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Geographical and Ecological Distribution of Some Macadamia Genotypes in Kenya and Prospects for Increased Production.

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ABSTRACT

Macadamia (Family Protaceae) is the most important nut crop in Kenya, grown as a source of household income and foreign exchange. Kenya is the fourth largest producer of Macadamia nuts contributing about 10% of world's total production. However, its production, expansion and commercialization are hampered by various constraints, especially suitable varieties for the various agro-ecological zones in Kenya. Selection and development of new varieties currently rely on existing germplasms and introductions from other growing countries. Considering that genetic diversity is crucial to breeding efforts, studies were done to locate valuable germplasms using geographical positioning system (GPS) and evaluate ecological adaptation. A total of 39 accessions, including breeding lines currently being tested under Kenya's Macadamia breeding programme, some cultivars introduced from Australia and Hawaii and some new selections were evaluated. A total of 39 GPS points were recorded and data analyzed using ArcView GIS version 3.3. Results indicated that all accessions were located between 0 and 3 degrees south of the equator and between 36 and 37 degrees East of the Greenwich Meridian. Only one accession was adapted to over 2000 meters above sea level while all the others were adapted to between 1300 to 1920 meters above sea level. Mapping of the accessions

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ABSTRACT

Macadamia (Family *Proteaceae*) is the most important nut crop in Kenya, grown as a source of household income and foreign exchange. Kenya is the fourth largest producer of Macadamia nuts contributing about 10% of world's total production. However, its production, expansion and commercialization are hampered by various constraints, especially suitable varieties for the various agro-ecological zones in Kenya. Selection and development of new varieties currently rely on existing germplasms and introductions from other growing countries. Considering that genetic diversity is crucial to breeding efforts, studies were done to locate valuable germplasms using geographical positioning system (GPS) and evaluate ecological adaptation. A total of 39 accessions, including breeding lines currently being tested under Kenya's Macadamia breeding programme, some cultivars introduced from Australia and Hawaii and some new selections were evaluated. A total of 39 GPS points were recorded and data analyzed using ArcView GIS version 3.3. Results indicated that all accessions were located between 0 and 3 degrees south of the equator and between 36 and 37 degrees East of the Greenwich

Meridian. Only one accession was adapted to over 2000 meters above sea level while all the others were adapted to between 1300 to 1920 meters above sea level. Mapping of the accessions on agro-ecological zones located them in six different agro-ecologies and four major soil types. Accessions of hybrid origin showed adaptability to higher altitude with high rainfall distribution. Our results suggest wide adaptability of Macadamia germplasm in Kenya and provide a basis for future expansion of Macadamia orchards.

Key words: Macadamia, geographic location, agro-ecological zones,

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INTRODUCTION

Macadamia nut (Family *Proteaceae*) is a dark green spreading semi-hard wood that can grow up to 20 meters (Duke, 1983). The genus *Macadamia* consists of 10 species but only two; *Macadamia integrifolia* Maiden and Betche (smooth-shelled), and *M. tetraphylla* L.A.S Johnson (rough-shelled) are cultivated for their edible nuts (McHargue, 1996). The two species are indigenous to the subtropical coastal region of Australia (Storey and Salleeb, 1966; McHargue, 1996). *Macadamia integrifolia* is native to Southern Queensland and *M. tetraphylla* is native to the northernmost part of New South Wales and the Southernmost part of Queensland. Where the two regions overlap, natural hybrids have been found (Storey and Salleeb, 1966).

Macadamia was introduced into Kenya in 1946 as six seeds of *Macadamia tetraphylla* from New South Wales which were planted by Bob Harries, then a coffee farmer in Thika district of Central Kenya (Harries, 2004). Over the following 18 years, seeds from the original six trees were used to propagate seedlings for expanding his farm and for farmers in Central, Eastern, Rift Valley, Western

and Coast Provinces of Kenya as an alternative cash crop to tea and coffee (Harries, 2004). Seeds of *M. integrifolia*, *M. tetraphylla* and a hybrid of the two were imported from Australia, Hawaii and California, and included in the seedling production. In 1968, scion material from superior *M. integrifolia* varieties were imported into the country from Hawaii, including HAES 246, HAES 328, HAES 333, HAES 508, HAES, 660 and HAES 669; grafted seedlings were produced and planted in different parts of the country (Waithaka, 2001).

Since most of the trees originated from seeds, there were wide variations in yield and quality of nuts. Average yields ranged from 5-10 kg/tree/season with less than 72% kernel oil content (Ondabu et al., 1996) and this slowed commercialization of Macadamia in Kenya. It was therefore necessary to improve the crop for higher yields and quality. Currently, the genetic improvement of Macadamia is based on introductions from other countries and selection of superior cultivars from existing germplasm. Knowledge of location of diverse germplasms for breeding and conservation therefore needs to be made available to breeders (de Vicente et al., 2006). The objectives of the current study were to determine the geographical distribution and ecological adaptation of selected Macadamia genotypes in Kenya.

MATERIALS AND METHODS

The monitored accessions included some selections being evaluated in the Macadamia breeding program of the Kenya Agricultural Research Institute (KARI) (M-2, M-20, M-25, KB-3, KB-4, KB-25, K-3, K-4, K-15, EB1, EB2, EBH, MU-23, MU-24, MU-25, TTW2). Other accessions included new introductions from Hawaii (H333, H508, H660) and Australia (A4, A16), some accessions that were found to have peculiar but otherwise agronomically important characters during a previous survey (EBA, K-5, MU-SM, MU-27, KRT1, KRT2, KRT3, EBT1, EBT2, EBT3, EBT4, TTW1, TTWT) and four accessions believed to be ancestors to Macadamia germplasm supplied by Bob Harries (MYK, H1, HWI, KLM).

