Variability of East Africa tamarind (*Tamarindus indica* L.) populations based on morphological markers

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Abstract

Tamarind was recently earmarked for conservation to support livelihoods in East Africa. The objective of the current study was to generate knowledge of tamarind morphological variations, their correlation to environment, relation to mitochondrial haplotypes and thus suitability as markers for germplasm and conservation units' selection in East Africa. We characterized variations in tamarind diameter at breast height (DBH), crown section area (CSA) and height (morphological characters) in different environment (temperature, rainfall, soils, habitats, Phytocoria, altitudes and latitudes) and mapped the variations in relation to established mitochondria haplotypes. Results show that tamarind mean height, DBH and CSA increased from Island to mainland Phytocoria; respectively < 5 m to 14 m, 61 cm to 189 cm and 28 m^3 to 229 m^3 and were influenced ($P<0.05$) by altitudes, phytocoria and habitats. Soil exchangeable potassium also influenced ($P = 0.03$) tamarind DBH while CSA further varied ($P<0.05$) between the Somalia Maasai and other mainland phytocoria. Correlation (R) between tamarind morphological variations and environment was 59.5% and interestingly, the variations coincided with haplotypes diversity in populations, suggesting in homogeneous environment, morphological variants could be useful as markers for germplasm and conservation unit selection. Further correlation analysis is however needed to ascertain level of precision with which morphological (DBH, height and CSA) variants will be useful as selection markers in tamarind conservation programmes where these traits are of interest.

Key words; tamarind, germplasm, selection, mitochondria haplotypes, conservation units

Introduction

Variations in tamarind morphological characters is widely reported; crown sectional area (CSA), diameter at breast height (DBH) and height in habitats and altitudes (Nyadoi, 2005), first fruiting age is 4-5 and 7 years respectively in Mexico and Madagascar and East Africa and India (Gunasena and Hughes, 2000), the colour, shape and sizes of flowers and fruits in populations (Pushpakumura *et al*., 2007). In Spine stickleback, Drosophila, Maize and Baobab (Sucena and Stern, 2000; Shapiro *et al*., 2004; Doebley, 2004; Assogbadjo *et al*., 2006) and in other species (Fisher, 1930; Reed and Frankham, 2001; Palo *et al*., 2003) a strong, weak or no genetic basis is reported for morphological variations. For tamarind, neither genetic nor environment basis for morphological variations is yet reported. Literature from other species cited here however show that such knowledge is needed for appraisal of morphological variations as germplasm/conservation units' selection markers in species' conservation programmes.

Morphological markers in germplasm/conservation units' selection strategies as opposed to costly molecular markers would be suitable for tamarind in Africa where, it is earmarked for product development to support livelihoods diversification (FAO, 2004; Jama *et al*., 2005). Its applicability in the region was however questionable, given the scanty knowledge on tamarind morphological variations, their correlations with environment and relations to genotypes. The objective of our study was therefore to generate knowledge of tamarind morphological variations, their correlation to environment and relation to haplotypes in East Africa. The study was pegged on a hypothesis that morphological variations in East Africa tamarind populations correlate less to environment and are coincident to mitochondrial haplotypes diversity.

Materials and Methods

Tamarind morphological characters studied, the study area and data collection

In the tamarind morphology character for study selection, reproductive phenological attributes such as fruiting /fruit yield, flowering and flower colours and shapes, though also indicators of genetic variation were left out. The reason for this was that these reproductive phenological characters require at least 24 months monitoring for proper reliable data for analysis and conclusions. The selected morphological characters in the current study were DBH, CSA and height of mature tamarind. These characters like the reproductive phenologies are also genetic and environment linked (Brack, 2005). Justifiably, they are comparable across sites at a given time unlike the reproductive (flower, fruiting) phenologies and additionally, they are also widely used as indicators of health, productivity and genetic variation in forestry species (e.g. Strand, 1998; Schoettle and Rochelle, 2000; Asogbadjo *et al*., 2006; Losada-Masqueera *et al*., 2006).

The studied sites and detailed sampling strategy for this study has also been published elsewhere (Nyadoi *et al*., 2009). In brief, the sampling sites covered Kenya, Uganda and Tanzania in East Africa. Within these countries, tamarind sampled sites were selected on the basis of being representative of diverse environments-niches of tamarinds; geographic regions, climatic zones (areas with temperature range of 20 to 29ºC, rainfall of less than 500 mm in semi arid–arid Kenya districts to cooler areas that receive annual rainfall of about 2000 mm per annum) and temperatures ranging from less than 20 to about 25 ºC in

Tanzania and Uganda) and being in the higher latitudes above equator and or lower latitudes below equator (Figure Ia, Table 1a). The sites also covered the six main vegetation types of East Africa namely; Zanzibar Inhambane Phytocoria in Kenya and Tanzania, the Somalia Masaai (the semi arid – arid parts of Kenya), lake Victoria regional, Guineo Congolia and Sudanian Phytocoria in Uganda and the Zambesia in Tanzania (White, 1983).

