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Relationship Between Tree Slenderness Coefficient and Growth Characteristics of *Gmelina arborea* (roxb.) Stands in Omo Forest Reserve, Nigeria.

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Abstract
Tree slenderness coefficient (TSC) serves as an index of tree stability or the resistances to windthrow. Hence, t*his study evaluated the relationship between TSC and growth characteristics using selected linear and nonlinear functions for Gmelina arborea stands in Omo forest reserve* **as** *predictive models in Nigeria. Data from temporary sample plots (TSPs) of 16, 20 and 26 years old plantation stands were fitted to eight selected models to determine the best predictive TSC models. The functional models were evaluated with the least values of A*kaike information criterion (AIC) *and standard error of the estimate (SEE). The significance of the estimated parameters was also verified with the plot of residuals against predicted to ascertain the goodness of fit of the best models. Result revealed that 95.87%/ha, 87.59%/ha and 82.49%/ha respectively for 26, 20 and 16 years old stands in this study area were of good vigour and could withstand windthrow. For the whole stand, the relationship between TSC and diameter at breast height was best predicted with Modified exponential models (AIC = 998.97 and SEE = 12.95) and was therefore recommended for predicting slenderness coefficient in the stands with plausible potentials for enhancing reasonable quantification of the stands' stability. Sustainable management of this plantation is also recommended for continuous of stable and productive stands.*

Keywords: *Exponential model, slenderness coefficient, Gmelina arborea, estimated parameters*.

Introduction

Gmelina arborea is a fast-growing deciduous tree occurring naturally in India, Thailand, Cambodia and southern provinces of China but planted extensively in Nigeria, Sierra Leone and Malaysia (Ajayi, 2013). It is commonly planted as avenue trees, in gardens and also in villages along with agricultural land, on village community lands and wastelands. It is light-demanding, tolerant of excessive drought but moderately frost hardy and has good capacity to recover in case of frost injury (Duke 1983). In Nigeria, large investments in *Gmelina arborea* plantations have been made particularly to provide raw materials for pulp and paper mills (Ajayi *et al*, 2004). The species is now being converted for timber production as a result of the failure of the mills to utilize them (Adetogun and Omole, 2007). These plantations have outgrown the pulpwood production rotation of 8 years (Akachuwku 1981; Evans, 1992). Furthermore, silvicultural treatments have been limited; leaving stands untended. Global concern for the sustainable management of these plantations has been expressed to achieve expected benefits (ITTO, 2001; 2003).

Trees show considerable variation and flexibility in their shape and size of crowns, height and trunk diameters (Givnish, 2002). These are governed by an inherited developmental tendency, which may, in turn, be modified by the environment where the tree grows. The size of a tree canopy and its height above the ground is significant to a tree in that it determines the total amount of light that the tree intercepts for photosynthesis (Midgley, 2003). The adaptive significance of tree height, have been through a mathematical model, that the higher a tree is the more light it intercepts during the day (Jahnke and Lawrence, 1965). The tree trunk size also has its adaptive significance to a tree. It must be strong enough to withstand the forces that act on it and the force exerted on it by the wind. These forces are the weight of the tree and the drag exerted on it by the wind, as demonstrated by Fraser (1962). Experimentally, the wind is much more important than weight in determining what thickness of trunk is necessary for a tree (Alexander, 1968). The slenderness coefficient of a tree is defined as the ratio of total height (H) to diameter outside bark at 1.3m above ground (DBH) when both H and DBH are measured in the same units (i.e. H/DBH, with both H and DBH measured in metres) (Onilude and Adesoye, 2007). It has been widely used as an index of the tree to resistance from windthrow. Tree slenderness coefficient often serves as an index of tree stability, or the resistances to windthrow (Navratil, 1996). A low slenderness coefficient value usually indicates a longer crown, lower centre of gravity, and a better-developed root system. Therefore, trees with higher slenderness coefficient values (that is slender trees) are much more susceptible to wind damage. Actions improving the stability of trees and stands could considerably limit these damages. Because of tree slenderness coefficient importance for indexing tree resistance to windthrow, it is, therefore, important to get to know slenderness of trees, considered to be a measure of their stability, especially of conifers as well as developing models that can predict this values.