Another species believed to be *Macadamia ternifolia* (MT) and maintained at KARI was also included in the study.

Geo-reference data (latitude, longitude and altitude) were taken for each accession selected for study using a GPS (Geographic Positioning Instrument, Etrex Vista, GARMIN). Hence, a total of 39 GPS data points were recorded.

Data analysis

Geographical data was analyzed using ArcView Geographic Information System version 3.3 to map the accessions on the Kenya map. Mapping on agro-ecological zones and soils was based on FAO Agro-Ecological Zoning (1993) and FAO Soil Classification (1986).

RESULTS

Geographic distribution of Macadamia accessions

The 39 accessions were located in only six districts in Central, Eastern and Coast provinces of Kenya. All accessions were located between about 0 and 1 degree south of the equator except those located in Taita Taveta in the Coast province that were located 3 degrees south of the equator. The accessions were located between 36 and 37 degrees east of the Greenwich Meridian. The general locations are shown in Figure 1.

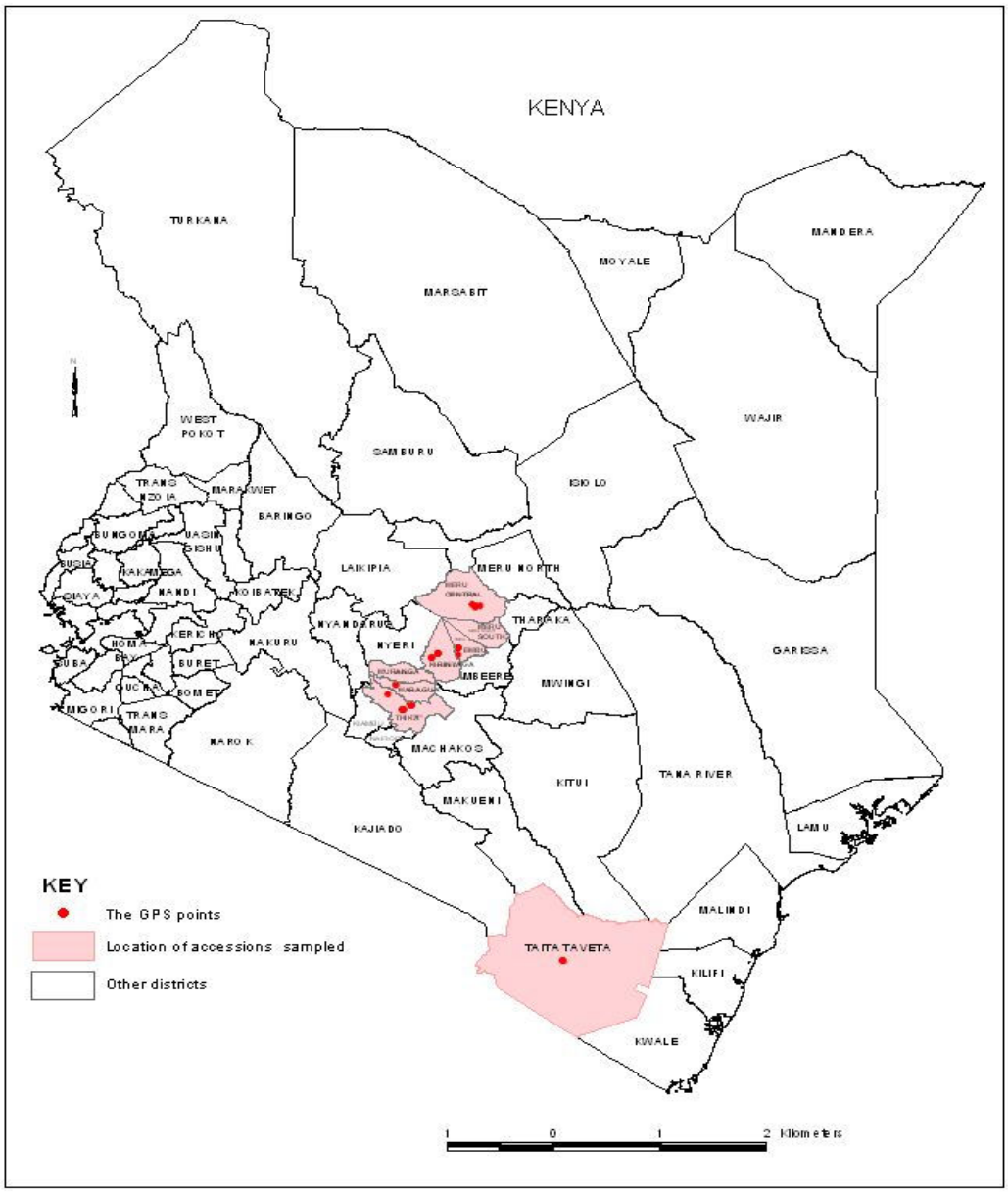
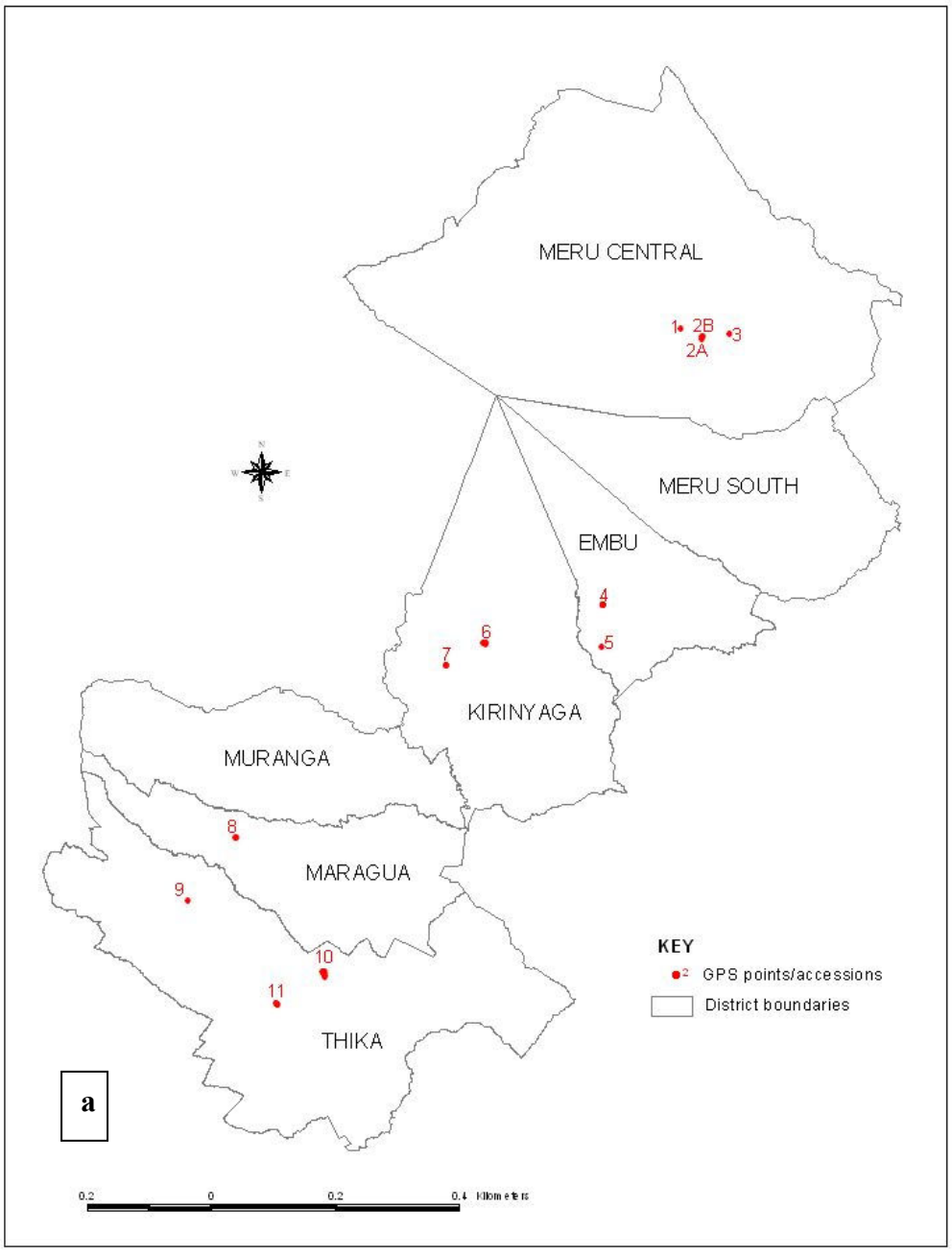