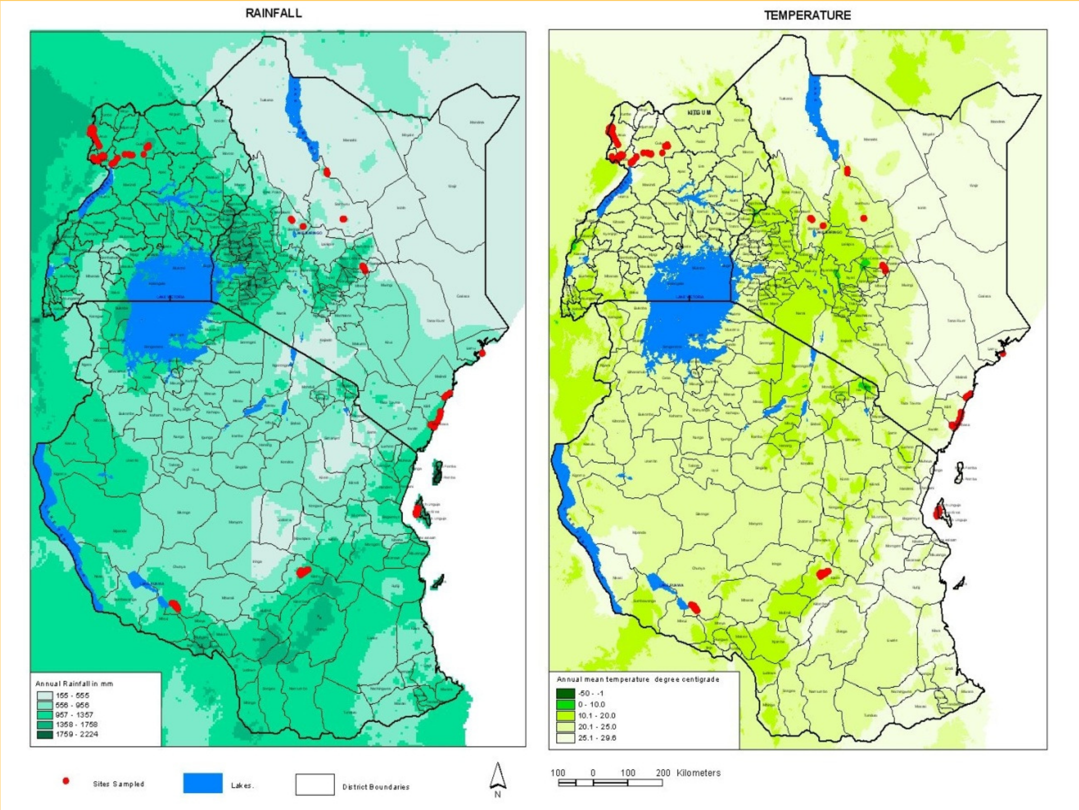

Figure 1a. Map of East Africa showing climatic zones (rainfall and temperature) where tamarind study were carried out

Table 1a. Latitudinal distribution of sampled tamarind trees in East Africa

Regions	Number of trees	Latitudes

	Sampled	
Uganda	61	0-30ºC North
Tanzania	58	0-30ºC South
Kenya	91	0-30ºC South and 0-30ºC North

Once in the selected study site, tamarind sampling was carried out on-farm, woodland and riverbanks. Within each habitat in a given study site, the first tamarind individual was sampled at random as encountered in the field, the next sample individuals were taken at systematic intervals of 500 meters apart or more (where the distribution of tamarind was low) and or less (100 meters) where tamarind was found growing in pure stands (in a plantation or natural forest). For each of the sampled tamarind in a habitat, the following data were recorded; the tamarind crown radii and height in meters and diameter at breast height (DBH) in centimeters. Tamarind crown radii measured at four perpendicular positions to the tree stem were measured with a length tape, tamarind height direct measurement were taken using a Blume- Leis hypsometer and the DBH were measured at 1.3 m above ground, using diameter tapes following standard tree inventory methods (Brack, 2005; Commonwealth of Australia, 2002). Soil samples were taken at 30 cm depth from five different random points within 18 m radius of the tamarind tree, the soils were composited and resampled to capture heterogeneity. The soil samples were taken to World Agroforestry Centre-ICRAF soil laboratory and later analysed for pH, exchangeable acidity, calcium, magnesium, potassium, phosphorus, copper, iron, manganese, zinc, carbon, nitrogen, percentage silt, sand and clay. The soil analyses were done following standard protocols (Anderson *et al*., 1993, with modifications according to ICRAF soil lab procedure). Geographic-GIS data were used to map tamarind sampled sites (Nyadoi *et al.*, 2009, also see Figure 1a). Haplotypes of tamarind generated based mitochondria and chloroplast molecular markers (Nyadoi PhD thesis submitted, Makerere University in Uganda) were obtained for populations studied.

Data management and analyses

Crown sectional area (CSA) for all sampled tamarind in East Africa were calculated based on the equations below;

$$CSA = \pi R^2 \quad \text{...1}$$

Where, R is average radii of the crown (round crowns), derived from four measured radius of the crown as follows;

$$R = (r^1+r^2+r^3+r^4) \div 4 \quad \text{...2}$$

Where, r^1, r^2, r^3 and r^4 are the four different radius of the crown measured at different perpendiculars to the tree crown. The diameter at breast height (DBH) of tamarind trees were measured (with a diameter tape) at a height of 1.3 m above ground while the tree heights were measured in meters or angles (straight stemmed trees on flat topography or leaning/trees in sloppy areas) using a Blume-Leis hypsometer.

