STRUCTURAL GRADE PROPERTIES OF SOME' SELECTED NIGERIAN TIMBER SPECIES: *Chlorophoral excelsa* (Iroko); *Khaya senegalensis* (Mahogany); *Ceiba pentandra* (Araba); *and* *Daniellia oliveri* (Maje).

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APRIL, 2014

DECLARATION

I hereby declare that this thesis has been prepared by me and that it is record of my own research work. It has not been presented in any previous publication for a higher degree.

All sources of information used that are not my own work are specifically acknowledged by means of references.

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(M.Sc/Eng/06739/2008-2009) **SIGNATURE**

CERTIFICATION

This M.Sc/Eng/06739/2008-2009 thesis entitled "Structural Grade Properties of some selected Nigerian timber species: *Chlorophoral excels*a (Iroko), *Khaya senegalensis* (Mahogany), *Ceiba pentandra* (Araba), and *Daniellia oliveri* (Maje) " by Gabriel Kayode , AKINWANDE meets the requirements governing the award of the Master of Science in Civil Engineering of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to the Almighty God the Creator of heaven and earth and to my immediate family, my wife Mrs Akinwande Ajoke and my Children .

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ABSTRACT

In this research work, structural grade properties of some selected Nigerian timber species namely: *Chlorophoral excelsa* (Iroko), *Khaya senegalensis* (Mahogany), *Daniellia oliveri* (Maje) and *Ceiba pentandra* (Araba) were carried out after classifying the species to international strength classification system using EN338 (2008) with the aid of statistical package Easyfit (2010). This was done after establishing the physical and mechanical properties of the species in the laboratory using ASTM D193 (2000) and EN408 (2003). *Chlorophoral excelsa* was assigned to strength Class D70 with characteristic density of 474.95 kg/m^3, bending strength of 74.76 N/mm^2 and modulus of elasticity of 9,899.32 N/mm^2. *Khaya senegalensis* was assigned to strength Class D70 with characteristic density of 800.21 kg/m^3, bending strength of 80.64 N/mm^2 and modulus of elasticity of 8,944.0 N/mm^2. *Daniellia oliveri* was assigned to strength Class D50 with characteristic density of 509.01 kg/m^3, bending strength of 57.6 N/mm^2 and modulus of elasticity of 6,865.87 N/mm^2 and *Ceiba pentandra* was assigned to strength Class C40 with characteristic density of 300.78 kg/m^3, bending strength of 41.16 N/mm^2 and modulus of elasticity of 4,423.64 N/mm^2. Also, the distribution models were established for *Chlorophoral exelsa*, Khaya senegalensis, *Daniellia oliveri and Ceiba pentandra to be* normal, lognormal ,gumbel and weibull respectively.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

From the earliest years of recorded history, trees have provided mankind with food and materials for shelter, fuel and tools. Timber is one of the earliest building materials used by our predecessors and most of us experience a strong affinity with the beauty and intrinsic characteristics of this natural material when it is used in the places we work and live.

Timber is the oldest known building material capable of transferring both the tension and compression forces making it naturally suited as a beam element. It has a very high strength to weight ratio, it is relatively easy to fabricate and to join and it often out performs alternative materials in hazardous environments and extremes of temperature (including fire). Timber does not corrode and many species if detailed correctly can be very durable . The unique properties of timber have made it a cornerstone contributor to the advance of civilization and development of society as we know it today.

Timber has been used in the construction of buildings, bridges, machinery, war engines, civil engineering works and boats since mankind first learnt to fashion tools.

Timber is a truly remarkable materials whilst most of the structural materials we use are processed from finite resources, requiring large amounts of energy and producing significant green house emissions, timber is grown using solar energy in natural soil which is fertilized by its own compost, fuelled by carbon dioxide and water by rain. Because it literally grows on trees, timber is the only structural engineering material which can be

totally renewed provided that trees are replanted (plantation) or natural regenerated (natural forests) after felling.

At the same time forest provide a number of unique and varied benefits that include protection of our climate, water and soil and a great range of recreational functions enjoyed by the general public.

In the hands of skilled professionals who have an appreciation and understanding of its natural characteristics, timber has significant advantages over alternative structural materials, enhancing the best designs with a sense of appropriateness, unity, serenity and warmth in achieving the marriage of form and function which is simply not possible with concrete and steel.

Before the emergence of modern structural materials such as steel and concrete, timber was the dominating structural material in the construction industry. The many species of timber used in timber engineering can be divided into two categories: soft wood and hard woods. Soft wood is a timber of a conifer where as hardwood is that of a deciduous tree . One of the oldest existing timber bridges is the 222 meters long chapel bridge in Luzern Switzerland which was built in 1333 (Stadelmann, 1990). This bridge is a well known tourist attraction. As with many other bridges in Switzerland, it is covered by a roof, which effectively protect the wood from biological deterioration. One aspect of long-term durability of timber structures is that they are often designed in such a way that damaged element can easily be replaced. Timber is naturally occurring organic material. There are more than 300,000 species of trees throughout the world, producing timber with a wide range of properties. Specific details of the properties of common species used in Nigeria

Appearance and physical properties of timber include its colour, texture, grain and density. Others include its thermal properties, acoustic properties, chemical resistance, termite resistance, electrical resistance and mechanical damping.

Strength properties are the key to structural design although other attributes may well come into consideration when assessing the overall performance of a component on structures.

Strength grading may be described as a set of procedures for assessing the strength properties of a particular piece of timber. The strength grade is arrived at by either visual grading or machine grading.

The starting point for the determination of many engineering timber properties is the standard short duration test where failures is expected within a few minutes. In the last decade much attention is given to study the behavior of timber and timber joints with respect to damaging effect of sustained loads (Duration of load effect). There are a number of load cases such as earthquakes and single blast where timber is exposed to substantially higher loading rates than in the standard short duration test. Example of single blast loads explosions but also vehicles that crash against a guard – rails. Both are associated with loading times of a few thousand of a seconds.

In a number of countries like the Netherlands and the United states of America timber guard –rail system are being considered as alternative for the traditional steel guard- rails. Often impact tests showed the ability of wood to withstand impact loads better than standard short duration test.

Mechanical properties most commonly measured and represented as strength properties for design include modulus of rupture in bending, maximum stress in compression parallel

to grain, compressive stress perpendicular to grain and shear strength parallel to grain, impact bending strength, tensile strength perpendicular to grain and hardness.

1.2 AIM AND OBJECTIVES OF THE STUDY

1.2.1 Aim

The aim of this research is to determine the structural grade properties of some selected Nigerian timber species used in buildings in Nigeria in accordance with EN338 (2008) and EN384 (2004).

1.2.2 Objectives

The objectives of this research work are:

i) Determine the moisture content, density, modulus of elasticity and bending strength of some Nigerian timber species: These are *Chlorophoral excelsa* (Iroko), *Khaya senegalensis* (Mahogany), *Ceiba pentandra* (Araba) and *Daniellia oliveri* (Maje) and classify these species based on EN384 (2004)

ii) Generate data on the derived material properties (tension and compression strengths parallel and perpendicular to grain, shear strength and shear modulus of the species based on EN 384 (2004) and JCSS (2006) requirements.)

iii) Determine the characteristic values of both the reference and the derived material of each species in accordance with EN 384 (2004) with the aid of a specialised statistical analysis distribution fitting packages (Easy fit 2010).

iv) Perform strength grading in order to assign appropriate strength class to each species based on EN 338 (2008) recommendations.

1.3 SCOPE OF STUDY

1.3.1 The scope of the research work is limited to carrying out

(i) A three – point bending test in accordance with EN408 (2003) and

(ii) A four - point bending test

Tests on four Nigerian Timber species, namely *Clorophoral excelsa* (Iroko), *Khaya senegalensis* (Mahogany), *Ceiba pentandra* (Araba) *and Daniellia oliveri* (Maje). The timber species were tested using three point bending test and four point bending test, to determine the bending strength, the modulus of elasticity and the strength class of the timber.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

Wood density is often considered to be the single most important wood property because of its strong influence on the quality of a wide range of solid wood and fiber products and has such received the most attention (Bunn, 1981). It was further suggested that density is probably the most important intrinsic wood property for most wood products. Bamber and Burley (1983) on the other hand pointed out that of all the wood properties, density is the most significant in determining end use. Similarly, Zobel and Van Buijtenan (1989) stated that density largely determines the value and utility of wood and overshadows the importance of other wood properties. However, the importance of density as an indicator of wood quality alone is debatable because variability is due to many intrinsic factors, defects and variations inherent in basic wood structures.

Another important element of wood quality is that of ''stiffness'' or its modulus of elasticity . The end use of wood material especially for structural timber is strongly related to the modulus of elasticity, Piter and Zerbino (2003). Modulus of elasticity defines the relationship between stress and strain within the elastic region. Timber is considered to be an isotropic material with three mutually perpendicular axes in the longitudinal, radial and tangential direction. The longitudinal modulus of elasticity is a quantitative measure of the stiffness of the wood along the grain. It is the most commonly measured elastic property and the most important elastic constant. Elasticity implies that deformation produced by the low stress are completely recoverable after loads are removed, and this is the accepted criterion of stiffness (Abubakar et al, 2011).

Structural timber displays considerable strength variability between and within members. One way of describing the variability phenomena and their consequences for instance is the strength of a timber beam shown in a model introduced by Riberholt et al. (1979). It was assumed that timber is composed of localized weak zones connected by segments of clear wood and that failure was primarily initiated in these weak zones. The weak zones correspond to knots or groups of knots, which are distributed along the length at random. The length of a timber beam affects the apparent strength since there is a higher probability of having weak sections within a longer beam than in a shorter one. Furthermore, the apparent strength of a timber beam will depend on the nature of the moment distribution along the beam. For instance, a beam with a point load at mid span can be expected to have an apparent strength that is higher than a beam of the same length loaded with a constant bending moment along the entire length.

Grading of timber (Johansson, 1999), a pre- requisite for the use of timber in load bearing construction is that the strength and stiffness properties are known and can be controlled to stay within desirable limits. This can be achieved in the same way as for man-made products such as steel, concrete, plastics and wood fibre board where a certain material quality is obtained by changing the composition of the raw materials or by changing some of the environmental conditions (temperature, pressure etc). As far as the mechanical properties of wood are concerned the only realistic way of obtaining quality within desired limits is grading. There are presently two types of strength grading systems based on Eurocode.

(1) Visual strength grading

(2) Machine strength grading.

Visual strength grading which is based on visual inspection to ensure that the pieces do not have visible defects in excess of the limits specified in the relevant grading rule.

Machine strength grading where the pieces are passed through a machine which measures one or several parameters non destructively. Based on these measurements strength and stiffness are predicted.

According to Hans (2001) the grading rules developed over the last 60 years differ widely with respect to current grading criteria, number of grades and grade limits. The current grading rules by European code consider that the characteristic values of bending strength, modulus of elasticity and density of the timber are equal to or greater than the corresponding values of the related strength class. This is due to the large number of wood species, timber qualities and building traditions. Glos (1995) however showed that all these grading rules have in common the general deficiency of visual grading methods namely that for practical reasons only visually recognizable characteristics can be taken into considerations and only simple combination rules are possible. Important strength determining characteristics such as density cannot be assessed satisfactorily.

The idea of using non- destructive measurements to predict strength and use that as a basis for grading timber was proposed concurrently in the United State of America and Australia in the late 1950s. The main purpose was to improve the accuracy of strength grading processes with the aim of achieving a better utilization of the available timber qualities.

Strength grading is not only a matter of strength in order to use timber as a structural material, its stiffness properties need to be known and controlled. The density is also of importance as the strength of mechanical connection in timber is linked to it.

Timber normally contains defects of various kinds, such as knots, top rupture, compression, slope of grain, decay, bark pockets, wane and resin pockets. The seriousness of these defects is not only a matter of how much each individual defect reduces the strength but also how often they occur. Knots have to be regarded as very serious defects as they can greatly reduce strength and are almost always present in large number of timber pieces.

Effects of climate and climate variations, wood is a hygroscopic material (Ranta Maurus, et al, 2001) which takes water from surrounding air, and the moisture content of wood tends to settle down to equilibrium with air humidity. As a consequence, a moisture content of wood is different under different weather conditions. This is of importance, because moisture content has a direct effect on the strength of wood, normally is lower when moisture content is higher. However not only the level of moisture content is important, but fast changes cause moisture gradients in wood which induce stresses in perpendicular to grain direction and may cause splitting of the wood. Changes in moisture content of wood products cause shrinkage or swelling as well as changes in strength and elastic properties. Shrinkage reduces member cross- sectional area, sectional modulus and moment of inertia. Traditionally it has been assumed that strength increase with drying, well compensates for section reduction due to shrinkage. Bending and compression strength generally increase with decreasing moisture content below the fiber saturation point. For member capacities similar trend is observed in spite of the opposite effect of shrinking dimensions of cross-section. Tension strength depends weakly on moisture content, and this dependence is normally neglected.

Strength under long – term loading ,Wood and wood products (Hoffneyer, 1978) experience a significant loss of strength and stiffness when loaded over a period of time.

The effect of ten years load duration may amount to a strength loss of approximately 40% for a solid wood and approximately 80% for some wood based panel products. This phenomenon of creep – rupture often called the duration of load (DOL) effect has therefore been subject of particular interest for everyone in the timber engineering community concerned with safe and efficient engineering design.

Among the numerous early investigations the work at Forestry product laboratory, Madison stand out, are those of Wood (1947,1951) showed the results of studies on 25 x 25 x410 mm beam subjected to a constant three point load in bending. The author also included short term ramp load test results from Markwardt and Luka (1948) and Luka (1950) as well as impact test by Elmendorf (1916) .The results became not only the basis for the assignment of load duration factor, but even the reference for all later duration of load research results. The master curve relating all three types of experiments is now commonly known as "The Madison curve". This empirical curve describing the time to failure as a function of the stress ratio (stress in ratio to the ultimate short term strength) was chosen to fit three preselected points corresponding to impact loading, short term ramp loading and long term loading stress ratios.

Strength of timber depends on the size of the stressed volume deep beam are weaker than shallow ones, wide and long tension members are weaker than narrow and short ones. Many maintain for instance that the effect for ordinary timber beams is due to cutting and grading practices. There is however no doubt that the effect is real for tension perpendicular to the grain and other brittle failures. The effect may be explained by the size effect always inherent in fracture mechanics problems or by the so called Weibull theory which will be described in the following. For a more general treatment, reference is made to (Gustafsson, 2001).

The Weibull theory (Weibull,1939), also called the weakest link theory, is based on the following assumptions:

1. The stressed volume V, consists of a large number N of basic volume, dv, each containing a weak spot.
2. The probability of failure of a basic volume i.e the probability that the stress is greater than the strength of the weak point where the cumulative distribution of the strength is the same for all basic volume.
3. Failure in one basic volume will lead to brittle failure of the total volume.

2.2 STRENGTH PROPERTIES OF TIMBER

The four important strength properties are Bending strength, Stiffness, Resistance to suddenly applied load and Compression strength parallel to grain. The strength properties of timber are as follows:

i. Maximum bending strength (Equivalent fiber stress in maximum load) . This property is a measure of maximum stress which timber can momentarily sustain when loaded slowly and continuously as a beam. It is of primary importance in timber subjected to transverse bending.
ii. Stiffness Modulus of elasticity (stiffness). This property is of importance in determining the deflection of a beam under load. The greater the stiffness, the less the deflection. It is usually considered in conjunction with bending strength, as for many uses, stiffness is an advantage. The modulus of elasticity is also the critical property determining the strength of a long column or strut, as distinct from a short column, for which maximum compressive strength is an essential property.

iii. Energy Consumed to Total Fracture (Total work). This property is a measure of the ability of the timber to absorb energy and is therefore of particular importance where timber are to be subjected to considerable bending under heavy loads as with shunting poles, wheel spokes. This properties is closely allied to the toughness of timber.

iv. Resistance to Suddenly Applied Load (Impact). The standard method of determining this property is to drop a weight from increasing height on to a beam supported near the ends. The height of drop at which the beam breaks is a measure of the property. An alternative method is to measure the energy absorbed in fracturing by a single blow, a notched specimen fixed at once end as a cantilever. A third method which is frequently used, is the toughness test. In this a test piece 250 mm long and 16 mm square, freely supported over a span of 200 mm is broken by a single blow centrally applied by a machine of the pendulum type. The energy absorbed by the test piece during fracture, calculated from the angle of swing of the pendulum before and after impact is taken as a measure of toughness of timber.

v. Maximum compressive Strength Parallel to Grain. This property measures the ability of the timber to withstand loads applied on the end grain and is of importance where use as short columns or props is contemplated. Resistance to end grain crushing is required in many types fastening and should then be considered in conjunction with two following properties.

vi. Resistance to Indentation (Hardness). This property is measured by the resistance offered by the timber to indentation to a given depth by a standard steel ball. The property is of importance when timber are joined together and also in timber to be used for such purposes as sport goods, bearing blocks.

vii. Shearing Strength. This property is a measure of the resistance of the timber when the forces acting on it tend to make one part slide over another, in direction parallel to that of the grain. It is of considerable importance in beams where the depth is large relative to the length and as mentioned above, the timbers fastened by bolts or other forms of connection.

viii. Resistance to Splitting (cleavage). A high resistance to splitting is of importance where timbers are to nailed or bolted. On the other hand a low value for this property may be an advantage where timbers have to be cleft before use. Resistance to splitting with many species may vary considerably with the plane of cleavage, the timber in such instance usually splitting more readily normal to the rings (radials) than parallel to the rings (tangentially).

ix. Effect of Moisture Content on Mechanical Properties. Reduction of moisture content from that of the green state to a value of generally between 25% - 30% for most species has no effect on the mechanical properties of timber, but further reduction causes a marked increase in most of the properties referred above, bending strength, stiffness, compressive strength, shearing strength and resistance to indentation are all increased as a result of seasoning, the degree of increase depending on the property, the species and the final moisture content. For many timbers, increase of over 100% are shown in compressive strength on seasoning from green state to moisture content of 12%. (Cookies, 2010).

2.2.1 Three - Point Bending Test

Determination of Modulus of Elasticity (Em) and Bending Strength (fm)

Three - point bending test that considered central deflection of piece relative to the support as specified by ASTM D 143-94 (2002) was used to generate the point statistics of the

strength and stiffness properties of the samples. The modulus of elasticity obtained from the three - point bending test is a function of the total deflection of the test piece, shear and bending deflection inclusive. In this way, the uncertainties inherent in the solid timber bending stiffness can be fully accommodated.

The total deflection of a structural member subjected to design loads due to deflection induced by bending and shear stresses is given by

Total deflection = Bending deflection + Shear deflection (2.1)

Bending and shear deflections of a simply supported beam relative to the beam support, subjected to a central point loads can be calculated respectively using:

$$\text{Bending deflection} = \frac{pL^3}{48EI} \quad (2.2)$$

$$\text{Shear deflection} = \frac{PL}{K} \quad (2.3)$$

Where P = applied load at the centre of the beam

L = span of the beam

I = moment of inertia

K = shear deflection coefficient

Substituting equations (2.2) and (2.3) into equation (2.1), the total deflection of a simply supported beam subjected to central point load can be calculated as follows.

$$\square\square = \frac{PL^3}{48EI} + \frac{PL}{K} \quad (2.4)$$

The apparent modulus of elasticity from equation (2.5)

$$E_{apparent} = \frac{PL^3}{48EI} \quad (2.5)$$

Eighty (80) pieces (20 pieces of each of the four species) of clear specimens, each of dimension 75 mm x 50 mm x 1500 mm (900mm between supports) were tested. On each specimen, the mid-span deflection was measured relative to the beam supports as specified in ASTM D143 (2004) as shown in Fig. 2.1

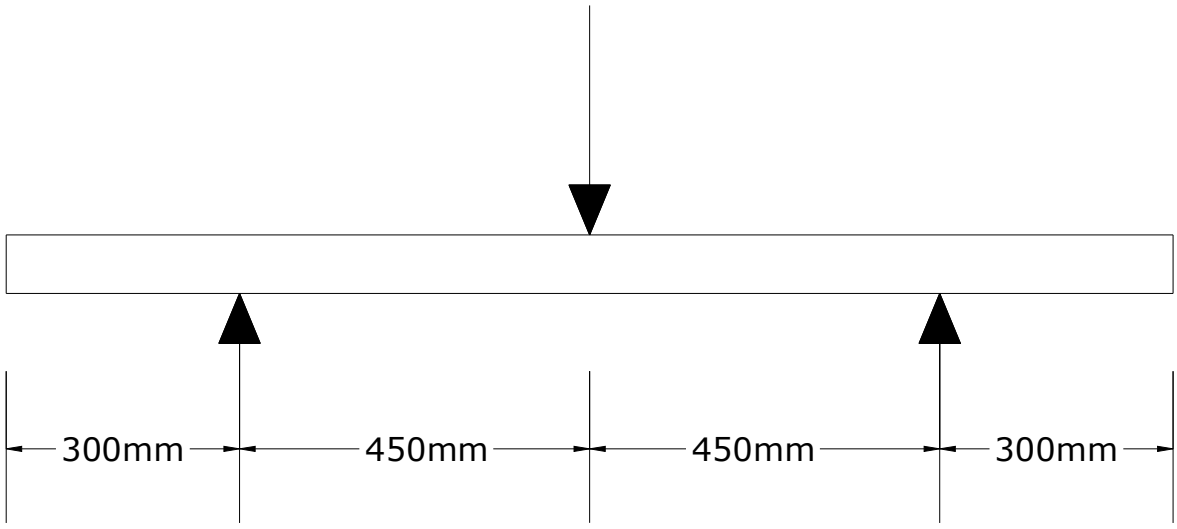


Fig.2.1 Experimental Set up for Three - Point Bending Test (Modulus of Elasticity, EN 408 (2003)

The modulus of elasticity, E_m was calculated for each specimen based on linear regression analysis of the load-deflection data. The bending strength fm was calculated from the maximum recorded load. Based on the linear regression analysis performed , the modulus of elasticity for each test piece was calculated from equation (2.6)

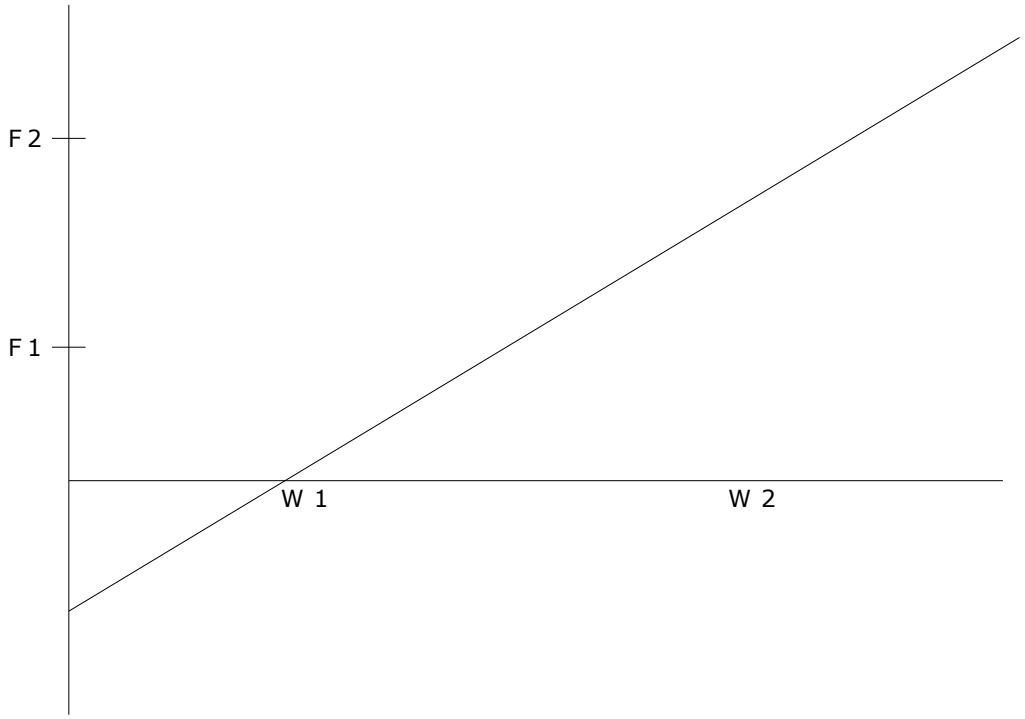
$$\text{Modulus of Elasticity} = \frac{L^3(F\ 2-F1)}{48I(w2-w1)} \qquad (2.6)$$

Where $\frac{(F2-F1)}{(w2-w1)}$ = the slope of the least square regression line.

L = span between the beam supports in mm

(F2-F1) = the increment of load on the straight line of the load- deformation least Square regression line in Newton

(1)



(2)

Key

1. Load (kN)
2. Deformation (mm)

Fig. 2.2 Load-deformation within the range of elastic deformation EN 408 (2003)

If (W2-W1) is the increment of deformation corresponding to (F2-F1) in mm, I is the moment of inertia (second moment of area in mm^4), Then the bending strength is computed using:

$$Fm = \frac{3FmaxL}{2bh^2} \quad (2.7)$$

Where L is span between the beam supports in mm, Fmax is maximum load piece rupture in Newton, b is the width of test piece in (mm) and h is the depth piece (mm).

2.2.2 Four - Point Bending test

Global modulus of elasticity was generated from four point bending test as specified in clause 10 of EN 408 (2003). Twenty pieces of each specie (75 mm x 50 mm x1500 mm) were tested. The distance between supports is 900mm, span/ depth ratio is 18 as specified in the code. Two - point loads were applied at the central third of each test piece. The testing arrangement is as shown in fig 2.3

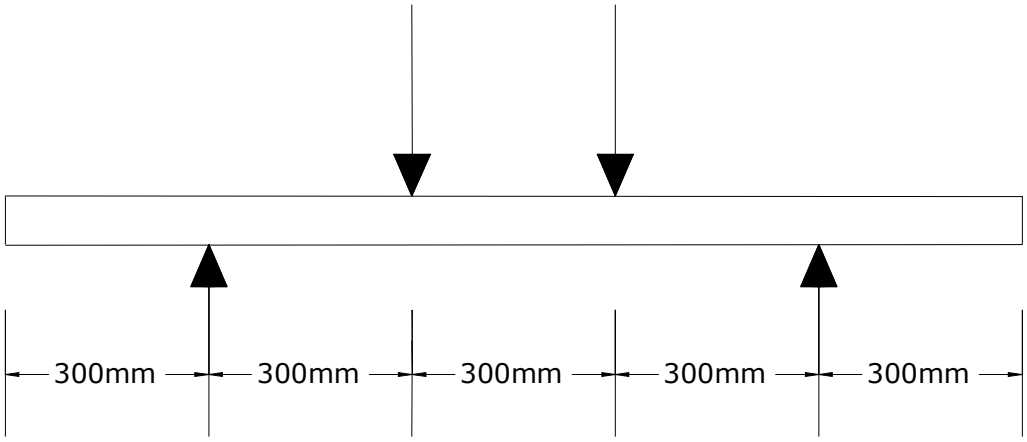


Fig.2.3: Experimental Set up for Four - Point Bending Test (Modulus of Elasticity EN 408 (2003))

Based on linear regression analysis, the Global Modulus of elasticity for each test piece can be obtained from equation (2.8) and the bending strength obtained from equation (2.9).

$$E_m = \frac{L^3(F2-F1)}{4.7bh^3(W2-W1)} \quad (2.8)$$

$$F_m = \frac{aFmax}{2w} \quad (2.9)$$

Where F_m, F_{max} are as before in equation (2.7), and a is the distance between support and w are sectional modulus respectively.

2.3: STATISTICAL WORK ON TIMBER

International Tropical Timber organization plays a key role in collecting, analyzing and disseminating information on the world timber situation. Member countries have been assisted through projects to strengthen their statistical and data collection and reporting functions. In addition, the ITTO Secretariat regularly reports on tropical timber production, trade and market trends and investigates a host of market-related issues. Statistics on tropical timber production, trade and prices, maintained in computer databases at ITTO headquarters, are analyzed and published each year in the Annual Review and Assessment of the World Timber Situation. Data from ITTO's Annual Review are widely used by member governments, trade groups and environmental NGOs. Many countries, both within and beyond the tropics, need more help to deliver forest-related statistical information to an adequate standard. A system of nominating statistical correspondents in member countries developed by ITTO has been particularly successful and has led to improved statistical information in several countries. ITTO also convenes training workshops to give participants, in many cases their country's nominated statistical correspondent, hands-on experience in the collection, analysis and dissemination of forestry statistics. Ongoing efforts are required due to the often rapid turnover of staff charged with carrying out statistical work in countries. In addition to its country-level work, ITTO collaborates with a number of other

international organizations (including Eurostat, FAO and the United Nations Economic Commission for Europe) through an inter-secretariat working group to improve and streamline the reporting of forestry statistics. The main output of this working group is the Joint Forest Sector Questionnaire. through which common forestry statistics are now collated globally. In addition to the annual statistical review produced by the ITTO Secretariat, the Organization's Tropical Timber Market Information Service (MIS) delivers a bulletin every two weeks containing market news, prices and trends for a wide range of tropical timber products to trade groups, executives and analysts worldwide. This is part of the effort by ITTO to promote a competitive timber industry and a transparent trade in tropical timber products. The Market information service bulletin published a range of data and information to meet producers' needs for information on trends and developments in the consumer markets as well as information from producer countries of interest to timber buyers.

