

Full Length Research Paper

## ***In-situ* morphological characterization of coconut in the Coastal Lowlands of Kenya**

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Characterization of *in situ* coconut (*Cocos nucifera* L.) genotypes using morphological descriptors is of primary importance for genetic resources. Variations in five traits were recorded on 48 selected coconut palms located at 0 to 177 m above sea level in the Coastal Lowlands of Kenya. The objective of our study was to characterize coconut palms in the coastal Kenya using morphological markers. Data was recorded on palms that included tall, dwarf and hybrid varieties. Data was analyzed using Genstat Ver 14.2 software. Phylogenetic tree construction, using the neighbour joining method, revealed that the germplasm fell into three major clusters comprising of 2, 25 and 21 genotypes, respectively. Principal component analysis (PCA) showed that the first component (CP1) accounted for 65.54% of the total variation and was associated with the number of green leaves. The second component (PC2) explained 19.71% of the total variation and was associated with stem height. The results from this study indicate that morphological variation for coconut germplasm at the Kenyan coast exists for both qualitative and quantitative characters. Coconut palms did not cluster on the basis of their origin based on the counties grown.

**Key words:** Morphological characterization, *Cocos nucifera* L., variation, genetic resources, genetic diversity, cluster analysis.

### INTRODUCTION

Coconut (*Cocos nucifera* L.), is a monocotyledonous plant of the family Arecaceae (Palmaceae), subfamily Cocoideae and the monospecific genus *Cocos*. It is an

important crop at the Kenyan coast, providing its growers with a source of livelihood. It also plays a significant role in the economic, cultural and social life of over 80

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tropical countries in the world. Coconut is cultivated mainly as an oil seed crop. The oil is rich in lauric acid and besides being cooking oil it has a variety of other uses (Harries, 1995). Almost every part of the coconut tree can be used in either making commercial products or meeting the food requirements of rural communities (Teulat et al., 2000). Perera et al. (2000) considered Southeast Asia as the centre of origin of coconut, whilst Melanesia is thought to be the most likely region for coconut domestication along the coasts and islands between Southeast Asia and the Western Pacific (Harries, 1995). Coconut has been found distributed in many parts of the world including Central and South America, East and West Africa, Southeast Asia, East Asia and the Pacific islands. According to Ohler (1984) dissemination was achieved by seeds floating in sea currents and subsequent germination on the shore, followed by further human dispersal. Geographic isolation, introgressive hybridization, mutation, and selection are the most likely causes of population differentiation of coconut. The mode of dispersal of coconut is likely to have resulted in founder effects influencing population differentiation (N'Cho et al., 1993). Tall and dwarf types are the two main stature and breeding habit categories used as the primary classification of coconut (Menon and Pandalai, 1958). Tall coconuts (talls) grow to a height of about 20-30 m and are allogamous, late flowering, and their nuts are medium to large in size. They are hardy and thrive in a wide range of environmental conditions. Dwarf coconuts (dwarfs) grow to a height of about 10-15 m and are autogamous, early flowering, and generally produce a large number of small nuts with distinctive colour forms (Menon and Pandalai, 1958). Introgression of talls and dwarfs and further selection and dissemination by man produced the wide range of varieties and pan-tropical distribution of coconut seen today (Harries, 1978).

The improvement of crop genetic resources depends on continuous infusion of desired traits of wild relatives, traditional varieties and use of improved breeding methods. These require an assessment of diversity to select superior varieties (Mondini et al., 2009). Diversity analyses in coconut palm to date have been done by morphological traits, biochemical and molecular markers (Dasanayaka et al., 2009). Using morphological and biochemical markers have disadvantages due to the long juvenile phase of the plants, high cost, long-term of field evaluation, potential environment factors' influence on the phenotype and limited number of available phenotypic markers (Manimekalai et al., 2006). However, morphological markers are easy to study. Assessment of the genetic diversity present within a species is a prerequisite for future sustainable breeding efforts and germplasm management. Molecular markers provide an important technology for evaluating levels and patterns of genetic diversity and have been utilised in a variety of plant species (Rafalski et al., 1996). To date, there are over 300

recorded ecotypes of coconut (Coconut Genetic Resources Network Database v. 2.2 COGENT/IPGRI), with evaluation and characterization being mainly carried out on morphological and reproductive traits (Fernando et al., 1995).

Currently, coconut production in Kenya is low despite its potential and adequate farmer-to-farmer dissemination of market access (Muhammed et al., 2012). The present level of productivity is low, which is probably due to pest and disease attacks, old and unproductive orchards and inadequate production of quality planting material for replanting and new planting (Muhammed et al., 2013). Decline of soil fertility, lack of a reliable and fast means of generating clean planting materials, general lack of value additions and poor agronomic packages contribute to low production (Muhammed et al., 2013).

