	3880 ± 1400^{b}	2870 ± 270^{c}	<0.001	913

The values presented as mean ± standard deviation, Means followed by the same letters indicate no differences at P < 0.05

Table 6. Average incidence of pest attacks on sweet potato varieties

	Kandee	Caromex	Gandiol1	P
Incidence of insect attacks on leaves (%)				
30 DAP	18.4 ± 12.7^{a}	5.3 ± 0.8^{b}	9.5 ± 3.8^{b}	<0.000
60 DAP	2.8 ± 2.4^{ab}	2.1 ± 0.9^{a}	3.5 ± 1.3^{b}	0.016
90 DAP	1.5 ± 1.1^{a}	15.1 ± 15.8^{b}	2.6 ± 1.3^{a}	<0.001
120 DAP	6.2 ± 3.2^{a}	5.4 ± 3.2^{a}	9.4 ± 4.3^{b}	<0.001
Overall	7.8 ± 10.2	5.9 ± 7.9	5.3 ± 4.1	0.060
CV	130.3	132.3	76.0	
Incidence of insect attacks on root (%)				
Insect	10.3 ± 3.7^{a}	20.0 ± 5.2^{a}	40.6 ± 13.1^{b}	0.010

DAP: Days after planting; The values presented as mean ± standard deviation, Means followed by the same letters indicate no differences at P<0.05

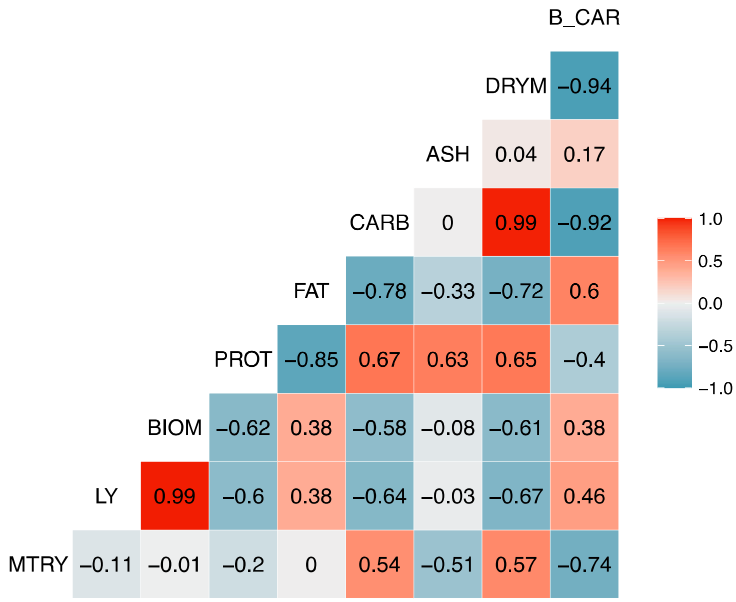

Fig. 2. Correlation between agronomic performance and nutritional quality of sweet potato tuberous roots

MTRY: Marketable Tuber Roots Yield, LY: Leaves Yield, BIOM: Biomass total Plant, PROT: Protein, FAT: Fat, CARB: Carbohydrate, ASH: Ash, DRYM: Dry matter content in Root, B_CAR: β-carotene

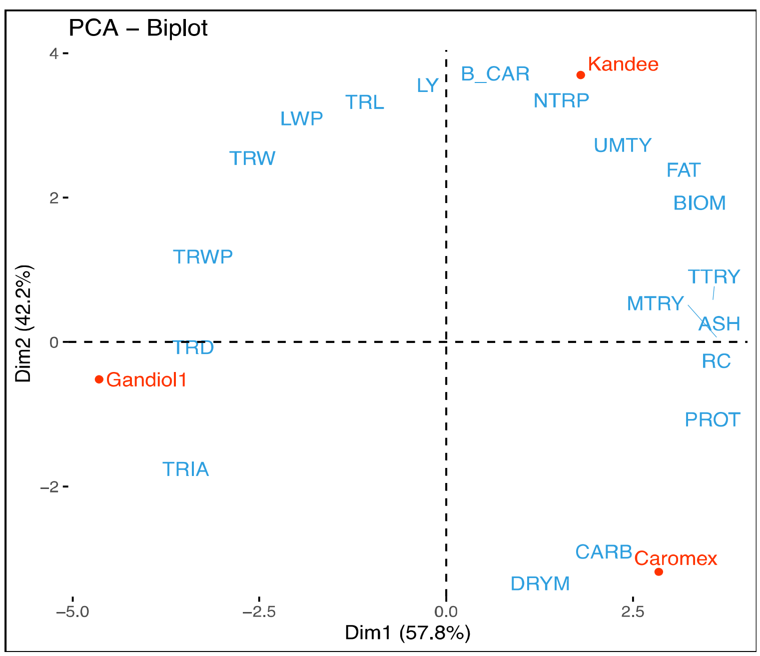

Fig. 3. Principal Component Analysis (PCA) biplot illustrated the agronimic and nutritional parameters of the 3 sweet potato varieties tested