A new Statistical branch has recently been created. Its function is to advise on the layout of experiments and to carry out statistical analyses of the results obtained, not only at the Forest Research Institute but also in the provinces. The usefulness of the new branch has already begun to be felt. The importance of forests and forest products in the economy of the country was forcibly emphasized by the experiences of the war years 1939-45. During this difficult period, not only did imports of forest products into India dwindle or cease, but India was called upon to export timber and other forest products to the Middle and Near East and to meet its greatly increased requirements from its own unaided resources. Great inroads were made on the forests of India. The Forest Research Institute was called in to find substitutes for many timbers in short supply and to help the war effort in numerous ways. The war showed clearly the great potential and actual usefulness of the Institute to the nation and high-lighted its deficiencies of equipment and personnel. When the war was over, a large reorganization scheme aiming at the extension and modernization of equipment and buildings and the strengthening of research personnel at an

estimated capital cost of over Rs. 6,000,000 (about US$ 1,800,000) was sanctioned by the Government of India. The scheme is in process of implementation. Postwar shortages of structural materials, firewood, and other forest products have underlined the need for intensified research in forestry and forest products. But financial difficulties have now cropped up, and the progress of reorganization will have to be slowed down, although much has already been accomplished.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

Timber boards for the test were bought from Kaduna market in Kaduna State. A total of 40 specimens for each species were used for determining modulus of elasticity in bending, of which 20 specimens were used centre line for three - point method and another 20 specimens for four - point method. Test pieces of sizes 75 mm x 50 mm x 1500 mm were prepared after seasoning for about three months by exposure to open air drying. This gives a span /depth ratio of 18 as required (EN408, 2002). A total of 40 specimens for each species were also used for the density and moisture content tests, in which twenty pieces of sizes for each specie 60 mm x 40 mm x 40 mm were prepared. The materials were prepared for test as shown in plate 1.



Plate 1 : Cross- Section of Timber Ready for Test

3.2 METHODS

3.2.1 Moisture content and density (EN13183-1 (2002)).

All test specimens were weighed to obtain the bulk weight and then oven dried at a temperature of 103 $\pm 2\,^{\circ}C$ to constant weight to obtain dry weight after cooling, the moisture constant of each specimen was calculated as follows.

$$Moisture\ Content = \frac{(Initial\ Weight - Oven\ dried\ weight)}{Oven\ dried\ weight} * 100 \qquad (3.1)$$

The density in kg/m^3 for each species was calculated from the following relationship.

$$\text{Density} = \frac{Oven\ dried\ weight\ (grams)}{Volume(cm^3)} * 1000 \qquad (3.2)$$

3.2.2 Modulus of Elasticity and Bending Strength

(a) Four - Point Bending Tests

The modulus of elasticity and the bending strength for each specimen Fig. 3.1 were obtained from four point bending test according to EN 408 (2003) procedure shows the test set up for the bending test. Each test piece was loaded at the third and central deformation recorded from a dial gauge. The maximum load at rupture was also recorded for each piece. The modulus of elasticity and the bending strength were obtained using Equation (2.8) and (2.9) respectively.

Plates (2) to (4) show the four - point tests for different timber specimens.

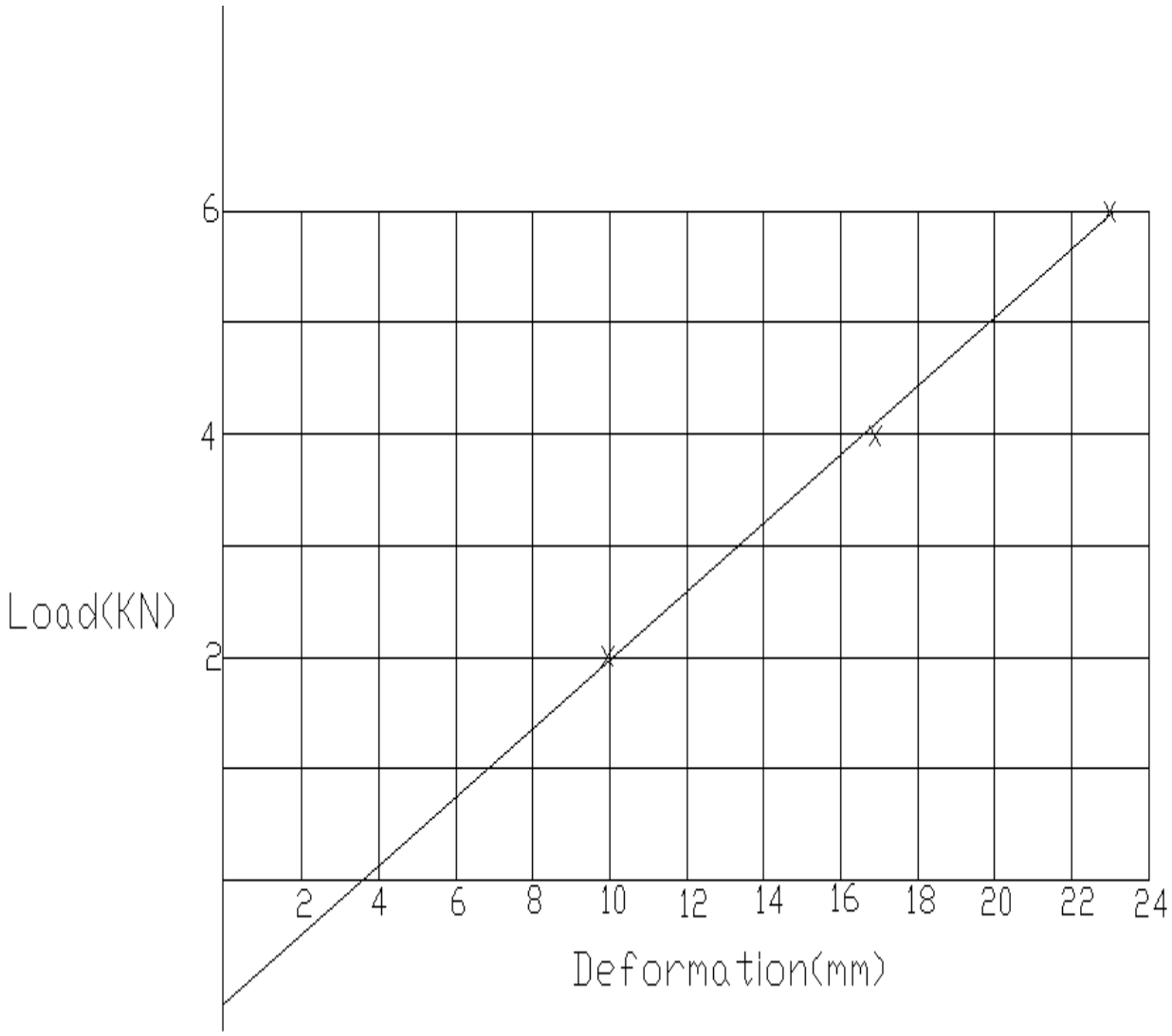


Fig 3.1. Load-Deformation for *Chlorophoral excelsa* within the range of elastic deformation EN408 (2003)

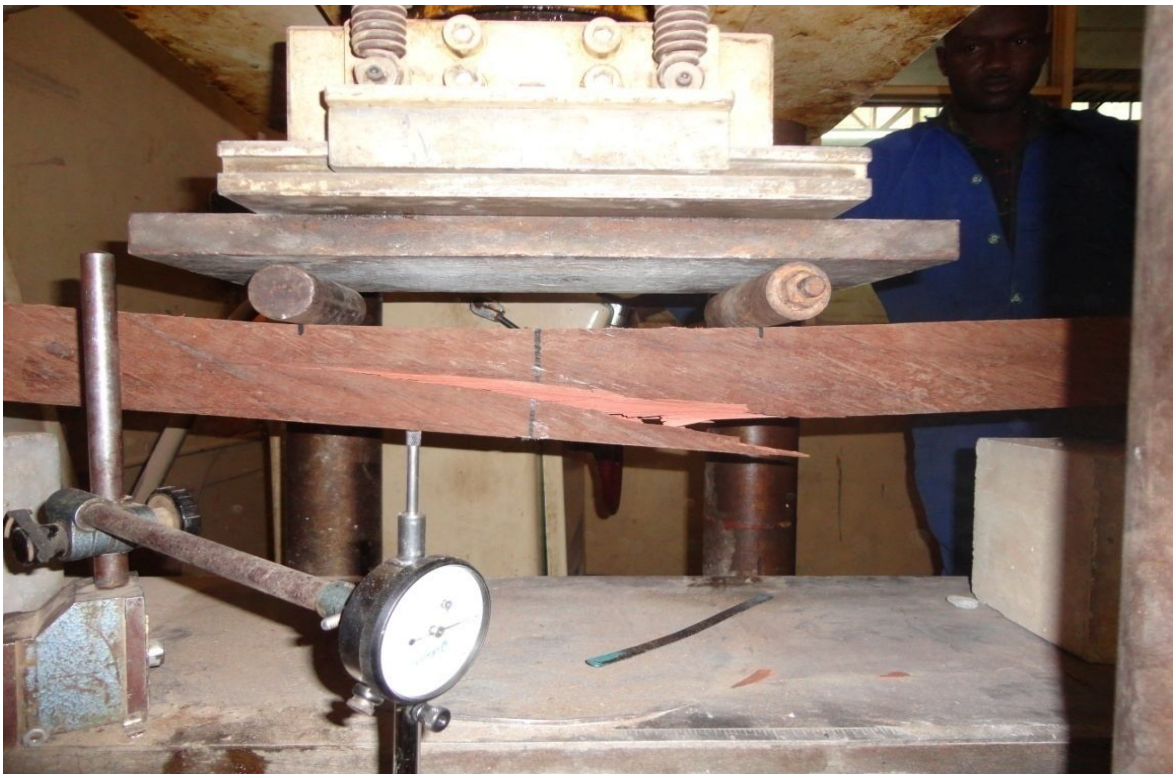


Plate 2: Four - Point Bending Test of *Khaya senegalensis* at point of Rupture



Plate 3 : Four - Point Bending Test of *Ceiba pentandra* at Point of Rupture



Plate 4: Four - Point Bending Test of *Chlorophoral excelsa* at Point of Rupture

(b) Three - Point Bending Test.

The modulus of elasticity and the bending strength for each specimen were obtained from the three - point bending test according to EN 408 (2003) procedure. Fig 2.1 shows the test set up for the bending test. Each test piece was loaded at the third and central deformation recorded from a dial gauge. The maximum load at rupture was also recorded for each piece. Load deformation graph Fig.2.2 were plotted. The modulus of elasticity and the bending strength were obtained using Equation (2.8) and (2.9) respectively. Plates (5) to (8) show the three - point tests for different timber specimens.



Plate 5 : Three - Point Bending Test of *Khaya senegalensis*



Plate 6 : Three - Point Bending Test of *Ceiba pentandra*



Plate 7 :Three - Point Bending Test of *Chlorophoral excelsa* at Point of Rupture

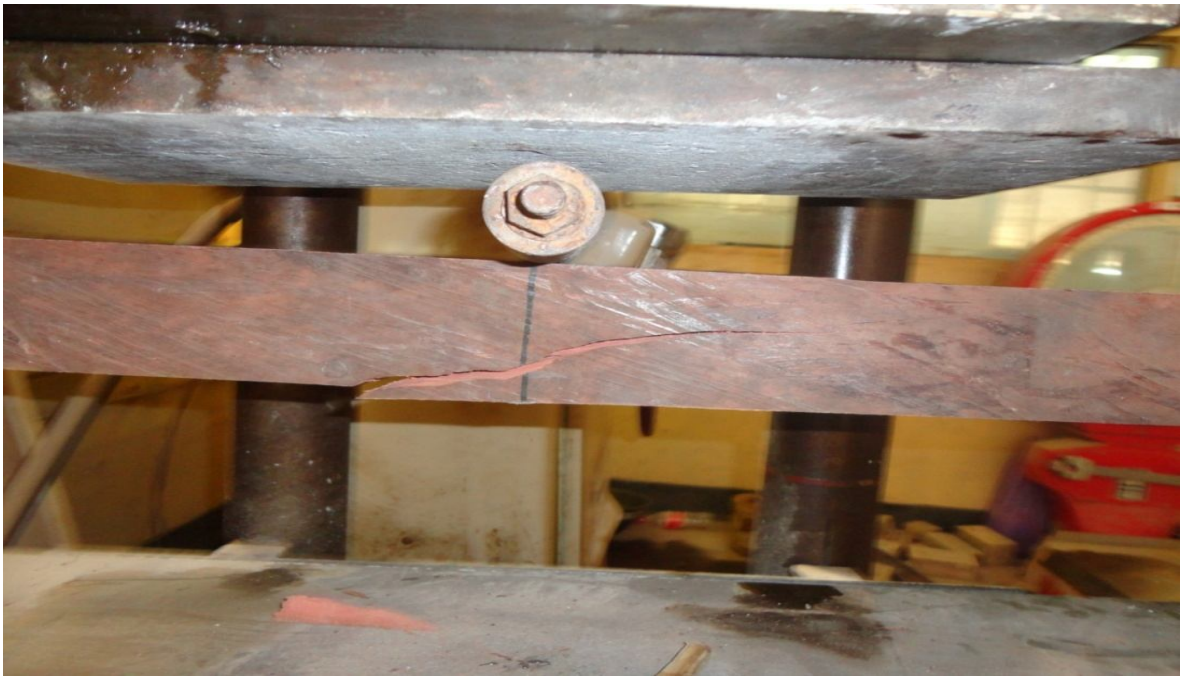


Plate 8 : Three - Point Bending Test of *Khaya senegalensis* at Point of Rupture

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

The grade properties of the four Nigerian timber species were determined based on methods of EN 408 (2003), EN 384 (2004) and EN 1995 (2004). The four timber species considered were *Chlorophoral excelsa* (Iroko), *Khaya senegalensis* (Mahogany), *Ceiba pentandra* (Araba) and *Daniellia oliveri* (Maje).

The results obtained are as presented:

4.1.1 Moisture Content and Density

The values of moisture contents obtained from the laboratory tests on the specimens were tabulated in the Tables (1) to (4) of the Appendix.

Similarly, the density values calculated based on the result obtained from laboratory are as shown in Tables (5) to (8) of the Appendix.

4.1.1.1 Calculation of Mean, Standard Deviation and Coefficient of Variation

Mean, standard deviation and coefficient of variation of moisture content of each of the four species are presented in Table 4.1, and the corresponding results for density given in Table 4.2.

Table 4.1 Mean, Standard Deviation and Coefficient of Variation of Moisture Content

Species	Moisture Content (%)		
	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION
Chlorophoral excelsa	17.69	0.60	0.034
Khaya senegalensis	20.10	0.84	0.041

Ceiba pentandra	19.32	0.71	0.036
Daniellia oliveri	20.20	0.21	0.010

The mean values of the moisture content for *Chlorophora excelsa* is 17.69%, *Khaya senegalensis* is 20.10% , *Ceiba pentandra* is 19.32% and *Daniellia oliveri* is 20.20% .

Similarly, the density values calculated based on the laboratory results were tabulated as shown in Tables (5) to (8) of the Appendix

Table 4.2 Mean, Standard Deviation and Coefficients of Variation of Density

Species	Density (kg/m^3)		
	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION
Chlorophoral excelsa	474.95	17.89	0.038
Khaya senegalensis	800.21	43.28	0.054
Ceiba pentandra	321.88	17.96	0.056
Daniellia oliveri	509.01	39.26	0.077

The corresponding coefficient of variation for the density of *Chlorophora excelsa* is 0.038, for *Khaya senegalensis* the coefficient of variation is 0.054, for *Ceiba pentandra* coefficient of variation is 0.056 and for *Daniellia oliveri* coefficient of Variation is 0.077.

4.1.2 Modulus of elasticity and bending strength

The modulus of elasticity and bending strength for each specimen were determined based on the results of the bending test conducted.

The results for three - point bending tests were tabulated as shown in Tables (9) to (12) of the Appendix. Also, the four - point bending test results were tabulated as shown in Table (13) to (16) of the Appendix.

The mean values and coefficient of variation of modulus of elasticity and bending strength are presented in Table 4.3 for three - point bending test and Table 4.4 for four - point bending test.

4.1.2.1 Moisture content adjustment

The European Strength class system EN 338 (2008) is based on a moisture content of 12% and like wise the reference moisture content in Nigeria as specified in NCP2, (1973) is 18%. The modulus of elasticity, bending strength and density values were adjusted to 12% and 18% using equations (4.1), (4.2) and (4.3) respectively. Bostron, 1994; Hekkikila and Hijjarvi,2008). The 12% moisture content adjustment equation for bending strength is given by equation (4.1) (Kucera, 1992)

$$F_m 12\% = \frac{fmeasured}{1+0.0295(12-u)} \quad (4.1)$$

Where F_m, 12% is the bending strength at 12% moisture content

$F_{measured}$ is the bending strength at the measured moisture content

u is the measured moisture content in %

The 12% moisture content adjustment equation for modulus of elasticity is given by equation (4.2) (Bostron, 1994).

$$E12\% = \frac{Emeasured}{1+0.0143(12-u)} \quad (4.2)$$

Where $E_{measured}$ is the modulus of elasticity at the measured moisture content

Likewise, Heikkila and Herajarvi (2008) gave moisture adjustment factor for density as:

$$\rho 12 = \rho w \left(1 - \left(\frac{(1-2)(w-12)}{100}\right)\right) \quad (4.3)$$

The 18% moisture content adjustment equation for bending strength is given by

$$F_m 18\% = \frac{Fmeasured}{1+0.0295*(18-u)}$$

Where F_m 18% is the bending strength at 18% moisture content

$F_{measured}$ is the bending strength at the measured moisture content

u is the measured moisture content in %

$$E18\% = \frac{Emeasured}{1+0.0143(18-u)}$$

$E_{measured}$ is the modulus of elasticity at the measured moisture content

Likewise moisture adjustment factore for density at 18% is given as

$$P18 = \rho w \left(1 - \left(\frac{(1-2)(w-18)}{100}\right)\right)$$

Volume effect for bending is dealt with in the European standard EN384 (2004) and Eurocode 5 (2008). For solid timber, the reference depth in bending is 150mm. For depth in bending less than 150mm, the characteristic values for bending strength, Fm,k are increased by the factor Kh given by equation (4.3) Eurocode5, 2008).

$$Kh = \left(\frac{150}{h}\right)^{0.2} \quad (4.4)$$

a.) The Three - Point Bending Test Results

In Table 4.3, the statistics of Bending strength and Modulus of Elasticity obtained from the three - point bending test were presented. The values were adjusted to 12% and 18%

moisture content. In addition, generated bending strength was adjusted to the reference depth of 150mm accordingly (Eurocode 5, 2004).

In Table 4.3, the mean values, and coefficients of variation of the structural grade properties (modulus of elasticity and bending strength) for *Chlorophora excelsa* are presented. The modulus of elasticity and the bending strengths were generated from three - point bending tests. The values were adjusted to 12% moisture content and 18% moisture content as required by EN 408 (2003) and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 4%, 21% and 13% respectively.

Table 4.3 : Bending strength and Modulus of Elasticity (3- Point Bending Test)

Species	Moisture Content (%)	Modulus of Elasticity		Bending Strength	
		Mean N/mm²	Coefficient of Variation	Mean N/mm²	Coefficient of Variation
Chlorophoral excels	17.69	9,453.08	0.21	51.00	0.13
	12.0	10,290.38	0.21	61.29	0.13
	18.0	10,340.28	0.21	61.97	0.13
Khaya senegalensis	20.10	8,197.63	0.21	52.56	0.17
	12.0	9,271.55	0.21	69.06	0.17
	18.0	8,967.00	0.21	63.86	0.17
Ceiba pentandra	19.32	5,913.57	0.38	29.76	0.22
	12.0	6,604.97	0.38	37.96	0.22

	18.0	6,468.57	0.38	36.16	0.22
Daniellia oliveri	20.20 12.0 18.0	8,156.68 9,240.18 8,922.21	0.20 0.20 0.20	56.64 74.71 68.82	0.21 0.21 0.21

The coefficient of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strength were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending strength) for *Khaya senegalensis* are presented in Table 4.3. The modulus of elasticity and bending strengths were generated from three - point bending tests. The values were adjusted to 12% moisture content and 18% moisture content as required by EN 408 (2003) and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 5%, 21% and 17% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending strength) for *Daniellia oliveri* are presentedin Table 4.3. The modulus of elasticity and bending strengths were generated from three - point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003) and 18% moisture content to suit Nigeria situationa NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 8%, 14% and 21% respectively. The coefficients of variation for tension and compression strengths

parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending strength) for *Ceiba pentandra* are presented in Table 4.3. The modulus of elasticity and bending strengths were generated from three - point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003)and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 6%, 14% and 22% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

b,) The Four - Point Bending Test

Also, the statistics of bending strength and modulus of elasticity obtained from four - point bending test and adjusted to 12% and 18% moisture content were presented in Table 4.4

Table 4.4 : Modulus of Elasticity and Bending strength for 4- Point Bending Test

Species	Moisture Content %	Modulus of Elasticity		Bending Strength	
		Mean N/mm²	Coefficient of Variation	Mean N/mm²	Coefficient of Variation
Chlorophoral excels	17.69	9,899.32	0.21	74.76	0.16
	12.0	10,776.14	0.21	89.84	0.16

	18.0	10,828.40	0.21	90.84	0.16
Khaya senegalensis	20.10 12.0 18.0	8,944.01 10,115.71 9,783.43	0.21 0.21 0.21	80.64 105.96 97.98	0.21 0.21 0.21
Ceiba pentandra	19.32 12.0 18.0	4,423.64 4,940.83 4,838.81	0.14 0.14 0.14	41.16 52.50 50.01	0.16 0.16 0.16
Daniellia oliveri	20.20 12.0 18.0	6,865.87 7,777.91 7,510.25	0.14 0.14 0.14	57.6 75.98 69.99	0.18 0.18 0.18

In Table 4.4, the mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending strength) for *Chlorophoral excelsa* are presented. The modulus of elasticity and bending strengths were generated from four - point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003)and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 4%, 21% and 16% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties

(modulus of elasticity and bending) for *Khaya senegalensis* are presented in Table 4.4. The modulus of elasticity and bending strengths were generated from four - point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003)and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 5%, 21% and 21% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending) for *Daniellia oliveri* are presented in Table 4.4. The modulus of elasticity and bending strengths were generated from four point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003)and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 8%, 14% and 18% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

The mean values and coefficient of variation of structural grade determining properties (modulus of elasticity and bending) for *Ceiba pentandra* are presented in Table 4.4. The modulus of elasticity and bending strengths were generated from four point bending tests. The values were adjusted to 12% moisture content to comply with EN408 (2003)and 18% moisture content to suit Nigeria situation NCP2 (1973). The coefficient of variation for density, modulus of elasticity and bending strength are 6%, 14% and 16% respectively. The coefficients of variation for tension and compression strengths parallel and perpendicular to

grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

4.1.3 Grading for moisture content, density, modulus of elasticity and bending strength

The properties of a physical process may suggest the form of its required distribution. For example, if a process is composed of the sum of many individual effects, the Normal or Lognormal distribution may be appropriate on the basis of central limit theorem (Ang and Tang,1975). Whereas, if the external conditions of a physical process are of interest, an extreme value distribution such as Gumbel or Weibull distribution may be a suitable model. Density, stiffness and strength properties of timber have been modeled with normal, lognormal and extreme value distributions (Kohler, et al.,2004; JCSS , 2006).

In Table 4.5 , the four timber specie are placed on the strength class based on the bending strength, modulus of elasticity generated from four bending test, density, tension strength parallel to grain, tension strength perpendicular to grain, compression strength parallel to grain, compression strength perpendicular to grain and shear strength according to EN338 (2008) and are as presented below.

Table 4.5 : Properties of selected Timber in Strength Classes according to EN338

Strength classes	*Chlorophoral excelsa* D70	*Khaya senegalensis* D70	*Daniellia oliveri* D50	*Ceiba pentandra* C40

Strength Properties N/mm^2				
Bending Strength parallel to grain (fm,k)	74.76	80.64	57.6	41.16
Tension Strength parallel to grain ft,o,k	24	21	18	6
Tension Strength perpendicular to grain (f t,90,k)	0,6	0,6	0,6	0,4
Compression Strength parallel to grain (f,c,0,k)	26	25	23	16
Compression Strength Perpendicular to grain (f,c,90,k)	8,8	8,4	2,9	2,0
Shear Strength (f v,k)	3,8	3,4	3,0	1,7
Stiffiness Properties kN/mm^2				
Mean Value of Modulus of Elaticity Parallel to Grain(E0mean)	10	9	7	4
5% Fractile Value of Modulus of Elasticity parallel to grain	9,4	8,7	6,0	3,5
Mean Modulue of Elasticity Perpendicular to grain (Emean)	0,75	1,72	0,64	0,23
Mean Shear Modulus (Gmean)	0,70	0,66	0,60	0,44
Density (Kg/m^3)				
Characteristic Density	474.95	800.21	509.01	300.78
Mean Density	500	820	520	310

4.2 DISCUSSION OF RESULTS

4.2.1 Test of Goodness of fit

In the assignment of distribution models, two or more distributions may appear to be plausible probability distribution models. In that case, test of goodness of fit tests can be used to delineate the relative degree of validity of the different distribution (Ang and Tang, 1975). Therefore, Kolmogorov Simirnov test was performed on the density, global

modulus of elasticity and bending strength for each of the four species, in order to assess if each data set comes from a population with a specific distribution. The basic procedure involves the comparison between the experimental cumulative frequency (Empirical Cumulative Distribution Function- ECDF) and the assigned theoretical distribution function. If the discrepancy is large with respect to what is normally expected from a given sample size, the theoretical model is rejected (Ang and Tang, 1975). The hypothesis is that '' The data follow a specified distribution''. Given N ordered data points $Y_1, Y_2, \ldots Yn$ the Kolmogorov- Simirnov test statistics is defined as.

$$D = \max \left(F(Yi) - \frac{i-1}{N}, \frac{i}{N} - F(Yi)\right) \quad (4.5)$$

Where, D is the statistics of the Kolmogorov - Simirnov test

F = the theoretical cumulative distribution of the distribution being tested.

The hypothesis regarding the distribution form is rejected if the test statistics, D, is greater than the critical value at 0.05 confidence level. In this study, Kolmogorov – Smirnov test was implemented using EASYFIT software. The results are presented in Table 4.6

In this study, Normal, Lognormal, Gumbel and Weibull distribution were fitted to the structural grade determining properties (Modulus of Elasticity, Bending Strength and Density) using a special statistical package EASYFIT.

4.2.2 Distribution model for Density

From Table 4.6, the critical value for Kolmogorov Smirnov test at $\alpha = 0.05$, for density of all the four species is 0.29. This value is greater than the K-S statistics of the normal, lognormal, gumbel and weibull distribution. It implied that all the four distributions can be used to model the density of this species However, considering the ranking of the validity of the four distribution models, it can be concluded that, the density of *Daniellia oliveri*

(Maje) can best be modeled using Normal distribution. This is followed by weibull distribution and then lognormal distribution. The density of *Chlorophoral excelsa* (Iroko) can best be modeled with Gumbel distribution. For *Khaya senegalensis* (Mahogany) the best theoretical distribution model is Weibull. While *Ceiba Pentandra* (Araba) can best be modeled with Normal distribution. In this analysis, the least K – S statistics corresponding to Normal distribution. This implied that, the best theoretical distribution model for timber density is Normal distribution.

In the study, the above mentioned four distributions were used to check data fitness for the grade determining properties using |Fit Distribution command in EASYFIT (2010).

However, the plots of the probability density function are superimposed on histograms for density, bending strength and modulus of elasticity. Figures 4.1 to 4.16 are plots of probability density function of the four timber species which constitute the possible values for density of the selected timber species for instance Fig. 4.1 is a plot of probability density function for *Chlorophoral excelsa* with random variables Xi= 505, 445, ,……, Xn= 474.95 Kg/m^3 . Then from the Figure, for any chance of I, $p(x) \geq 0$ and Figures 4.17 to 4.28 are for the cumulative distribution function of the four timbers species.