One of the major challenges of forestry development in Nigeria is the dearth of periodic information on stand conditions. However, sustainable management of forest stands can only be ensured if current and reliable information on growth condition of the stand is available which can be used by forest managers/management to provide accurate and timely information on current growing stock. Forestry like any other business venture requires effective management of its resources. As a result requires quantifiable information on the trees not only for the management decision but also to show the growth, productive capabilities and resistance capability of the trees. Good forest management requires accurate and up to date information on the current growing stock and future growth potential.

The objective of this study is therefore to estimate slenderness coefficient value for *Gmelina arborea* to develop slenderness coefficient predictive models.

Methodology

The study area

This study was carried out in the Plantation section (Area J4) of Omo Forest Reserve (Fig 1). It is situated between latitudes 6° 45' and 7° 15'N and longitudes 4° 8' and 4° 40'E. The reserve shares its northern boundary with Shasha and Ago Owu forest Reserves in Osun State and Oluwa forest reserve in Ondo State. The topography of the reserve is generally gently undulating with an average elevation of 12m above sea level (Akindele and Abayomi, 1993). The soils in the area are typical of the variety of soils normally found in intensively weathered areas of the basement complex formations on the West Coast of African. The reserve has a typical humid tropical climate with an annual rainfall of about 1426mm which is common with more than 65% occurring between April and October. A mean annual temperature of 26.5°C has been reported for the reserve, while a minimum of 19.5°C and maximum of 32.5°C was reported for the rainy season and dry seasons respectively (Ogun State Forestry Plantation Project, (OSFPP), 2015).

Sampling Techniques and Data Collection

Three age series (16 (5ha), 20 (5ha) and 26 (5ha) years old) of *G. arborea* stands were assessed. A total of 10 temporary sample plots (size 20 x 20m) were randomly laid in each age series. A complete enumeration of all trees in each plot were assessed. The following variables were assessed: diameters (cm) at breast height (dbh), base (Db), middle (Dm) and top (Dt), total height (H (m)), Merchantable height (MH (m)), crown length (CL (m)) and crown diameter (CD(m)).