The tall and dwarf coconut types as well as their intermediates, which are thought to be their hybrids, have traditionally existed at the Kenyan coast. However, no genetic or morphological diversity studies on coconut at the Kenyan coast have been conducted and documented. Therefore, an *in situ* morphological characterization of the coconut grown at the coastal lowlands of Kenya was conducted with a view to understand and document the morphological diversity among coconut populations at the Kenyan coast. Knowledge of the degree of morphological relationships is of importance for crop improvement and may help in establishing core collection for future research work.

## MATERIALS AND METHODS

The study was conducted in the coastal lowlands of Kenya in April 2013. A total of 48 samples were included in the study. There were 45 tall palms designated East African Talls (EAT), including the suspected hybrids and three East African Dwarfs (EAD) that broadly represented all varieties of coconut from different coconut-growing regions at the Kenyan coast. For the character assessment, eight varieties were included that researchers and farmers considered as hybrids. Of these, 15 palms were sampled from gardens/house yards, 16 from small farm fields while 17 were sampled from large farm fields. Samples were specifically taken from areas where the palms grown were morphologically different and there was a marked change in altitude or cropping systems, where a formidable barrier such as a mountain or a river existed or where local people were ethnically different (in terms of dialect) from previous collection sites. This strategy aimed at reducing chances of sampling duplicates. Selected areas in coastal regions were sampled to cover different agro ecological zones, designated as Coastal Lowland (CL), Sugarcane zone (CL2), Coconut - cassava Zone (CL3), Cashew-cassava Zone (CL4) and Millet-livestock zone (CL5) (Table 1 and Figure 1). The range of altitudes covered was 0 m above sea level at Faza in Lamu County to 177 m above sea level at Rabai, Kilifi County. Palms with similar features growing in ecologically distinct sites, were assumed to be of different eco-strains and were both sampled and characterized. For every palm tree sampled, Global Positioning System (GPS) data was recorded and the tree photographed while notes were taken on the general structure and appearance of the population, origin of the population and the collection sources. Adjacent palm status was also recorded.