Fig. 1: Map showing the geographical locations of the 39 accessions in Kenya**.**

A close-up of the locations in central (Thika, Maragua and Kirinyaga districts) and eastern (Embu and Meru districts) provinces is shown in Figure 2a while that of the coast province (Taita Taveta district) is shown in Figure 2b.


MERU CENTRAL
1
2B
2A
3
MERU SOUTH
EMBU
4
5
6
7
KIRINYAGA
MURANGA
8
MARAGUA
9
10
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THIKA
a
KEY
GPS points/accessions
District boundaries
0.2
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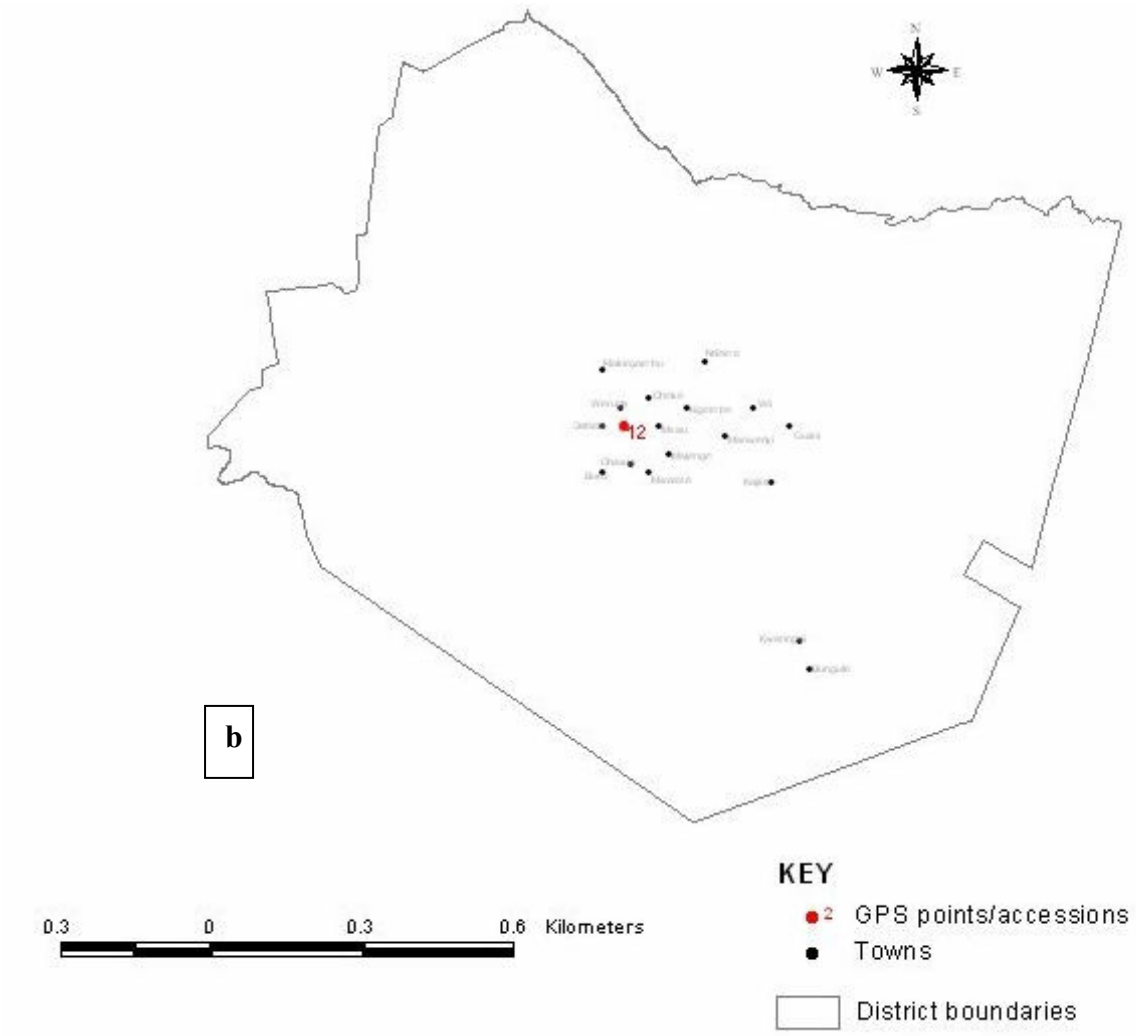


Fig. 2: Location of Macadamia accessions; **a-** in Thika, Maragua, Kirinyaga, Embu and Meru Districts, **b**-in Taita Taveta district. Numbers 1-12 represent the general locations within the districts and they represent one or more accessions as shown in Table 1.

Table 1: GPS readings for Macadamia accessions represented by number 1-12 sampled from Thika, Maragua, Kirinyaga, Embu, Meru and Taita Taveta districts

Point number	Accession	Latitude	Longitude	Point number	Accession	Latitude	Longitude
1	MU-27	S00º03.569’	E037º34.526’	8	A4	S00º48.105’	E036º55.935’
2A	MU-24	S00º04.252’	E037º36.329’		A16	S00º48.108’	E036º55.982’
	MU-25	S00º04.461’	E037º36.321’	9	KB-25	S00º53.584’	E036º51.746’
2B	MU-23	S00º04.274’	E037º36.446’	10	H508	S01º00.002’	E037º03.650’
3	MU-SM	S00º04.093’	E037º38.736’		H333	S01º00.029’	E037º03.678’
4	EBT4	S00º27.750’	E037º27.748’		H660	S00º59.928’	E037º03.608’
	EBH	S00º27.764’	E037º27.758’		KB-4	S00º59.948’	E037º03.590’
	EBT3	S00º27.761’	E037º27.767’		M-20	S00º59.983’	E037º03.640’
	EBT2	S00º27.750’	E037º27.769’		M-2	S00º59.892’	E037º03.575’
	EB1	S00º27.747’	E037º27.766’		M-25	S00º59.792’	E037º03.506’
	EB2	S00º27.738’	E037º27.768’		MT	S00º59.782’	E037º03.447’
	EBT1	S00º27.725’	E037º27.777’		KB-3	S00º59.787’	E037º03.619’
5	EBA	S00º31.463’	E037º27.691’	11	KLM	S01º02.624’	E036º59.539’
6	K-15	S00º31.085’	E037º17.441’		HWI	S01º02.620’	E036º59.521’
	K-4	S00º31.125’	E037º17.536’		H1	S01º02.589’	E036º59.455’
	K-3	S00º31.124’	E037º17.581’		MYK	S01º02.612’	E036º59.498’
	K-5	S00º31.125’	E037º17.563’	12	TTW1	S03°25.151’	E038°20.204’
7	KRT3	S00º33.014’	E037º14.230’		TTW2	S03°25.155’	E038°28.207’
	KRT2	S00º33.019’	E037º14.219’		TTWT	S03°25.150’	E038°20.206’
	KRT1	S00º33.011’	E037º14.224’				

Adaptation to altitude

All the accessions were located between 1300 and 2150 meters above sea level. Twenty six out the 39 accessions were located between 1450 and 1650 meters above sea level. Only one accession, MU-27 was located at over 2000 meters above sea level (Fig. 3).