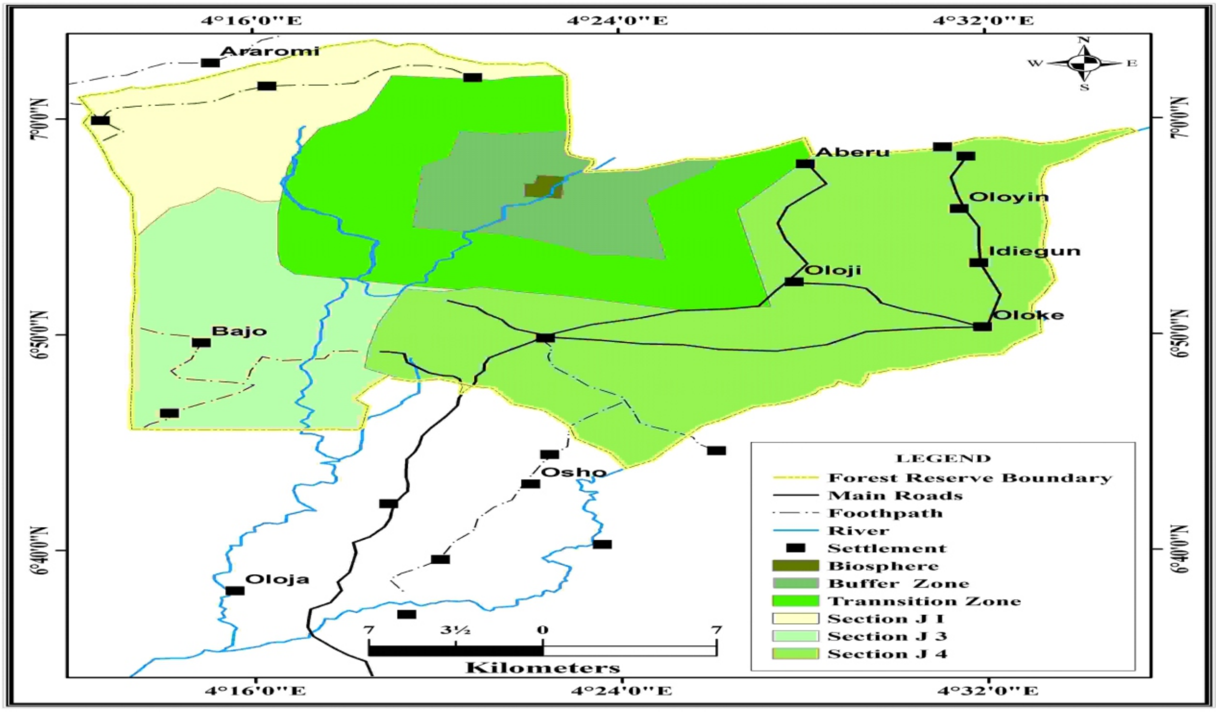

Fig 1: Map of Omo Forest Reserve showing the study area (Area J4)

Data computation

- Basal Area Estimation

The Basal Area (BA) of individual trees was estimated using the formula in equation 1 (Husch *et al*, 2003)

BA=

$$BA = \frac{\pi}{4}D^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where BA = Basal area (m^2), D = dbh (cm).

- Volume Estimation

The volume of individual trees were estimated using Newton equation developed for trees volume estimation (Husch *et al*, 2003)

$$V = \frac{H}{6}(A_b + 4A_m + A_t) \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where V = Stem volume (m^3), H = stem height (m), A_b = Tree cross -sectional area at the base, A_m = Tree cross-sectional area at the middle and A_t = Tree cross - sectional area at the top

- Slenderness coefficient (TSC)

$$TSC = \frac{THt}{dbh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

According to Navratil*et al*, (1996), slenderness coefficient values were classified into three categories.

TSC values > 99…………… High slenderness coefficient

70 < TSC values > 99……….Moderate slenderness coefficient

TSC values < 70 …………….Low slenderness coefficient

Crown variables estimation

- Crown ratio (CR)

$$CR = \frac{CL}{THt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

- Crown projection area (CPA)

$$CPA = \frac{\pi\left(CD^2\right)}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where THT = Total height and CL = Crown length and CD = Crown diameter

Table 1: List of selected model functions

Model No	Model Name	Model
1	Simple linear	$TSC = a + b*D$
	Exponential functions	
2	Exponential	$TSC = a*\exp^{bD}$
3	Modified exponential	$TSC = a*\exp^{b/D}$
4	Natural logarithm	$TSC = a + b*\ln(D)$
5	Reciprocal logarithm	$TSC = \frac{1}{a + b*\ln(D)}$
	Growth functions	
6	Exponential association 2	$TSC = a(1 - \exp^{-b*D})$
7	Exponential association 3	$TSC = a(b - \exp^{-c*D})$
8	Saturation growth rate	$TSC = \frac{a*D}{(b + D)}$

TSC = Tree slenderness coefficient, D = dbh (m), exp = exponential, ln = natural logarithm and a,b&c = regression coefficient/parameter estimate

Model evaluation

The models developed were evaluated with a view of selecting the best estimator for tree slenderness coefficient. The evaluation was based on the following criteria:

a. The Mean Square Error (MSE). This is a measure of the spread of the data and therefore an indication of the precision of the predicted response. MSE is expressed as:

$$MSE = RSS/_{n-p} \quad \text{.......................... 6}$$

a. Akaike information criterion (AIC). The AIC is of the form:

AIC = $AIC = 2k - 2*\ln(L)$ 7

Where: K = number of estimated parameters in the model, ln = Natural logarithm and L = the maximized value of the likelihood function for the model.

The significance of each regression coefficient in the models was tested using the Student t-test. The t-value will be compared with the critical value of t at α = 0.05 level. Where t-calculated for the regression coefficient exceeded the critical value of t, the independent variable will be considered significant and vice-versa. Suitable models are those with least AIC and MSE values.