Table 4.6 Kolmogorov Simirnov test result

Property	Distribution	*Khaya senegalensis*			*Clorophoral excelsa*			*Ceiba pentandra*			*Daniellia oliveri*		
		D	a (0.05)	Rank	D	a (0.05)	Rank	D	a (0.05)	Rank	D	a (0.05)	Rank
Density	Normal	0.1351	0.29	2	0.24325	0.29	3	0.13817	0.29	1	0.08857	0.29	1
	Lognormal	0.14037	0.29	3	0.25149	0.29	4	0.1478	0.29	3	0.10338	0.29	3
	Gumbel	0.16549	0.29	4	0.18226	0.29	1	0.18371	0.29	4	0.15016	0.29	4
	Weibull	0.1276	0.29	1	0.22094	0.29	2	0.144435	0.29	2	0.10133	0.29	2
Modulus of Elasticity	Normal	0.15129	0.29	3	0.11762	0.29	1	0.2578	0.29	3	0.16389	0.29	4
	Lognormal	0.13429	0.29	1	0.15062	0.29	3	0.19835	0.29	2	0.14726	0.29	3
	Gumbel	0.13914	0.29	2	0.18042	0.29	4	0.2578	0.29	4	0.14457	0.29	2
	Weibull	0.18318	0.29	4	0.13217	0.29	2	0.18605	0.29	1	0.14266	0.29	1

Bending Strength	Normal	0.26429	0.29	4	0.25551	0.29	3	0.23836	0.29	1	0.17597	0.29	4
	Lognormal	0.2569	0.29	3\	0.27768	0.29	4	0.261	0.29	2	0.16007	0.29	3
	Gumbel	0.25684	0.29	2	0.21468	0.29	1	0.2697	0.29	4	0.15054	0.29	1
	Weibull	0.22655	0.29	1	0.2461	0.29	2	0.26298	0.29	3	0.15765	0.29	2

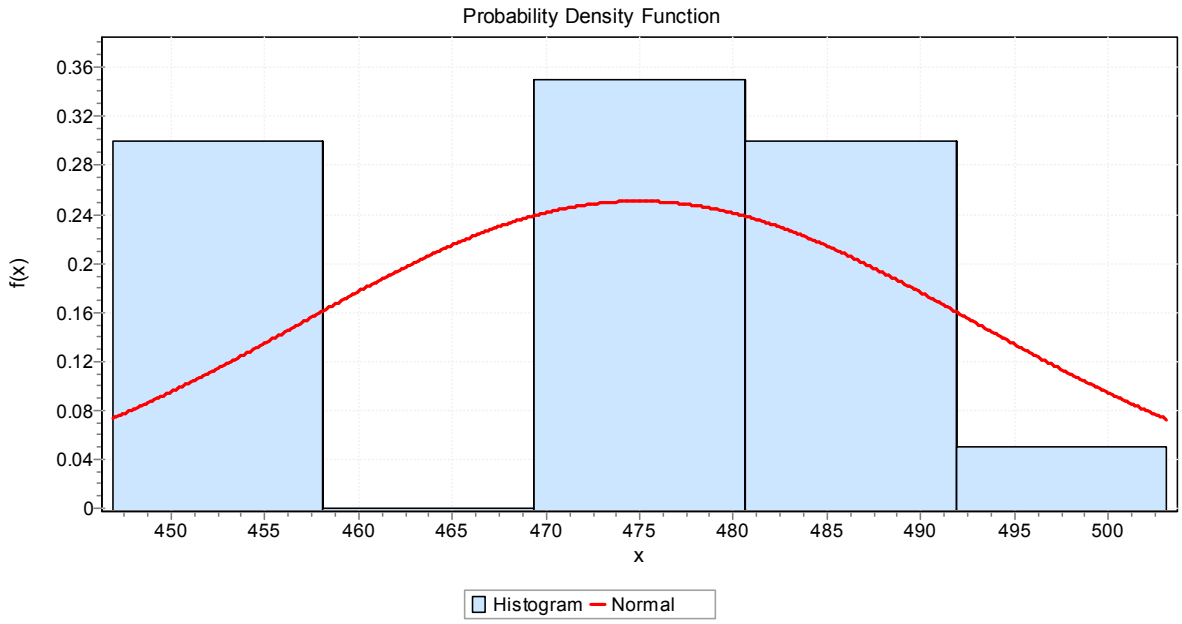


Fig. 4.1: Probability Density Function for *Chlorophoral excelsa* considering Density (Normal Distribution)

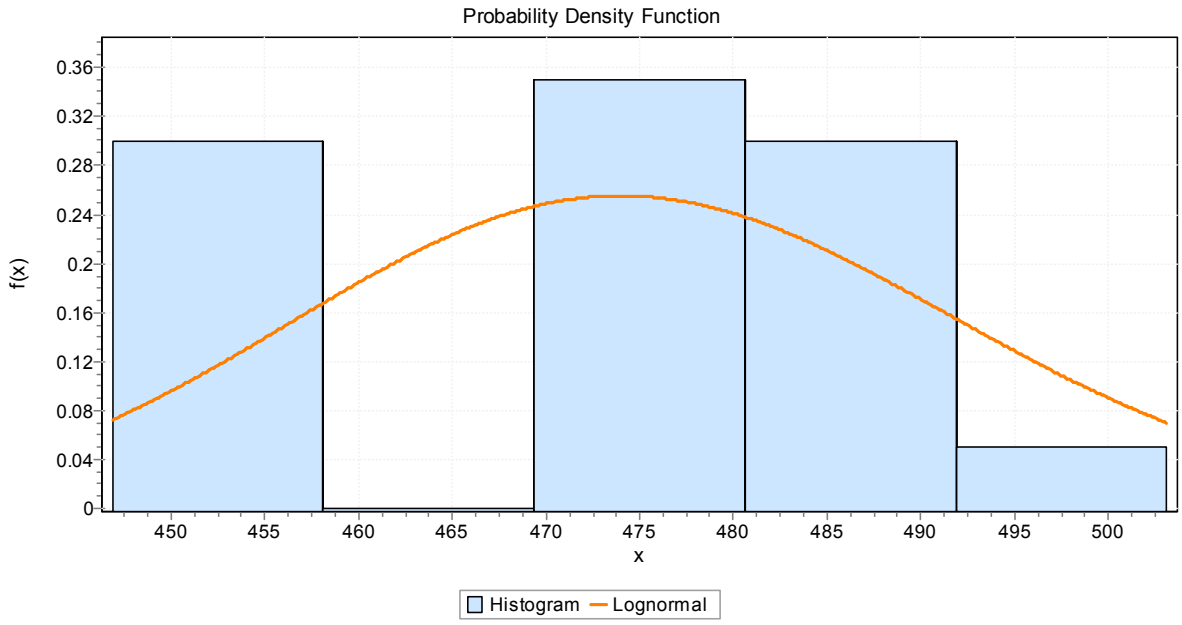


Fig. 4.2: Probability Density Function for *Chlorophoral excelsa* considering Density (Lognormal Distribution)

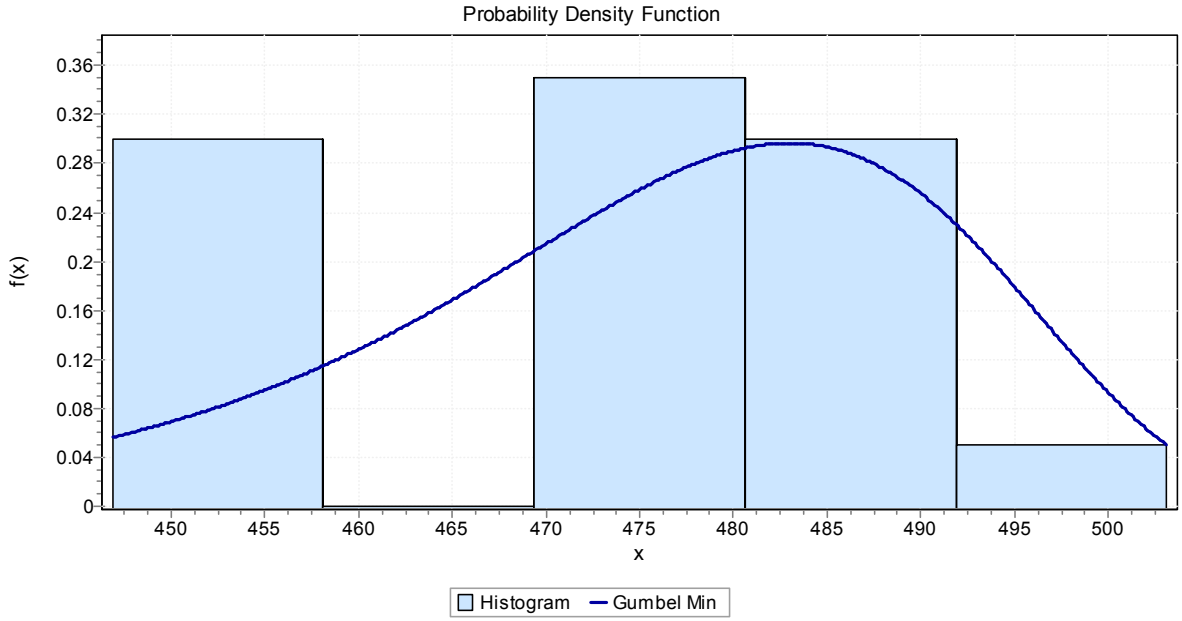


Fig. 4.3: Probability Density Function for *Chlorophoral excelsa* considering Density (Gumbel Distribution)

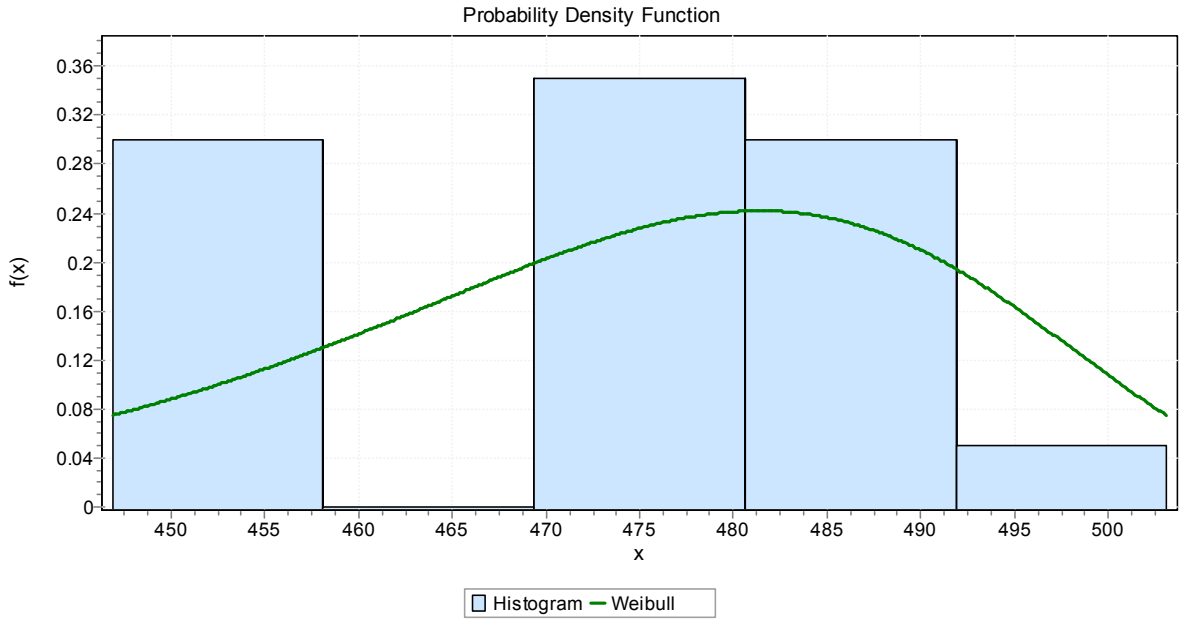


Fig. 4.4: Probability Density Function for *Chlorophoral excelsa* considering Density (Weibull Distribution)

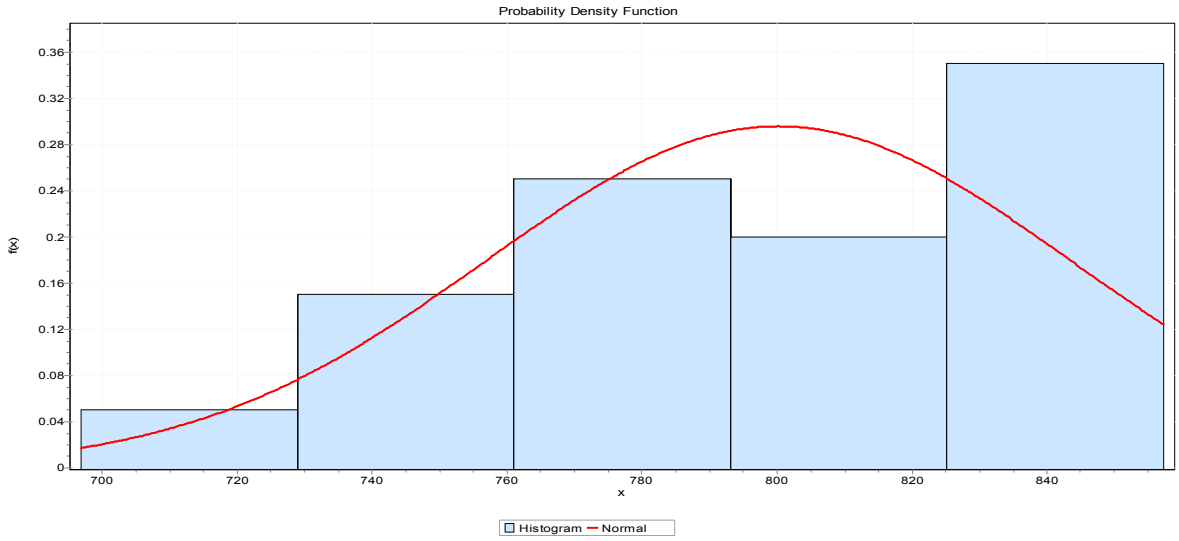


Fig. 4.5: Probability Density Function for *Khaya senegalensi* considering Density (Normal Distribution)

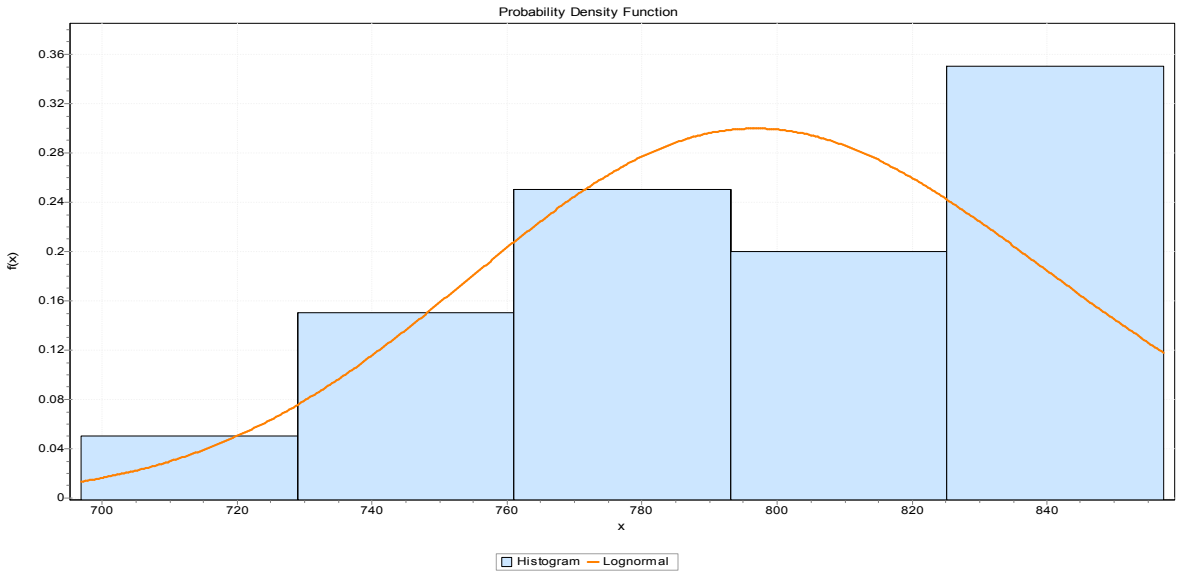


Fig. 4.6: Probability Density Function for *Khaya senegalensis* considering Density (Lognormal Distribution)

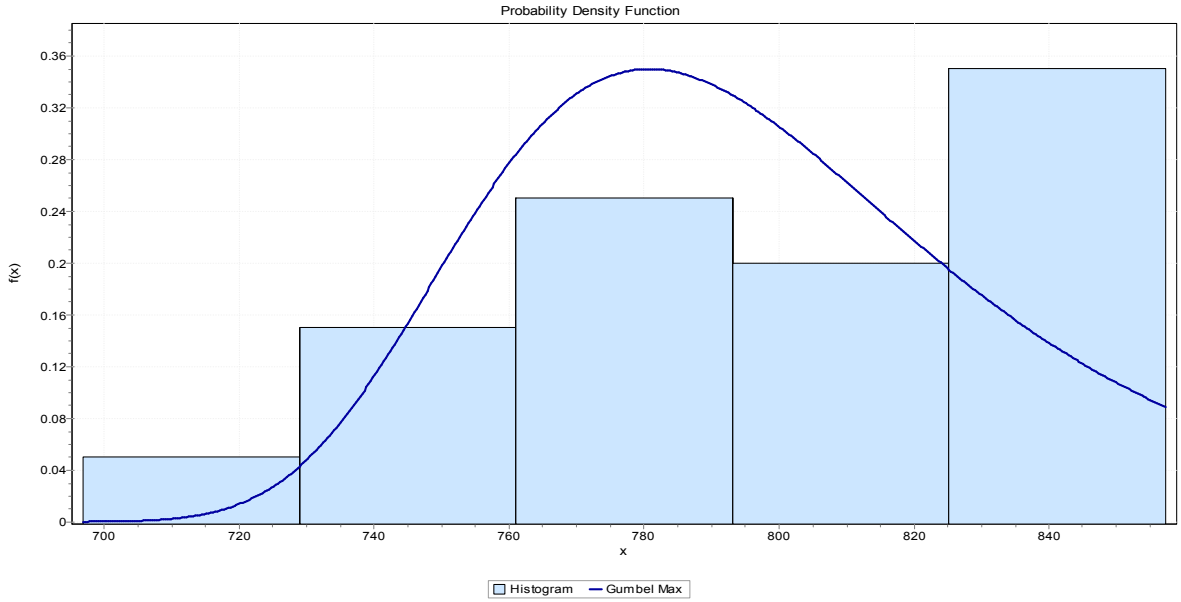


Fig. 4.7: Probability Density Function for *Khaya senegalensis* considering Density (Gumbel Distribution)

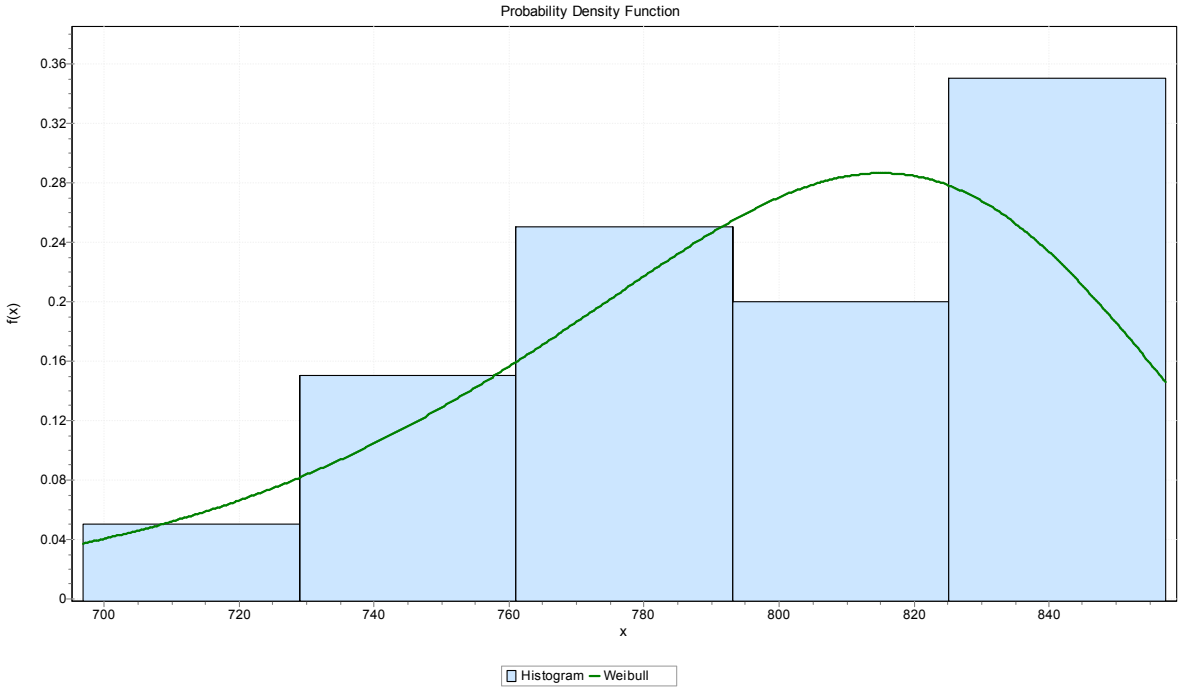


Fig. 4.8: Probability Density Function for *Khayas sene8galensis* considering Density (Weibull Distribution)

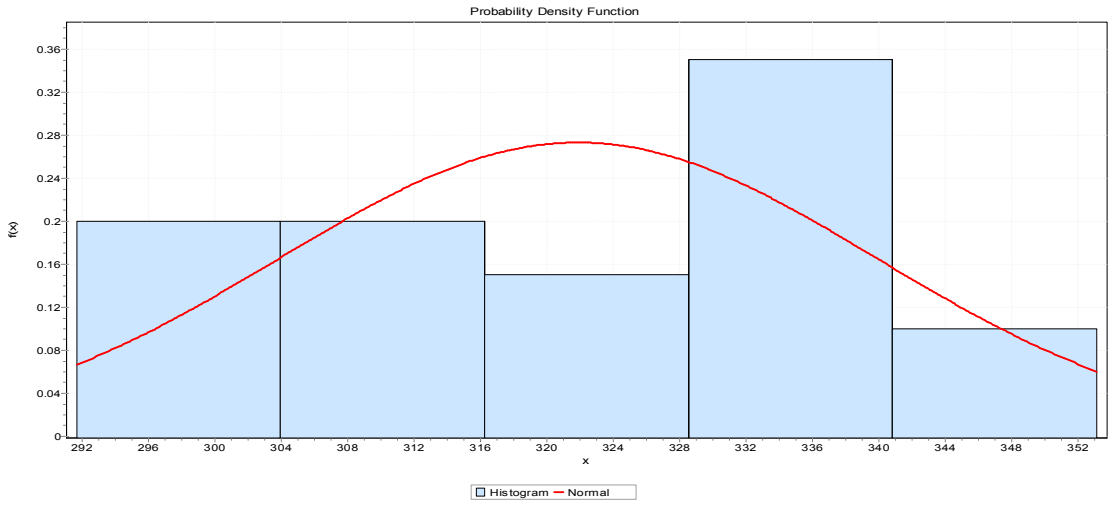


Fig. 4.9 : Probability Density Function for *Ceiba pentandra* considering Density (Normal Distribution)

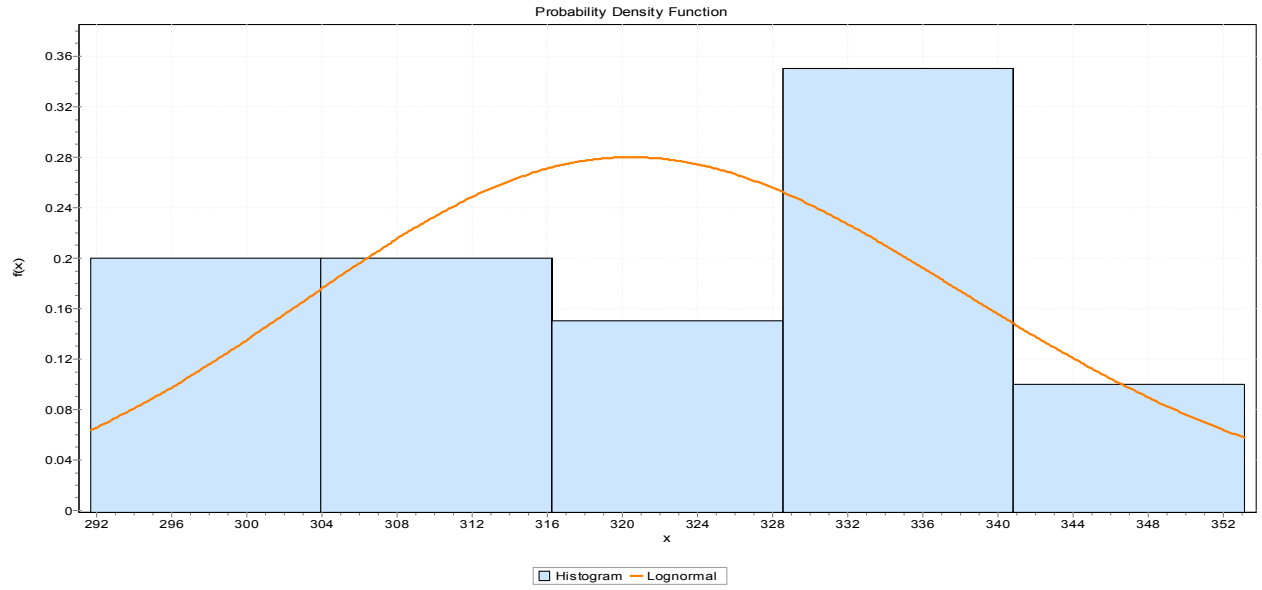


Fig. 4.10: Probability Density Function for *Ceiba pentandra* considering Density (Lognormal Distribution)

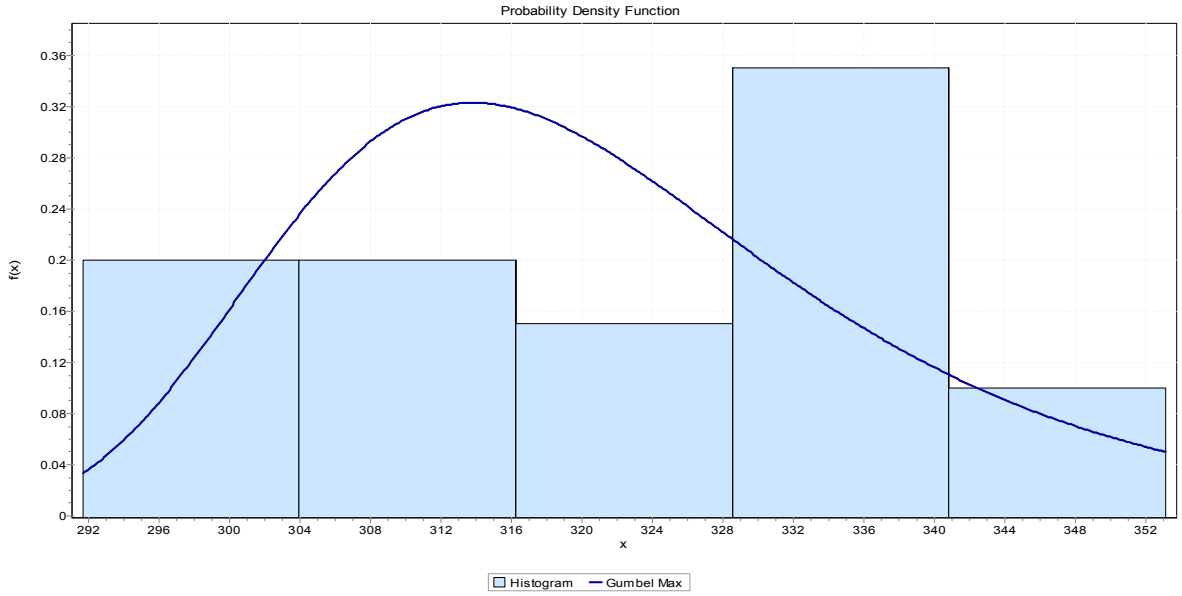


Fig. 4.11: Probability Density Function for *Ceiba pentandra* considering Density (Gumbel Distribution)

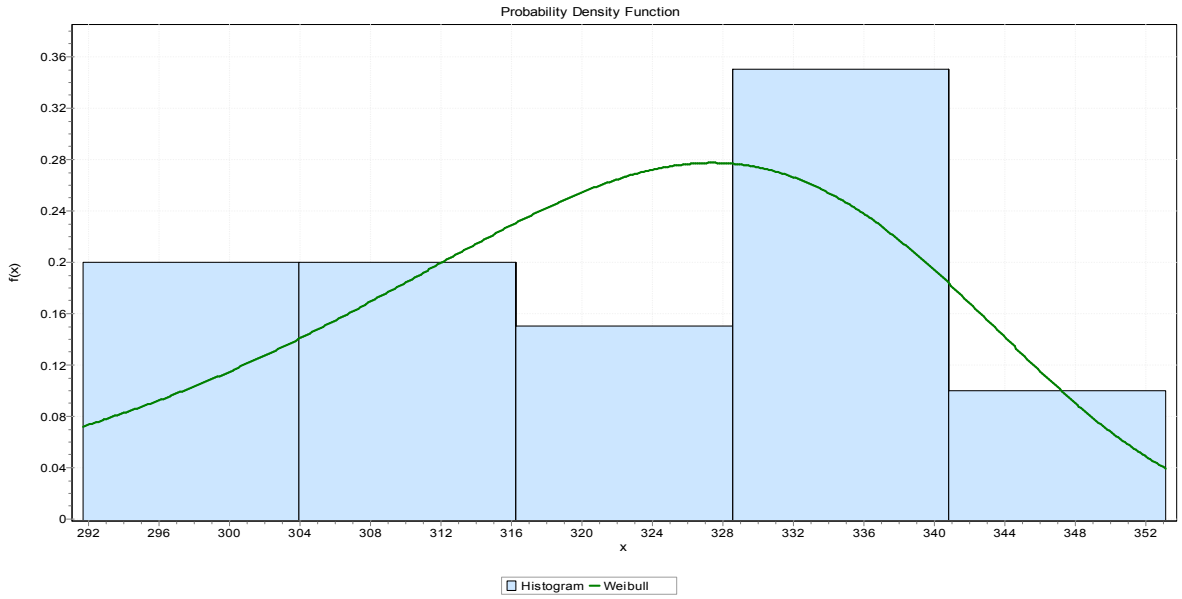


Fig. 4.12: Probability Density Function for *Ceiba pentandra* considering Density (Weibull Distribution.)