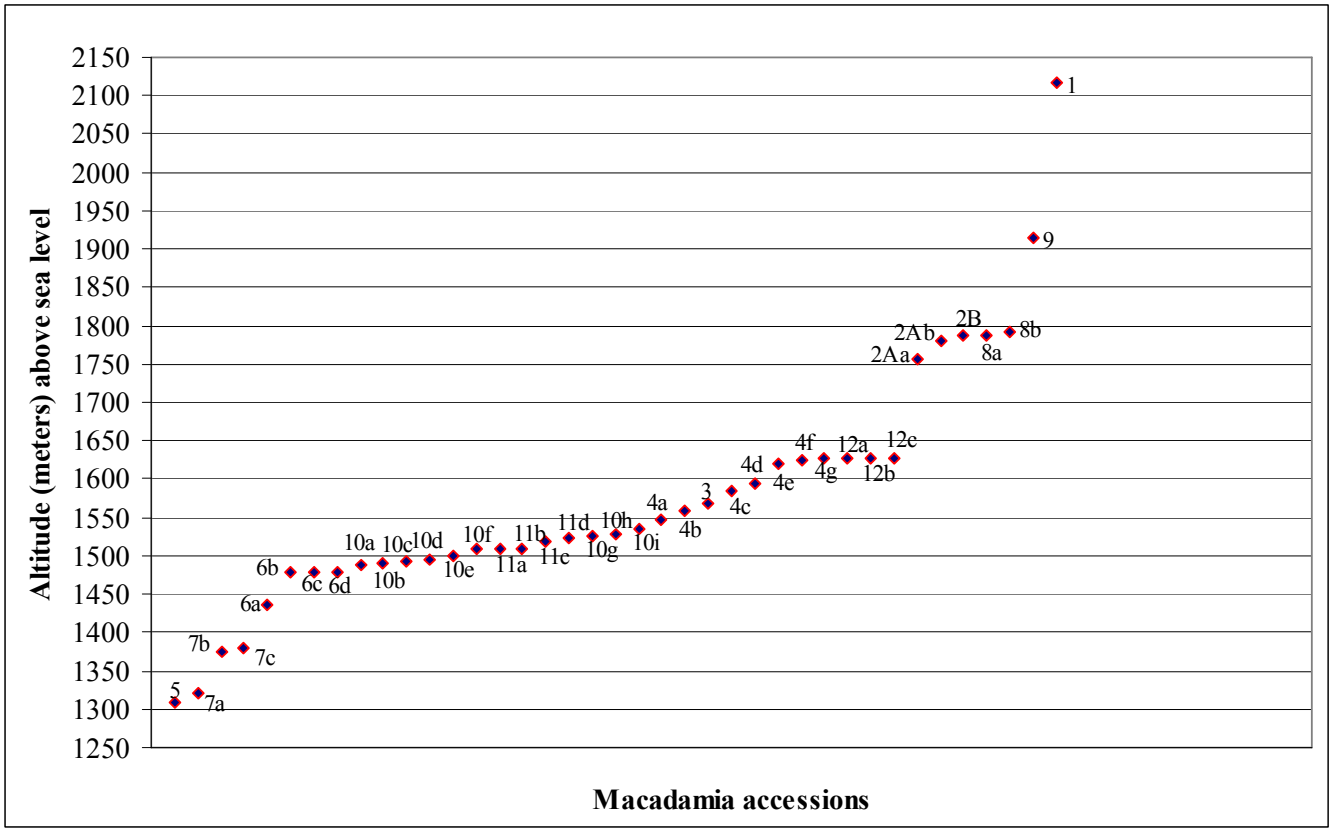


Fig. 3: Distribution of the 39 Macadamia accessions in relation to altitude (meters above sea level). **Key: 1** (MU-27) and **2A** (a-MU-24, b-MU-25), **2B** (MU-23) and **3** (MU-SM), **8** (a-A4, b-A16,) and **9** (KB-25), **4** (a-EBT4, b-EBH, c-EBT3, d-EBT2, e-EB1, f-EB2, g-EBT1), **6** (a-K-15, b-K-4, c-K-3, d-K-5), **5** (EBA), **7** (a-KRT3, b-KRT2, c-KRT1), **10** (a-H508, b-H333, c-H660, d-KB-4, e-M-20, f-M-2, g-M-25, h-MT,i-KB-3), **11** (a- KLM, b-HWI, c-H1, d-MYK) and 12 (a-TTW1, b-TTW2, c-TTWT). Specific values for altitude in meters above sea level for each accession are shown in **Table 2**.

Table 2: Altitude in meters above sea level for 39 Macadamia accessions studied.

Point number	Specific point	Accession	Altitude (m)	Point number	Specific point	Accession	Altitude (m)	Point number	Specific point	Accession	Altitude (m)
1		MU-27	2118	7	a	KRT3	1321	11	a	KLM	1509
2A	a	MU-24	1756		b	KRT2	1375		b	HWI	1510
	b	MU-25	1779		c	KRT1	1379		c	H1	1519
2B		MU-23	1786	8	a	A4	1787		d	MYK	1524
3		MU-SM	1569		b	A16	1793	12	a	TTW1	1626
4	a	EBT4	1546	9		KB-25	1914		b	TTW2	1626
	b	EBH	1528	10	a	H508	1487		c	TTWT	1627
	c	EBT3	1584		b	H333	1490				
	d	EBT2	1595		c	H660	1493				
	e	EB1	1619		d	KB-4	1494				
	f	EB2	1624		e	M-20	1500				
	g	EBT1	1626		f	M-2	1508				
5		EBA	1308		g	M-25	1526				
6	a	K-15	1436		h	MT	1527				
	b	K-4	1478		i	KB-3	1536				
	c	K-3	1479								
	d	K-5	1479								

Distribution in relation to Agro-ecological zones

Mapping of the 39 GPS points distributed the Macadamia accessions in six different agro-ecological zones. The zones are located in five agro-climatic zones characterized by different mean temperatures, moisture index, annual rainfall and suitability for different cash and food crops (Table 3**)**.