Results and discussion

The statistical summary of the growth data set used in this study presented in Table 2 revealed that there were steady growths in the plantations. The dbh was able to explain the relationship that existed within the growth variables. Basal area and volume per hectare among others for assessed plantation age followed the same trend with the tree dbh. According to Husch *et al* (2003), basal area per hectare is computed from the dbh of the standing trees. The TSC was observed to be minima in 16 years old plantation (72.02±1.92) while it was highest in 26 years old plantation (95.00±1.17). This might be as a result management efforts on these plantations. Most of the trees in 26 years old plantation (61%) can withstand wind whereas only 17.51% of trees/ha in 16 years old plantation are prone to wind throw (Table 5).

The correlation coefficients between tree

Figure 1: pH of the maize-water melon seed fermented batter.
MW1 = 100%maize; MW2 = 95%maize + 5%watermelon seed; MW3 = 90%maize + 10%watermelon seed; MW4 = 85% + 15%watermelon seed.

Figure 2: Total titratable acidity (% lactic acid) of the fermented batters from 0 h and 12 h
MW1 = 100% maize; MW2 = 95% maize + 5% watermelon seed; MW3 = 90% maize + 10% watermelon seed; MW4 = 85% + 15% watermelon seed.

Table 2: Proximate composition (%) of maize–watermelon seed flour blends

Samples	Moisture	Ash	Crude fibre	Protein	Fat	Carbohydrate
MW1	11.37 ± 0.00^{a}	0.96 ± 0.01^{d}	3.23 ± 0.35^{a}	1.68 ± 0.14^{d}	11.60 ± 0.14^{d}	71.17 ± 0.62^{a}
MW2	11.06 ± 0.14^{a}	1.95 ± 0.21^{c}	2.78 ± 0.14^{a}	1.98 ± 0.07^{c}	15.03 ± 0.35^{c}	67.21 ± 0.09^{b}
MW3	8.28 ± 0.15^{b}	2.93 ± 0.02^{b}	2.69 ± 0.15^{a}	3.53 ± 0.04^{b}	17.02 ± 0.28^{b}	65.57 ± 0.01^{c}
MW4	8.07 ± 1.64^{b}	2.98 ± 0.14^{a}	1.49 ± 0.00^{b}	4.43 ± 0.01^{a}	18.01 ± 0.01^{a}	65.02 ± 0.15^{c}

Means with different superscript in a column indicate that values are significantly different.
MW1 = 100% maize; MW2 = 95% maize + 5% watermelon seed; MW3 = 90% maize + 10% watermelon seed; MW4 = 85% + 15% watermelon seed.

Table 3: Mineral element composition (mg/100g) of maize–watermelon seed flour blends

Samples	Calcium	Potassium	Magnesium	Copper	Manganese
MW1	748.00 ± 2.83^{a}	114.00 ± 2.83^{d}	412.00 ± 2.83^{d}	3.20 ± 0.42^{b}	2.70 ± 0.28^{b}
MW2	674.00 ± 2.83^{b}	156.00 ± 4.24^{c}	444.00 ± 2.83^{c}	3.90 ± 0.42^{ab}	3.40 ± 0.57^{b}
MW3	676.00 ± 2.83^{b}	166.00 ± 2.83^{b}	528.00 ± 2.83^{b}	4.30 ± 0.42^{ab}	3.50 ± 0.42^{b}
MW4	588.00 ± 2.83^{c}	188.00 ± 2.83^{a}	672.00 ± 2.83^{a}	4.90 ± 0.28^{a}	6.60 ± 0.57^{a}