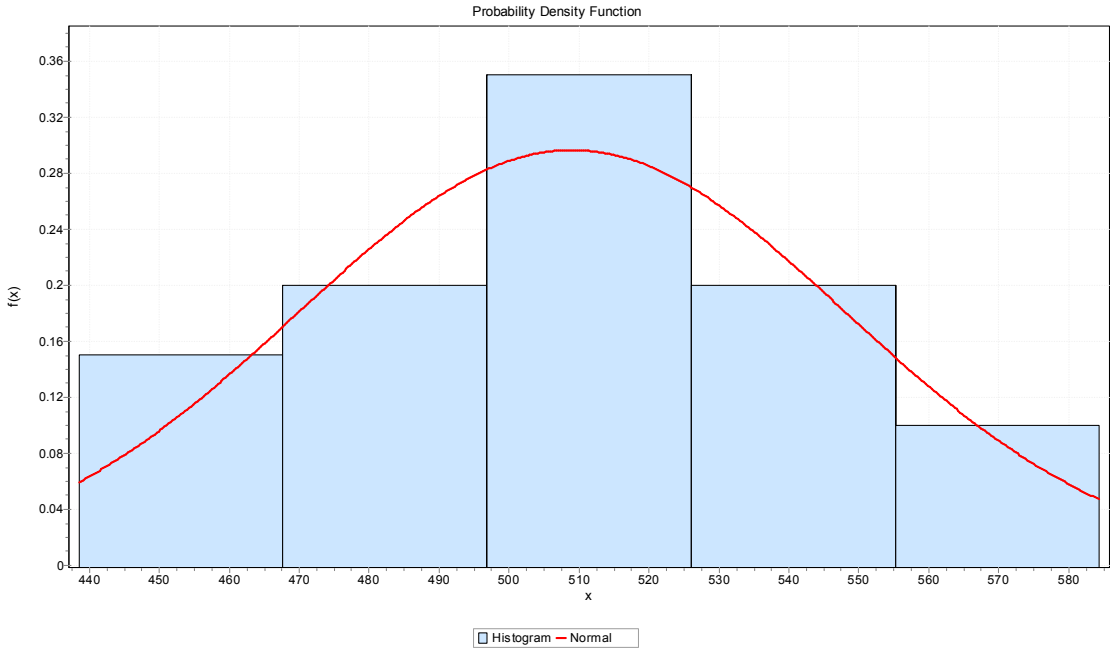


Fig. 4.13: Probability Density Function of for *Daniellia oliveri* considering Density (Normal Distribution)

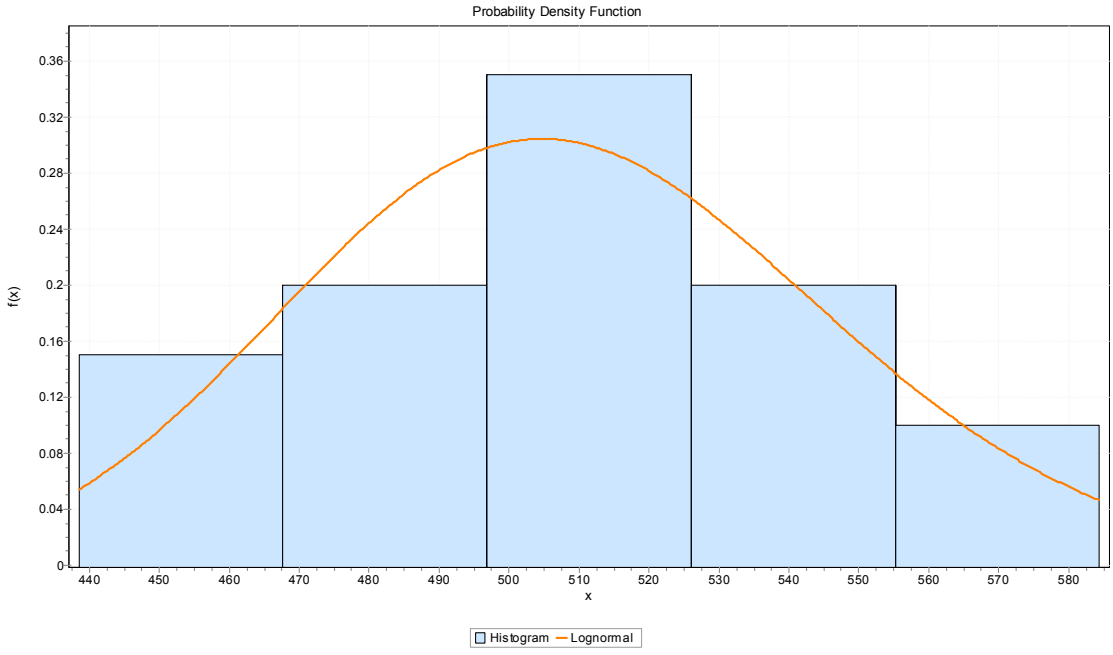


Fig. 4.14: Probability Density Function of for *Daniellia oliveri* considering Density (Lognormal Distribution)

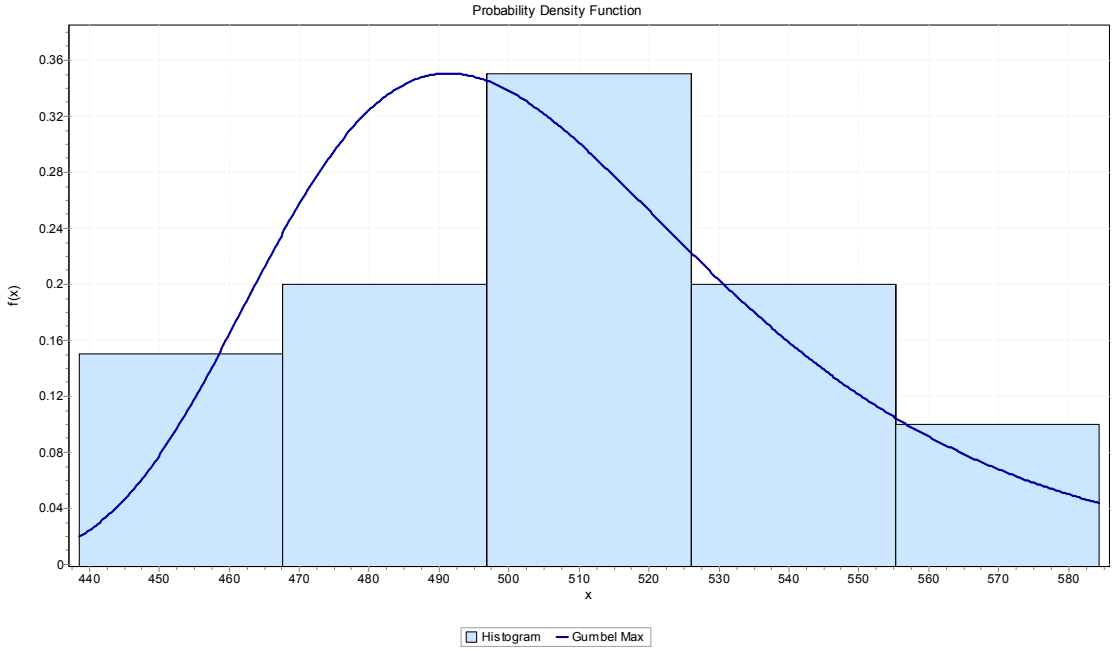


Fig. 4.15: Probability Density Function for *Daniellia oliveri* considering Density *(*Gumbel Distribution)

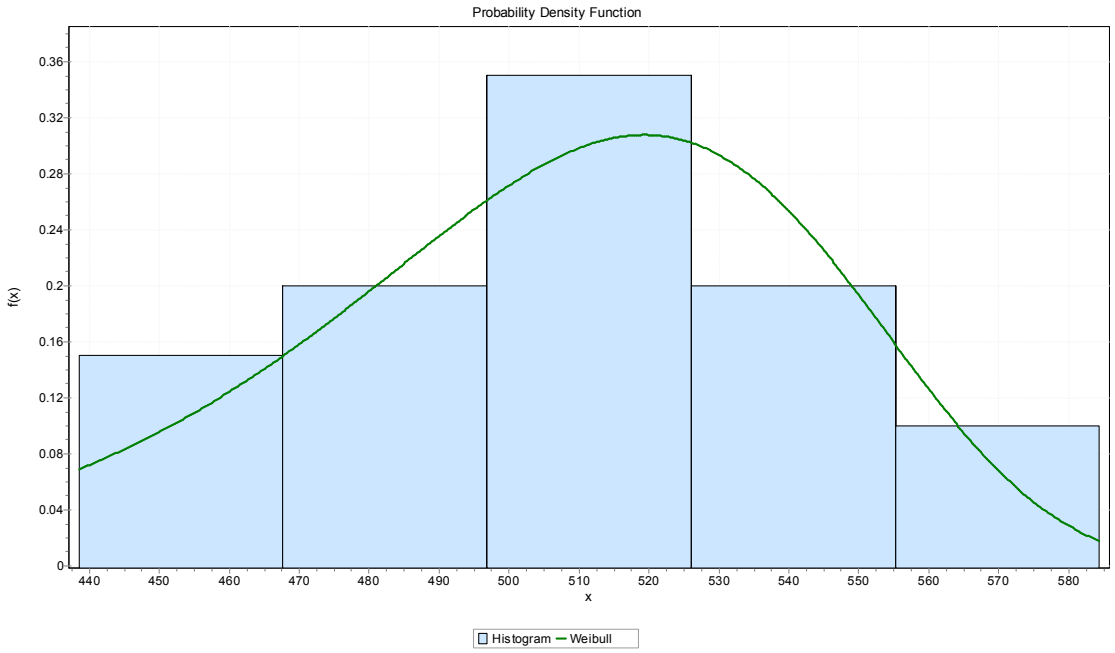


Fig. 4.16: Probability Density Function for *Daniellia oliveri* considering Density *(*Weibull Distribution)

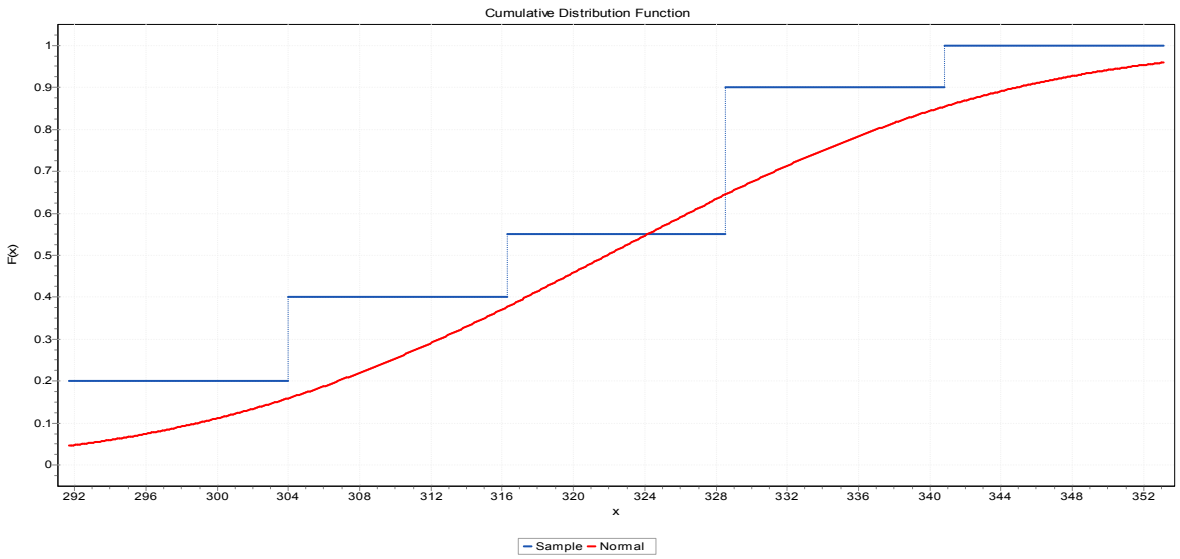


Fig. 4.17: Cumulative Density Function for *Ceiba pentandra* considering Density (Normal Distribution)

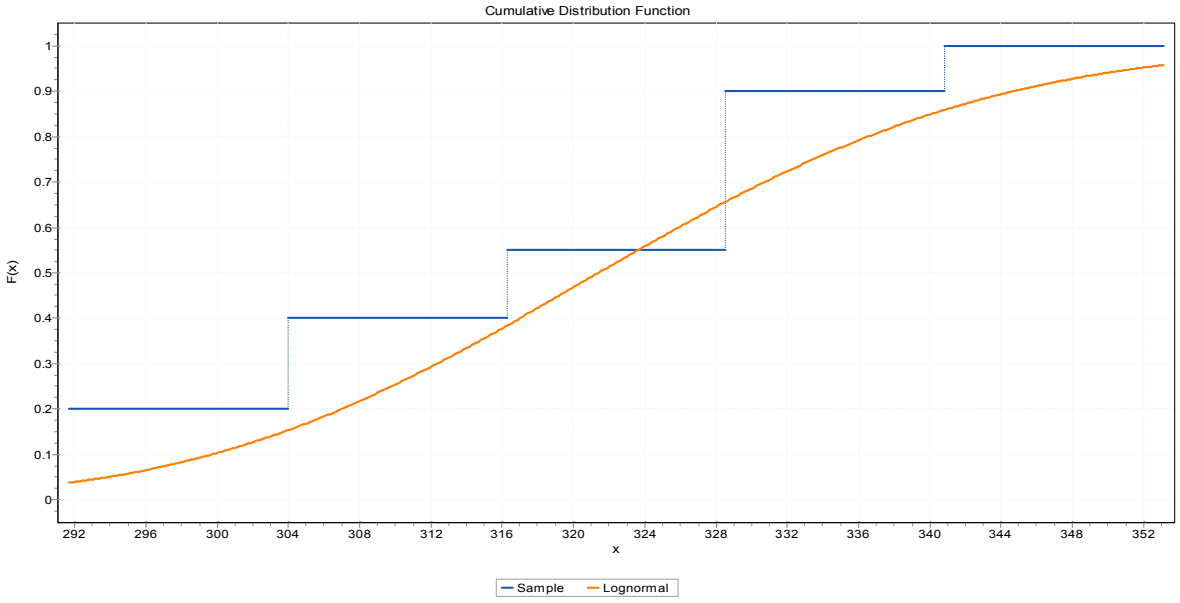


Fig. 4.18 : Cumulative Density Function for *Ceiba pentandra* considering Density (Lognormal Distribution)

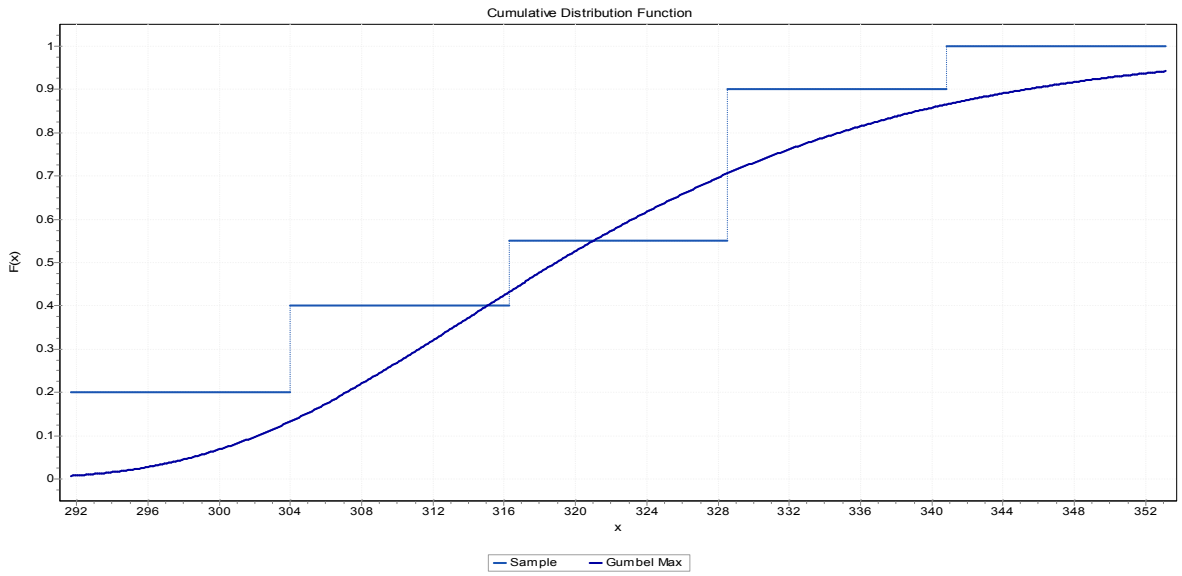


Fig .4.19: Cumulative Density Function for *Ceiba pentandra* considering Density (Gumbel Distribution)

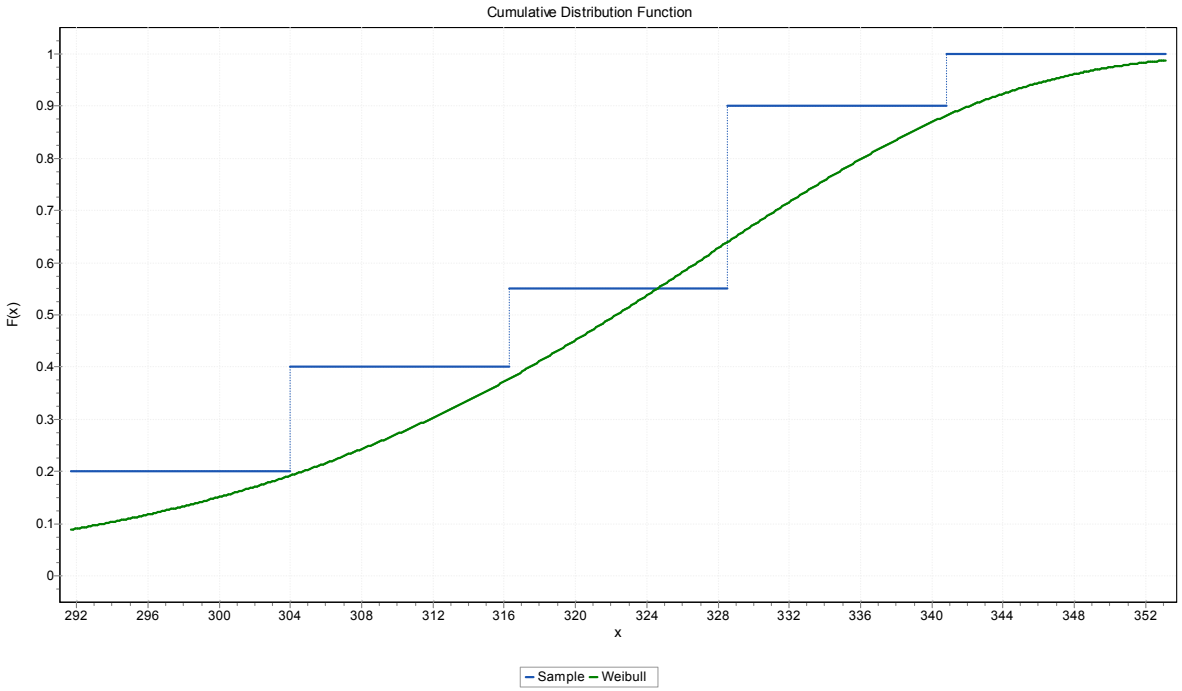


Fig. 4.20: Cumulative Density Function for *Ceiba pentandra* considering Density (Weibull Distribution)

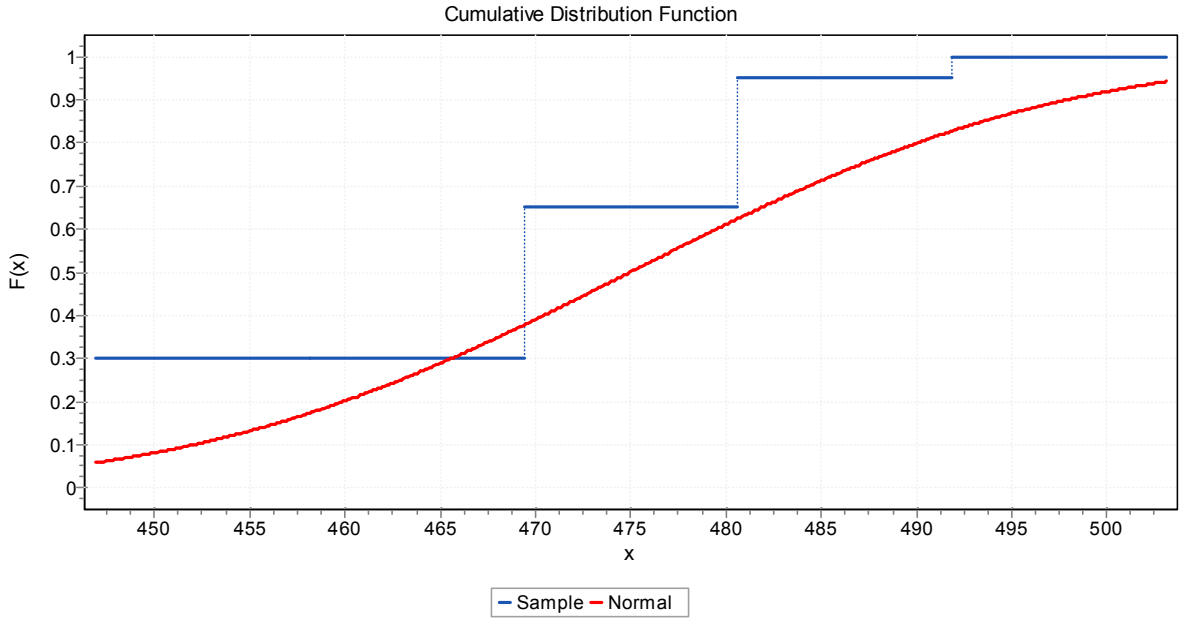


Fig. 4.21: Cumulative Density Function for *Chlorophoral excelsa* considering Density (Normal Distribution)

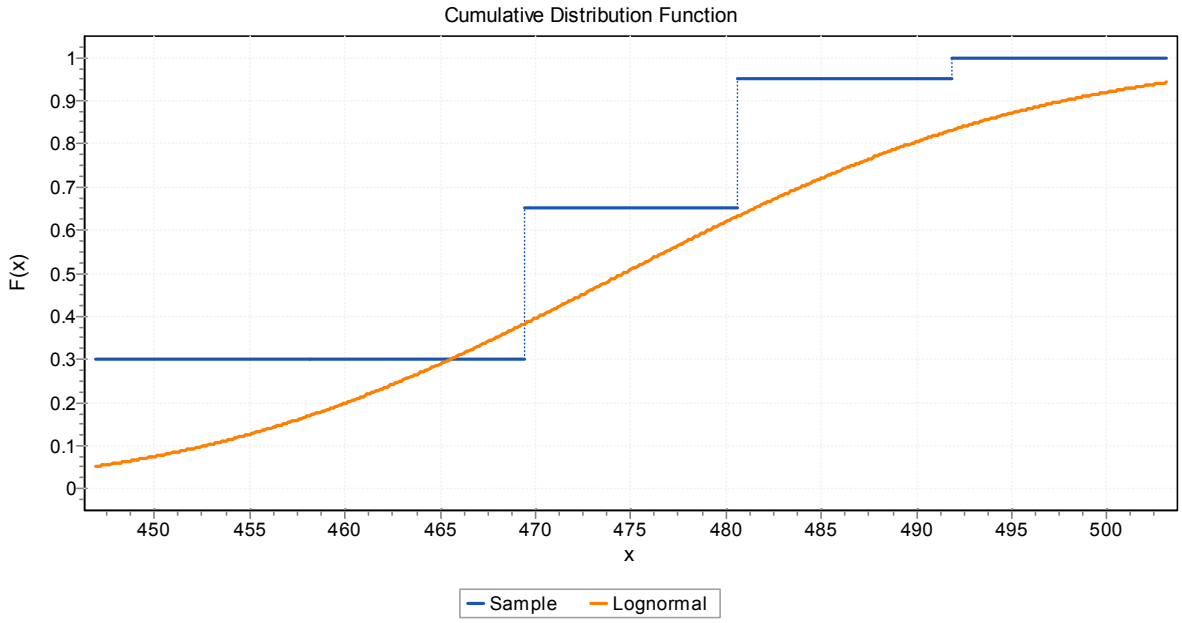


Fig. 4.22: Cumulative Density Function for *Chlorophoral excelsa* considering Density (Lognormal Distribution)

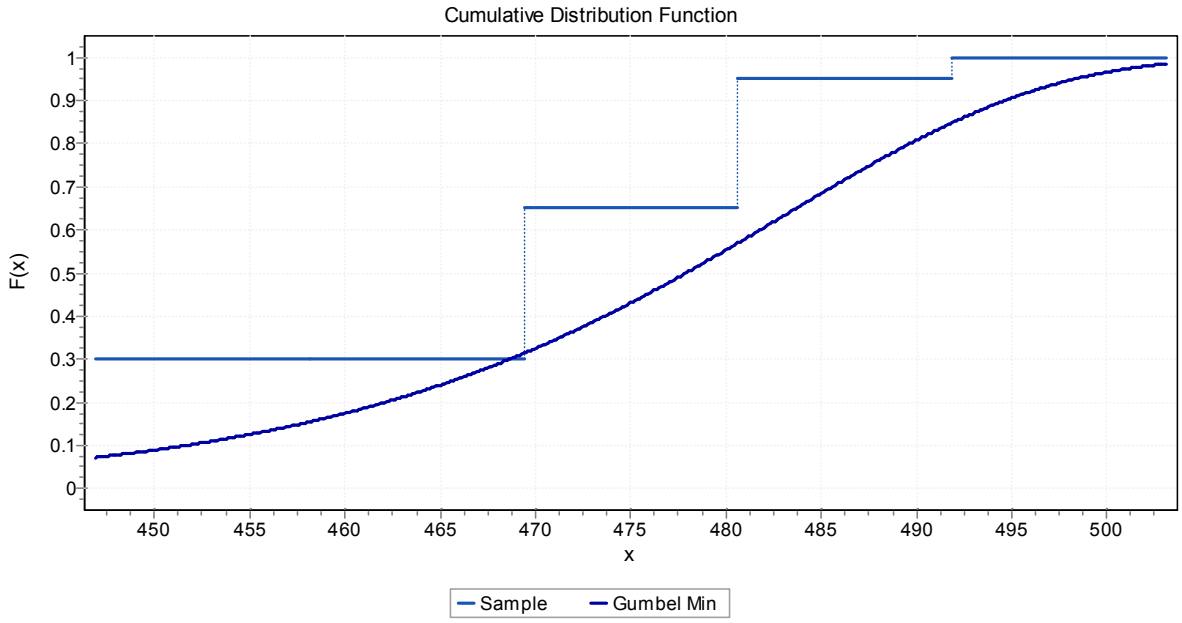


Fig. 4.23: Cumulative Density Function for *Chlorophoral excelsa* considering Density (Gumbel Distribution)

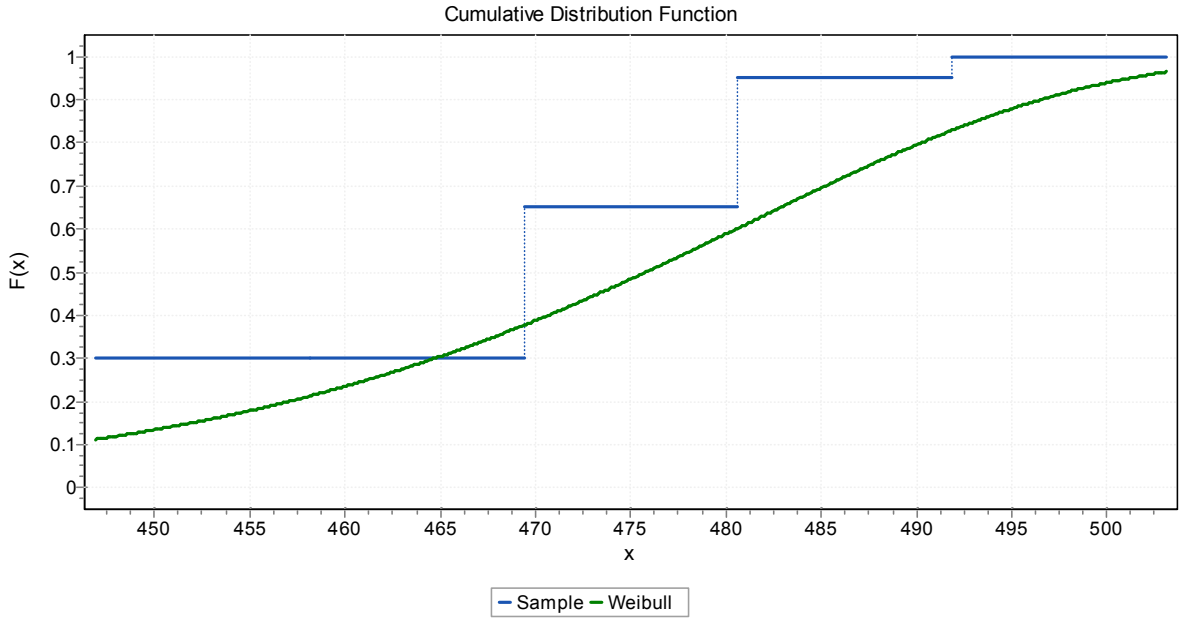


Fig. 4.24: Cumulative Density Function for *Chlorophoral excelsa* considering Density (Weibull Distribution)

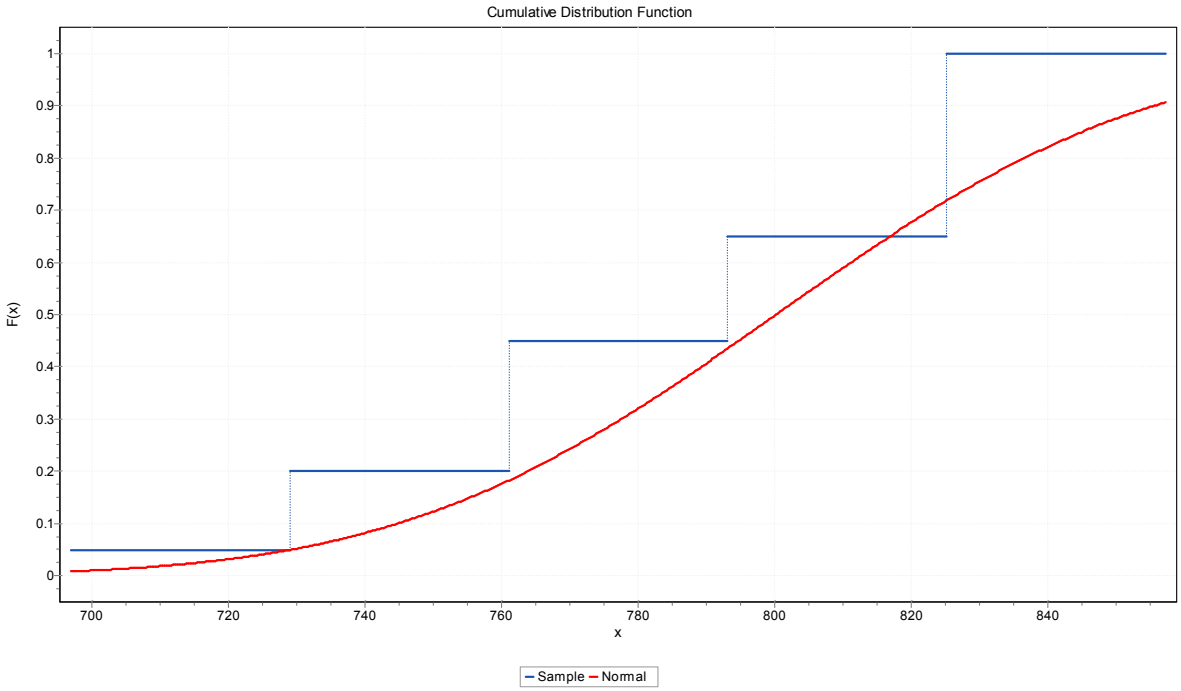


Fig .4.25: Cumulative Density Function for *Khaya senegalensis* considering Density (Normal Distribution)