Table 3: Agro climatic zones representing agro-ecologies of the 39 Macadamia accessions studied.

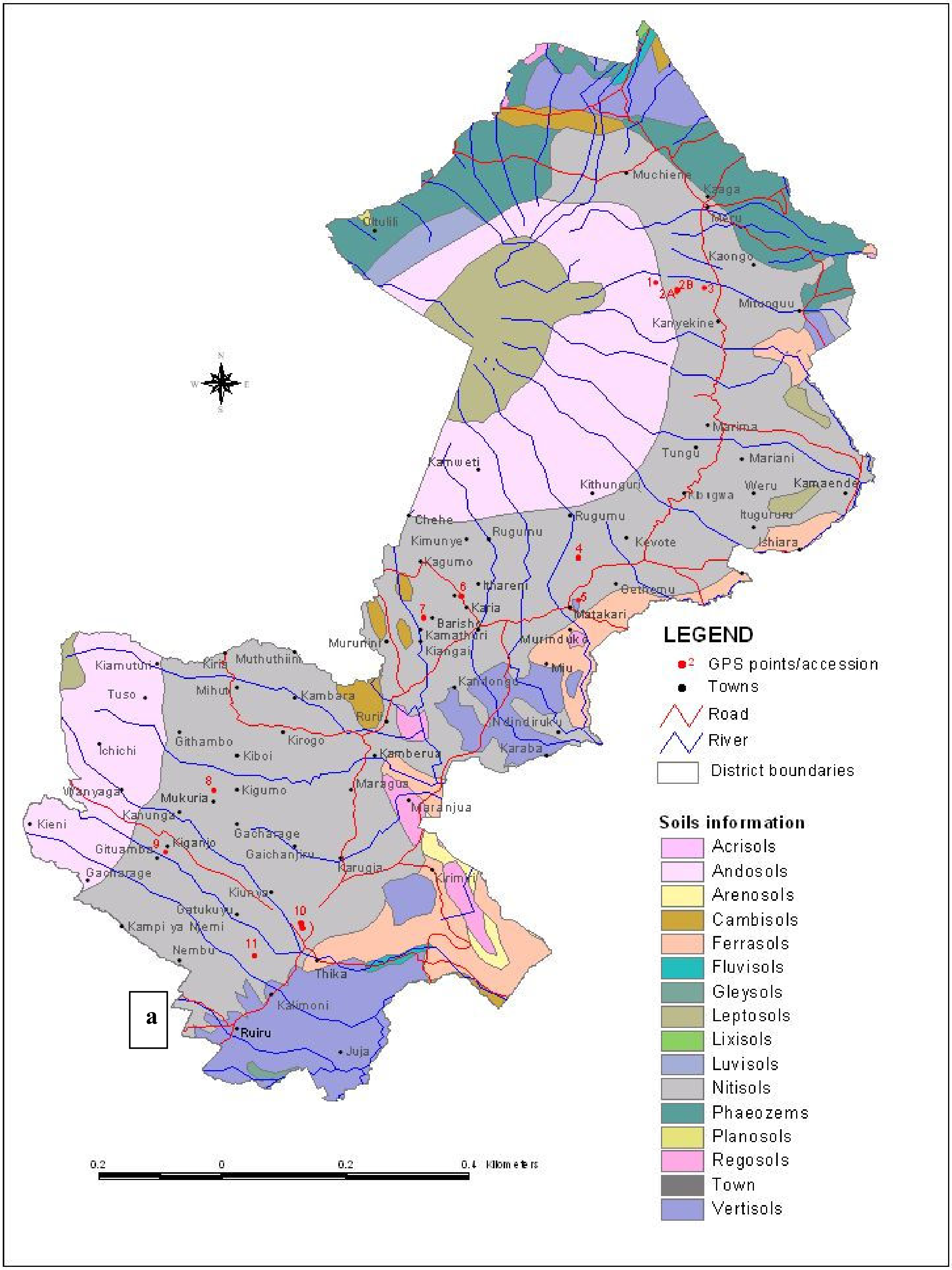
Zone belt	Agro-climatic classification	Macadamia accessions	Land use potential	Annual mean Temperature (°C)	Moisture index (%)*	Annual Rainfall (mm)
UHO	0 Perhumid	MU-24, MU-25, MU-27	Forest zone	10-15 seasonal night frost	>80	>2700
LH1	I Humid	MU-23, MU-SM, A4, A16, KB-25	Tea Dairy Zone	15-18 Normally no frost	>80	1100-2700
UM1	I Humid	EB1, EB2, EBH, EBT1, EBT2, EBT3, EBT4	Coffee Tea zone	15-18	>80	1100-2700
UM2	II Sub-humid	K-3, K-4, K-5, K-15	Main coffee zone	18-21	65-80	1000-1600
UM3	III Semi-humid	EBA, KRT1, KRT2, KRT3, H333, H508, H660, M-2, M-20, M-25, MT, KB-3, KB-4, H1, HWI, KLM, MYK.	Marginal coffee zone	18-21	50-65	800-1400
UM4	IV Semi-humid to Semi-arid (transitional)	TTW1, TTW2, TTWT	Sunflower maize zone	18-21	40-50	600-1100

Adapted and modified from Sombroek et al., (1982). Key: UH- Upper highland; LH – Lower highland; UM – Upper midland

* - $\frac{\text{Annual rainfall}}{\text{Potential evaporation}} \times 100$

Adaptation to soil types

All the accessions except five were located in areas predominant of nitosols (Figure 4a - 4b).