**Table 1.** Names and sources of the Kenyan coast coconut germplasm used in the study.

Characterized germplasm code	Local Name	County	District	Division	Location	Village	Dialect	Type
KLF/MAG/MAG/GOG/NGA/03	Nazi	Kilifi	Magarini	Magarini	Gogoni	Ngarite	Giriama	Tall
KLF/MAG/MAG/GOG/NGA/01	Nazi	Kilifi	Magarini	Magarini	Gogoni	Ngarite	Giriama	Tall
KLF/MAG/MAG/GOG/NGA/04	Nazi	Kilifi	Malindi	Magarini	Gogoni	Ngarite	Giriama	Tall
KLF/MAG/MAG/GOG/NGA/02	Nazi	Kilifi	Malindi	Magarini	Gogoni	Ngarite	Giriama	Tall
KLF/MAL/MAL/GED/CHA/03	Nazi wa panda	Kilifi	Malindi	Malindi	Gede	Chafisi	Giriama	Tall
KLF/MAL/MAL/WAT/JIB/01	Mnazi	Kilifi	Malindi	Malindi	Watamu	Jimba	Giriama	Tall
KLF/MAL/MAL/WAT/JIB/02	mnazi	Kilifi	Malindi	Malindi	Watamu	Jimba	Giriama	Tall
KLF/RAB/KAM/KAM/MBU/09	Mtsamuri	Kilifi	Rabai	Kambe/Ribe	Kambe	M'bungoni	Kambe	Tall
KLF/RAB/KAM/PAN/MAE/10	-	Kilifi	Rabai	Kambe/Ribe	Pangani/Maereni	Maereni	Kambe	Tall
KLF/RAB/MWA/MIK/MAW/08	Mtsamuli	Kilifi	Rabai	Mwawesa	Mikahani	Mawe Mabomu	Rabai	Dwarf
KLF/RAB/RAB/RAB/BUN/02	-	Kilifi	Rabai	Rabai	Rabai	Buni	Rabai	Tall
KLF/RAB/RAB/RAB/BUN/03	Mnazi msemwa	Kilifi	Rabai	Rabai	Rabai	Buni	Rabai	Tall
KLF/RAB/RAB/RAB/BUN/04	Mnazi Mtune	Kilifi	Rabai	Rabai	Rabai	Buni	Rabai	Tall
KLF/RAB/RAB/RUR/JIB/05	Mnazi wa Kawaida	Kilifi	Rabai	Rabai	Ruruma	Jimba B	Rabai	Hybrid
KLF/RAB/RAB/RUR/JIB/06	Mnazi wa Kawaida	Kilifi	Rabai	Rabai	Ruruma	Jimba B	Rabai	Hybrid
KLF/RAB/RAB/RUR/JIB/07	Mnazi wa Kawaida	Kilifi	Rabai	Rabai	Ruruma	Jimba B	Rabai	Hybrid
KWL/KWA/MAT/KIK/KIG/02	Mnazi	Kwale	Kwale	Matuga	Kikoneni	Kigato	Digo	Tall
KWL/KWA/MAT/KIK/KIG/01	Mnazi	Kwale	Kwale	Matuga	Waa	Kigato	Digo	Tall
KWL/KWL/MAT/WAA/KOM/05	Gao	Kwale	Kwale	Matuga	Waa	Kombani	Digo	Tall
KWL/KWL/MAT/WAA/KOM/04	Gao	Kwale	Kwale	Matuga	Waa	Kombani	Digo	Tall
KWL/KWL/MAT/WAA/MWA/03	mnazi	Kwale	Kwale	Matuga	Waa	Mwatate	Digo	Tall
KWL/KWL/MAT/WAA/TSU/06	Kisamili/Kipemba	Kwale	Kwale	Matuga	Waa	Tsunguni	Digo	Dwarf
KWL/MSA/LUN/KIK/KAM/03	Kipini	Kwale	Msambweni	Lungalunga	Kikoneni	Kambe	Digo	Tall
KWL/MSA/LUN/KIK/KAM/05	Tonga	Kwale	Msambweni	Lungalunga	Kikoneni	Kambe	Digo	Tall
KWL/MSA/LUN/KIK/KAM/02	Nazi yaKinyamwezi	Kwale	Msambweni	Lungalunga	Kikoneni	Kambe	Digo	Tall
KWL/MSA/LUN/KIK/KAM/01	Kipemba	Kwale	Msambweni	Lungalunga	Kikoneni	Kambe	Digo	Tall
KWL/MSA/LUN/KIK/KAM/04	Kisamli	Kwale	Msambweni	Lungalunga	Kikoneni	Kambe	Digo	Tall
KWL/MSA/MSA/MIL/MAB/01	-	Kwale	Msambweni	Msambweni	Milalani	Mabatani	Digo	Hybrid
LMU/LMUE/FAZ/FAZ/FAZ/38	Mnazi waKawaida	Lamu	LamuEast	Faza	Faza	Faza	Arab	Tall

Table 1. Contd.

Characterized germplasm code	Local Name	County	District	Division	Location	Village	Dialect	Type
LMU/LMUE/FAZ/FAZ/FAZ/41	Mnazi Mfupi	Lamu	LamuEast	Faza	Faza	Faza	Bajuni	Hybrid
LMU/LMUE/FAZ/FAZ/FAZ/40	Mnazi Mfupi	Lamu	LamuEast	Faza	Faza	Faza	Bajuni	Hybrid
LMU/LMUE/FAZ/FAZ/FAZ/36	Mnazi wa Kawaida	Lamu	LamuEast	Faza	Faza	Faza	Arab	Tall
LMU/LMUE/FAZ/FAZ/FAZ/42	Kongoo	Lamu	LamuEast	Faza	Faza	Faza	Bajuni	Hybrid
LMU/LMUE/FAZ/FAZ/FAZ/43	Kongoo	Lamu	LamuEast	Faza	Faza	Faza	Bajuni	Tall
LMU/LMUE/FAZ/FAZ/FAZ/37	Mnazi wa Kawaida	Lamu	LamuEast	Faza	Faza	Faza	Arab	Tall
LMU/LMUE/FAZ/FAZ/FAZ/39	Mnazi wa Yellow	Lamu	LamuEast	Faza	Faza	Faza	Arab	Tall
LMU/LMUW/AMU/AMU/POW/50	Jongo	Lamu	LamuWest	Amu	Amu	Power	Bajuni	Tall
LMU/LMUW/AMU/MKO/MAK/49	Mnazi Mfupi	Lamu	LamuWest	Amu	Mkomani	Makafuni	Bajuni	Hybrid
LMU/LMUW/AMU/MKO/MAK/48	Mnazi wa Pombe	Lamu	LamuWest	Amu	Mkomani	Makafuni	Bajuni	Tall
LMU/LMUW/AMU/MKO/MAK/47	Zipue	Lamu	LamuWest	Amu	Mkomani	Makafuni	Bajuni	Tall
LMU/LMUW/AMU/MKO/MSU/46	Kongoo	Lamu	LamuWest	Amu	Mkomani	Msumarini	Bajuni	Tall
LMU/LMUW/AMU/MKO/MSU/45	Mnazi wa Kipemba	Lamu	LamuWest	Amu	Mkomani	Msumarini	Bajuni	Dwarf
LMU/LMUW/AMU/MKO/MSU/44	Kongoo	Lamu	LamuWest	Amu	Mkomani	Msumarini	Bajuni	Tall
TR/TD/KIP/KIP/BAH/35	-	Tana River	Tana Delta	kipini	kipini	Bahongo	Arab	Tall
TR/TD/KIP/KIP/WAK/31	Mnazi Kongoo	Tana River	Tana Delta	kipini	kipini	Wakehoya	Meru	Tall
TR/TD/KIP/KIP/WAK/32	-	Tana River	Tana Delta	kipini	kipini	Wakehoya	Meru	Tall
TR/TD/KIP/KIP/WAK/33	Mnazi Kongoo	Tana River	Tana Delta	kipini	kipini	Wakehoya	Arab	Tall
TR/TD/KIP/KIP/WAK/34	Kithamli	Tana River	Tana Delta	kipini	kipini	Wakehoya	Arab	Tall