The tamarind height, DBH and CSA data, GIS-environment (altitudes, habitats, vegetation types/Phytocoria, rainfall and temperature, latitudes, island-mainland niche status and soil) data were organized in excel and imported into SAS (SAS–SAS Institute-SAS version 9.2, 2008). The data collected on tamarind and their environments were subjected to a multivariate analysis of variance to test the nature and predictive power of independent measures (factors) as well as the relationships and differences seen in the dependent measures (Steel *et al.*, 1997). Interrelationships between dependent variables and independent variables were the subject of investigation in the tamarind study, thus multivariate analysis of variance (MANOVA) which is suitable for elucidation of such relationships was adopted (SAS–SAS Institute-SAS version 9.2, 2008). The multivariate analysis of variance (MANOVA) was conducted using the linear square mean model i.e.

$$Y_{jk} = \mu + a_i + b_j + b_i(x - x_i^{-}) + .\in_{ijk} \quad \ldots\ldots 3$$

where Y_{ijk} is the k^{th} observation in the j^{th} subgroup of the i^{th} group, μ is the parametric mean of the population, a_i is the random contribution of the i^{th} group a, and b_j the random contribution for the j^{th} subgroup b of the i^{th} group, $\in_{ijk}$ is the error term of the k^{th} individual in the j^{th} subgroup. Where as, a, b and etc. are fixed effects of environment factors on observed variable y. In this study, y refers to height or diameter at breast height or crown sectional area of tamarind, a, b are the environment factors evaluated for effect on y and these included different habitats (on-farm, woodland and riverbanks), vegetation types (Phytocoria), altitude, higher latitudes in the Northern ranges of tamarind above the equator and lower latitudes in the Southern ranges below equator, rainfall, temperature and soil parameters.

In the MANOVA model, the mean annual rainfall and temperature, altitudes and soil parameters were taken as covariates, habitats, vegetation types (islands-Zanzibar Inhambane, mainlands-Somalia Masaai, Zambesia, Lake Victoria regional, Guineo-Congolia and Sudanian phytocoria) and latitudes North-South were the fixed effect factors. Observed morphological variability in tamarind populations were overlaid in the East African map showing genetic (haplotypes) variability in tamarind populations and the observed patterns discussed. The tamrind studied for the morphological variability in the different environments were the same characterised for haplotypes, therefore the results of variability were comparable. Details on the haplotype studies are however not part of this manuscript but subject of another manuscript and a PhD thesis for the first author, already submitted in Makerere University, Uganda.

Results

Morphological attributes of tamarind in East Africa

Effect of environmental factors on morphological attributes of East Africa tamarind

As detailed in results presented in this section, multivariate analysis of variance revealed significant effect of Phytocoria, habitat, altitude, soil and latitudes on tamarind morphologies while temperature and rainfall had no effect. And, where as the correlations between environment and tamarind morphologies were 59.5% on analysis where soils data were not included, the correlations reduced to 13% in sub-samples where soil parameters were included.

Tamarind height

The mean height of tamarind differed significantly among Phytocoria (P=0.0002), habitats (P = 0.01) and with altitudes (P<0.0001) in the populations (Table 1). The mean height of tamarind was 4.4 meters in Zanzibar Inhambane Phytocoria (Kenya coastal districts, Lamu and Tanzania's Zanzibar Islands) and 12.79 meters in the mainland-Somalia Maasai (Kitui, Tharaka, Baringo-Pokot and Samburu in Kenya), Sudanian-Guineo Congolia, Lake Victoria Regional mosaic (Arua, Nebbi and Gulu in Uganda) and in the Zambesia-Iringa, Kilolo, Chunya in Mbeya in Tanzania, (Tables 2).

Table 1. Mean Squares of East African tamarind morphological attributes based on Multivariate analysis of Variance (MANOVA).

Source of variation	DF	Mean Square	F Value	Pr > F
Phytocoria	5	84.63	4.96	0.0002*

Habitat	2	75.82	4.45	0.01*
N-S geographic position	1	25.58	1.50	0.22
Mean annual rainfall	1	3.49	0.20	0.65
Altitude	1	270.17	15.85	<.0001*

*difference significant at $p<0.05$, correlation environment with tamarind morphologies (R=59.5%, N = 175), N-S (latitudes North and South).