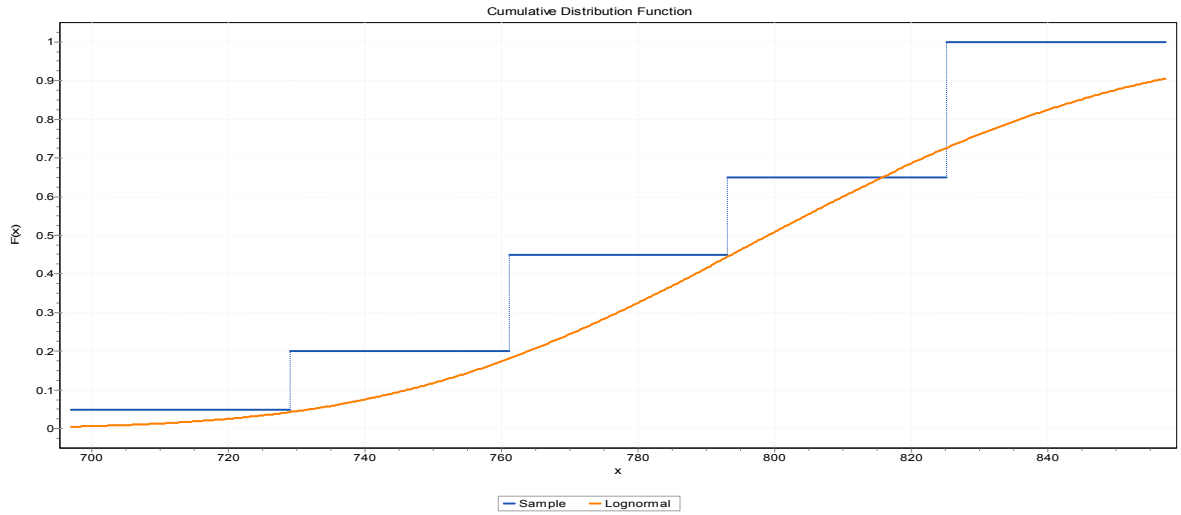


Fig 4.26:. Cumulative Density Function for *Khaya senegalensis* considering Density (Lognormal Distribution)

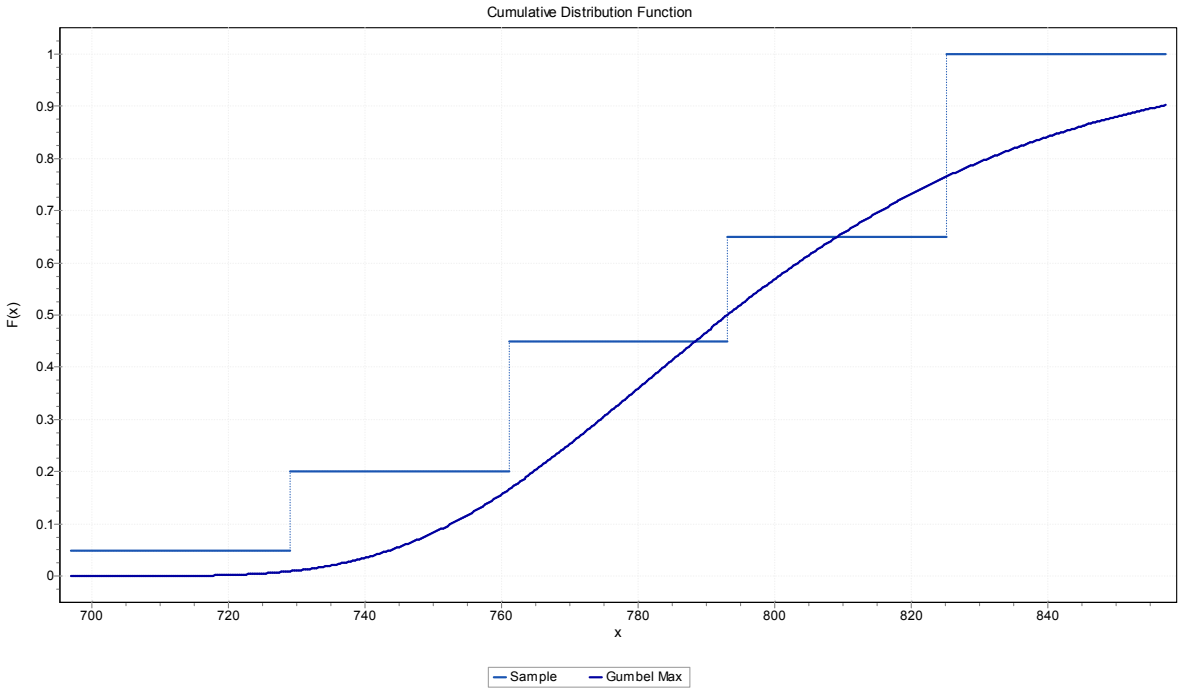


Fig. 4.27: Cumulative Density Function for *Khaya senegalensis* considering Density (Gumbel Distribution)

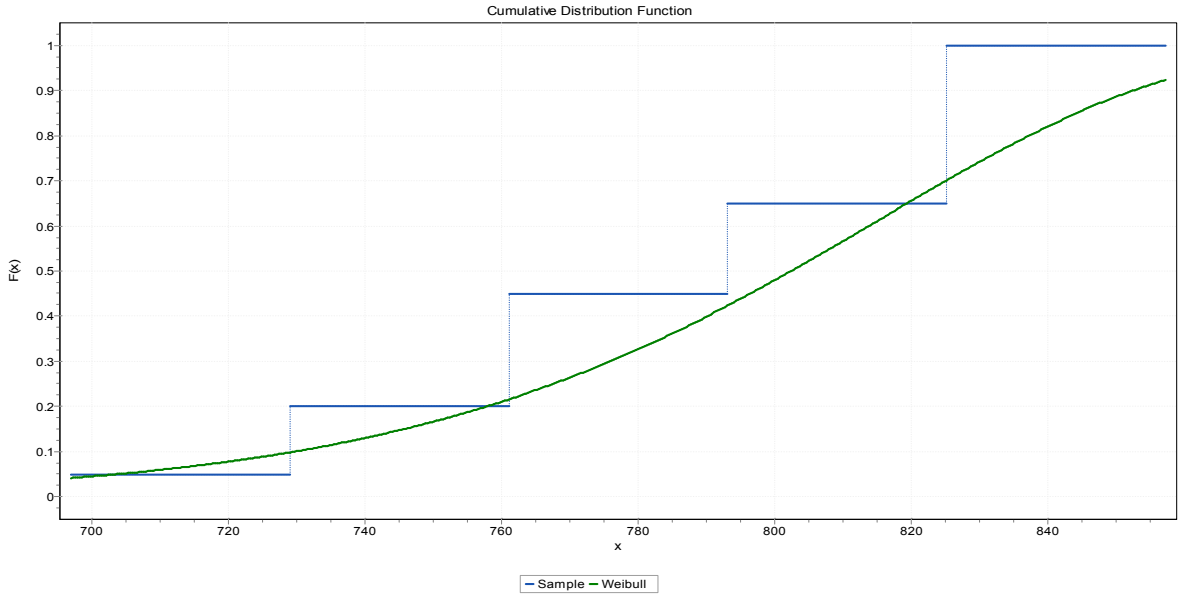


Fig. 4.28: Cumulative Density Function for *Khayas senegalensis* considering Density (Weibull Distribution)

4.2.3 Distribution Model for Bending Strength.

The critical value for Kolmogorov Smirnov test at $\alpha = 0.05$, considering bending strengths for all the four species as presented in the Table 4.6 is also 0.29. This value is greater than the corresponding K – S statistics of normal, lognormal, gumbel and weibull distribution. Each of the four distribution models can therefore be used to model the bending strength of timber. Considering the ranking of the validity of the four distribution model, it is observed that, the most fitted distribution model for bending strength of solid timber is the gumbel distribution with the least K – S statistics of 0.150

Similarly, the random variables and the corresponding probabilities of the selected timber species for bending strength are presented in Fig. 4.29 to Fig. 4.44 and the cumulative distribution function of bending strength are presented in Figs . 4.45 to 4.58 .

The results of K – S tests are presented in the form of interactive tables that help to decide the model that describes the data in the best way.

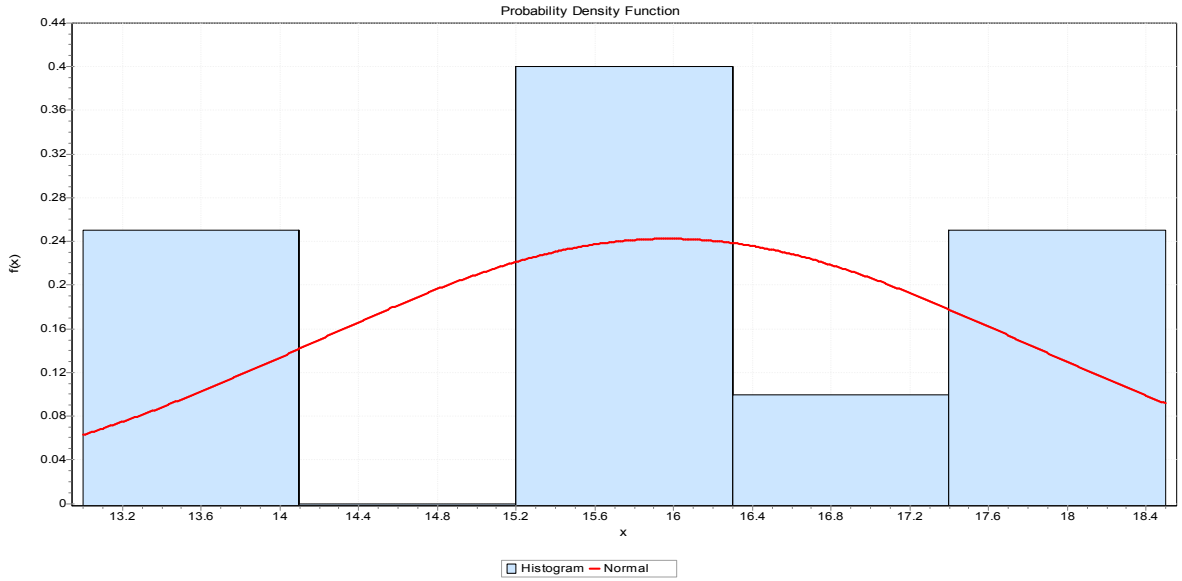


Fig. 4.29: Probability Density Function for Chlorophoral excelsa considering bending strength (Normal Distribution)

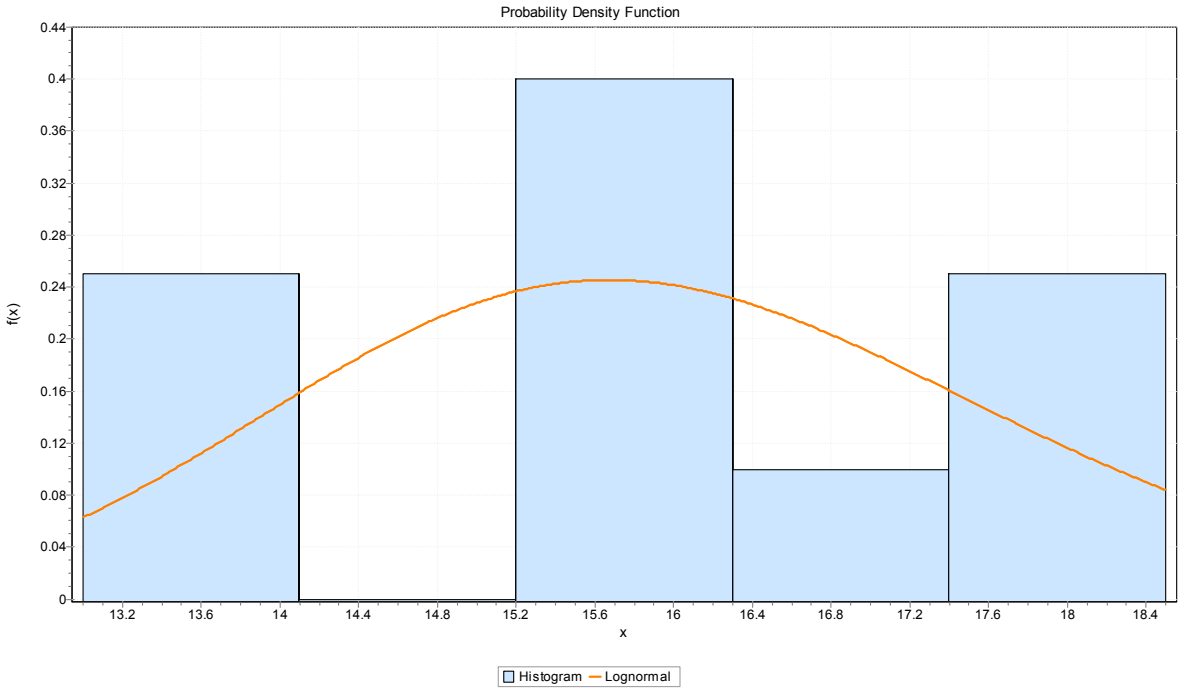


Fig. 4.30: Probability Density Function for Chlorophoral excelsa considering bending strength (Lognormal Distribution)

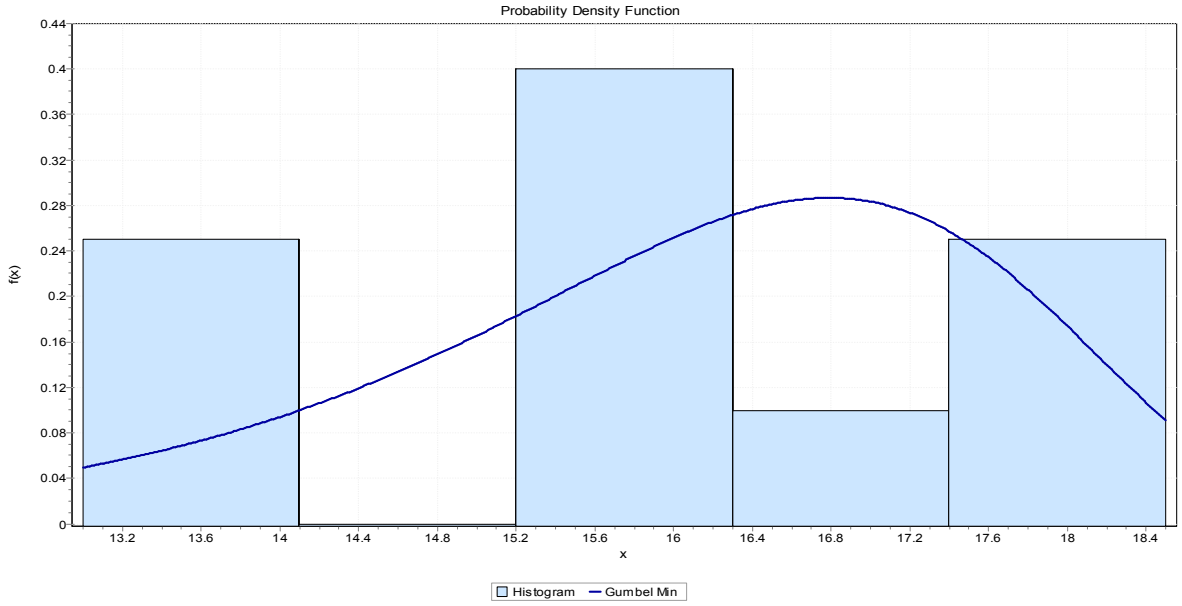


Fig. 4.31: Probability Density Function for Chlorophoral excelsa considering bending strength (Gumbel Distribution)

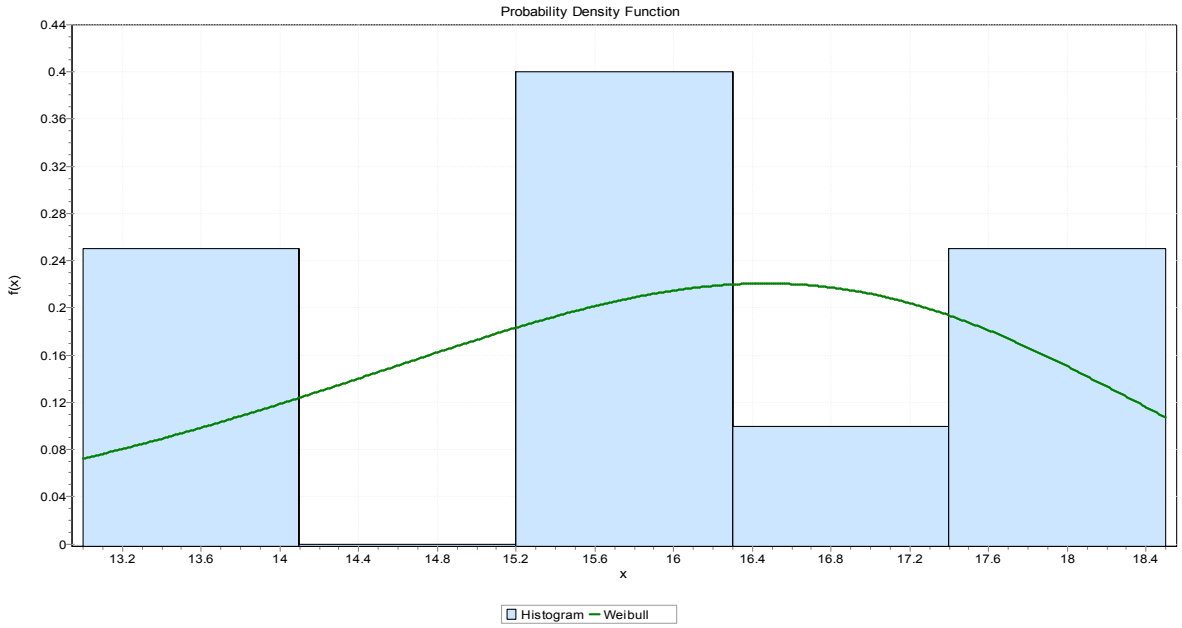


Fig. 4.32: Probability Density Function for Chlorophoral excelsa considering bending strength (Weibull Distribution)

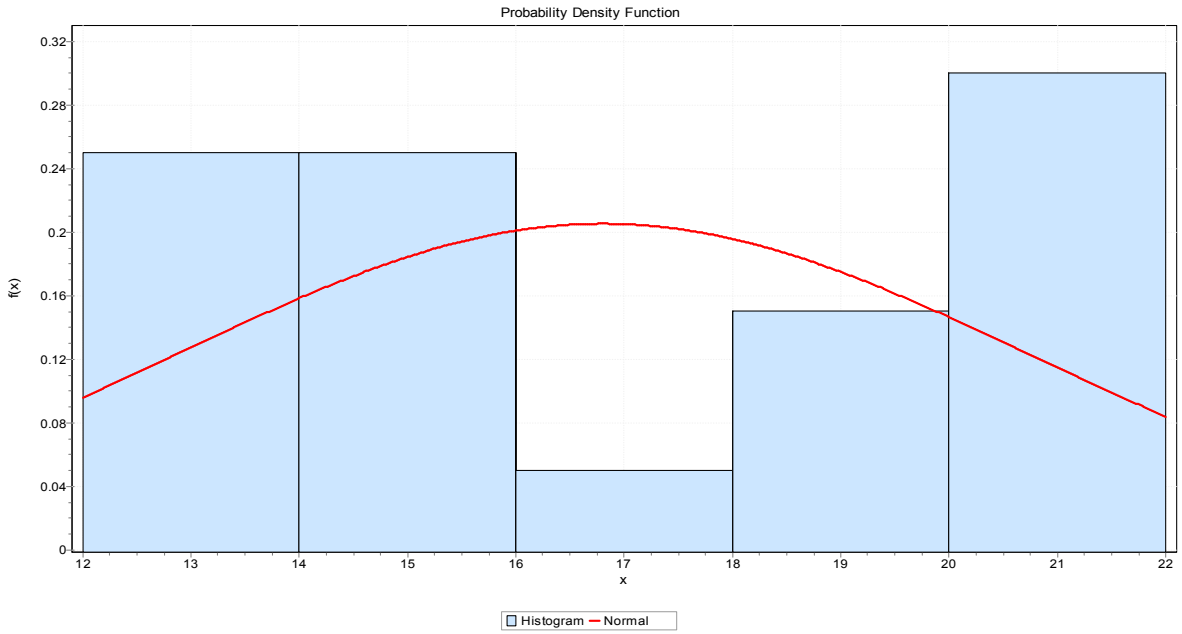


Fig 4.33 : Probability Density Function for *Khaya senegalensis* considering bending Strength (Normal Distribution)

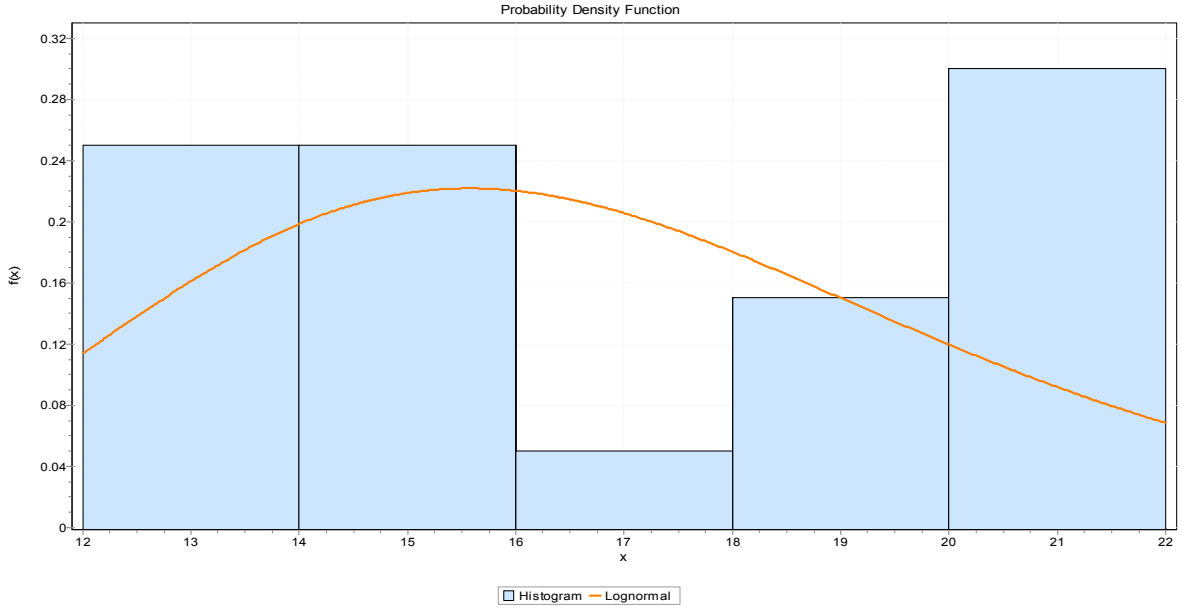


Fig. 4.34: Probability Density Function for *Khaya senegalensis* considering bending Strength (Lognormal Distribution)

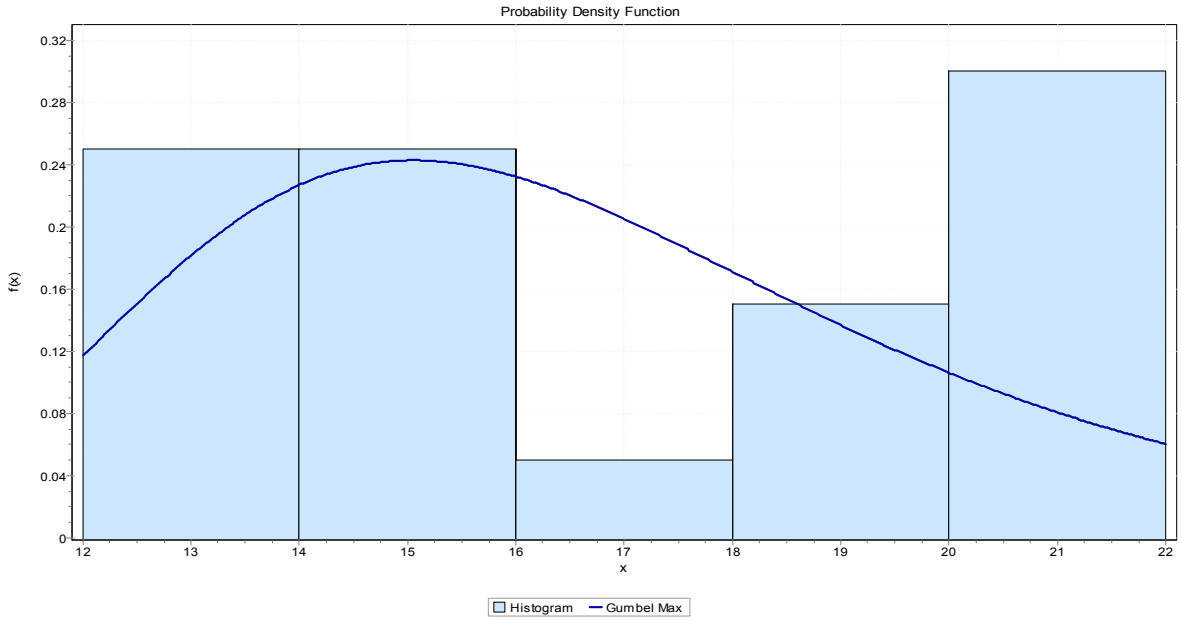


Fig. 4.35: Probability Density Function for *Khaya senegalensis* considering bending Strength (Gumbel Distribution)

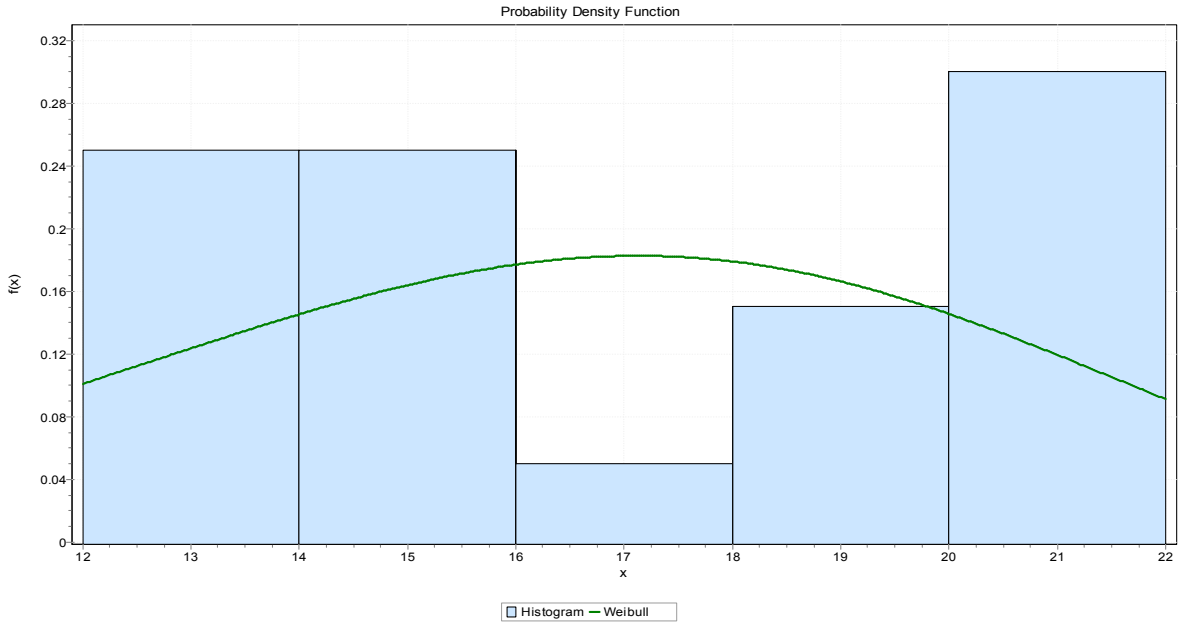


Fig. 4.36: Probability Density Function for *Khaya senegalensis* considering bending Strength (Weibull Distribution)

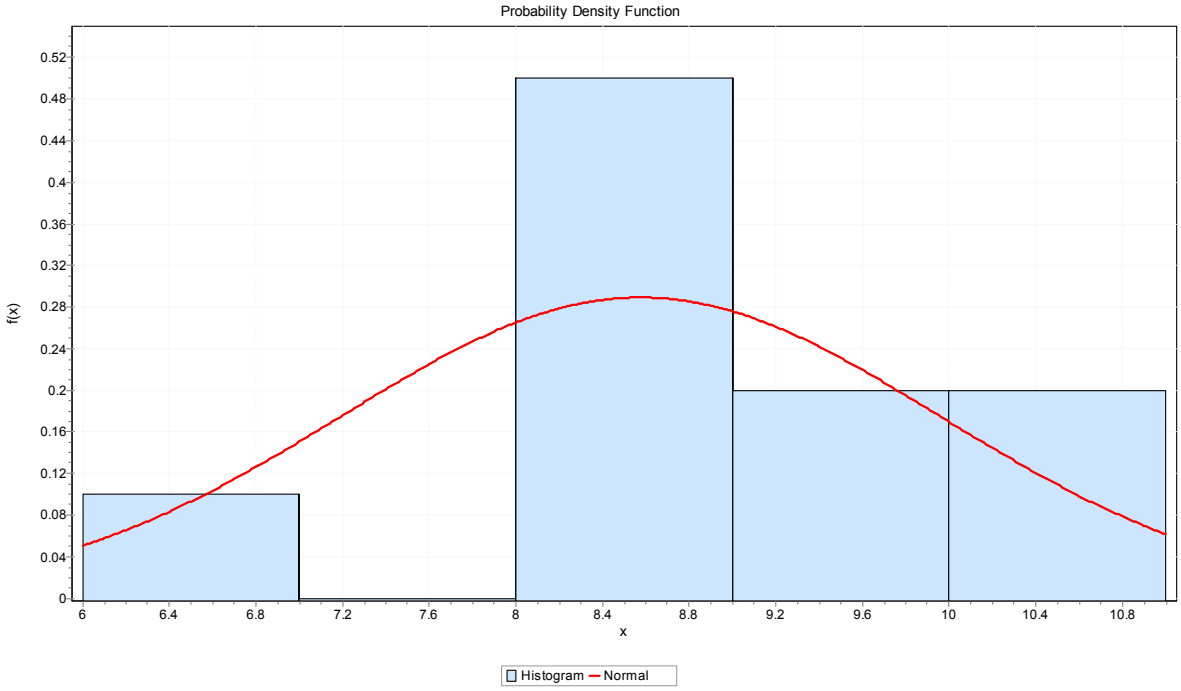


Fig. 4.37: Probability Density Function for *Ceiba pentandra considering Bending Strength* (Normal Distribution)

