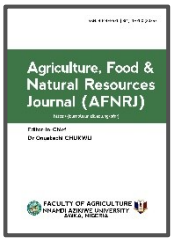
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Original Article

Evaluation of probability distribution functions for fitting stem diameters of *Tectona grandis* plantation in Adekunle Ajasin University, Ondo State, Nigeria

OPEN ACCESS

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ABSTRACT

Modeling frequency distributions of tree variables, such as Diameter at Breast Height (DBH) plays an important role in forest inventories, growth prediction, and management. The objective of the study was to evaluate the 2 and 3-parameters Gamma, Log logistics, Log normal and Weibull, distribution functions fitted to the DBH of Teak (Tectona grandis Linn. F.) plantation in Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria for sustainable management. The method adopted for this research was complete enumeration of the Teak plantation of size 80 m2 x 40 m2. The performance of the selected probability distribution functions (PDFs) was compared using Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D) and Chi-square ($\chi 2$) tests. The results showed that the highest frequency (526) of trees fall between the DBH of 0.11-0.14 m. The Weibull 3-parameter distribution had the best fit with K-S= 0.0222, A-D= 0.3908 and $\chi 2$=10.868 and followed by Weibull 2-parameter distribution with K-S= 0.0238, A-D= 0.4944 and $\chi 2$=10.443. Hence, Weibull 3 and 2-parameters were adjudged as the most suitable distribution also based on the smallest relative rank sum of 17 and 27, respectively in the study area. The study recommends the Weibull 3-parameter for DBH class distribution of the Tectona grandis plantation in the study area for plausible management and value projection.

KEYWORDS: *Diameter at Breast Height, Enumeration, Goodness of fit, Management, Model*

INTRODUCTION

Teak (*Tectona grandis* Linn. f.) is widely recognized as one of the most valuable timber-producing tree species globally. Belonging to the family Verbenaceae, teak is predominantly distributed across tropical and subtropical regions (Yadav, 2021; Martha *et al*., 2021). The genus name Tectona is derived from the Portuguese word teca, itself originating from the Greek tekton, meaning carpenter. The species epithet grandis is Latin for "large" (Sreekumar & Sanil, 2021).

Naturally occurring teak forests are found in India, Myanmar, the Lao People's Democratic Republic, and Thailand (Sreekumar & Sanil, 2021; Kollert *et al*., 2024). In India, teak is known by various vernacular names: Sagun (Hindi), Thekku (Malayalam), Sagwan (Marathi), Saguan (Kannada), Singuru (Oriya), Tekkumaram (Tamil), and Adaviteeku (Telugu). Internationally, it is referred to as Kyun and Lyiu in Myanmar, Teck in French, Teca in Spanish, Mai Sak in Thailand, Djati in Indonesia, and Fati in Malay (Arunkumar *et al*., 2024).

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Teak is a deciduous species that can reach heights of 20–35 meters and diameters at breast height (DBH) of 29–54 centimeters over a period of 50 years. The bole is often fluted at the base and has a pale brown to grey bark (Sreekumar & Sanil, 2021). Noteworthy specimens include a teak tree in Thailand with a DBH of 3.2 meters and height of 46 meters, the largest known standing teak in Myanmar's Baw Forest Reserve at 2.4 meters DBH and 46 meters tall, and India's largest teak tree in Parambikulam, Kerala, standing 40 meters tall with a DBH of 2.1 meters (Hlaing & Teplyakov, 2012). Teak is known to live for as long as 500 years (Arunkumar *et al*., 2024).

In the global timber market, Tectona grandis is highly valued for producing top-quality hardwood under sustainable plantation systems in tropical regions (Kollert *et al*., 2024). It is prized for its exceptional mechanical and physical characteristics, including elasticity, strength, and durability (Arunkumar *et al*., 2024). These properties, combined with its attractive grain, color, and ease of machining, make teak a preferred material for fine furniture, cabinetry, wood carving, and door and window production (Palanisamy *et al.,* 2009).

Teak's growth, distribution, and stand formation are influenced by several ecological factors such as climate, soil type, elevation, and light availability (Asigbaase *et al*., 2024). The species has been successfully introduced to numerous countries beyond its native range, including Indonesia, Sri Lanka, Vietnam, Malaysia, several countries in East and West Africa (e.g., Tanzania, Ivory Coast, Nigeria, Ghana, and Togo), the Caribbean (e.g., Cuba, Puerto Rico, Panama, Trinidad and Tobago), and parts of South and Central America (e.g., Brazil, Costa Rica). Globally, teak plantations cover approximately 3 million hectares, with about 94% located in tropical Asia—primarily in India (44%), Indonesia (31%), Thailand (7%), and Myanmar (6%). Africa accounts for around 4.5% of global teak plantations, notably in Côte d'Ivoire and Nigeria, while the remainder is in tropical America (Kollert *et a*l., 2024).