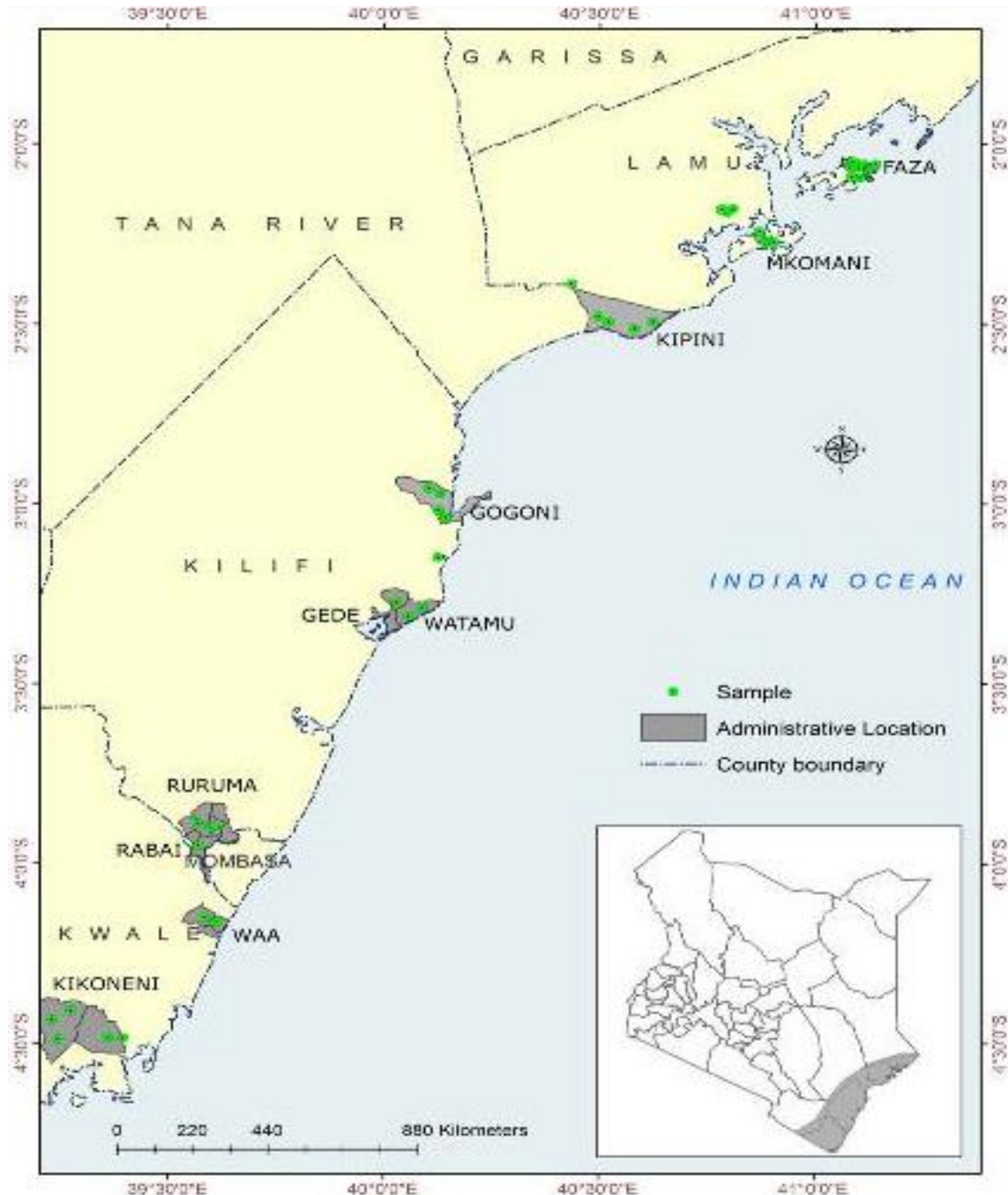
A total of five traits were characterized, which included stem, crown, leaf and fruit morphology as well as stress severity of the crop assessment using the descriptors listed for coconut by Bioversity International (Batugal et al., 2005). The characters assessed for the 47 selected palms are listed in Table 2. In addition, vegetative, reproductive parts, apple and nut traits were assessed based on the protocol of the coconut descriptor list of the International Plant Genetic Resources Institute (IPGRI, 1995).