Table 2. Tamarind height variation in different Phytocoria (vegetation types) in East Africa based on Multivariate analysis of Variance (MANOVA)

Phytocoria	**Height least square mean**	**Standard Error of Means**
Sudanian	11.54	1.35
Guineo –Congolia	12.79	1.59
Lake Victoria regional	12.72	1.88
Somalia – Maasai	14.54	1.12
Zanzibar Inhambane	04.41	1.48
Zambesia	11.39	1.09

The MANOVA also revealed significant differences in tamarind mean height between the mainland (Sudanian, Guineo Congolia, Lake Victoria regional, Somalia Masaai and Zambesia) and island (Zanzibar Inhambane) Phytocoria (Table 3). Further, MANOVA revealed significant differences in height mean within the mainland Phytocoria; between the Somalia Masaai and the rest of the mainland Phytocoria (Sudanian, Guineo Congolia and Lake Victoria regional) but not with the Zambesia (Table 3). Within Phytocoria, tamarind mean height was 11.88 meters with a standard error of 0.47, on-farm, 12.07 with a standard error equal to 0.83 in river banks and 9.75 meters with a standard of 0.65 in the woodlands. Differences in the mean height of tamarind were significant between on-farm and woodland (P = 0.005), and between riverbank and woodland (P = 0.02) while mean height differences between the on-farm and riverbank habitats were not significant (P = 0.82). Differences were considered significant when $P \leq 0.05$.

Table 3. Variation in height of Tamarind in six Phytocoria of East Africa based on Multivariate analysis of Variance (MANOVA).

i/j	**1**	**2**	**3**	**4**	**5**	**6**
1		-0.61	-0.53	-1.73	3.78	0.07
		0.54	0.59	0.09	0.0002*	0.95
2	0.61		0.05	-0.81	3.14	0.61
	0.54		0.96	0.42	0.002*	0.54
3	0.53	-0.05		-0.74	3.01	0.52
	0.59	0.96		0.46	0.003*	0.60
4	1.73	0.81	0.74		4.05	2.35
	0.09	0.42	0.46		<.0001*	0.02*
5	-3.78	-3.14	-3.01	-4.75		-4.05
	0.0002*	0.002*	0.003 *	<.0001*		<.0001*
6	-0.07	0.61	-0.52	-2.35	4.05	
	0.95	0.54	0.60	0.02*	<.0001*	

* - Significant differences-*P values* between mean height of tamarind between the two compared phytocoria, i/j- pairwise comparison of mean heights between phytocoria, 1 – Sudanian phytocoria, 2- Guineo Congolia, 3- Lake Victoria regional, 4-Somalia Masaai, 5-Zanzibar Inhambane, 6- Zambesia

The mean height of tamarind in the Northern latitudes above equator was 10.32 meters with standard error of 0.72 while in the Southern latitudes it was 12.15 m (standard error of mean, 0.98). Differences in the mean heights of tamarind between the Northern and Southern ranges was not significant (P>0.05). Soil pH, exchangeable acidity, calcium, magnesium, potassium, phosphorus, copper, iron, manganese, zinc, carbon and nitrogen had no significant influence on tamarind height variations in populations (Table 4). The effect of percentage silt, clay and sand in the soil on tamarind morphological variations could not be examined in the MANOVA model. Exploration using excel analysis tools however showed that these factors have negligible influence on tamarind height (y) variations i.e. $y = -0.03x+12.79$, $R^2 = 0.05$ with altitude, $y = 0.41x+7.02$, $R^2 = 0.02$

(percentage silt in the soil), y = 0.27x+8.62, R^2 = 0.07 (percentage clay) and for sand y = -0.13x+12.69 with R^2 = 0.05 (detailed raw data not included in this manuscript).

Table 4. Tamarind height variation in environments (soil included) in East Africa based on multivariate analysis of variance (MANOVA)

Source of variation	DF	Mean Square	F Value	Pr > F
Phytocoria	4	18.32	1.02	0.41
Habitat	2	2.80	0.16	0.86
Altitude	1	29.88	1.66	0.21
Mean annual rainfall	1	11.19	0.62	0.44
Soil pH	1	4.87	0.27	0.61
Soil exchangeable acidity	1	12.27	0.68	0.41
Soil exchangeable Calcium	1	6.42	0.36	0.55
Soil exchangeable Magnesium	1	11.29	0.63	0.43
Soil exchangeable Potassium	1	6.45	0.36	0.55
Soil exchangeable phosphorus	1	0.02	0.00	0.97
Copper	1	0.57	0.03	0.86
Iron	1	4.98	0.28	0.60
Manganese	1	58.01	3.22	0.08
Zink	1	0.02	0.00	0.97
Carbon	1	8.77	0.49	0.49
Nitrogen	1	44.13	2.45	0.13

Tamarind crown sectional area (CSA)

Multivariate analysis of variance (MANOVA) revealed significant effect of Phytocoria, habitats, altitudes and latitudes on tamarind crown sectional area (CSA). Tamarind mean CSA differed significantly among Phytocoria (P<0.05), habitats (P = 0.03), altitudes (P<0.05) and (P<0.05) between North – South latitudes populations (Table 5). The CSA was 20 m^2 in Zanzibar Inhambane to 229 m^2 in Somalia Masaai (Table 6).

Table 5. Tamarind crown section area variation in different environments in East Africa (R=59.5%) based on Multivariate analysis of Variance (MANOVA).