Means with different superscript in a column indicate that values are significantly different.
MW1 = 100% maize; MW2 = 95% maize + 5% watermelon seed; MW3 = 90% maize + 10% watermelon seed; MW4 = 85% + 15% watermelon seed.
Table 4: Phytochemical and antioxidant property of maize–watermelon seed flour blends

slenderness coefficients and tree DBH, basal area, volume and age were negative (Table 3). This result indicates that the tree slenderness coefficient values tend to decrease for larger trees, and the largest slenderness coefficient values occur for the trees with small DBH. The correlation coefficients between tree slenderness coefficient and DBH were higher than those correlation coefficients between the other variables. This indicates that tree DBH is a better predictor of the slenderness coefficient than age or volume. The results confirm that the slenderness coefficient generally decreases with increasing stand age. This trend was in agreement with the reports of several authors on the growth attributes and management scenarios for plantation species in Southwest, Nigeria (Onyekwelu, 2001; Onyekwelu*et al*., 2003; Eguakun and Oyebade, 2015). Tree height, crown length and crown diameter also showed a negative low correlation with slenderness coefficient. The results of this study were similar with the report of Wang *et al;* (1998) where the relationship of tree slenderness coefficients and tree characteristics for major species in boreal mixed forests were evaluated using empirical models.

Assuming that a slenderness coefficient value over 99 is considered to be at the high risk of windthrow as suggested by Navratil (1996), the result of this study indicated that the trees of the sampled stands in Omo Forest Reserve do not belong to the high-risk category of windthrow. The relationship between windthrow and slenderness coefficient is indirect. Lower slenderness coefficient can be an indicator of larger crowns, lower centre of gravity and a better-developed root system. The desirable height/dbh ratios for adequate wind resistance vary according to species and country. In general, trees with a higher slenderness coefficient (low taper) are much more susceptible to damage than trees with low slenderness coefficient (high taper). Since smaller slenderness coefficient is usually indicating higher resistance to windthrow, the relationships confirmed suggest that silvicultural treatments, such as producing long-crowned trees, and maintaining appropriate stand density through spacing, thinning, or gradually harvesting overstory trees, can help reduce the risk of windthrow (Wang *et al*., 1998; Eguakun and Oyebade, 2015).

Eight candidate models were selected to predict TSC in this study using dbh as a major predictor since it has the highest correlation coefficient and practically, it is the easiest variable to measure. All the models show a strong fit to the tree slenderness coefficient data. The observed goodness of fit of the models was in agreement with the previous works on the relationship between tree slenderness coefficient and tree or stand characteristics (Orzeł, 2007; Orzeł and Socha 1999; Wang *et al*., 1998; Eguakun and Oyebade, 2015). Hence, the least values of AICC and standard error were used to select the best model that explains the relationship. Based on this criterion, the modified exponential model was adjudged the best among the candidate models. This study revealed significant variations (Fig 2 – 4) among the tree growth characteristics (dbh, height and volume) and indicative of relationships between these variables and tree slenderness coefficient (TSC) within the *G. arborea* plantations in Omo Forest Reserve, Nigeria. Hence, this model is therefore recommended for predicting slenderness coefficient in the stand.

Table 2: Summary of mean growth variables

Growth variables	16 years	20 years	26 years
DBH (cm)	21.50±0.04	22.71±0.03	61.51±0.04
H (m)	16.08±0.04	17.72±0.02	21.57±0.03
MH (m)	11.98±0.00	11.12±0.00	15.00±0.00
CL (m)	4.79±0.08	4.49±0.12	6.57±0.12
CD (m)	8.64±0.144	8.97±0.24	13.47±0.25
BA (m^2/ha)	38.40±0.04	41.21±0.07	263.38±0.06
VOL (m^3/ha)	387.22±0.05	349.08±0.04	3224.52±0.12
TSC	72.02±1.92	78.46±1.90	95.00±1.17
CPA (m^2/ha)	62230.40±0.07	83251.60±0.10	151094.00±0.06
CR	0.28±0.01	0.39±0.01	0.32±0.00

DBH = diameter at breast height, H = total height, MH = merchantable height, CL = crown length, CD = crown diameter, BA = basal area, VOL = volume, TSC = tree slenderness coefficient, CPA = crown projection area, CR = crown ratio and ±Standard error.