LEGEND
GPS points/accession
Towns
Road
River
District boundaries
Soils information
Acrisols
Andosols
Arenosols
Cambisols
Ferrasols
Fluvisols
Gleysols
Leptosols
Lixisols
Luvisols
Nitisols
Phaeozems
Planosols
Regosols
Town
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0.2
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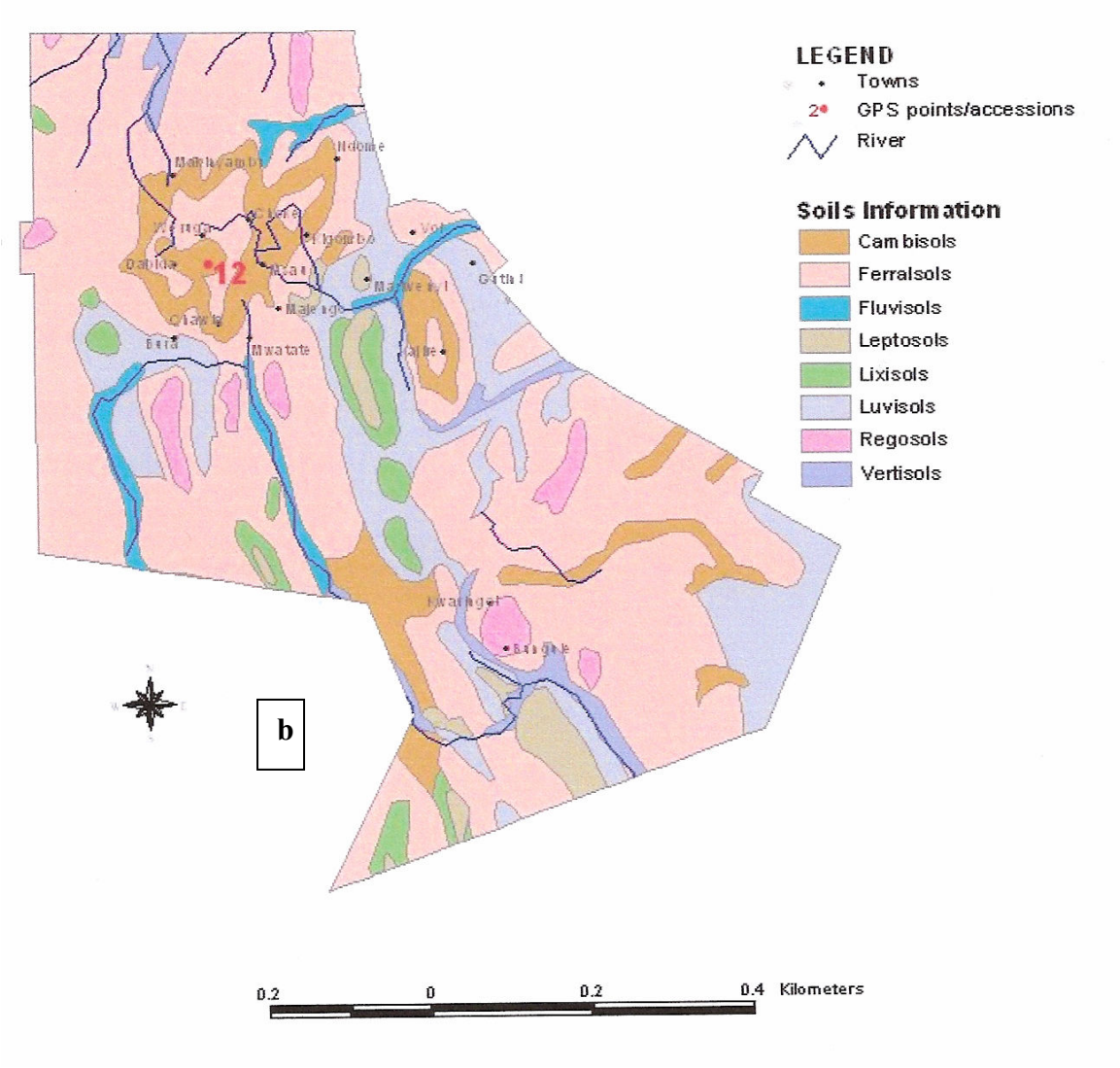

Fig. 4: Maps showing distribution of Macadamia accessions in relation to soil types. Numbers 1-12 represent the general locations within the district soil map and they represent one or more accessions; **a-** East and Central province: **Andosols** 1 (MU-27), **Nitosols** 2A (MU-24, MU-25), 2B (MU-23), 3 (MU-SM), 4 (EBT4, EBH, EBT3, EBT2, EB1, EB2, EBT1), 6 (K-15, K-4, K-3, K-5), 7 (KRT3, KRT2, KRT1), 8 (A4, A16,) and 9 (KB-25), 5 (EBA), 10 (H508, H333, H660, KB-4, M-20, M-2, M-25, MT, KB-3) and 11 (KLM, HWI, H1, MYK), **Vertisols** 5 (EBA), and **b-** Coast Province: **Cambisols -**12 (TTW1, TTW2, TTWT).