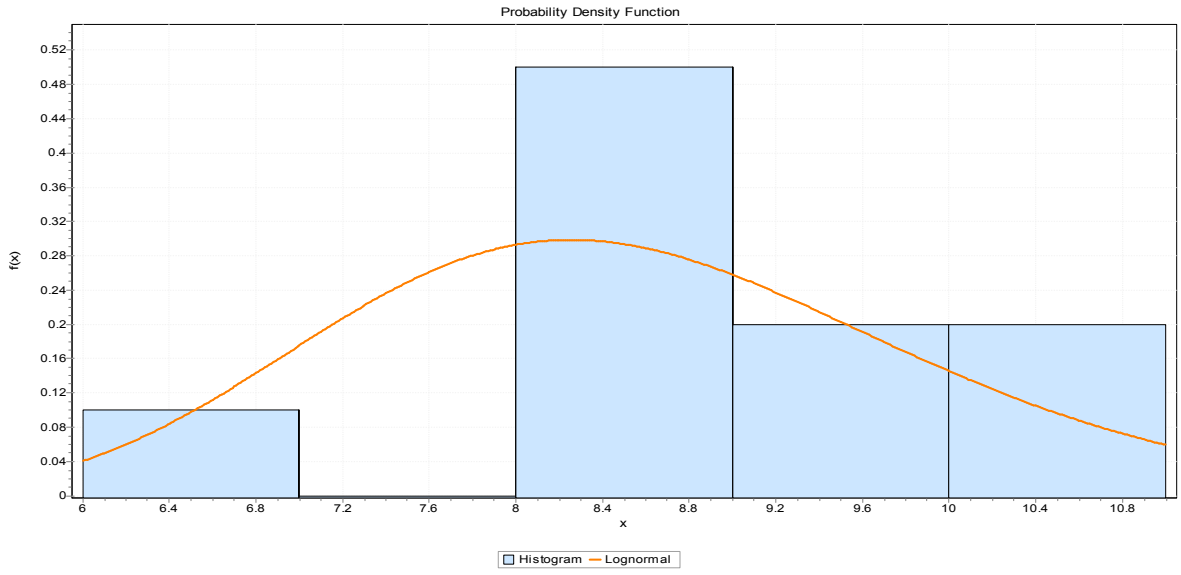


Fig. 4.38: Probability Density Function for *Ceiba pentandra considering Bending Strength* (Lognormal Distribution)

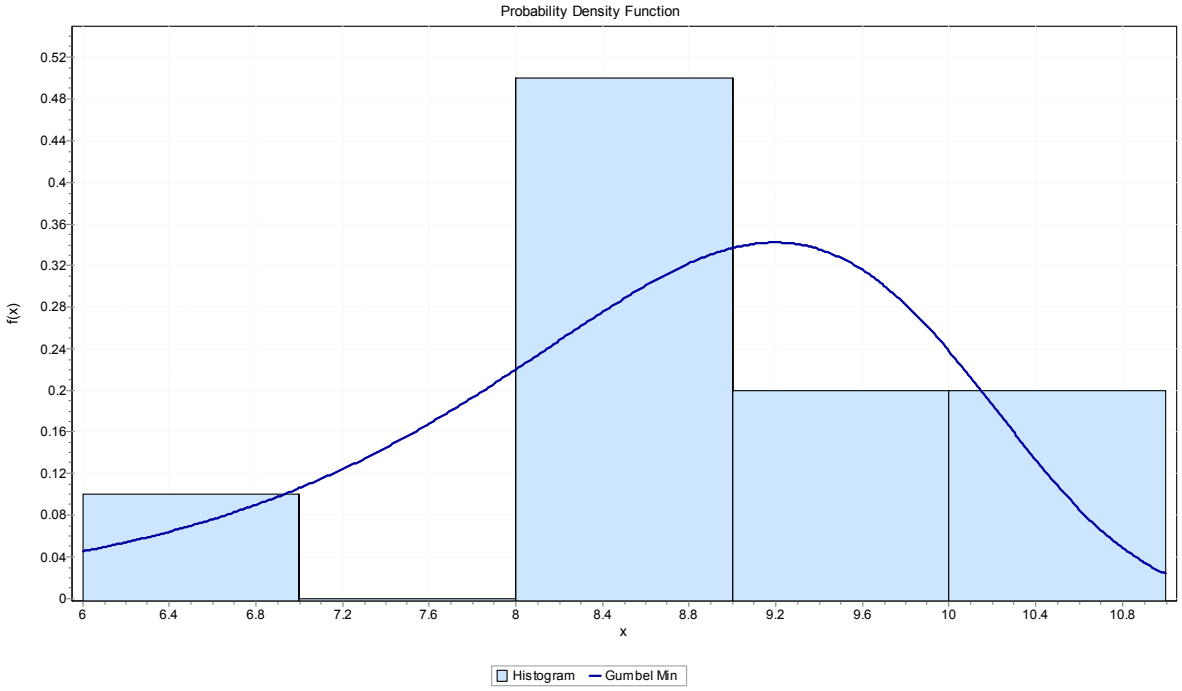


Fig. 4.39: Probability Density Function for *Ceiba pentandra considering Bending Strength* (Gumbel Distribution)

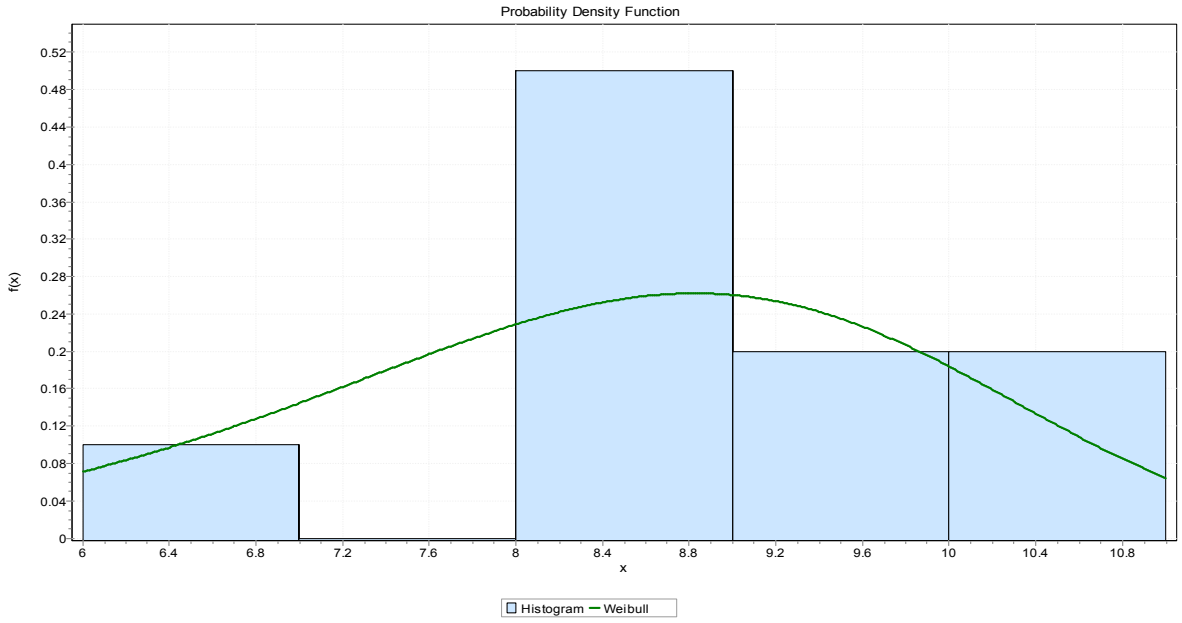


Fig. 4.40: Probability Density Function for *Ceiba pentandra considering Bending Strength* (Weibull Distribution)

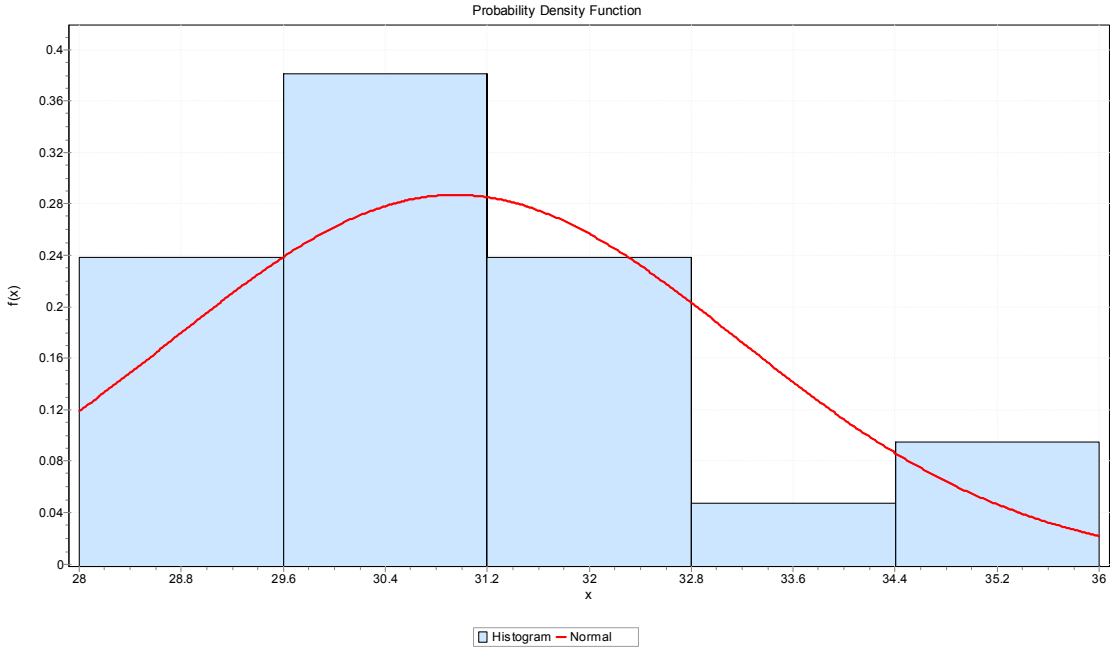


Fig. 4.41: Probability Density Function for ***Daniellia oliveri considering Bending Strength*** (Normal Distribution)

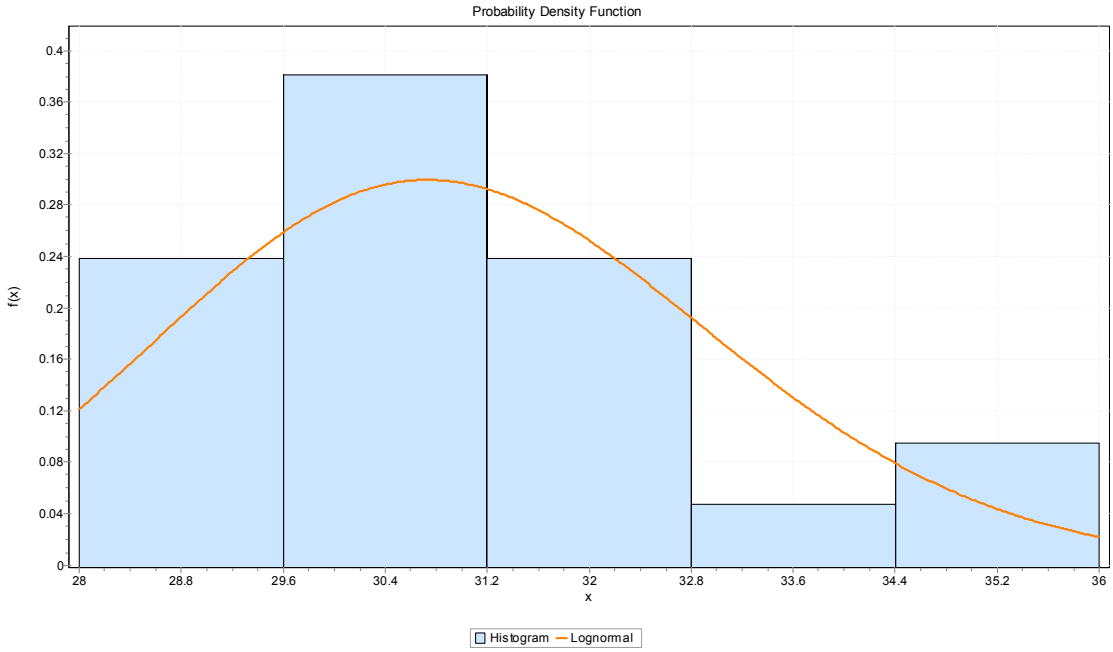


Fig. 4.42 : Probability Density Function for ***Daniellia oliveri considering Bending Strength*** (Lognormal Distribution)

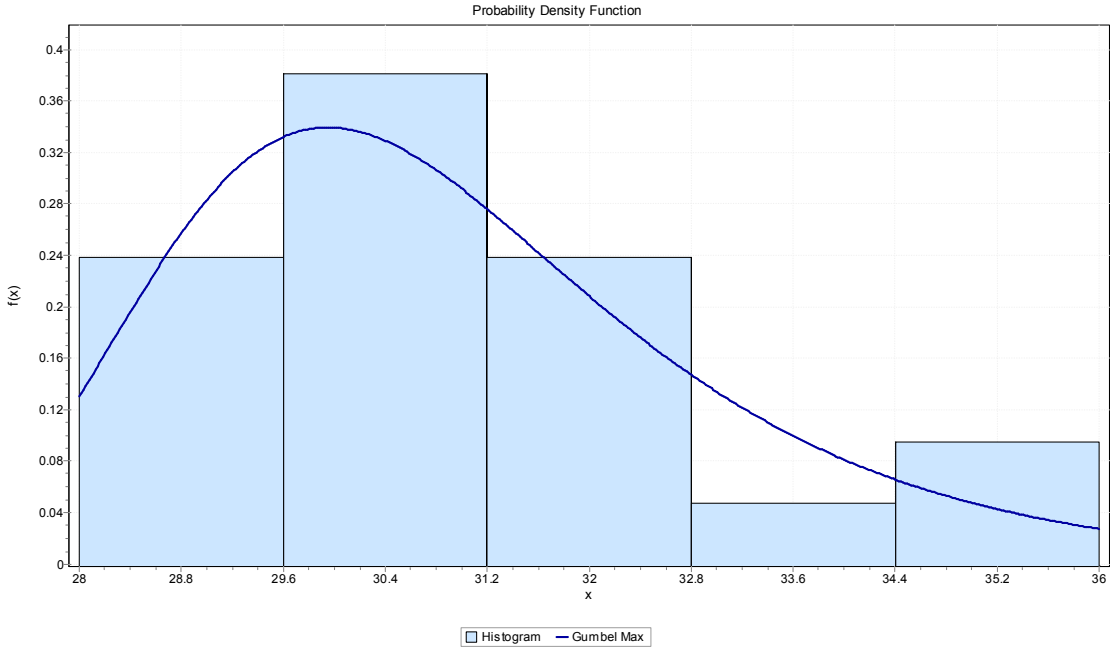


Fig .4.43: Probability Density Function for ***Daniellia oliveri considering Bending Strength*** (Gumbell Distribution)

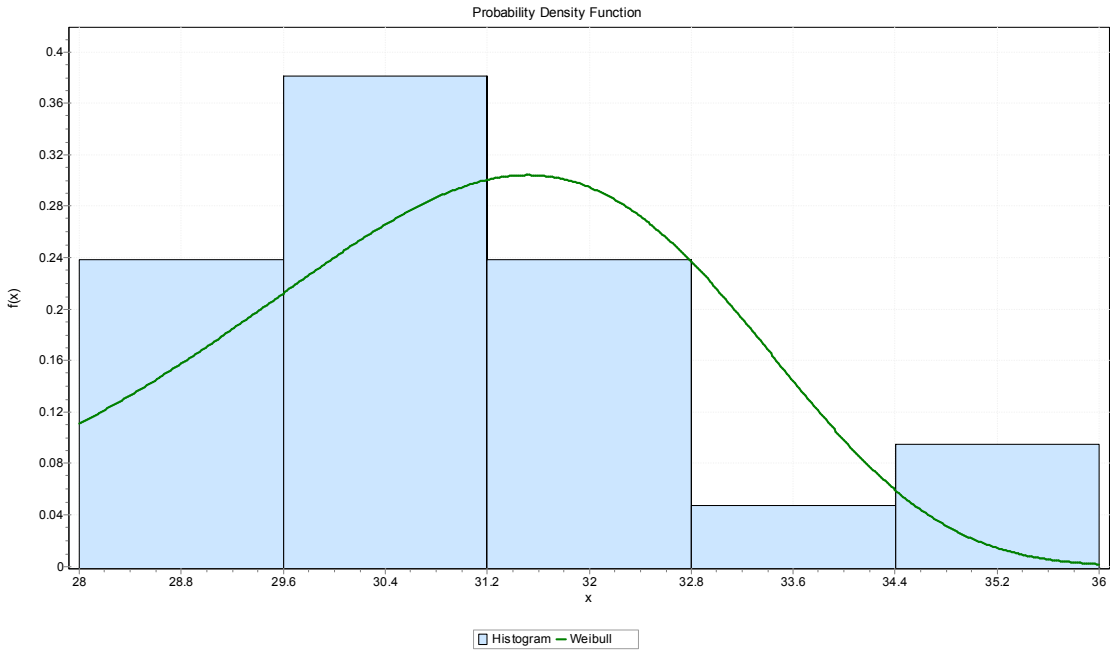


Fig. 4.44: Probability Density Function for ***Daniellia oliveri considering Bending Strength*** (Weibul Distribution)

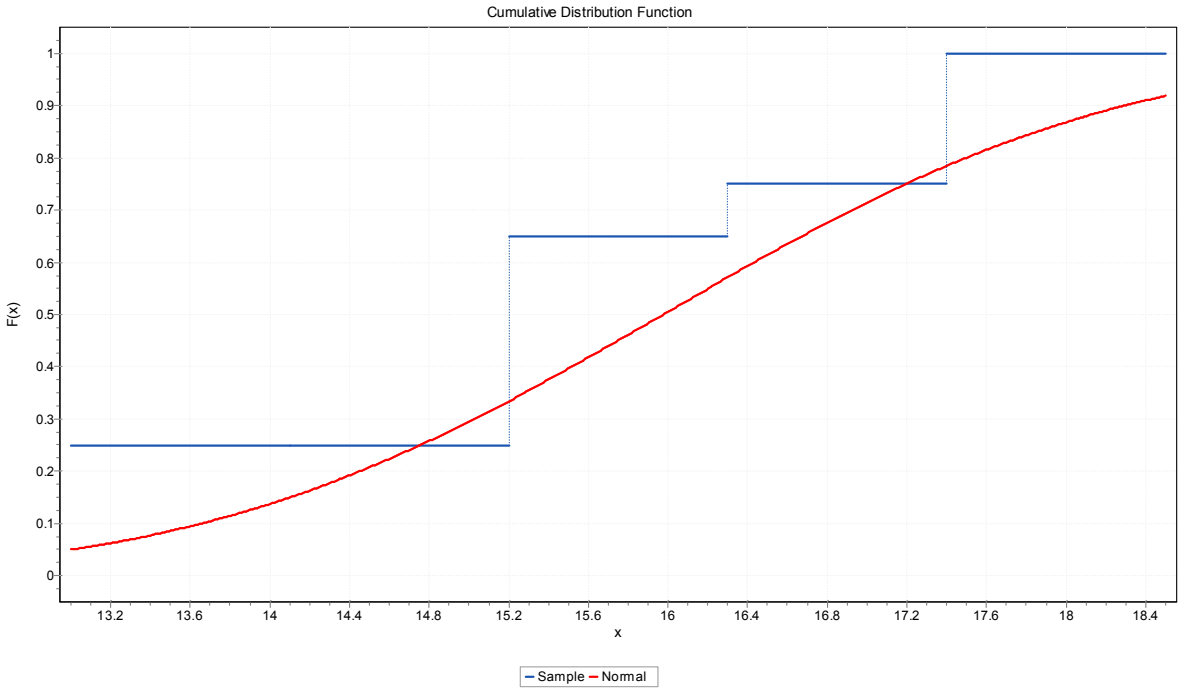


Fig .4.45 : Cumulative Distribution Function for *Chlorophoral excelsa* considering Bending Strength (Normal Distribution)

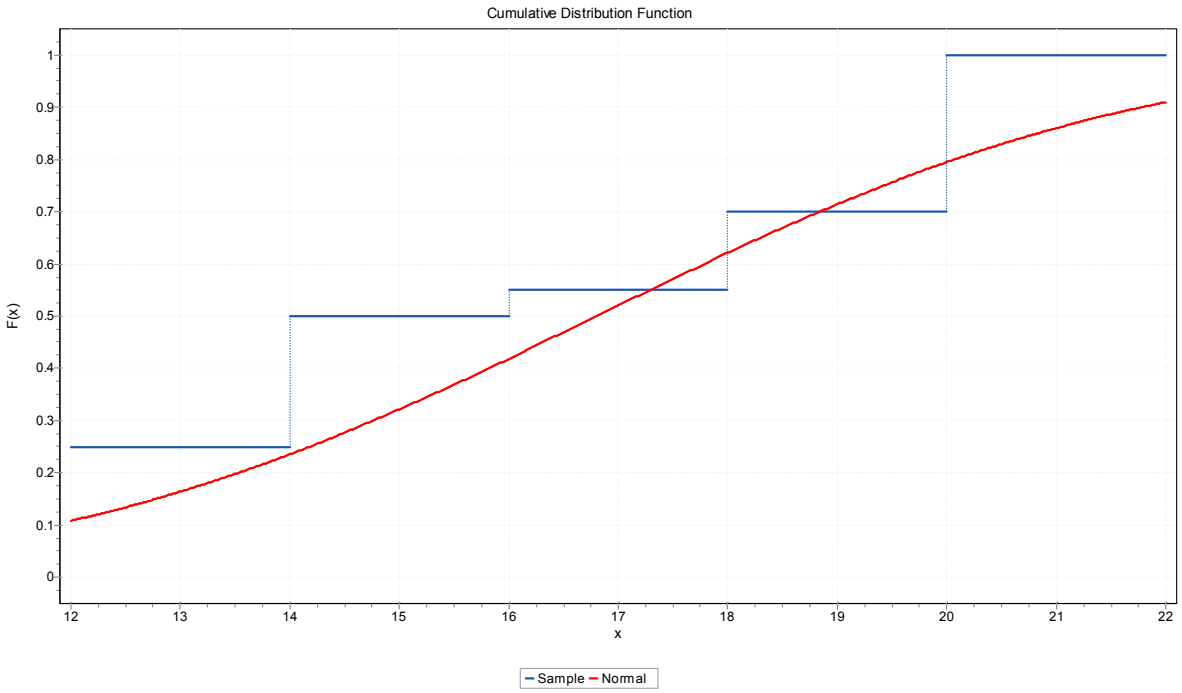


Fig. 4.46: Cumulative Distribution Function for *Khaya senegalensis* considering Bending Strength (Normal Distribution)

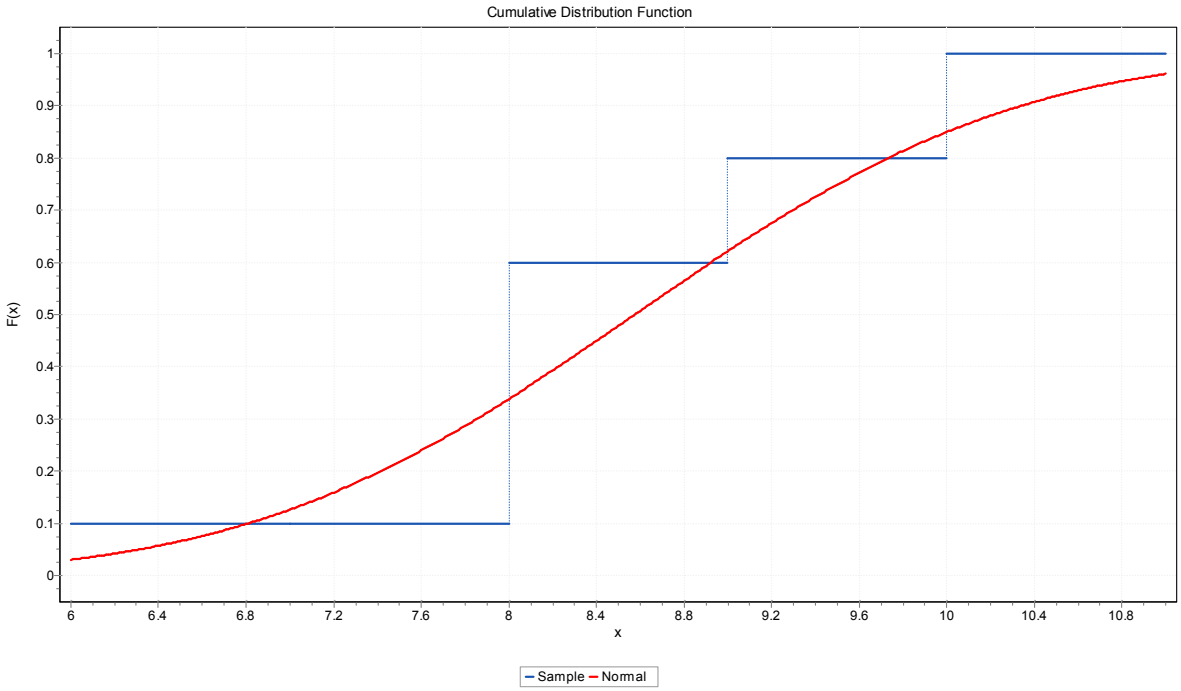


Fig. 4.47: Cumulative Distribution Function for *Ceiba pentandra* considering Bending Strength (Normal Distribution)

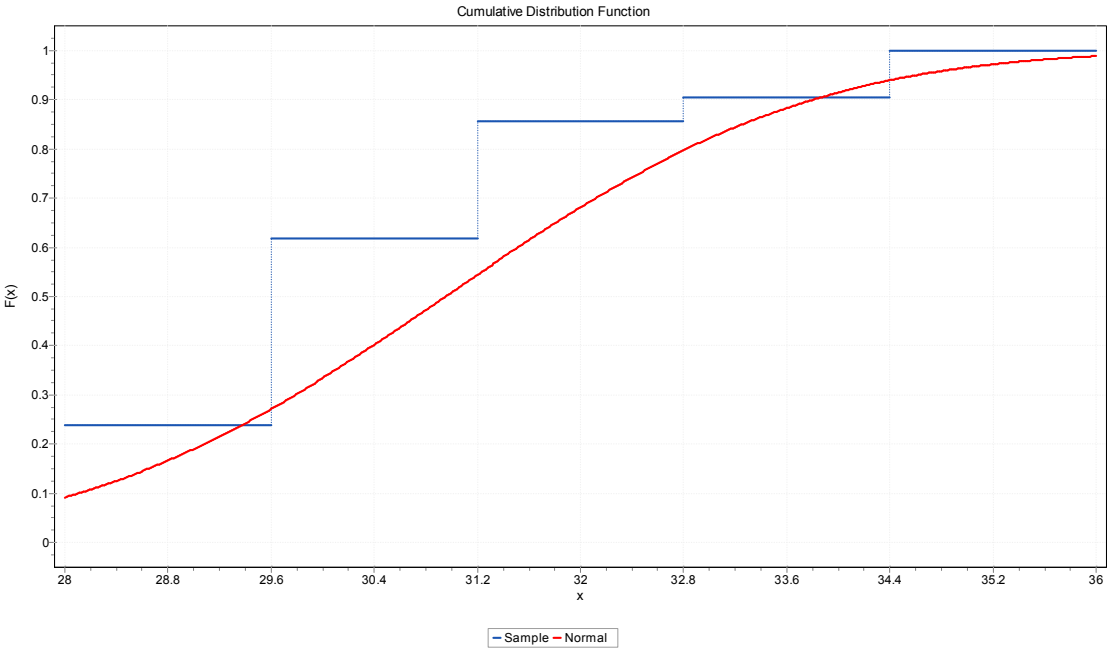


Fig .48: Cumulative Distribution Function for *Daniellia oliveri* considering Bending Strength (Normal Distribution)

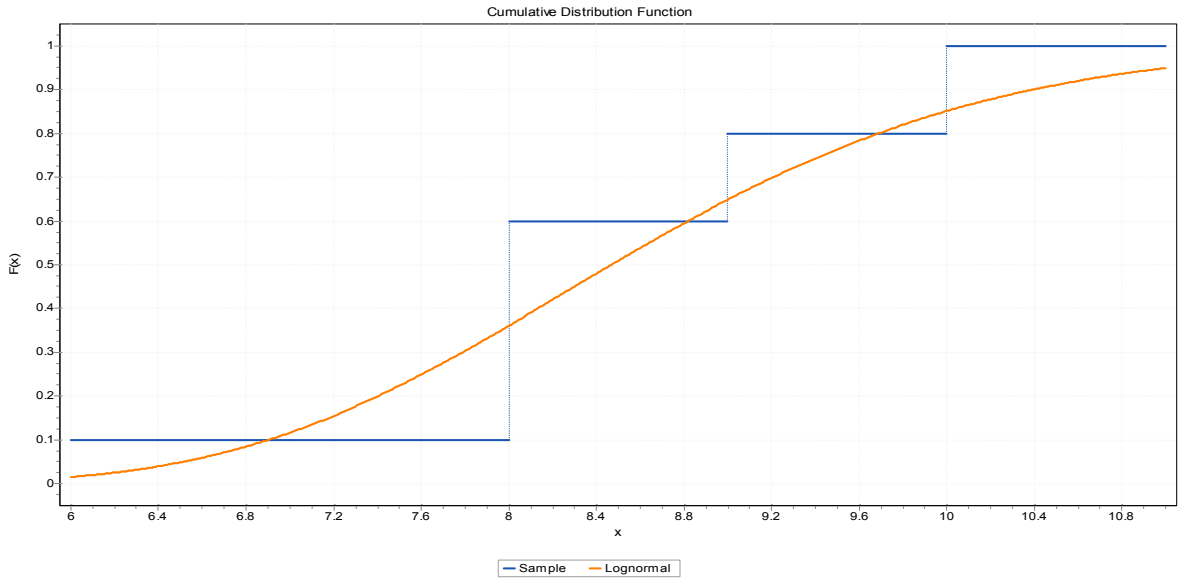


Fig. 4.49: Cumulative Distribution Function for *Ceiba pentandra* considering Bending Strength (Lognormal Distribution)