The quantitative and qualitative morphological traits of coconut characterized were classified using dissimilarity coefficients and the neighbour joining from the usual Euclidean distance of complete linkage clustering method.

## RESULTS AND DISCUSSION

In this study, seven trees had yellow stalks and immature nuts; two had red yellow; one had red; 12 exhibited green; 19 had green yellow; four showed red yellow-green (brown) while two trees had orange stalks as well as immature nuts. The fruit morphology from five trees were oblong; 13 ovoid; 26 angled and four round. Seventeen trees sampled had no boles while 18 and 13 exhibited low and high bole categories, respectively. Crown

morphology was categorized as spherical (14 trees), hemispherical (seven trees), V-shaped (seven trees) and X-shaped (19 trees). Twenty one trees were observed to have almost round fruit shape while 15, nine and eight trees had ovoid, oblate and pointed fruit (without husk) respectively. Tree height ranged from 12.1 m (KLF/RAB/KAM/PAN/MAE/10) to 1.4 m (TR/TD/KIP/KIP/WAK/34). Width of scar at 1.5 m height varied from 1.2 m (KLF/RAB/KAM/PAN/MAE/10) to 0.4 m



**Figure 1.** Map of the Coastal Lowlands of Kenya indicating the sites where *in situ* characterization of coconut (*Cocos nucifera*) was conducted in this study.

(KLF/RAB/BUN/03). On vertical descriptors, 31 trees were characterized as erect, one angled, one bowed while 15 had curved stems. The number of green leaves showed variation ranging from 51 (LMU/MUW/AMU/AMU/POW/50) to 9 (TR/TD/KIP/KIP/BAH/35). Longest petiole length recorded was 3.5 m for KWL/MSA/MSA/MIL/MAM/01 and the shortest was 0.6 m, recorded for

LMU/MUW/AMU/MKO/MSU/44 and TR/TD/KIP/KIP/BAH/35.

The Counties and their respective divisions where the study was conducted are given in Table 1. In addition, global positioning system (GPS) data is shown in Figure 1. Generally, genotype clustering did not follow the geographical origins from which the genotypes were sampled, suggesting an exchange of germplasm among

**Table 2.** Descriptors for coconut characters as listed by IPGRI .

Trait type	Character assessed
Stem Morphology	Height from the ground to the oldest green leaf (m)
	Height of 10 leaf scars starting from 15 m from ground surface (m)
	Width of leaf scar at 1.5 m height (m)
	Height of 10 leaf scars starting from 15 m from ground surface (m)
	Vertical descriptors of the stem
	Bole category Stem type - dwarf, tall or hybrid
Crown morphology	Number of green leaves
	Overall appearance /Shape of crown
Leaf Morphology	Length of leaf 14 (m)
	Petiole length (m)
Fruit morphology	Fruit appearance
	Fruit (without husk) appearance/shape
	Color of immature nuts
Stress severity assessment	General biotic stress susceptibility