In forestry, tree stem diameter is one of the most fundamental and widely measured variables (Bilous *et al*., 2024). It serves as a key indicator of tree size and forest stand structure due to its strong correlation with other growth parameters, such as basal area, tree height, and wood volume (Chen *et al*., 2025). The diameter at breast height (DBH) is especially important for modeling tree growth and stand dynamics. Probability distribution functions of univariate data like DBH are essential tools in describing tree populations and predicting diameter and volume growth for sustainable forest management (Antúnez *et al*., 2025). These models, commonly referred to in forestry as "distributions," help define the frequency and variability of stem diameter within a stand (Magalhães *et al*., 2024).

Since the 1950s, foresters have been developing models to describe right-skewed diameter distributions of forest stands (Martin *et al*., 2025). Classical statistical models commonly used for this purpose include the Normal, Beta, Exponential, Lognormal, Weibull, Gamma, and Johnson's SB distributions (Gorgoso-Varela *et al*., 2024). The selection of an appropriate diameter distribution function is typically based on statistical analysis of empirical diameter data. These diameter distribution studies are crucial in forest modeling and simulation, offering insights into stand structure and dynamics. According to Tiétiambou *et al*. (2025), diameter distribution functions help determine whether there is an adequate population of small trees in a stand to replace mature ones, thus serving as indicators of long-term forest sustainability.

Modeling diameter at breast height (DBH) distributions generally follows a two-stage approach (Kwon *et al*., 2024). In the first stage, a probability density function (PDF) is fitted to observed DBH data. In the second stage, the parameters of the fitted distribution are modeled using regression techniques based on known stand attributes—a process known as the parameter prediction method (Kwon *et al*., 2024). For example, Thomas & Cao (2006) developed a diameter distribution model for even-aged stands of European beech in Denmark using the Weibull distribution, where model parameters were estimated by fitting the cumulative density function through nonlinear least squares. Similarly, Fallah *et al*. (2006) demonstrated that regression-based methods can effectively model tree diameter distributions.

In complex and heterogeneous forest stands, data collection can be challenging, often leading to violations of standard statistical assumptions. However, selecting suitable distribution functions tailored to such complex structures offers a practical solution to these limitations. This selection of the probability distribution functions is entirely dependent on the researcher's judgement (Alo *et al*., 2017).

Accurate modeling of diameter distributions is essential for forest inventory, growth projections, and resource evaluation. Commonly used distributions in tropical forest studies include the Weibull, Lognormal, and Gamma models, which have proven effective in representing tree diameter variability (Rijal & Sharma, 2024).

This study aims to compare various statistical models for fitting the diameter distribution of *Tectona grandis* (teak) at Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria. Specifically, it evaluates the performance of Weibull, Lognormal, Gamma and Log logistic (2P and 3P). The objective is to identify the most appropriate PDFs for describing the diameter data of teak plantation at Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria, thereby supporting sustainable forest management practices.

MATERIALS AND METHOD

Description of study area

Adekunle Ajasin University, Akungba-Akoko (AAUA) is a State government owned and operated Nigerian University. The University covered a total land area of 8.04 km^2. It is situated in Akoko South West Local Government Area of Ondo State between latitudes 7°28"9.15' to 7°29"15.18' North of the equator and longitudes 5°44"15.96' to 5°46"14.78' East of

Greenwich Meridian. Akungba-Akoko town shared boundaries with Supare- Akoko in the West, Iwaro-Oka in the East, Ikare-Akoko in the North and in the South with Oba-Akoko (Ajayi & Arowosoge, 2018). Ajayi & Arowosoge (2018), observed that the ecological zone which used to be rainforest is gradually becoming derived savannah due to erratic rainfall pattern resulting from climate change effects; the zone is characterized by two distinct seasons: the raining season which occur between May and September and the dry season which falls between September and March. The zone has a mean annual rainfall of 1250mm and the average temperature which ranges between 18°C and 35°C (Ajayi & Arowosoge, 2018; Ajayi 2021).