Table 3: Correlation matrix between TSC and growth variables

	TSC	*DBH*	*THt*	*MH*	*CL*	*CD*	*BA*	*Vol*	*CR*	*CPA*	*Age*
TSC	1										
DBH	-0.999*	1									
H	-0.563*	0.999*	1								
MH	-0.465	1.000*	1.000*	1							
CL	-0.318	0.986*	0.991*	0.990*	1						
CD	-0.477	0.999*	0.998*	0.999*	0.981*	1					
BA	-0.762*	0.999*	0.999*	0.999*	0.991*	0.998*	1				
Vol	-0.865*	0.999*	0.999*	0.999*	0.990*	0.999*	1.000*	1			
CR	-0.781*	0.999*	0.997*	0.998*	0.977*	0.999*	0.997*	0.998*	1		
CPA	-0.385	-0.998*	-0.995*	-0.996*	-0.972*	-0.999*	-0.995*	-0.996*	-0.999*	1	
Age	-0.892*	0.964*	0.995*	0.957*	0.905*	0.970*	0.954*	0.956*	0.975*	-0.979*	1

*Significant at 5% probability level, DBH = diameter at breast height, H = total height, MH = merchantable height, CL = crown length, CD = crown diameter, BA = basal area, VOL = volume, TSC = tree slenderness coefficient, CPA = crown projection area and CR = crown ratio

Model	**Paramete**	**AICC**	**R**	**SEE**		**Rankin**
Simple linear ()	a = 38.362 b = -4.630	1008.913	0.583	13.289	0.000	6^{th}
Exponential ()	a = 18.281 b = -1.006	1004.513	0.595	13.140	0.000	5^{th}
Modified exponential ()	a = 3.858 b = 0.411	998.972	0.910	12.954	0.000	1^{st}
Natural logarithm ()	a = 6.731 b = -6.597	1003.416	0.698	13.103	0.000	4^{th}
Reciprocal logarithm ()	a = 0.015 b = 0.008	999.120	0.813	12.959	0.000	2^{nd}
Exponential association 2 ()	a = 95.004 b = 43.168	1089.813	0.500	16.352	0.000	8^{th}
Exponential association 3 ()	a = 695.047 b = 1.224	1011.557	0.581	13.344	0.000	7^{th}
Saturation growth rate ()	a = 54.290 b = -0.255	999.358	0.809	12.967	0.000	3^{rd}

Table 5: Tree slenderness coefficient classification

TSC Range	**Value (%/ha)**			**Overall result (%)**	**Implication**
	16 years old	**20 years old**	**26 years old**		
> 99	17.51	12.41	4.13	21.60	Prone to wind throw
70 – 99	39.55	52.55	34.87	32.07	Moderate
< 70	42.94	35.04	61.00	46.34	Withstand wind throw