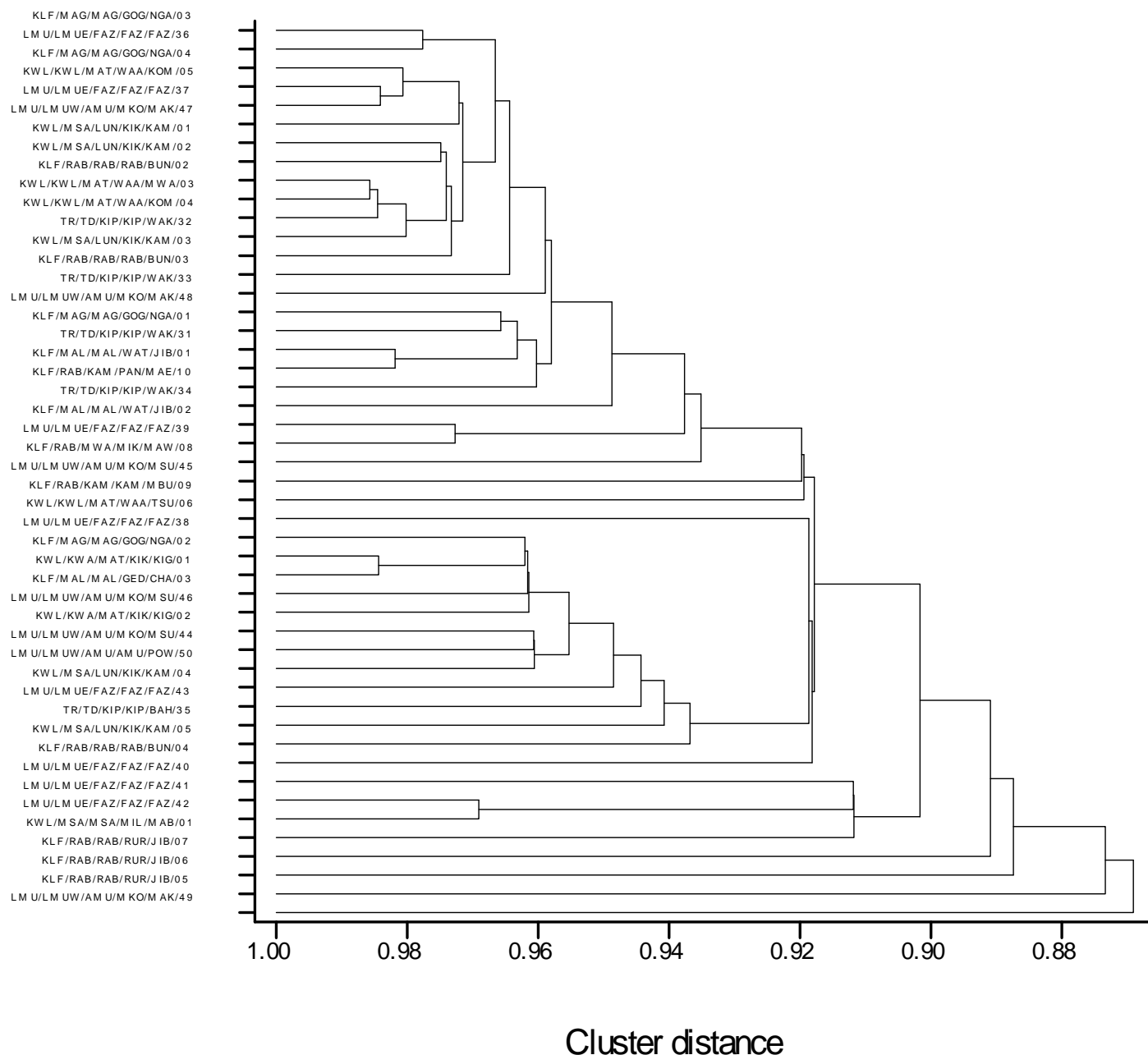
**Table 3.** Principle component loadings (latent vectors) of 11 traits in 48 genotypes of coconut at the coastal lowlands of Kenya.

Trait	PC1	PC2	PC3	PC4
Plant height (m)	-0.004	-0.115	0.036	0.025
Width of leaf scar at 1.5 m height	-0.003	0.019	0.032	0.008
Bole Category	0.016	0.146	0.922	-0.203
Crown morphology	-0.006	0.007	-0.014	-0.234
Fruit appearance (with husk)	-0.004	0.026	0.063	-0.079
Fruit appearance (without husk)	0.014	-0.062	-0.329	-0.718
Length of 14 <sup>th</sup> leaf (m)	0.009	-0.016	0.049	0.098
No of green leaves	0.999	-0.021	-0.010	0.035
Petiole length (m)	0.002	-0.009	0.022	0.041
Stem height (m)	0.019	0.980	-0.156	-0.002
Vertical descriptor of the stem	0.040	0.007	0.090	-0.608
Percent variation	65.54	19.71	8.14	2.74
Latent roots	2649.2	796.4	328.9	110.9
Cumulative percent of total variation	65.54	85.25	93.39	96.13

the coastal population probably due to the fact that farmers could have acquired planting materials from fellow farmers across the region. It is evident from our results that many genotypes from different origins overlapped; an indication of morphological redundancy in the characterized germplasm.