Sampling techniques and Data collection

The data collected on the teak plantation was through complete enumeration of the stands because of the size (80 m^2 x 40 m^2) of the plantation. This plantation was established in 2018 and its bare 7 years old. The data were collected on the field by measuring the diameter at breast height (DBH) with the use of girth tape for all the tree in the stand excluding trees of DBH ≤ 2 cm. this plantation is young and compose of tree with small diameters. The data was recorded in the data sheet for further analysis.

Data analysis

The data collected from the field was analyze through descriptive statistics (summary) using Microsoft excel, probability distribution function (Weibull 2P and 3P, Beta, lognormal 2P and 3P, gamma 2P and 3P and log logistic 2P and 3P distribution) using Easy fit software version 2021. These PDFs performance were verified using the Kolmogorov-Smirnov (K-S) statistic, Anderson Darling test and Chi-square,

Two parameters Weibull distribution function

Weibull models are used to describe various types of observed failures of components and phenomena. They are widely used in reliability and survival analysis (Alo *et al*., 2017; Alhassan *et al*., 2025) as obtained in Equation 1.

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right) \quad (1)$$

The parameters of the distribution are given by the set θ = {α and β,} with α>0 and β>0; where α is a scale parameter, β is the shape parameter that determines the appearance or shape of the distribution and. The parameter λ combines both scale and shape features as λ=α−β.

x= Random variables/observations.

Three parameters Weibull distribution functions (Alo *et al*., 2017)

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}-\frac{y}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x}{\beta}-\frac{y}{\beta}\right)^{\alpha}\right) \quad (2)$$

Parameters: continuous shape parameter (α>0), continuous scale parameter (β>0), continuous location parameter (ϒ≡0 yields the two-parameter Weibull distribution)

Two and three parameter lognormal distribution function

The lognormal distribution is a continuous probability that models right-skewed data and it is used for growth rate that are independent of size, models time of failure in reliability studies and species abundance.

Two parameter (2p) lognormal distribution

$$f(x) = exp\left(-\frac{1}{2}\left(\frac{Inx-\mu}{\sigma}\right)^2\right)/x\sigma\sqrt{2\pi} \quad (3)$$

Three parameter (3p) lognormal distribution (Alo et al., 2017)

$$f(x) = exp\left(-\frac{1}{2}\left(\frac{In(x-y)-\mu}{\sigma}\right)^2\right)/(x-y)\sigma\sqrt{2\pi} \quad (4)$$

Two and three parameter Gamma distribution function

The gamma distribution term is mostly used as a distribution which is defined as two parameters – shape parameter and inverse scale parameter, having continuous probability distributions. It is related to the normal distribution, exponential distribution, chi-squared distribution and Erlang distribution. 'Γ' denotes the gamma function.

Gamma 2P diameter distribution function

$$f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\, exp\left(-\frac{x}{\beta}\right) \quad (5)$$

Gamma 3P diameter distribution function (Alo et al., 2017)

$$f(x) = \frac{(x-y)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\, exp\left(-(x-y)/\beta\right) \quad (6)$$

Log logistics 2P and 3P diameter probability distribution functions

The log-logistic distribution (known as the Fisk distribution in economics) is a continuous probability distribution for a non-negative random variable. It is used in survival analysis as a parametric model for events whose rate increases initially and decreases later.

Log logistics 2P diameter distribution function

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\left(\frac{x}{\beta}\right)^{\alpha})^{-2} \quad (7)$$

Log logistics 3p diameter distribution function (Alo et al., 2017)

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}-\frac{y}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x}{\beta}-\frac{y}{\beta}\right)^{\alpha}\right)^{-2} \quad (8)$$

RESULTS AND DISCUSSION

Summary statistics

The total number of trees (N) measured was 1455 with Mean DBH ± Standard error of 0.109±0.0078 m, Minimum of 0.022 m and Maximum of 0.20 m.

Diameter Distribution Class of the Study Area

The results in Table 1 shows the diameter class at breast height of the living trees in the plantation of *Tectona grandis* excluding DBH ≤ 2cm. It was revealed that the highest frequency (526) of the trees in the plantation falls within the range of 11-13.9 cm (Table 1). The kurtosis and the skewness of the *Tectona grandis* were -0. 157 and – 0.134, respectively (Table 1). This implies that the low negative skewness indicates that a large proportion of trees are clustered in the upper diameter classes. This pattern indicates that there are fewer trees in the lower DBH classes, which may not be adequate to replace trees in the upper DBH class in the future. This typical of tree plantation since they belong even-age class. The highest DBH value determined on the plantation was 20 cm, the average DBH was 10.886cm (11cm) and the lowest DBH value recorded was 2.2cm. The trend among diameter class was presented in Fig.1.