Source	DF	Mean Square	F Value	Pr > F
Phytocoria	5	56202.09	4.94	0.0003*
Habitat	2	41747.19	3.67	0.03*
N-S geographic position	1	108523.68	9.53	0.002*

Mean annual rainfall	1	565.95	005	0.82
Altitude	1	400208.32	35.16	<.0001*

*Significant differences -*P values*

Table 6. Different Phytocoria crown section area Mean Squares of East African tamarind based on Multivariate analysis of Variance (MANOVA)

Phytocoria	Crown sectional area least mean square	Standard Error of Means
Sudanian	39.67	34.90
Guineo-Congolia	139.82	41.18
Lake Victoria regional	103.85	48.67
Somalia Masaai	229.07	28.87
Zanzibar Inhambane	-10.59	38.13
Zambesia	182.82	28.06

Analysis of the effect of different Phytocoria on CSA revealed that as in the case of height, the island (Zanzibar Inhambane phytocoria) significantly influenced CSA and so did the Somalia Masaai Phytocoria within the mainland ($P \leq 0.05$, Table 7). The mean CSA on-farm was 140.19 m^2 with a standard error of 12.03, in riverbanks the CSA mean was 111.39 m^2 with a standard error of 21.34 and in the woodlands the mean CSA was 90.74 m^2 with standard error equal to 16.83. The differences in mean CSA of tamarind was not significant between the on-farm and riverbanks habitats ($P = 0.19$) and between the river bank and woodland ($P = 0.79$) while the differences between on-farm and woodland tamarind mean CSA was significant ($P = 0.01$). The mean CSA ranged from 54.7 m^2 with a standard error of 18.7 in the South to 173.5 m^2 with a mean error of 25.3 in the Northern latitudes and these differences were significant ($P \leq 0.05$).

Table 7. Tamarind crown section area variation among Phytocoria in East Africa based on Multivariate analysis of Variance (MANOVA).

i/j	**1**	**2**	**3**	**4**	**5**	**6**
1		-1.88	-1.11	-4.21	1.03	-2.71
		0.06	0.27	<.0001*	0.30	0.01*
2	1.88		1.00	-1.61	2.18	-0.73
	0.06		0.32	0.11	0.03*	0.47
3	1.11	-1.00		-1.97	1.60	1.19
	0.27	0.32		0.04*	0.11	0.23
4	4.21	1.61	1.97		4.35	1.34
	<.0001*	0.11	0.04*		<.0001*	0.18
5	-1.03	-2.18	-1.60	-4.35		-4.34
	0.30	0.03 *	0.11	<.0001*		<.0001*
6	2.71	0.73	1.19	-1.34	4.34	
	0.01*	0.47	0.23	0.18	<.0001*	

* - Significant differences-*P values* between mean crown sectional area of tamarind between the two compared phytocoria, i/j- pairwise comparison of mean heights between phytocoria, 1 – Sudanian phytocoria, 2- Guineo Congolia, 3- Lake Victoria regional, 4- Somalia Masaai, 5-Zanzibar Inhambane, 6- Zambesia

Soil pH, exchangeable acidity, calcium, magnesium, potassium, phosphorus, copper, iron, manganese, zinc, carbon and nitrogen had no significant effect on variation of CSA of the sampled tamarind in populations (Table 8). Based on Microsoft excel analysis tools, exploratory analysis of the effect of percentage sand, clay and silt in the soil revealed no significant influence of these soil parameters on the variation of tamarind crown sectional area in populations. Although raw data is left out in this manuscript, variation of tamarind crown sectional area (y) with these soil parameters were as follows;

$y = -0.53x + 170.7$ with $R^2 = 0.04$ across for altitudes.

$y = 3.47x + 82.06$ with $R^2 = 0.07$ for soil silt.

$y = -0.56x + 119.40$ with $R^2 = 0.003$ for percentage clay in the soil.

y = -0.79x + 112.38 with R^2 = 0.01 for percentage sand in the soil.

Table 8. Tamarind Crown Section Area variation in environment (soil included), based on Multivariate analysis of variance (MANOVA)

Source	DF	Mean Square	F Value	Pr > F
Phytocoria	4	3998.83	0.51	0.73
Habitat	2	4542.23	0.57	0.57
Altitude	1	4472.82	0.57	0.46
Mean annual rainfall	1	148.74	0.02	0.89
Soil pH	1	1327.59	0.17	0.68
Soil exchangeable acidity	1	413.77	0.05	0.82
Soil exchangeable Calcium	1	2026.36	0.26	0.62
Soil exchangeable Magnesium	1	5683.81	0.72	0.40
Soil exchangeable Potassium	1	6663.87	0.84	0.37
Soil exchangeable phosphorus	1	1489.58	0.19	0.67
Copper	1	5679.64	0.72	0.40
Iron	1	292.02	0.04	0.85
Manganese	1	5486.01	0.69	0.41
Zink	1	507.51	0.06	0.80
Copper	1	6755.68	0.85	0.36
Nitrogen	1	10495.71	1.33	0.26

Tamarind diameter at breast height

The multivariate analysis of variance (MANOVA) revealed significant variation in the diameter at breast height of East African tamarind among Phytocoria (P=0.03) and with altitudes (P<0.05), habitats and latitudes North-South had no significant effect (P> 0.05, Table 9). Like for height and crown sectional area, the Zanzibar Inhambane Phytocoria had significant effect (P ≤ 0.05) on diameter at breast height of tamarind, mean DBH was 61.77 cm in this phytocoria and 183-199 cm in the mainland (Table 10 and Table 11).