Coconut can cross-pollinate and it is possible that crop at the coast has several hybrids which could not be discriminated by morphological analysis probably due to environmental influence on the traits and not necessarily

that coconut at the coast share a common ancestry. Principal Component Analysis (PCA) showed that the first four components explained 96.13% of the total variation (Table 3). Principal component 1 (PC1) accounted for 65.54% and was associated with the number of green leaves. PC2 explained 19.71% of the variation and was associated with stem height. PC3 accounted for 8.14% of the total variation and was mainly associated with bole category and fruit husk appearance, while PC4 explained 2.74% of the total variation and was associated with



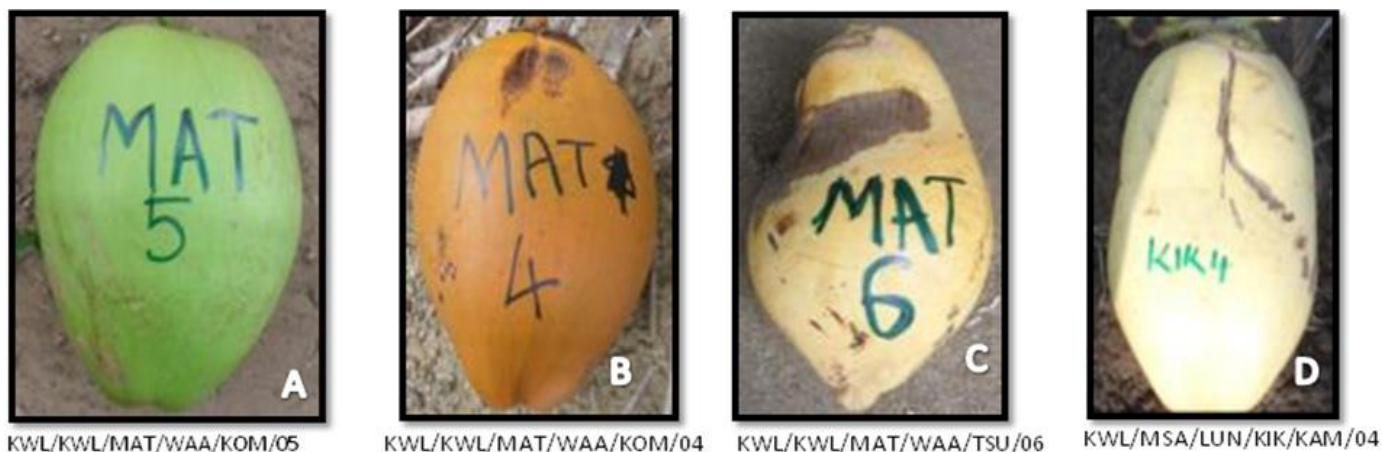
**Figure 2.** Dendrogram of the similarities among 48 coconut genotypes using the nearest neighbour method of cluster analysis.

vertical stem descriptors.

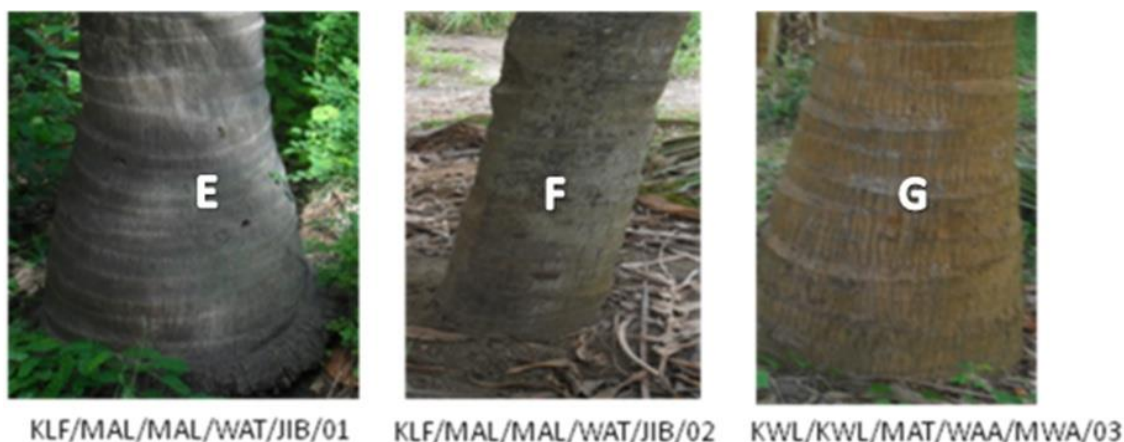
Dissimilarity coefficients and the neighbour joining from the usual Euclidean distance of complete linkage clustering method divided the 48 coconut genotypes into two major clusters (Figure 2). Genotype LMU/LMUW/AMU/MKO/MAK/49 was grouped in a cluster of its own while other genotypes were grouped together. LMU/LMUW/AMU/MKO/MAK/49 was the shortest nut at on 2.28 m. Genotypes KLF/RAB/RAB/RUR/JIB/05, KLF/RAB/RAB/RUR/JIB/06 and KLF/RAB/RAB/RUR/JIB/07 formed a minor cluster mainly due to their tall palm types, stalk color and height