TTRY: Total tuberous root yield; MTRY: Marketable tuberous root yield; UTRY: Unmarketable tuberous root yield; LY: Leaves Yield; BIOM: total Biomass per Plant; NTRP: Number of Tuberous Roots per Plant; TRD: Tuberous Roots Diameter (cm); TRL: Tuberous Roots Length (cm); TRW: Tuberous Roots Weight; TRWP: Tuberous Roots fresh Weight per Plant (g plant-1); LWP: Leaves Weight per Plant (g plant-1); PROT: Protein, FAT: Fat, CARB: Carbohydrate, ASH: Ash, DRYM: Dry matter content in Root, B_CAR: β-carotene

3.8 Correlation between Agronomic Performance and Nutritional Quality of Sweet Potato Roots

Analysis of the correlation revealed significant associations between the parameters of agronomic yield and nutritional quality of the harvested products (Fig. 2). The significant associations noted between agronomic performance and nutritional quality were, on the one hand, the association between marketable root yield and the quantity of dry matter contained in tuberous roots (r = 0.57, *P* = 0.040). On the other hand by a weak positive correlation between marketable root yield and the quantity of carbohydrates found in the roots (r = 0.52, *P* = 0.05). Leaf yield contributed strongly to the amount of total biomass produced by the variety (r = 0.99, *P*<0.001). Significant associations were noted between the quantity of protein and ash found roots (r = 0.67, *P* = 0.02). The quantity of carbohydrates in sweet potato roots increased with the quantity of dry matter (r = 0.99, *P* <0.001).

3.9 Characterization of the Three Sweet Potato Varieties

The Principal Component Analysis (PCA) presented in Fig. 3 resulted in a Biplot dispersion scheme with two main axes (1 and 2) that explain the total variance (100%) between yield parameters, agro morphological characteristics and nutritional quality of tuberous roots. The first axis explains 57.8% of the variability and discriminates the Gandiol1 variety from the Kandee and Caromex varieties. The second axis explains 42.2% of the variability and contrasts Kandee with the other two varieties.

Therefore, the Gandiol1 variety was characterized by a higher yield per plant, a larger diameter of tuberous roots but also a high incidence of attacks on these roots. As for the Caromex variety, it was specifically distinguished due to its nutritional qualities such as its pronounced dry matter, carbohydrate and protein content. Kandee variety has been characterized agronomically by a high number of tuberous roots per plant, a high total root yield but also by a high quantity of unmarketable root yield. For nutritional quality, the tuberous roots of Kandee are characterized by a high concentration of β-carotene and fat.

4. DISCUSSION

After two growing seasons, research showed that the agronomic performance of the three sweet potato varieties (Kandee, Caromex and Gandiol1) was comparable in harvested fresh tuber root. By this, we can see that the varieties with colored flesh (Kandee and Caromex) performed as well as the local white flesh variety (Gandiol1). The few published studies available on sweet potato in Senegal, showed higher estimated root yields (44 t ha^{-1}) than those found in this study [12]. However, the yield estimates were based on parameters that are more questionable and were less accurate than our measured yield. in our study, the measured yields were in the same range of values as those reported by many similar studies in the African region [13,14]. However, much higher yields have been noted by other authors such as Laurie et al. [15] in South Africa with yields as high as 60 t ha^{-1} and in Turkey by Çaliskan et al. [16] who reported yields ranging from 6.72 to 112.6 t ha-1 for the different varieties of sweet potato. It was also important to mention that most of the studies carried out in stations under controlled conditions often showed better yields. Moreover, it has been shown that the yield is a function of the genetics of the variety type [17], environmental and cultural factors such as planting density [18,19], soil type and by variations in soil fertility status [20]. Koala et al. [21] and Masumba et al. [22] measured the performance of sweet potato varieties, of which Caromex and Kandee and reported yields much lower than ours. Moreover, the results obtained on these two varieties with colored flesh showed some evidence for the performance of these varieties as they even exceeded the expected yields and were 15.3 and 14.5 respectively for Caromex and Kandee [23].