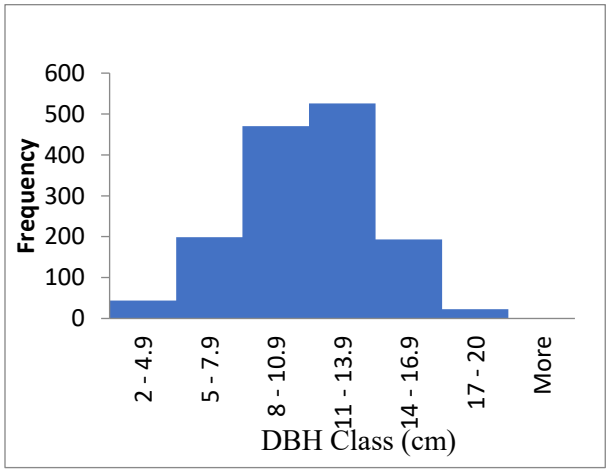


Figure 1: Diameter Class Distribution of Tectona grandis plantation in the study area

Goodness of fit for diameter probability distribution functions (PDFs)

The goodness of fit of the distributions were tested with Kolmogorov Smirnov (K-V), Anderson Darling and Chi–Square as shown in Table 2 Based on ranking eight probability distributions were selected which include; Weibull 2P and 3P, Gamma 2P and 3P, Lognormal 3P and 2P and Log logistics 2P and 3P and this ranking were used to determine the best fit probability distribution functions model.

The result in Table 2 revealed the summary of the goodness of fit of the two (2) distribution models for DBH and their evaluation statistics is presented. The diameter distribution models were fitted using the Kolmogorov-Smirnov test (K-S), Anderson Darling test (A-D) and Chi-Squared test (X^2). The Kolmogorov Smirnov test indicate that the four 2P distributions can provide good fits for the diameter data, because of their calculated D-values, ranking and values of parameters (shape and scale), (Gamma: 0.06179, 25, α (13.494), and β (0.80671), Weibull: 0.06179, 9, α(4.0952), and β(11.99), Log normal: 0.09223, 39, α(0.31079), and β(2.3441), and log logistics: 0.08885, 38, α(5.6151), and β(0.10419). This implies the null hypotheses were accepted for all the distributions, meaning that the data followed the specified distribution. However, Weibull 2P distribution was more flexible in fitting the diameter data when tested with Kolmogorov Smirnov because it has the lowest calculated D-values and ranking. Weibull distribution was adjudged more flexible in research carried out by Aliyu & Bamanga, (2024) and Oladoye *et al*., (2024). These scientists, using Kolmogorov-Smirnov tests showed that Weibull distributions could determine diameter distribution of trees. Some researchers suggest that Weibull distribution had greater capability to define tree's diameter distribution (Ige & Israel, 2024). Several authors (Akindele, 2002; Ige & Israel, 2024; Liu & Yen, 2025; Alkan, 2025) have demonstrated the use of Weibull probability distribution functions for predicting diameter distribution in even – aged stand.

The Anderson Darling test indicate that the four distributions can provide good fits for the diameter data, because of their calculated D-values and ranking (Gamma;10.874,23, Weibull;0.02378,9, Log normal; 0.09223,39 and Log logistics 0.08885,38). This implies that Weibull 2p shows the best fit the data because the statistics values show the less flexibility and the rank is the lowest. The use of Chi–Square test indicates that Gammz and rank (58.693,25), Weibull (10.443,1), Log normal (148.24,35) and Log logistics (122.35,33). However, the Weibull distribution for Chi–Square test was more flexible in fitting the diameter data because it has the lowest calculated value.

The diameter distribution models were fitted using the Kolmogorov-Smirnov test (K-S), Anderson Darling test (A-D) and Chi-Squared test (X^2). The Kolmogorov Smirnov test indicate that the four 3P distributions can provide good fits for the diameter data, because of their calculated D-values , ranking and values of parameters (shape and scale), (Gamma: 0.04573, 22, α (140.94), β (0.25444), and γ(25.02), Weibull: 0.02216, 2, α(4.123), β(11.99), and γ(0.04078) ,Log normal: 0.03487, 22, α(0.0361), β(0.19664), and γ(0.71321) and log logistics: 0.03124,16, α(3.91335), β(6.6499E.6) and γ(6.6499E.6). This implies the null hypotheses were accepted for all the distributions, meaning that the data followed the specified distribution. However, Weibull 3P distribution was more flexible in fitting the diameter data when tested with Kolmogorov Smirnov because it has the lowest calculated D-values and ranking. Weibull distribution was adjudged more flexible in research carried out by Aliyu & Bamanga, (2024) and Oladoye *et al*., (2024). These scientists, using Kolmogorov-