Table 9. Diameter at breast height of East African tamarind in different environments (R=59.5%, N = 175) based on MANOVA

Source	DF	Mean Square	F Value	Pr > F
Phytocoria	5	20469.57	2.46	0.03*
Habitat	2	10782.34	1.30	0.28
N-S geographic position	1	22487.55	2.71	0.10
Mean annual rainfall	1	1939.36	0.23	0.63
Altitude	1	70222.28	8.45	0.01*

* - Significant differences-*P values* between mean diameter at breast height of tamarind in environments

Table 10. Tamarind diameter at breast height in different Phytocoria in East Africa based on MANOVA

Phytocoria	Diameter at breast height least square means	Standard Error of Means
Sudanian	189.59	29.82
Guineo -Congolia	189.52	35.18
Lake Victoria regional	183.84	41.58
Somalia Masaai	199.56	24.67
Zanzibar Inhambane	61.77	32.57
Zambesia	161.99	23.97

Table 11. Tamarind diameter at breast height variation in different Phytocoria in East Africa based on MANOVA

i/j	1	2	3	4	5	6
1		0.00	0.11	-0.26	3.07	0.61
		0.99	0.91	0.79	0.002*	0.54
2	-0.00		0.19	-0.21	2.17	0.55
	0.99		0.85	0.83	0.03*	0.59
3	-0.12	-0.19		-0.29	2.00	0.39
	0.91	0.85		0.77	0.04*	0.69
4	0.26	0.21	0.29		2.92	1.28
	0.79	0.83	0.77		0.003 *	0.20
5	-3.07	-2.17	-2.00	-2.92		-2.63
	0.002*	0.03*	0.04*	0.003*		0.01*
6	-0.61	0.55	-0.39	-1.28	2.63	
	0.54	0.59	0.69	0.20	0.0091*	

* - Significant differences-*P values* between diameter at breast height of tamarind between the two compared phytocoria, i/j- pairwise comparison of diameter at breast height between phytocoria, 1 – Sudanian phytocoria, 2- Guineo Congolia, 3- Lake Victoria regional, 4-Somalia Masaai, 5-Zanzibar Inhambane, 6- Zambesia.

The least square mean diameter at breast height of tamarind was 173.68 cm with a standard error of 10.28 on-farm, 147.61 cm with standard error of 14.38 in woodlands and 171.85 cm with standard error of 18.23 in riverbanks. Based on MANOVA, differences in DBH among habitats were not significant ($P \geq 0.05$). The DBH was 137.3 cm with a standard error of 15.94 in Northern and 191.42 cm with a standard error of 21.61 in Southern latitudes but these differences were not significant ($P \geq 0.05$). Soil exchangeable potassium had significant effect on DBH (Table 12) but the correlation between tamarind morphology and environment was only 13.7% for the 55 samples in which soil analysis were done ($P = 0.03$, Table 12).

Table 12. Tamarind diameter at breast height in different environments (soil included) in East Africa (R=13.7%, n= 55) based on MANOVA

Source of variation	DF	Mean Square	F Value	Pr > F
Phytocoria	4	2928.29	0.73	0.58
Habitat	2	1573.02	0.39	0.68
Altitude	1	8458.23	2.11	0.16
Mean annual rainfall	1	1046.63	0.26	0.61
Soil pH	1	274.36	0.07	0.79
Soil exchangeable acidity	1	5192.50	1.29	0.26
Soil exchangeable Calcium	1	9638.57	2.40	0.13
Soil exchangeable Magnesium	1	2755.82	0.69	0.41
Soil exchangeable Potassium	1	19652.49	4.89	0.03*
Soil exchangeable phosphorus	1	3788.09	0.94	0.34
copper	1	12006.67	2.99	0.09
Iron	1	9380.39	2.34	0.14
Manganese	1	8987.22	2.24	0.14
Zink	1	47.92	0.01	0.91
Carbon	1	132.59	0.03	0.86
Nitrogen	1	574.32	0.14	0.71

*significant effect of soil parameter on the variation of tamarind diameter at breast height in populations

Like the DBH (Table 12), soil exchangeable potassium increased from the Zanzibar Inhambane (with a mean of 0.41 parts per 100 g of soil) to the mainland where it was about 1 part per 100g of soil (Table 13). Percentage silt, clay and sand effect on tamarind morphological variations could not be examined in MANOVA model, but exploratory analysis using Microsoft excel analysis tools showed negligible relationships;

$y = -0.58x + 216.04$ with $R^2 = 0.0624$ in different altitudes.

$y = 1.16x+123.01$ with $R^2 = 0.06$ for soil exchangeable potassium,

$y = 6.99x + 95.02$ with $R^2 = 0.31$ for percentage silt in the soil.

$y = 2.24x + 136.54$ with $R^2 = 0.03$ for percentage clay in the soil

$y = -1.46x + 180.18$ with $R^2 = 0.0421$ for percentage sand in the soil.