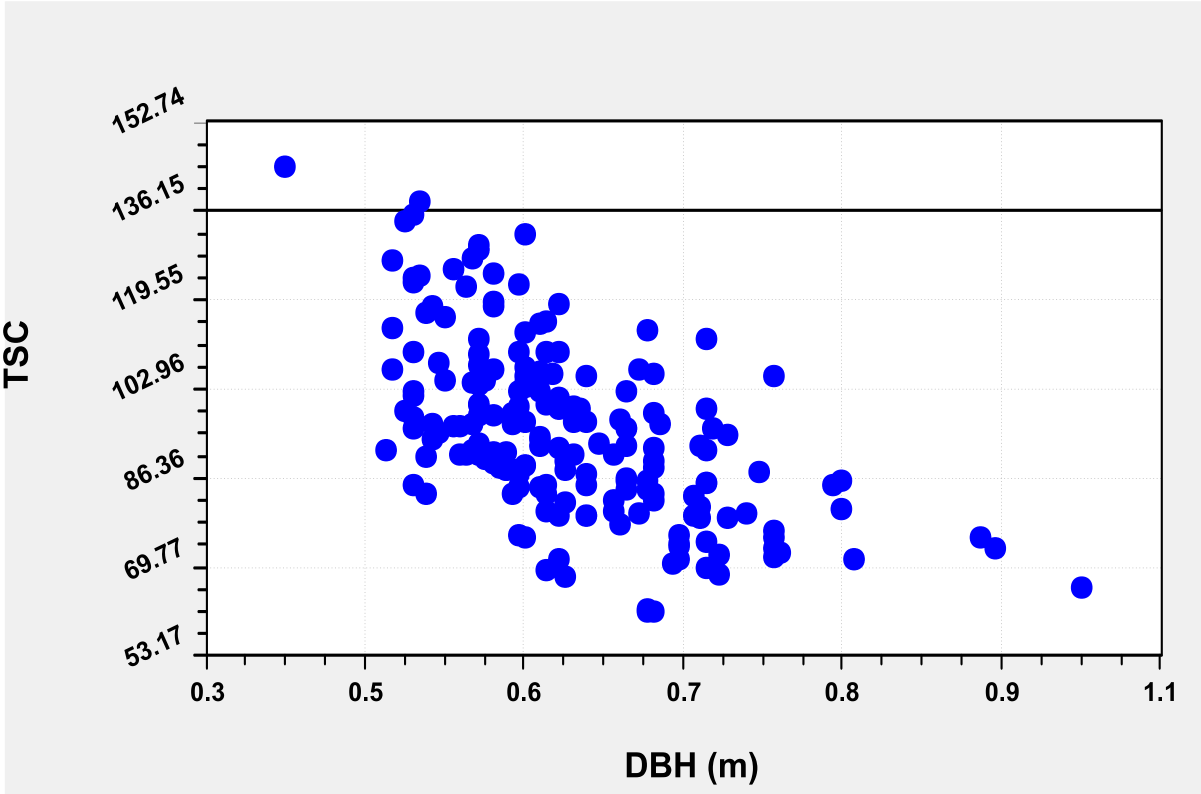

Fig 2: Relationship between TSC and dbh (m)