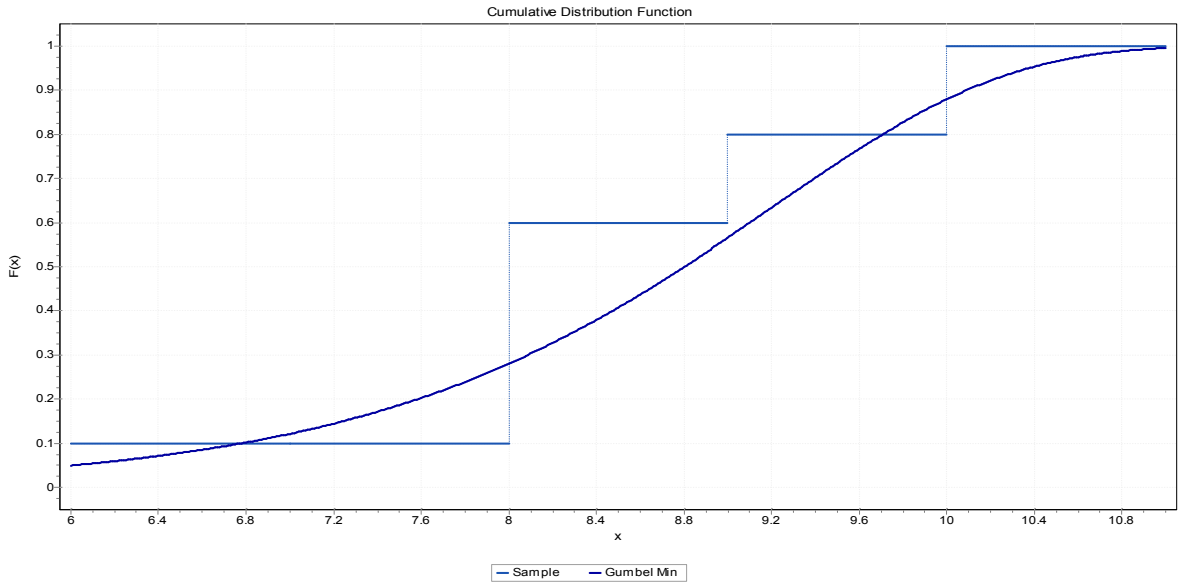


Fig .4.50: Cumulative Distribution Function for *Ceiba pentandra* considering Bending Strength (Gumbel Distribution)

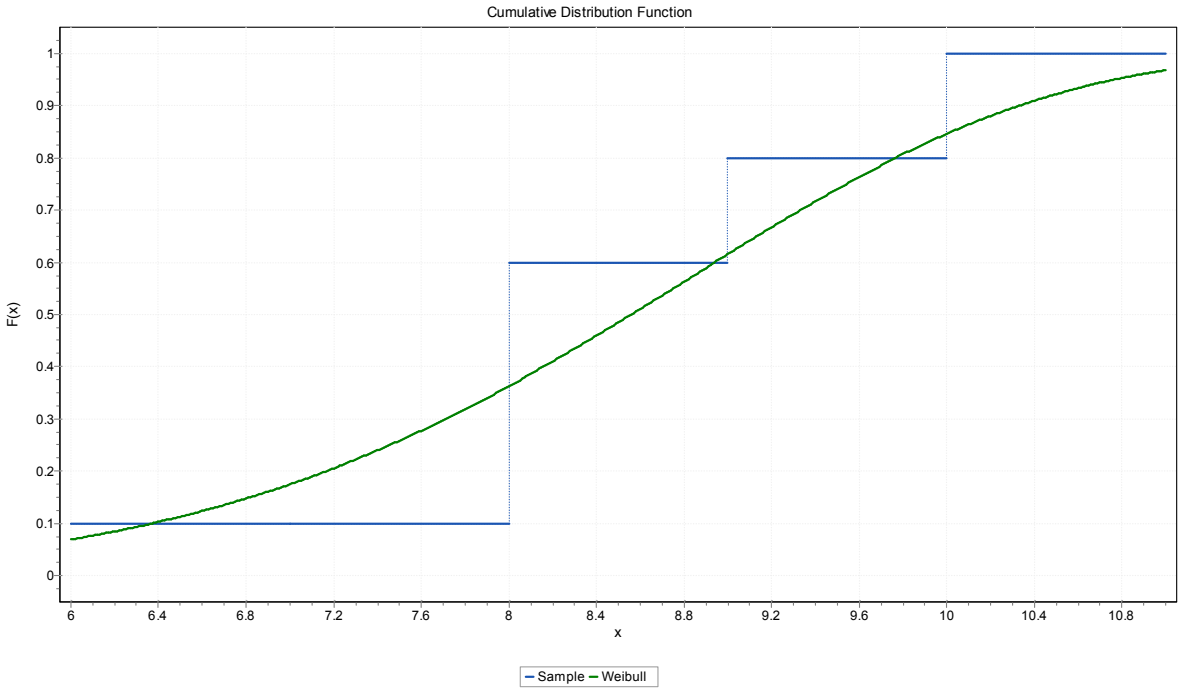


Fig . 4.51: Cumulative Distribution Function for *Ceiba pentandra* considering Bending Strength (Weibull Distribution)

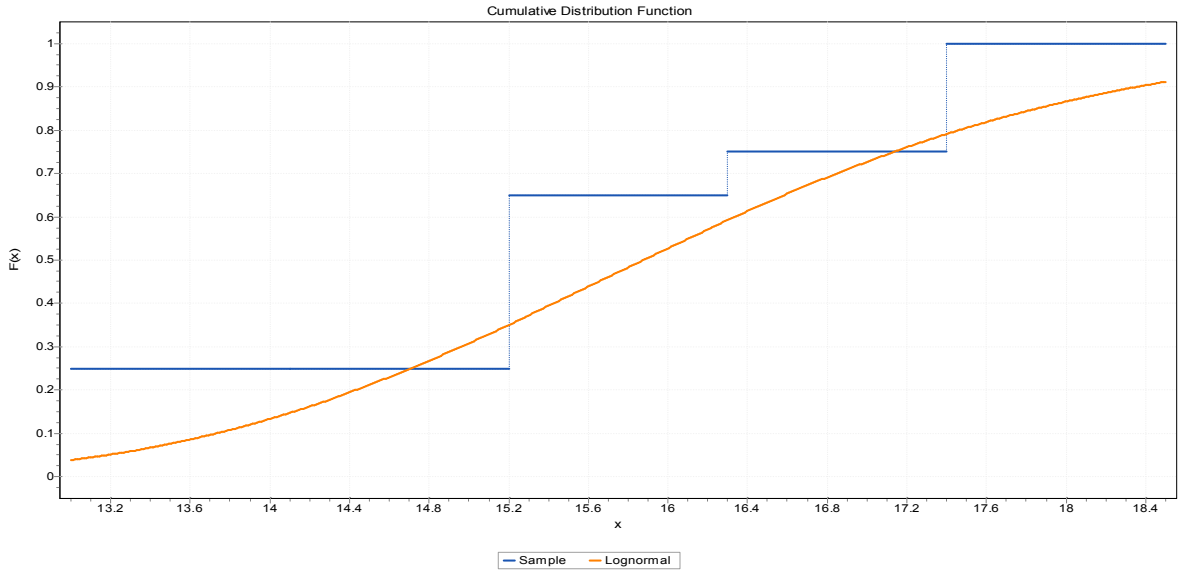


Fig .4.52: Cumulative Distribution Function for *Chlorophoral excelsa* considering Bending Strength (Lognormal Distribution)

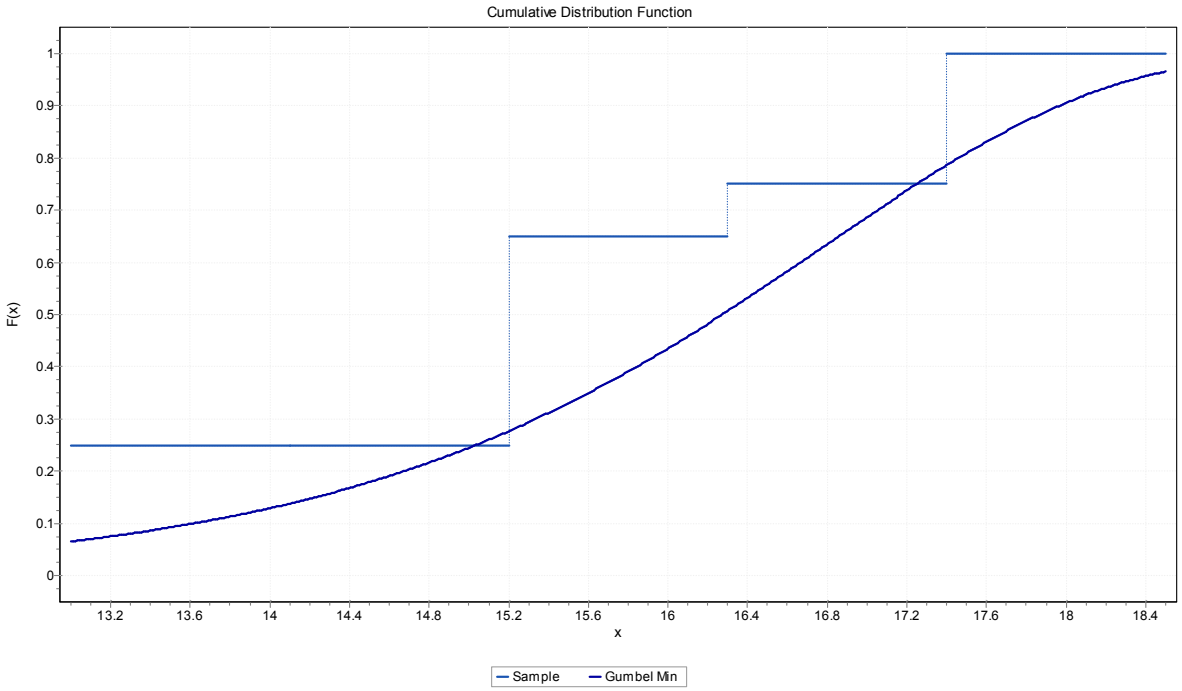


Fig. 4.53: Cumulative Distribution Function for *Chlorophoral excelsa* considering Bending Strength (Gumbel Distribution)

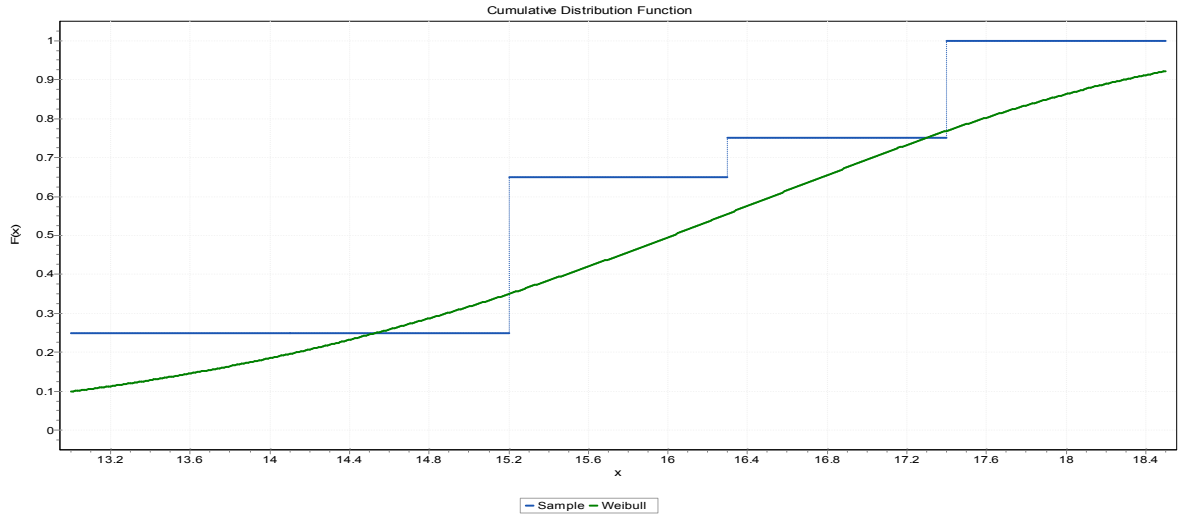


Fig. 4.54: Cumulative Distribution Function for *Chlorophoral excelsa* considering Bending Strength (Weibull Distribution)

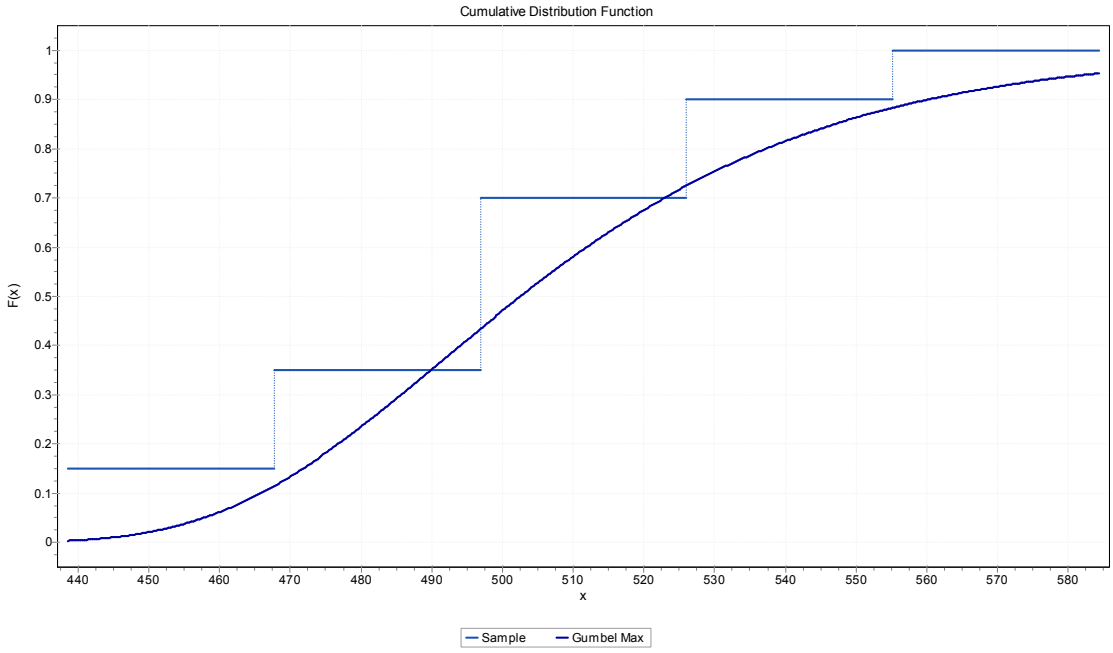


Fig . 4.55: Cumulative Distribution Function for *Daniellia oliveri* considering Bending Strength *(*Gumbel Distribution)

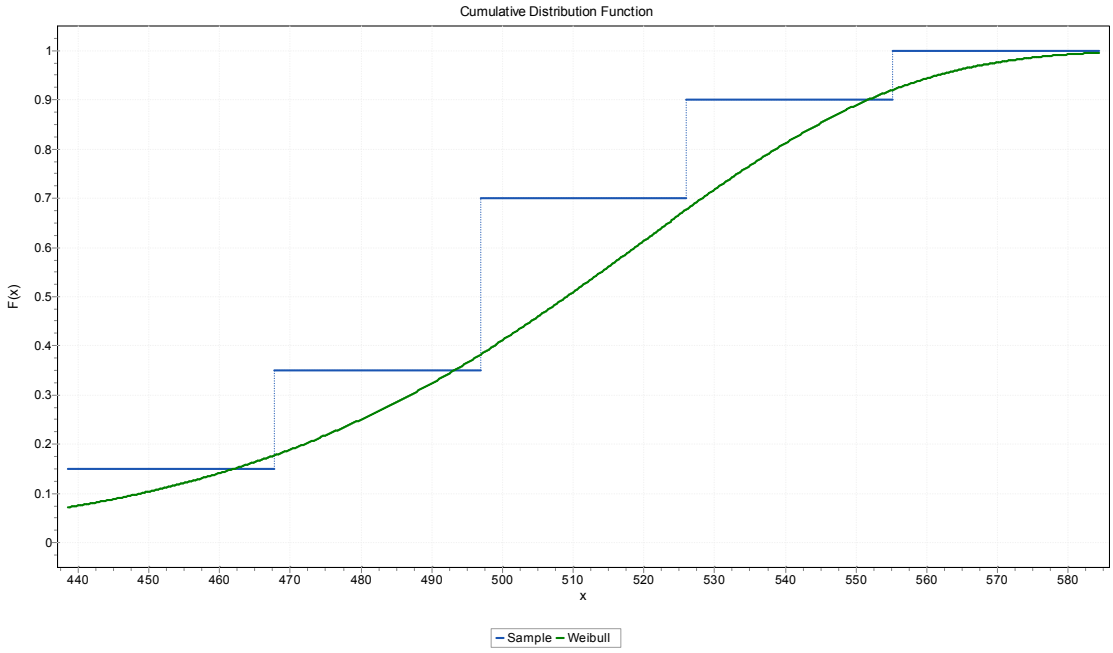


Fig .4.56: Cumulative Distribution Function for *Daniellia oliveri* considering Bending Strength (Weibull Distribution)

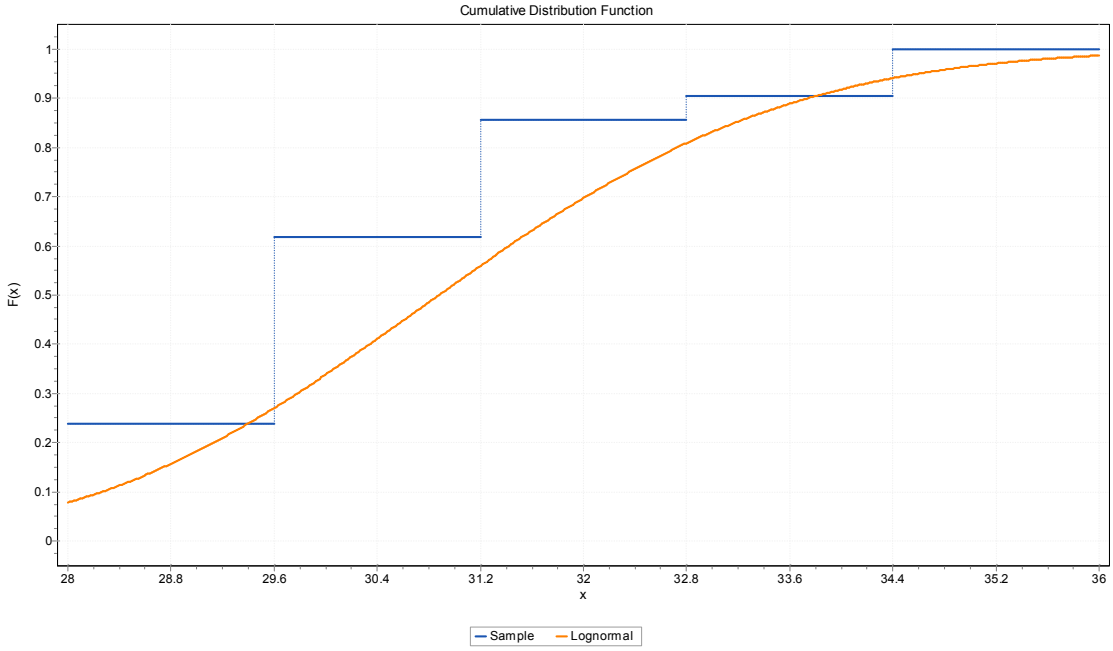


Fig .4.57: Cumulative Distribution Function for *Daniellia oliveri* considering Bending Strength (Lognormal Distribution)

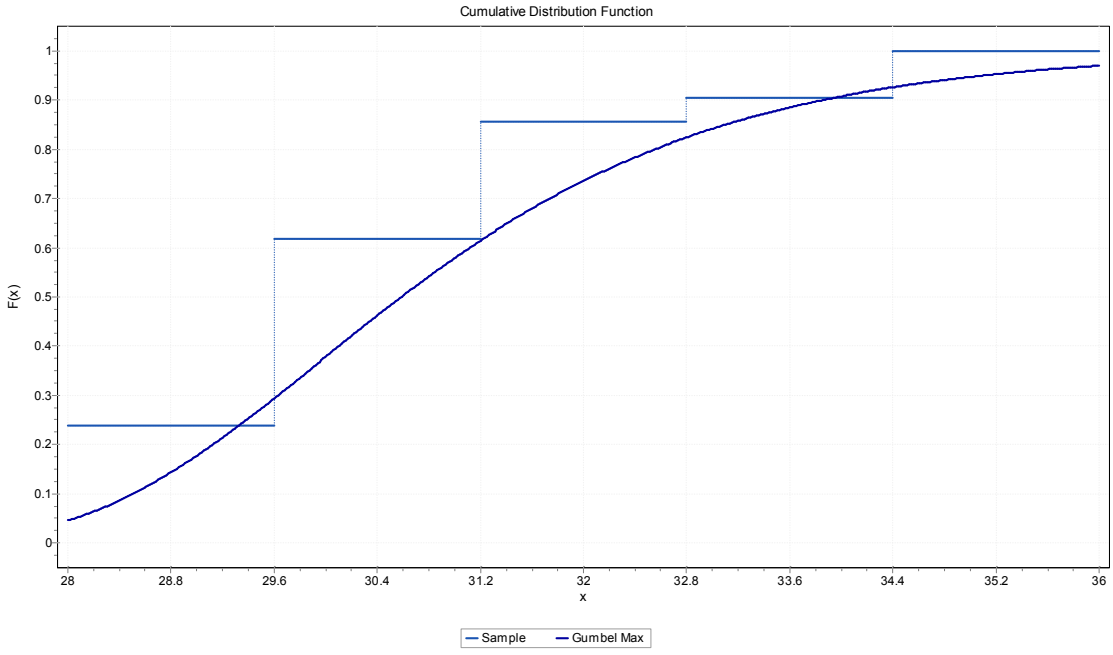


Fig. 4.58: Cumulative Distribution Function for *Daniellia oliveri* considering Bending Strength (Gumbel Distribution)

4.2.4 Distribution Model for Modulus of Elasticity

The critical value for Kolmogorov Simirnov test at $\alpha = 0.05$, for all the species as presented in Table 4.6 is 0.29. This value is greater than the corresponding K –S statistics of the normal, lognormal, gumbel and weibull distribution. This is a clear indication that each of the four distribution models can be used to model the modulus of elasticity of timber. Considering the ranking of the validity of the four distribution models, it is observed that, the most fitted distribution model for modulus of elasticity of solid timber is normal distribution, with the least K – S statistics of 0.11762 . The probability density function for modulus of elasticity are presented in Figs. 4.59 to 4.74 and the cumulative distribution function for modulus of elasticity are presented in Figs. 4.75 to 4.88.

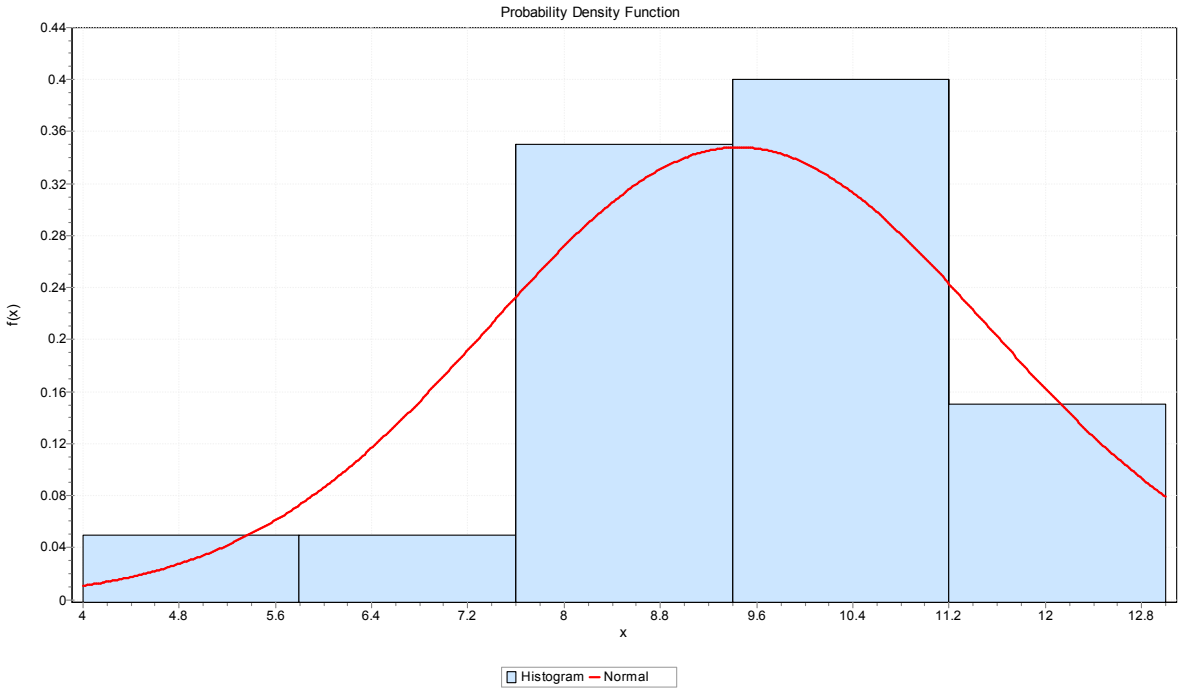


Fig .4.59: Probability Density Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Normal Distribution)

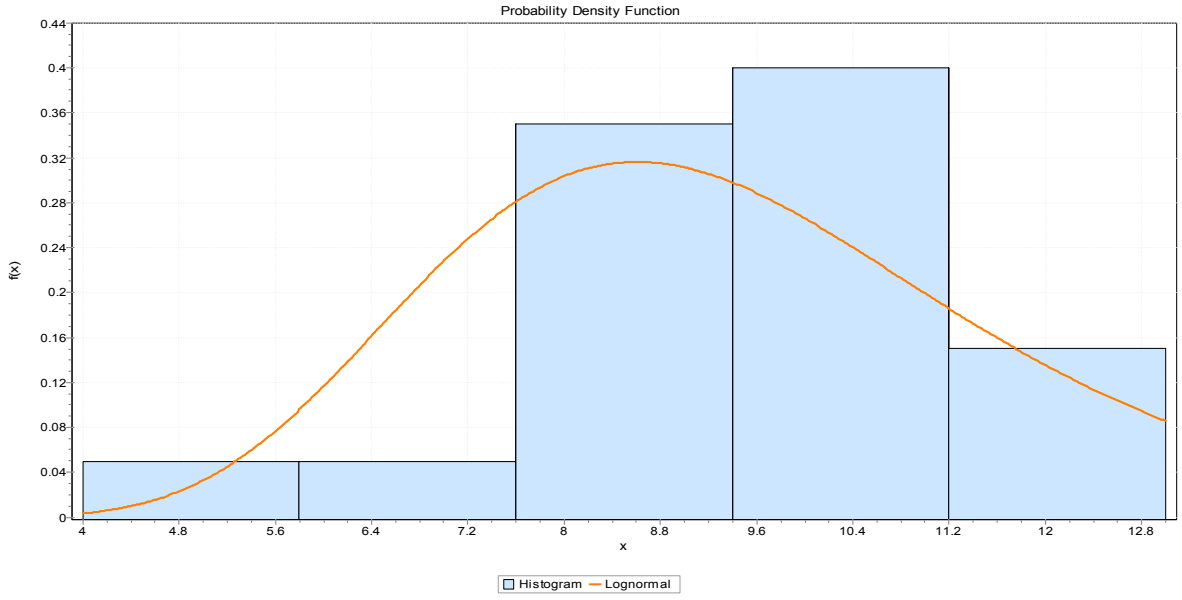


Fig. 4.60: Probability Density Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Lognormal Distribution.)

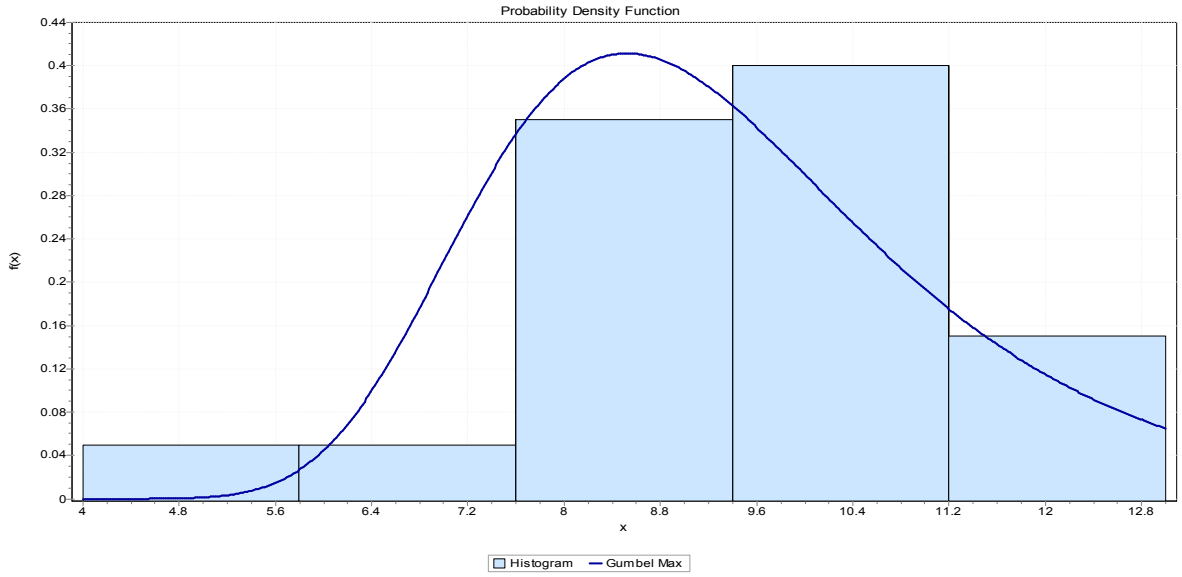


Fig .4.61: Probability Density Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Gumbel Distribution).