DISCUSSION

The accessions studied were sampled from six districts in Central, Eastern and Coast provinces of Kenya. All accessions were sampled between about 0 and 1°S of the equator except those located in Taita Taveta in the Coast Province that were at 3°S. All accessions were sampled between 36 and 37 °E of the Greenwich Meridian. This location is far north and west of Macadamia's center of origin in the coastal rainforest of southeast Queensland and northeast of New South Wales in Australia from 26 to 29° south of the equator (Peace et al., 2002) and about 152 and 153.5° east of the Greenwich Meridian. This indicates Macadamia has a potential for wide distribution. This potential is confirmed by the fact that it has spread and continues to thrive in several other countries with varying climatic conditions although the crop is of subtropical origin (Peace et al., 2008).

All accessions were adapted to between 1300 and 2150 meters above sea level. Only accession MU-27 was adapted to over 2000 meters. Accessions could further be divided into those adapted to between 1300 m and 1650 m and those adapted to between 1750 m and 2150 m asl. Accessions between 1300 m and 1650 m were those related to both *M. integrifolia* and *M. tetraphylla* while those between 1750 m and 2150 m above sea level included exclusively those previously selected as Macadamia hybrids, MU-23, MU-24, MU-25, A4, A16 and KB-25 (Tominaga and Nyaga, 1997). Other accessions in this category included KB-3 and KB-4, whose original mother trees were located at 1760 and 1750 m above sea level (Tominaga and Nyaga, 1997; Wasilwa et al., 2003). Altitudes above 1700 m above sea level correspond to the agro ecological zones (AEZ) UHO and

LH1, characterized by low annual mean temperatures of 10-18°C and high annual rainfall of 1100 mm to over 2700 mm. This suggests adaptation of Macadamia hybrids to higher altitudes with cooler climate. Apart from accessions KRT1, KRT2 and KRT3, all other accessions related to *M. tetraphylla* were adapted to an altitude of between 1500 m and 1700 m above sea level. According to Peace et al. (2008), *M. integrifolia* prefers tropical climate while hybrids and *M. tetraphylla* prefer cooler climates. However, these altitudes far exceed those stated for the centers of diversity in Australia for the two species, *M. integrifolia* (5-600 m above sea level) and *M. tetraphylla* (100-800 m above sea level) (Costello et al., 2008). Moreover, in Hawaii, one of the leading producers, Macadamia is grown from sea level to 2200 ft (670 m) above sea level (Miller, 1951).

Accession MU-27 was mapped on Andosols. Andosols are highly porous, dark-coloured soils developed from parent material of volcanic origin, such as volcanic ash, tuff or pumice (Yerima and Ranst 2005). They typically occur in wooded highland areas (Encyclopædia Brittannica, 2009a) such as the location of MU-27 in UHO which is a forest zone. This is similar to the soils found in the center of diversity of Macadamia in Southeast Queensland. Costello et al. (2008) described these soils as predominantly alluvial or volcanic, and well-drained, occurring in Araucarian notophyll vine forest on basic and intermediate volcanics and alluvia in higher rainfall areas.

Most of the other accessions were located in areas predominant of nitosols. Nitosols are extensively found in tropical and sub-tropical regions. They are strongly weathered kaolinitic soils that are also deep and well drained (Baligar et al., 2004). Only one accession, EBA and accessions in the Coast province, TTW1, TTW2 and TTWT were mapped on vertisols and cambisols. Vertisols has a high content of an expanding

clay (montmorillonite) that forms deep cracks in drier seasons (Encyclopædia Brittannica, 2009b). They also form from highly basic rocks such as basalt in climatic zones with distinct wet and dry seasons or those that are seasonally humid or subject to erratic drought and floods (Buol *et al*., 2003). They are found between 50° N and 45° S of the equator and are dominantly found in eastern Australia, especially inland Queensland and New South Wales (Encyclopædia Brittannica, 2009b) as well as Africa where they cover over 100 million hectares of land (Ahmad, 1996).

Cambisols are the second most extensive soil group found mainly in landscapes with high rates of erosion, and in regions with parent material resistant to clay movement; they are not common in humid tropical climates (Encyclopædia Brittannica, 2009c). This is consistent with the agro-ecological zone for TTW1, TTW2 and TTWT (UM4) which is semi-humid to semi-arid (Sombroek et al.,1982). Duke (2001) reported that although Macadamia yields well on deep well-drained loams and sandy-loams, it can grow on a wide range of soils except infertile coastal sands, heavy clays and gravelly ridges and can torelate adverse conditions once established.

The results of our study showed that in Kenya, Macadmia is adapted to a wide range of soils and within the range of temperature (15-25°C) and rainfall (700-2600 mm) considered best for Macadamia growing (Miller, 1951; Duke, 2001). The results also showed that Macadamia is adapted to a wide range of agro ecological zones ranging from sunflower maize zone to forest zone located at altitudes ranging from 1300 to slightly over 2000 m above sea level. However, there are only few selections available for commercialization and there is huge potential for future expansions, especially through selection breeding and artificial cross breeding. Accessions related to Macadamia hybrids

were mostly located in UHO and LH1 that correspond to altitudes over 1700 m above sea level. These are high rainfall areas with potential for planting more Macadamia hybrid cultivars. Cultivars suitable for low altitude areas also need to be selected. Such cultivars can be selected from available germplasms and validated through local adaptability trials or introduced from countries such as Australia and Hawaii which are already growing Macadamia in low altitudes.

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