Table 13. Soil exchangeable potassium (parts per 100g of soil) in East Africa Phytocoria

Phytocoria	**1**	**2**	**3**	**4**	**5**	**6**
	1.65	2.14	1.09	0.48	0.83	0.53
	3.87	0.81	1.41	0.97	0.31	1.03
		1.01	2.03	2.1	0.28	2.86
		0.69	0.68	1.75	0.48	2.29
		0.88	1.03	1.39	0.41	1.06
		0.45	1.47	0.52	0.7	1.31
		0.37		0.9	0.86	0.44
		1.34		1.04	0.26	1.18
		0.4		0.53	0.11	
		0.93		1.37	0.33	
				0.75	0.51	
				0.64	0.37	
					0.52	
					0.1	
					0.26	
					0.17	
Mean	2.76	0.90	1.29	1.04	0.41	1.34

*phytocoria, 1 – Sudanian phytocoria, 2- Guineo Congolia, 3- Lake Victoria regional, 4- Somalia Masaai, 5-Zanzibar Inhambane, 6- Zambesia

Tamarind haplotypes in different Phytocoria of East Africa

Majority of tamarind haplotypes types (four different ones – denoted 1, 2, 3 and 4) were present in the semi arid – arid (annual mean rainfall ≤ 500 and < 1500 mm) Somalia Masaai Phytocoria where the morphologies of tamarind were also superior and significantly differed from the other Phytocoria (Figure 1). Two haplotypes (1, 5) were present in the Guineo-Congolia, Sudanian, Lake Victoria region and Zambesia Phytocoria where temperature ranged between 20-25ºC and annual rainfall was 1300 mm/year or more. The Zanzibar Inhambane Phytocoria had three haplotypes (1, 2, and 3) also present in the mainlands. The morphological variation coincided with haplotypes differences; the Somalia Masaai with four mitochondria haplotypes had significantly ($p \leq 0.05$) bigger tamarind than the Guineo-Congolia, Lake Victoria, Sudanian and Zambesia (where only two haplotypes were found), or the Zanzibar Inhambane (which had three haplotypes all of which were also present in the Somalia Masaai Phytocoria).

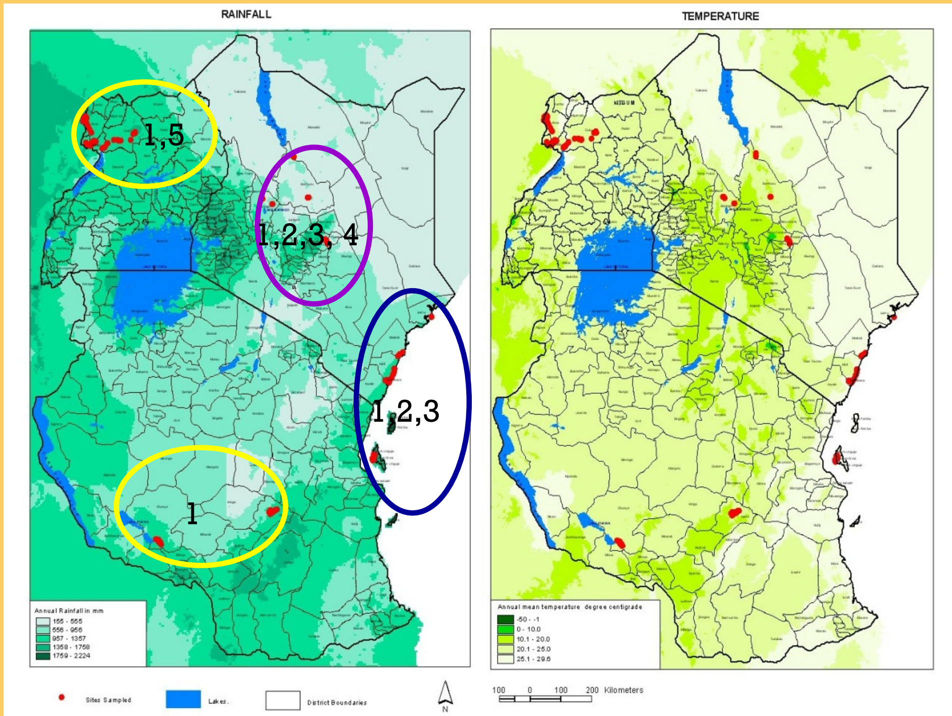

Figure 1 Tamarind height, CSA, DBH variations (R=59.5%) with environment-vegetation, habitat, altitude, latitude, soil exchangeable, potassium and mitochondria haplotypes (1, 2, 3, 4, 5) in East Africa

1.2.3. > p<0.

Somalia Masaai Phytocoria

1, 5 > p<0.

Guineo–Congolia, Sudanian, Lake Victoria, Zambesia

1, 2,

Zanzibar Inhambane

* Mitochondrial haplotypes obtained from genetic diversity studies of tropical tamarind populations (Nyadoi Priscilla -PhD thesis submitted, Makerere University Uganda)

Discussion and conclusions

Overall, the results of this study show that tamarind morphologies (height, DBH and CSA) vary under different environment within East Africa. All the three morphological attributes investigated decreased with increase in altitude but were not affected by rainfall or temperature and soil parameters with the exception of soil exchangeable potassium which influenced DBH. Tamarind CSA decreased from North to South, both CSA and height were affected by habitat while DBH was not. Like altitude, Phytocoria influenced variation of all the three morphological attributes. Interestingly, tamarind morphological variations were in conformity with haplotypes diversity in populations. Tamarind diameter at breast height was similar between the North and South-latitudes. In general, tamarind sizes decreased from mainland to island (Zanzibar Inhambane) Phytocoria and from on-farm to woodland habitat, with the exception of DBH.