Smirnov tests showed that Weibull distributions could determine diameter distribution of trees. Again, some researchers suggest that Weibull distribution had greater capability to define tree's diameter distribution (Ige & Israel, 2024). Several authors like Akindele, (2002); Ige & Israel, (2024); Liu & Yen, (2025); and Alkan, (2025) have demonstrated the use of Weibull probability distribution functions for predicting diameter distribution in even – aged stand.

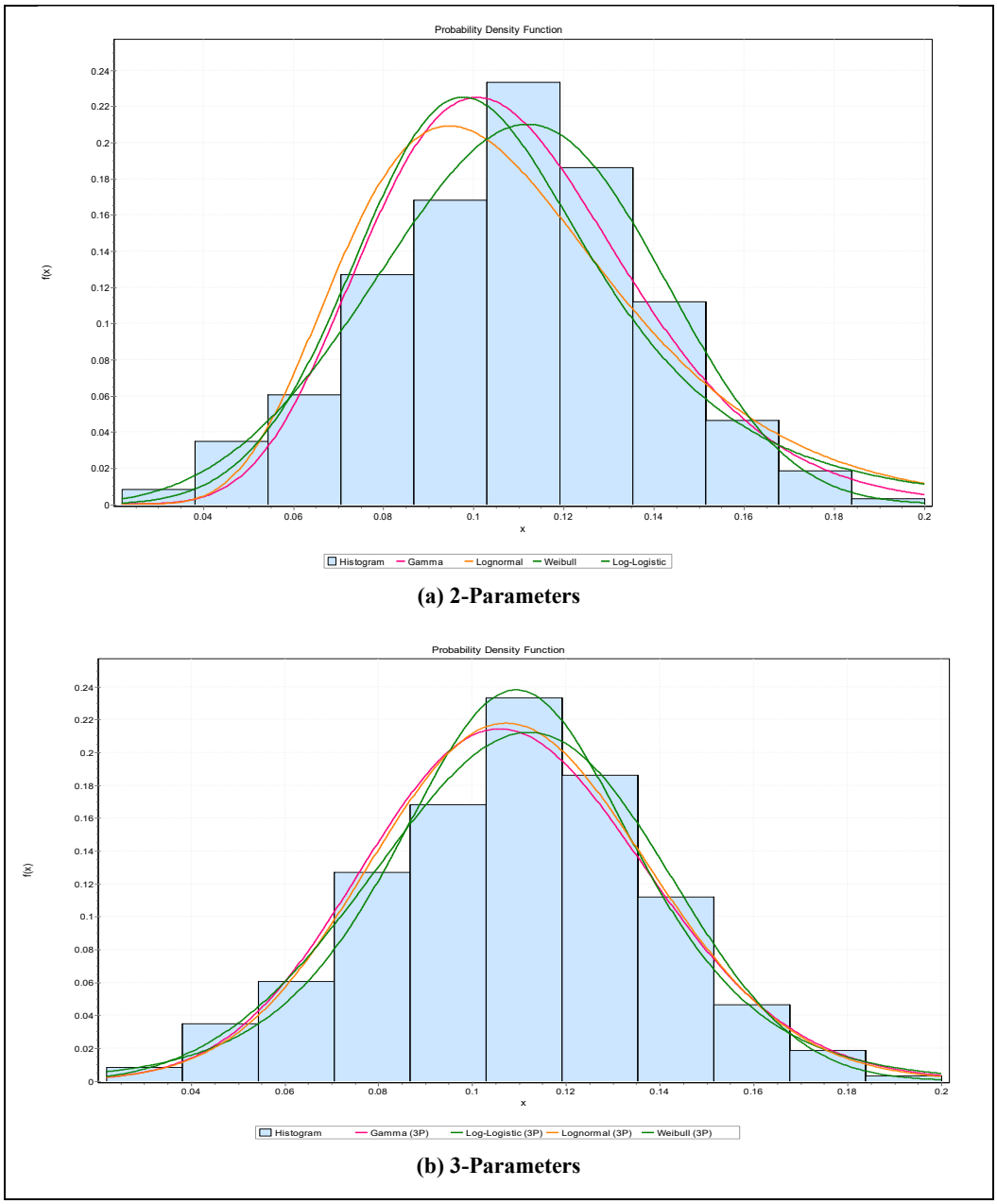
The Anderson Darling test indicate that the four distributions can provide good fits for the diameter data, because of their calculated D-values and ranking (Gamma; 3.2365, 18, Weibull; 0.39082, 3, Log normal; 1.9511, 30 and Log logistics; 1.8115, 16). This implies that Weibull 3p shows the best fit the data because the statistics values show the less flexibility and the rank is the lowest. The use of Chi–Square test indicates that Gamma and rank (27.418, 17), Weibull (10.868,12), Log normal (13.392,17) and Log logistics (20.167,17). However, the Weibull distribution for Chi–Square test was more flexible in fitting the diameter data because it has the lowest calculated value.