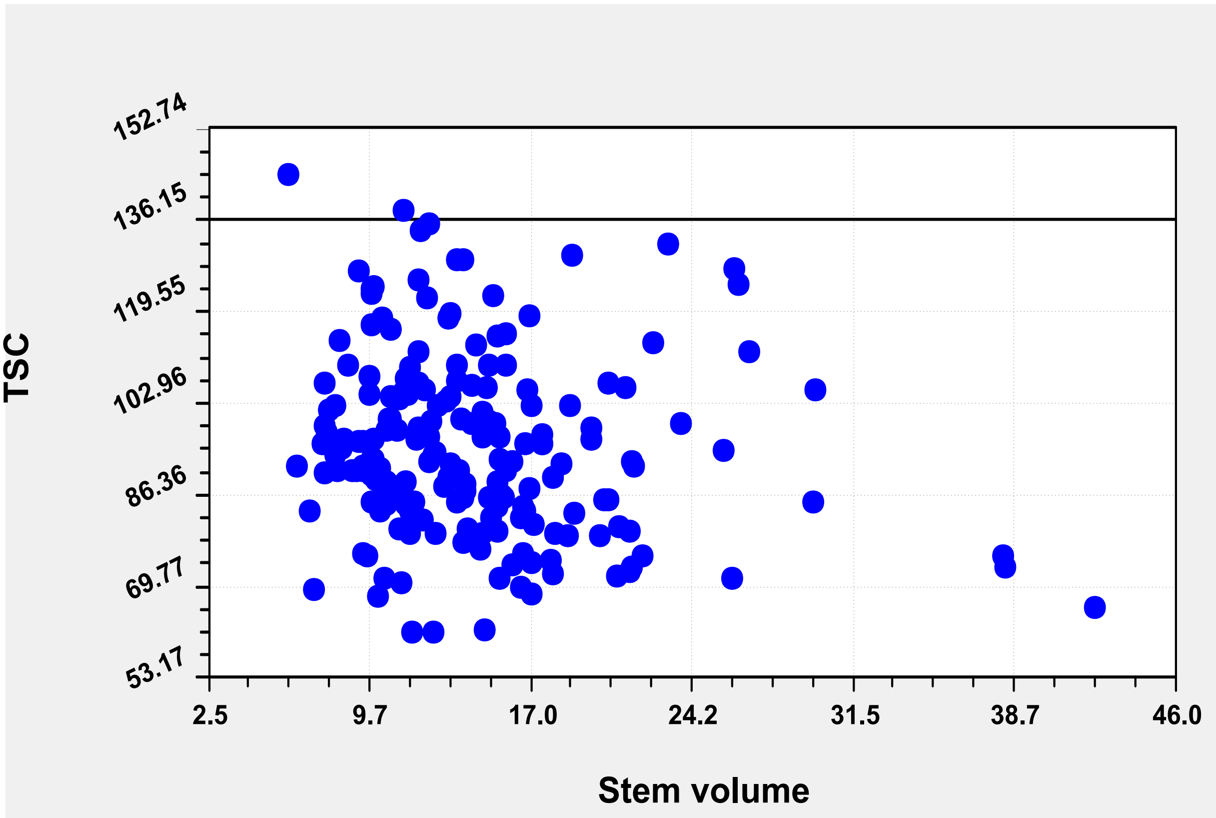

Fig 3: Relationship between TSC and stem volume (m^3)

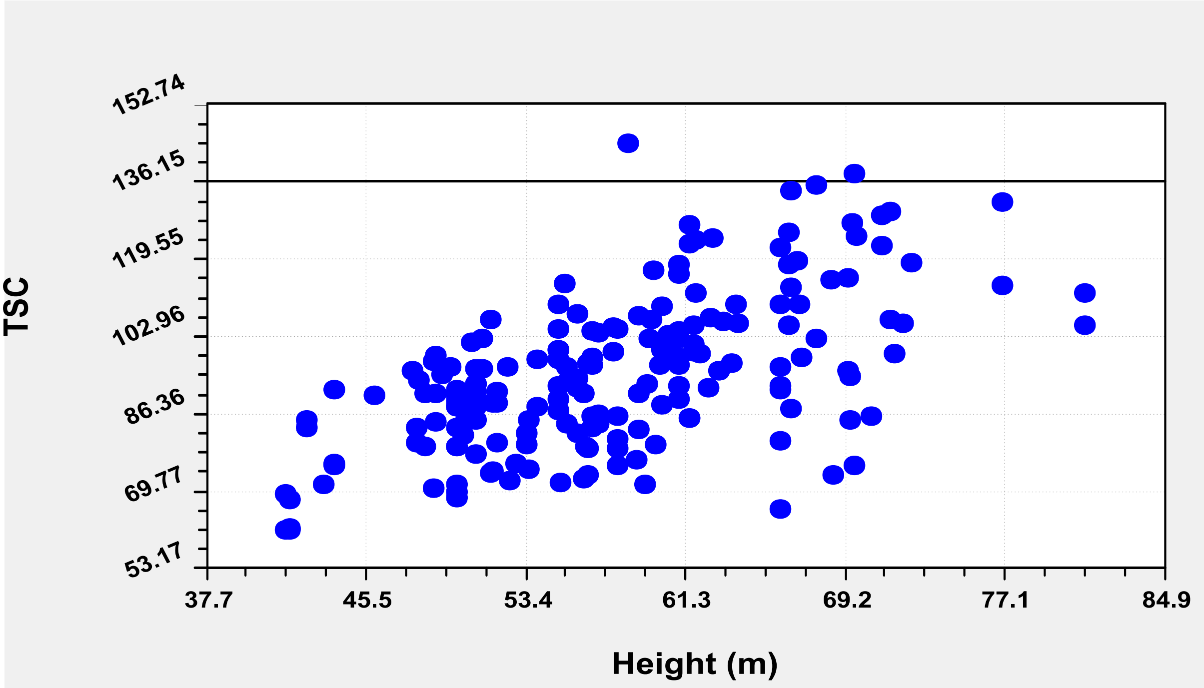

Fig 4: Relationship between TSC and height (m)

Conclusion

The study has projected the possibility of occurrence of windthrow among this species in Nigeria and advances the need for enhancing stability among other species to reduce susceptibility to windthrow and other environmental degradation within the plantations in Nigeria. Diameter at breast height was observed to be a common useful independent variable in all the selected models used in the study. Based on the evaluation of the models examined in this study, the modified exponential model was recommended as tree slenderness model for *Gmelina arborea* stand in Omo Forest Reserve for further use.

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