The non significant effect of soil factors with the exception of exchangeable potassium on DBH suggests that tamarind is a highly adapted tree species and this is agreement with literature on the species adaptability (Gunasena and Hughes, 2000; El-Sidig *et al*., 2006). Potassium is essential for plant growth and this has been proved even on other tree species and pasture (Losada-Masqueera *et al*., 2006; Prietzel *et al*., 2007). Potassium metabolism is comparable to nitrogen and in other studies it has been shown that tree height and DBH are particularly sensitive to nitrogen and potassium availability (Shepherd, 2000). The increase in tamarind DBH with increase in soil exchangeable potassium therefore supports and or is supported by previous studies on other species, for example those of Losada-Masqueera and his colleagues (Losada-Masqueera *et al*., 2006) who found that growth in DBH of trees and pasture decreased with reduction in the concentration of soil exchangeable potassium.

Tamarind crown sizes increase from lower latitudes in the South below equator to higher latitudes in Northern ranges above equator contrasts findings in some other tree species where the reverse was reported (Strand, 1998; Schoettle and Rochelle, 2000). Northern or higher latitude populations of tamarind in this study include the Somalia Masaai phytocoria, which happens to be a semi arid-arid part of Kenya. It is probable that farmers in this region engaged more in tamarind and other tree species management for climate amelioration and possibly for nutritional and food security purposes. A combination of management and ecological effect may thus have led to bigger sized tamarind trees in these Kenyan habitats. Management such as mulching may also explain the bigger sizes of tamarind trees on-farm. Small tamarind tree sizes in woodlands on the other hand are attributable to competition for resources in absence of management. Human harvesting of mature (bigger) tamarind trees from the woodlands for timber and charcoal reported in East Africa (Nyadoi, 2005) could also be another factor in woodlands. Additionally, given that soil factors had negligible influence on tamarind morphologies except on DBH, observed differences in CSA and height among habitats may be due to differential management and or utilisation. Such factors are known to cause morphological and genetic evolutionary divergences in populations (Young *et al*., 2000; Frankham, *et al*., 2002; Omeja *et al*., 2004).

Although it has been suggested in past studies that decrease in tamarind tree sizes with increasing altitude could be due to temperature limitations (Jama *et al*., 1989). The results of the current study suggest morphological variations in tamarind are independent of temperature and rainfall but attributable to variation in altitude itself. Even then, superior height, DBH and CSA of tamarind encountered in the semi arid-arid zones (Somalia Masaai region) in Kenya and not in cooler Uganda and Tanzania regions suggest that temperature may have role in morphological evolution. Seemingly, synergic effect of a range of climatic-environment factors, temperatures inclusive, shaped morphological variability in tamarind populations. The current results show that temperature alone or rainfall alone may have no significant influence on morphological variability in tamarind. These results provide more evidence in support of a recent global study which revealed that the combined effect of a range of environment factors influence species dynamics at population and community levels (Vellend and Gebber, 2005; Kreft and Jetz, 2007). Long term model studies of the combined effect of a range of environmental factors (including those investigated in this study) on tamarind morphologies may generate more knowledge to help explain observed variability in populations.

As revealed by correlations in the MANOVA results, environment factors investigated in this study explained 59.5% of the variations observed in tamarind morphologies, the remaining 39.5% could be due to genetic differences or other environmental factors. Differential anthropogenic management and utilization practices may be one of the environment factors responsible for morphological variations observed in tamarind populations. Investigation on domestication (particularly on-farm planting) and utilization of tamarind at a regional level in East Africa may appraise this hypothesis.

Coincident differentiation of tamarind haplotypes and morphologies is also evidential of partial genetic basis for morphological variations. This also reinforces findings for example where clime adaptations have shown genetic basis (Gockel *et al*, 2002). Coincidence of lack of variability for both tamarind haplotypes (genotypes) and DBH (morphology) among habitats is additional clue that genetic variability may be the cause of the morphological differentiation in populations. Elsewhere in literature, studies done on Drosophila, Spine sticklebacks, frogs, maize and *Mumulus* have also implicated genetic basis for morphological diversity (Wang *et al*., 1999; Sucena and Stern, 2000; Gockel *et al*., 2002; Shapiro *et al*., 2004; Doebley, 2004). Thus findings on the tamarind study add knowledge to reinforce and or are also reinforced by these studies of other taxa.

The current study show that morphological variability exists for tamarind and that the variations are in part environment linked and occur in pattern with genetic diversity of the populations. The findings generally give clue that tamarind morphological variants in populations could guide germplasm and conservation-units selection within homogeneous environments in East Africa. Nevertheless, further analysis of tamarind morphological variants' correlation with their genotypes within environment is needed to ascertain the level of precision with which they will be useful as selection markers.

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