Table 2: Goodness of fit of probability distribution functions (PDFs) for *Tectona grandis* plantation in the study area.

PDFs	Parameters	Goodness of Fit			
		Kolmogorov-Smirnov (K-S) (P- value and rank)	Aderson Darling (AD) (P- value and rank)	Chi- Square (χ^2) (P- value and rank)	Rank
Gamma 2p	α =13.494 β =0.80671	0.06179 (2.8289E-5, 25)	10.847 (0.000, 23)	58.693 (6.4006E-9, 24)	72
Weibull 2p	α =4.0952 β =11.99	0.02378 (0.37706, 9)	0.4944 (0.000,8)	10.443 (0.40255,10)	27
Log normal 2p	α =0.31079 β =2.3441	0.09223 (3.1495E-11, 39)	20.743 (0.000,33)	148.24 (0,35)	107
Log logistic 2p	α = 5.6151 β = 0.10419	0.08885 (1.8867E-10, 38)	18.806 (0.000,31)	122.35 (0.000,33)	102
Gamma 3p	α =140.94 β =0.25444 g=-25.02	0.04573 (0.00441,22)	3.2365 (0.000,18)	27.418 (0.00224,17)	57
Weibull 3p	α=4.123 β=11.943 γ=0.04078	0.02216 (0.46563,2)	0.39082 (0.000,3)	10.868 (0.36789,12)	17
Log normal 3p	α =0.0361 β =0.19664 γ= 0.71321	0.03487 (0.05681,22)	1.9511 (0.000,20)	13.392 (0.20256,17)	59
Log logistic 3p	α =3.9134 β =6.6499E.6 γ=6.6499E.6	0.03124 (0.1145,16)	1.8115 (0.0000,16)	20.167 (0.0277,17)	49

Comparison of diameter probability distribution graph functions

The graphs shown in this section is the comparison of the diameter probability distribution functions which also demonstrate the type of probability distribution function that best fit the data in the study area. The result on the evaluation of the two-parameter probability distribution function graphs which are Gamma, Weibull, Lognormal and Log Logistics indicated that Weibull 2 parameter distribution function shows the best fit for the data on graph (Figure 2a). The result on the comparison of the three-parameter probability distribution function graphs which are Gamma, Weibull, log normal and log logistics indicated that Weibull 3 parameter distribution function shows the best fit for the data on graph. This result for all evaluation of three-parameter probability distribution functions revealed that Weibull (3P) distribution function performed better than others because it was more consistent than the other distribution functions used for this study (Figure 2b). This is consistent with findings of Ogana *et al*., (2015) and Alo *et al*., (2017) where they reported Weibull (3P) distribution function as the best to described tree diameter in Oluwa Forest Reserve, Ondo State, Nigeria and Eda Forest Reserve in Ekiti State, Nigeria, respectively.



(a) 2-Parameters

(b) 3-Parameters

Figure 2: Comparison of 2P and 3P probability Distribution graphs for *Tectona grandis* in the study area.

CONCLUSION AND RECOMMENDATIONS

The two and three-parameter Gamma, Weibull, Lognormal and Log Logistics probability distribution functions were evaluated for this study. The Weibull 3-parameters distribution function showed the best fit for the data in the study area, followed by Weibull 2-parameters. The study recommends the Weibull 3-parameter for DBH class distribution of the *Tectona grandis* plantation in Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeris for plausible management and value projection.

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Authors' Contributions

OJO conceptualized the study. BAO & EA designed the experiment, collected data, performed data analysis, and wrote the first draft of the manuscript. OSA performed literature

searches and reviewed the first draft of the manuscript. All authors read and approved the final draft of the manuscript.

Ethical Statement

Not applicable

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