In contrast to the agronomic performances, the nutritional values of the 3 varieties of sweet potato were different. The most significant difference was the β-carotene content. It was found in previous studies that: More orange was the flesh, more β-carotene was contained by the variety [24,25]. So Kandee was also more concentrated in β-carotene (9100 µg 100 g^{-1}) but this quantity found was slightly below the quantities reported in the catalogue of this variety (11030 µg 100 g^{-1}; [23]. Even if some authors claimed that there was no environmental influence on the β-carotene content of sweet potato varieties [26], the β-carotene content in Caromex in this study was much lower than expected. The flesh came out cream-colored after harvesting and was not orange in color as reported [23]. The variation in color and β-carotene content in Caromex could be influenced by the amount of water or fertilization level, as reported by [27]. These parameters were not calculated for the specific needs of a variety but rather according to the standard needs of sweet potatoes in general.

Multivariate analysis between agronomic and nutritional parameters revealed that the marketable roots yield increased as a proportion of the dry matter content in the roots. The dry matter content was also positively correlated with the carbohydrate content of the roots. Both the dry matter and carbohydrate content contributed to the acceptability of the hedonic properties of sweet potato roots [1]. Often many orange-fleshed sweet potatoes had low dry matter content [15]. Indeed, it has been one of the major challenges for plant breeding programs to find varieties that are both rich in dry matter and carotenoids. Furthermore, studies showed a negative correlation between the dry matter and the beta-carotene content [28,29]. However, it was noted that in our study, the amount of dry matter found in the three varieties was more than 30% of the total weight of root and was therefore considered as average for Kandee and Gandiol1 and high for Caromex [1,30]. In our study areas, the acceptability of the Kandee variety has been already reported by Badiane et al. [7].

None of the cultivated varieties seemed to have a resistance to insect attacks. They were all attacked, both at the leaf and root levels. Attacks on the leaves were not at a level of severity that would prevent the photosynthetic activity of the plants. Concerning the attack on tuberous roots, Gandiol1 and Caromex suffered from more than Kandee, probably related to the nature of their rooting. Indeed, Kandee tuberous roots were deeper in the soil and were therefore difficult to reach by certain insects such as weevils, unlike other varieties whose tuberous roots outcrop the soil: the shallower tuberous roots make harvesting less painful, but also imply more working time, especially more time to replenish the ridges to protect the tubers from insect and rodent attacks [2].

Soil characterization of our experimental site revealed that its texture was a major asset in favour of the introduction of sweet potato in the agro-ecological zone of the groundnut basin. Previous studies have shown that sweet potato roots develop best in sandy loamy textured soils [20]. This soil texture also facilitates good irrigation water circulation and harvesting of mature roots. However, the low proportion of potassium and nitrogen reported by soil tests justified fertilizer application. Potassium has been identified as one component responsible for the formation of tuberous roots in sweet potato and therefore plays an essential role in producing good yields [31,32].

The high success rate of cuttings has been an encouraging element because it allows evaluating the adaptability of cuttings in the growing environment, in agro-ecological conditions. Like the crop, it can be a major element in the choice of the variety. The fewer cuttings to be replaced, the better it is for the producer who can limit his production costs and the time spent on making replacements. This workload can also be reduced by the rapid occupation of space by lianas of varieties that prevent weed development. Even though the Gandiol1 variety was more deployed in the first few months of cultivation, the study showed that it was the less deployed varieties, i.e. those with an erect growth habit, that are more likely to prevent weed development in that they tend to produce more stems making the space dense [33]. However, it should be noted that measuring the length alone was not enough. Some plants might have cut vines with several branches, which also allow this structure to dance. On the other hand, fairly long vines do not occupy a lot of space and can be invasive at times and may require more weeding work at harvest time. Thus, measuring the length of the vines should be combined with counting the number of stems per plant and the Leaf Area Index (LAI) measurement, and to a lesser extent calculating the weed infestation rate by measuring the yield of the weeds.

5. CONCLUSION

This study showed that sweet potato varieties have performed well in the agro-ecological zone of the groundnut basin of Senegal and have comparable in agronomic performances. The difference between these varieties lies in the nutritional composition, especially in the content of dry matter and carbohydrates, which are positively associated with the yield of marketable tuberous roots, The Kandee variety has the best concentration of β-carotene and its culture should be promoted to prevent vitamin A deficiency in rural areas. Optimization of β-carotene content yields by cultural practices adapted to the area or by an appropriate fertilization system should also be considered.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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