of 10 leaf scar starting from 1.5m from the ground; as did genotypes KLF/MAG/MAG/GOG/NGA/03, KLF/MAG/MAG/GOG/NGA/04, LMU/LMUE/FAZ/FAZ/FAZ/36, KWL/KWL/MAT/WAA/KOM/05 and LMU/LMUE/FAZ/FAZ/FAZ/37. They were dwarf, had the same crown morphology, vertical stem type as well as length of 14th leaf (m). Other genotypes that belonged to the same cluster were LMU/LMUW/AMU/MKO/MAK/48, KLF/MAG/MAG/GOG/NGA/01, TR/TD/KIP/KIP/WAK/31 and KLF/MAL/MAL/WAT/JIB/01. They were all tall palm types with brown stalk, erect vertical stem as well as high





**Plate 1.** Appearance and colour of the palm fruits of some of the nuts at the coasts of Kenya. A, ovoid and green; B-angled and yellow red; C, angled and yellow; D, yellow.



**Plate 2.** The bole categories of palm tress at the coastal lowlands of Kenya. E, Low bole; F, no bole; G, high bole.

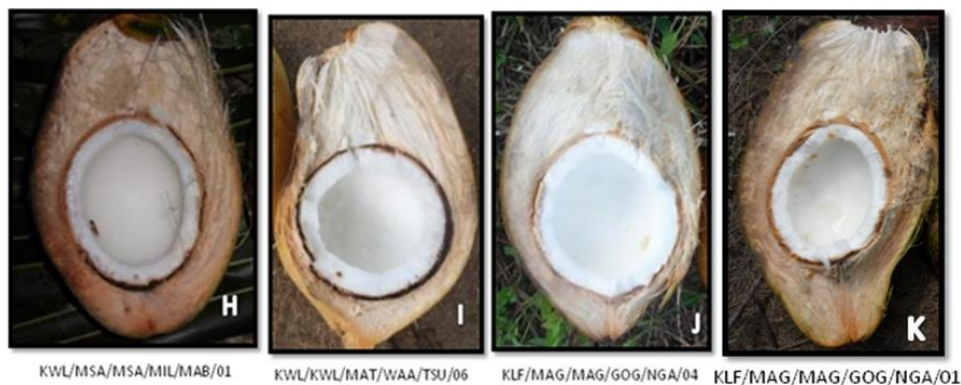
bole type and same length of the 14<sup>th</sup> leaf. Similarly, close proximity was observed for LMU/LMUE/FAZ/FAZ/FAZ/38, KLF/MAG/MAG/GOG/NGA/02, KWL/KWA/MAT/KIK/KIG/01, KLF/MAL/MAL/GED/CHA/03 and LMU/LMUW/AMU/MKO/MSU/46.

It is clear from the dendrogram, PCA and as shown by the Plates 1 to 4 that coconut germplasm at the Kenyan coast is diverse in various morphological categories. It is our view that in Kenya, just as reported in Sri Lanka (Fernando et al., 1995), coconut can be found growing in a range of environmental conditions other than the optimal conditions and maintain their productivity despite the stress and management conditions which included palm trees not of uniform age, unweeded fields, progeny generations mixed in a population, no pure stands and lack of fertilization. In almost all instances, even the age of the palms was not known. In addition, we noted that coconut plantations in Kenya, especially of EATs have

undergone preferential selections for yield, nut size, nut shape, nut colour, kernel thickness and tolerance to drought, pest and disease as argued by Perera et al. (1996).

In some cases it was evident there could have existed hybrid varieties as some EATs bearing green yellow or red green fruits could be seen suggesting hybridity between the EATs, which usually bear green fruits and the EADs that commonly bear yellow fruits. There also existed tall palms with yellow nuts, and intermediates with the dwarfs suggesting under-dominance of yellow nuts over green ones. Selecting for variations explained by the PCA and cluster patterns obtained from different genotypes and probably environments could be useful for selection of genetically diverse genotypes for improvement programs in coconut. However, owing to the fact that morphological characters are under heavy control of the crop growing environment, diversity studies using DNA markers is recommended for the characterized





**Plate 3.** Fruit appearances/shapes of some of the nuts at the coastal lowlands of Kenya. H, almost round; I, almost round; J, almost round; K, pointed.



**Plate 4.** Crown morphology of some of the palm trees at the coasts of Kenya. L-X, shaped; M, spherical.

germplasm in this study.

### Conflict of interests

The authors have not declared any conflict of interest.

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