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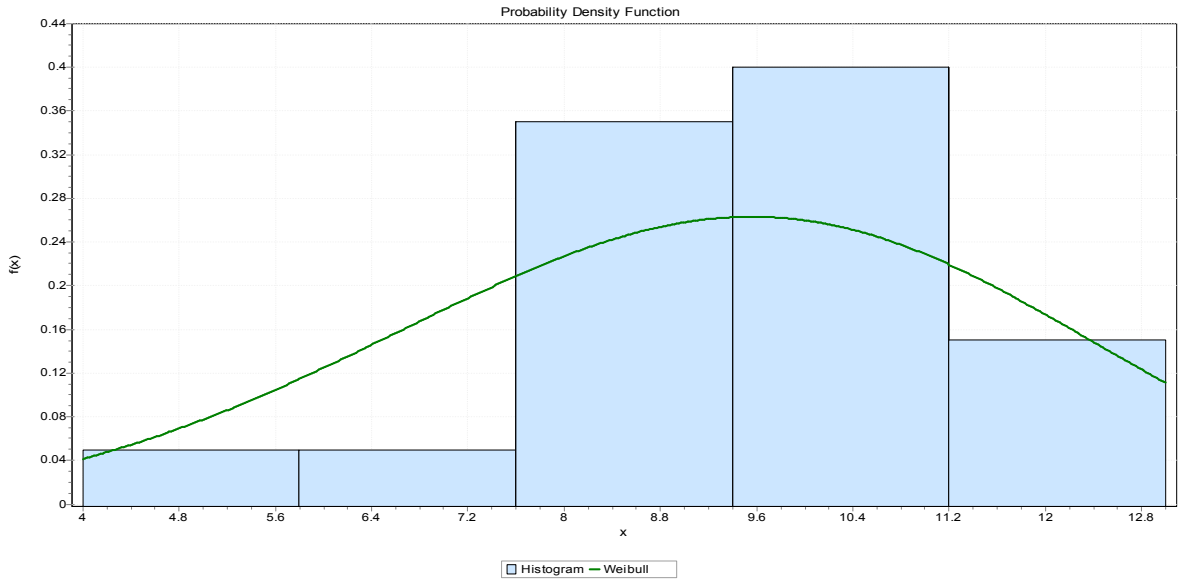


Fig. 4.62: Probability Density Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Weibull Distribution).

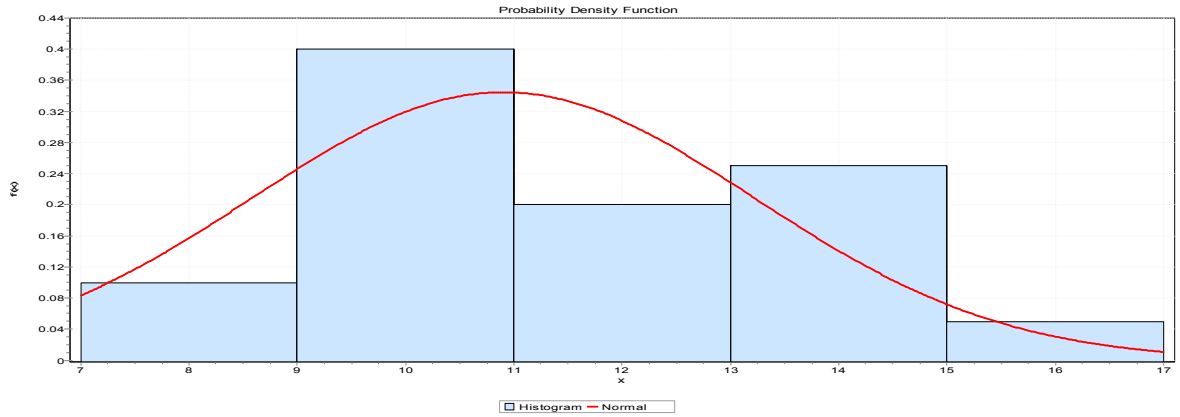


Fig. 4.63: Probability Density Function for *Khaya senegalensis* considering Modulus of Elasticity (Normal Distribution).

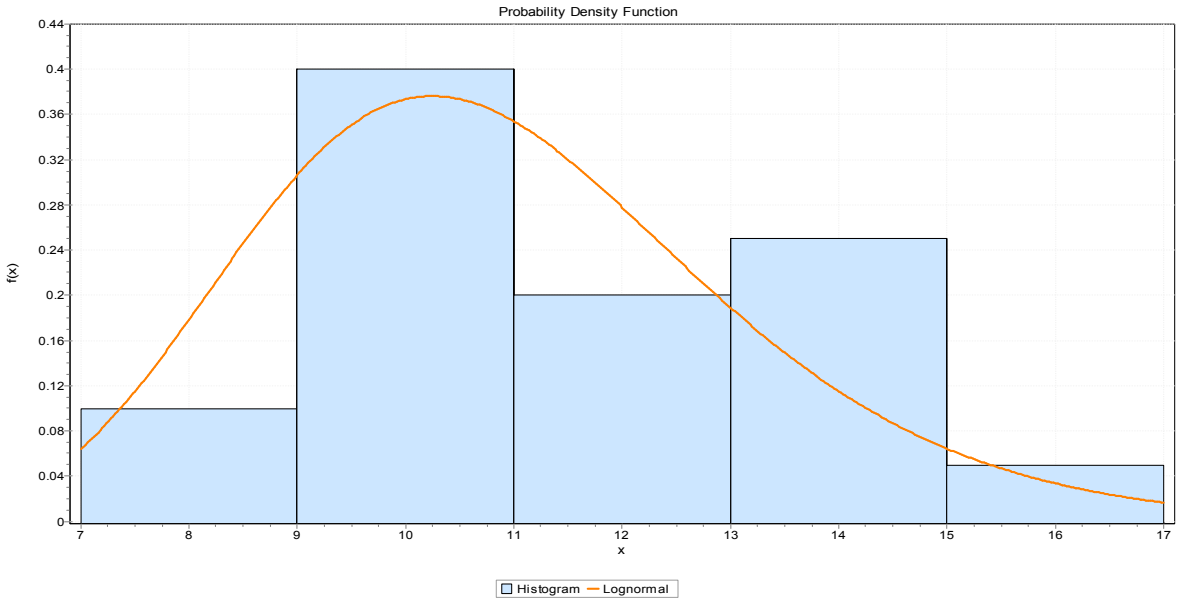


Fig. 4.64: Probability Density Function for *Khaya senegalensis* considering Modulus of Elasticity (Lognormal Distribution).

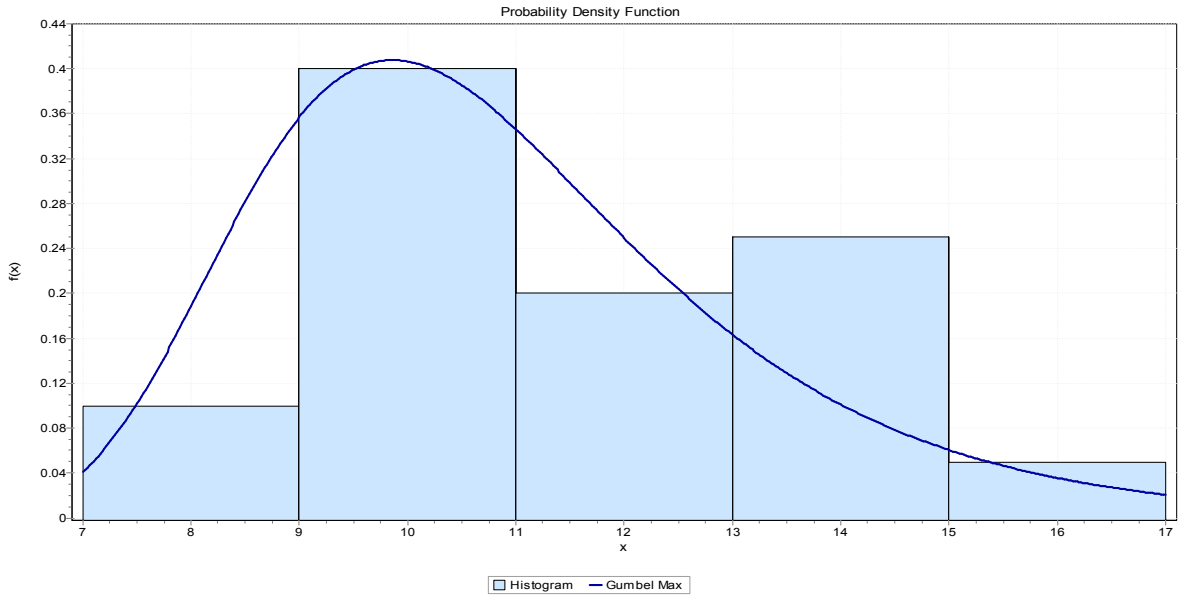


Fig. 4.65: Probability Density Function for *Khaya senegalensis* considering Modulus of Elasticity (Gumbel Distribution).

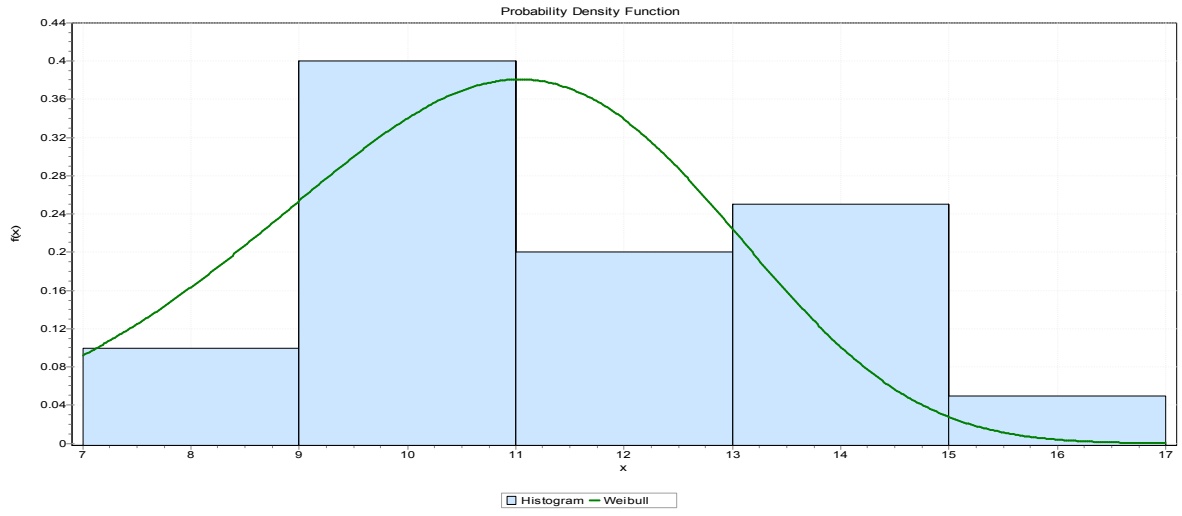


Fig. 4.66: Probability Density Function for *Khaya senegalensis* considering Modulus of Elasticity (Weibull Distribution).

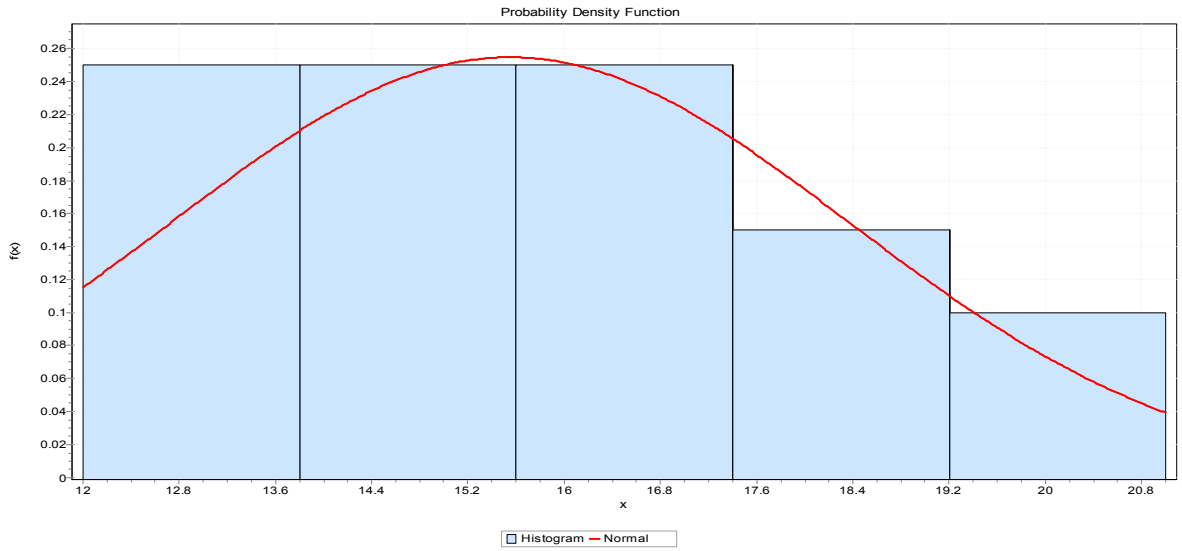


Fig .4.67: Probability Density Function for *Ceiba pentandra* considering Modulus of Elasticity (Normal Distribution).

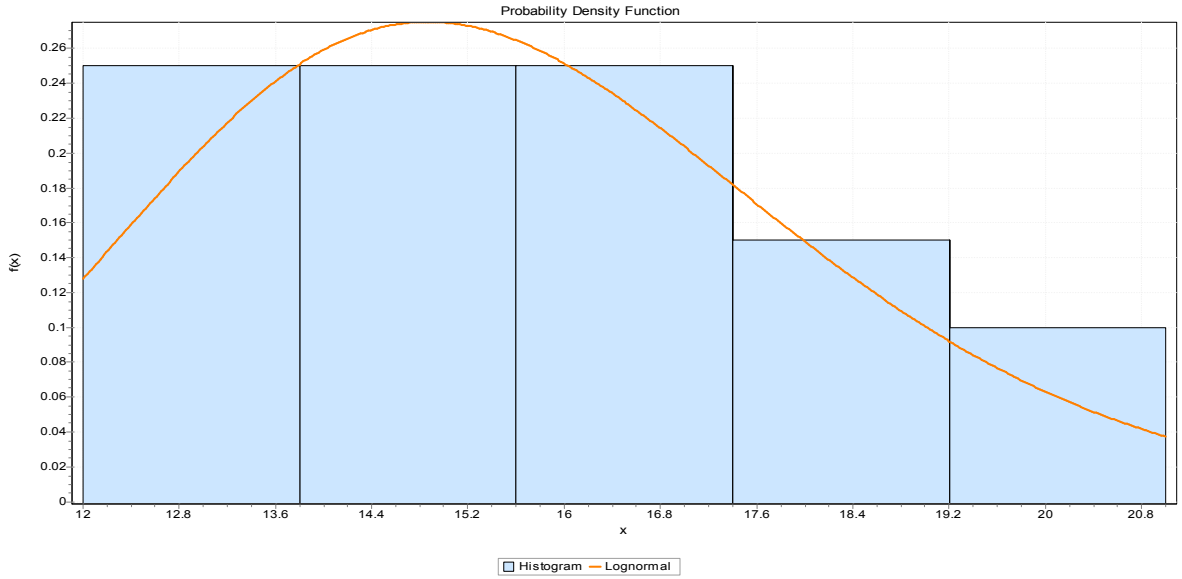


Fig. 4.68: Probability Density Function for *Ceiba pentandra* considering Modulus of Elasticity (Lognormal Distribution).

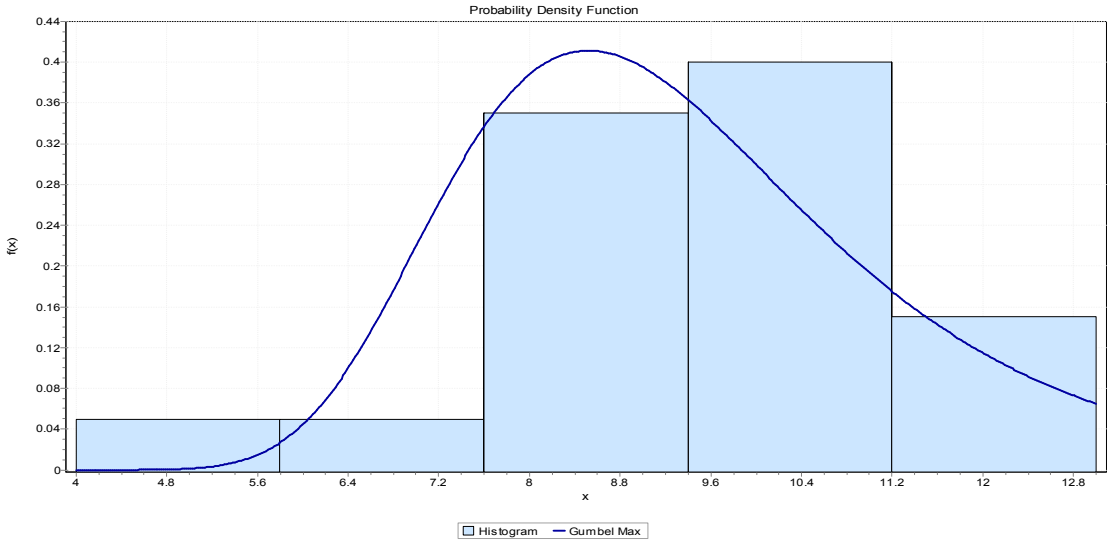


Fig. 4.69: Probability Density Function for Ceiba pentandra considering Modulus of Elasticity (Gumbel Distribution).

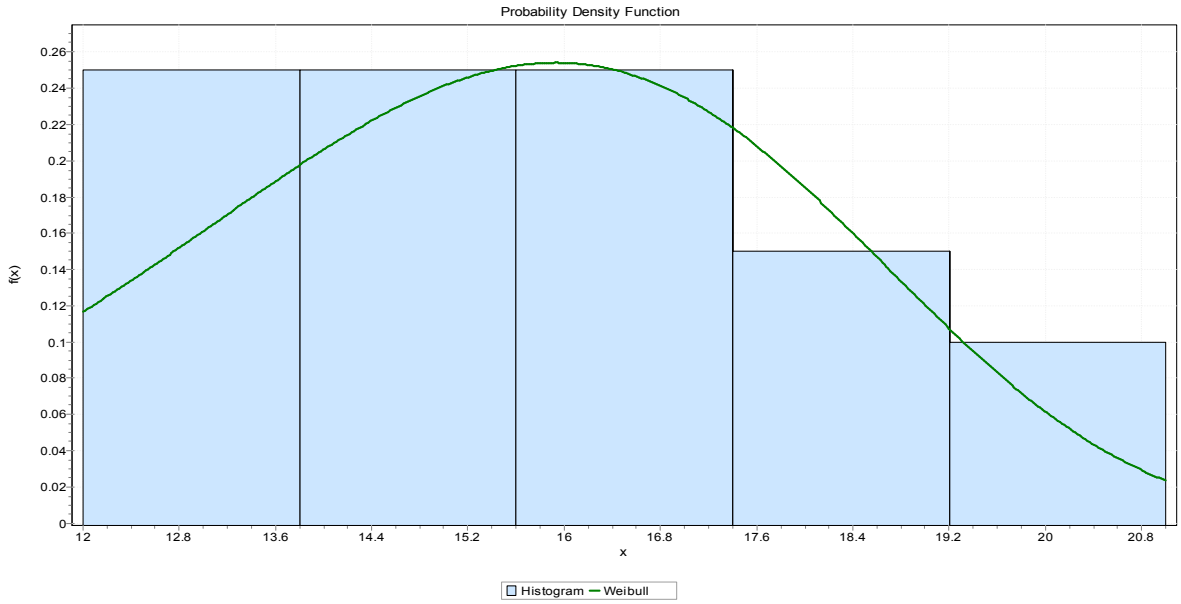


Fig. 4.70: Probability Density Function for *Ceiba pentandra* considering Modulus of Elasticity (Weibull Distribution).

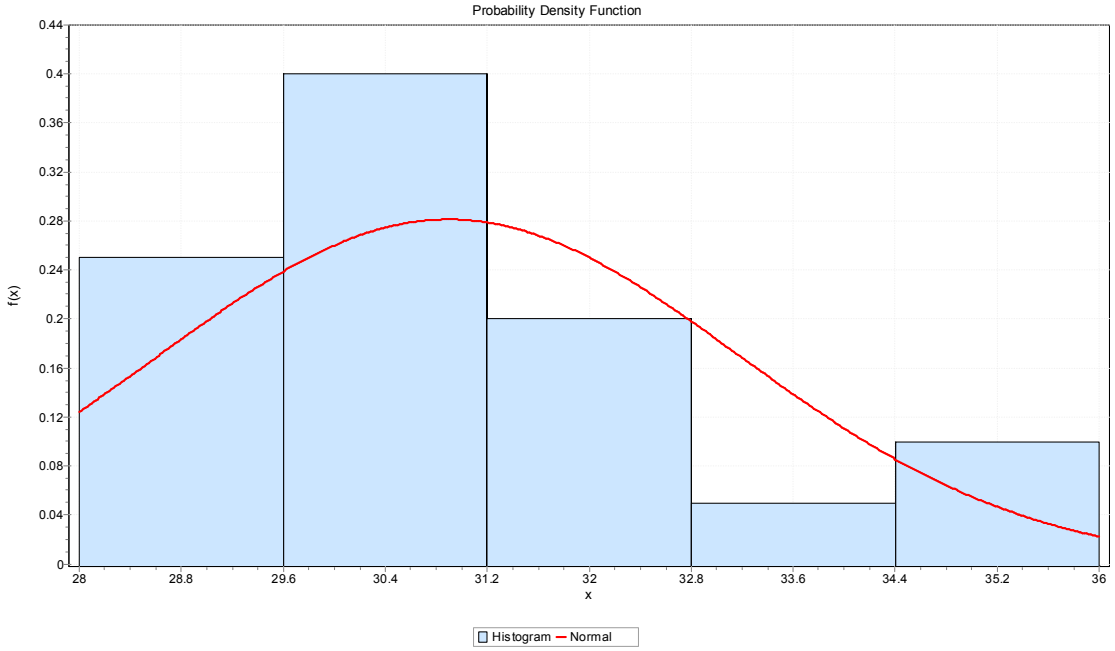


Fig .4.71: Probability Density Function for *Daniellia oliveri* **considering Modulus of Elasticity** (Normal Distribution).

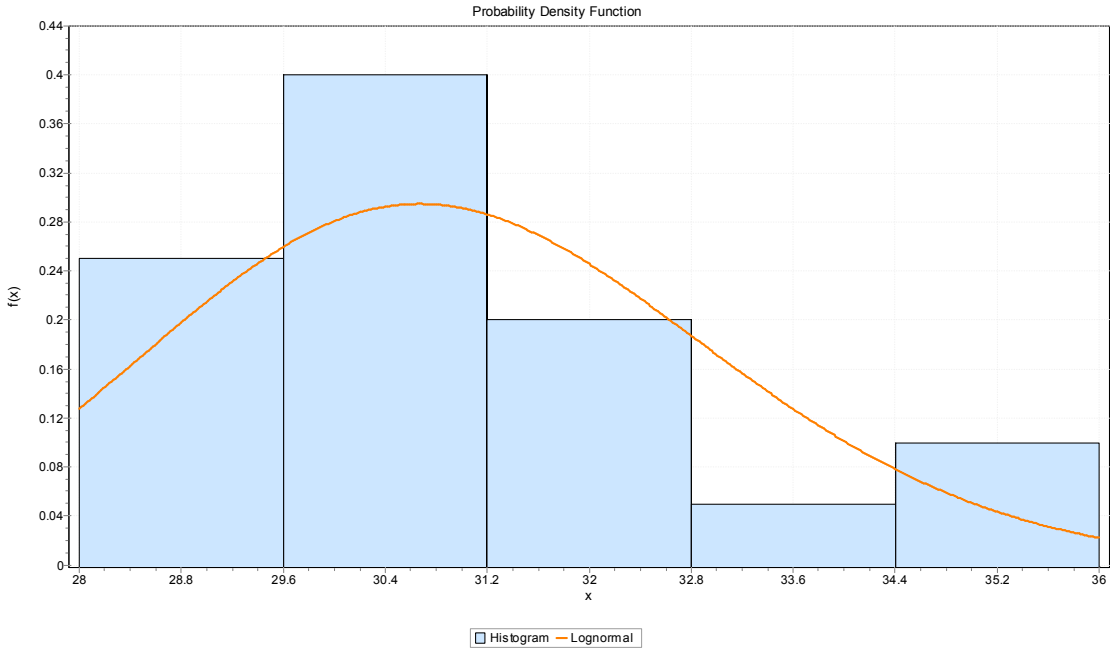


Fig .4.72: Probability Density Function for *Daniellia oliveri* **considering Modulus of Elasticity** *(*Logormal Distribution).

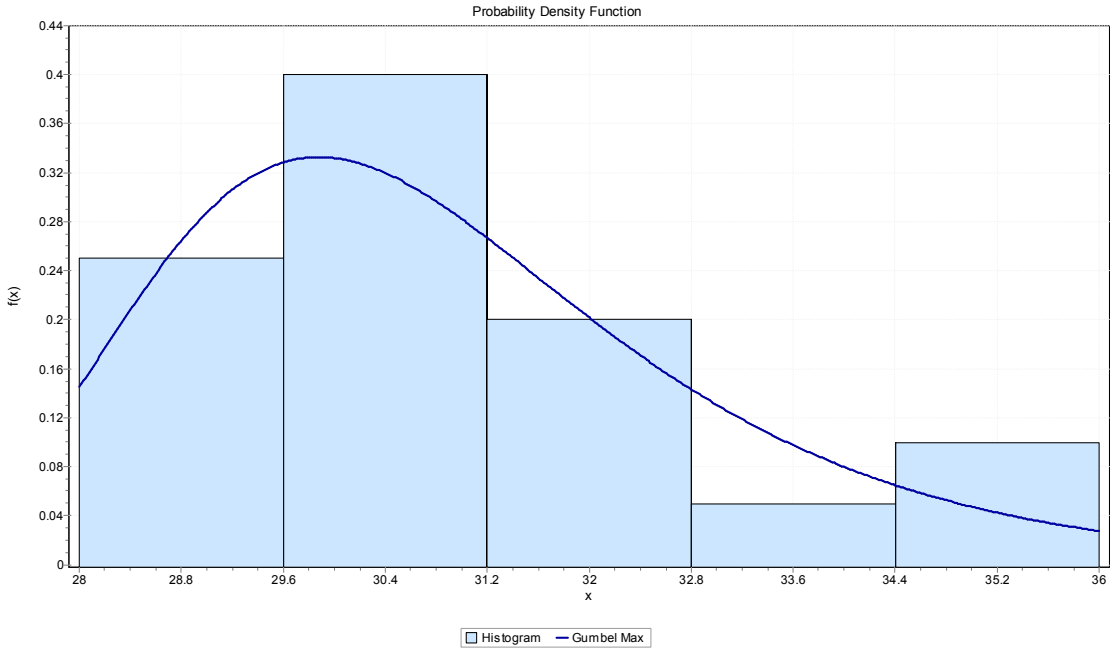


Fig. 4.73: Probability Density Function for *Daniellia oliveri* **considering Modulus of Elasticity** (GumbelDistribution).

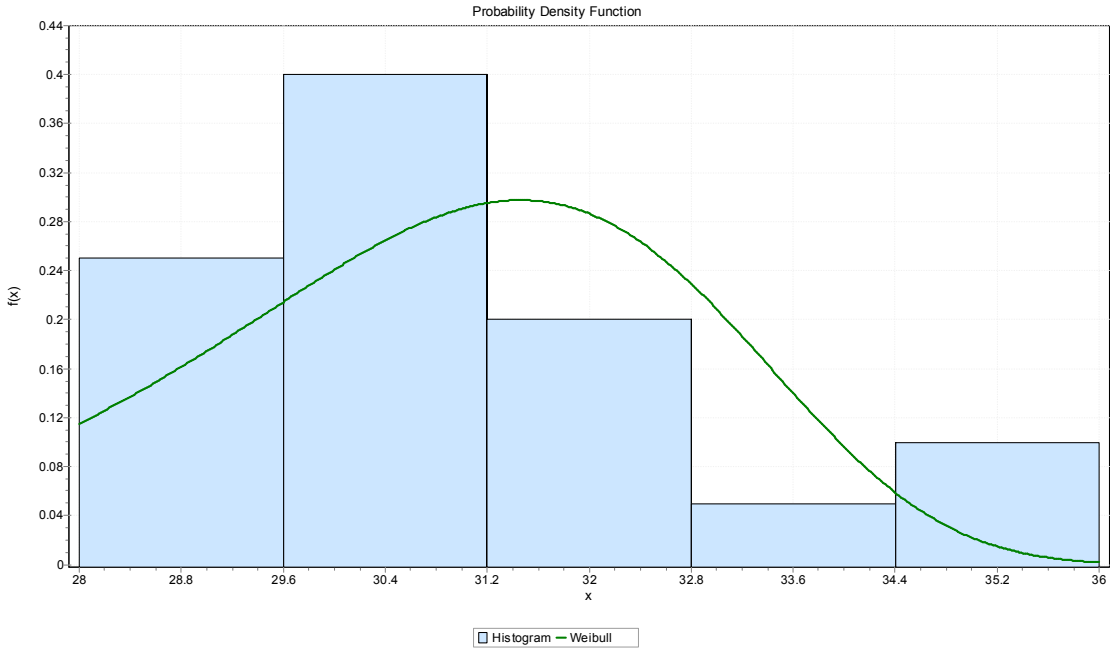


Fig. 4.74: Probability Density Function for *Daniellia oliveri* **considering Modulus of Elasticity** (Weibull Distribution).

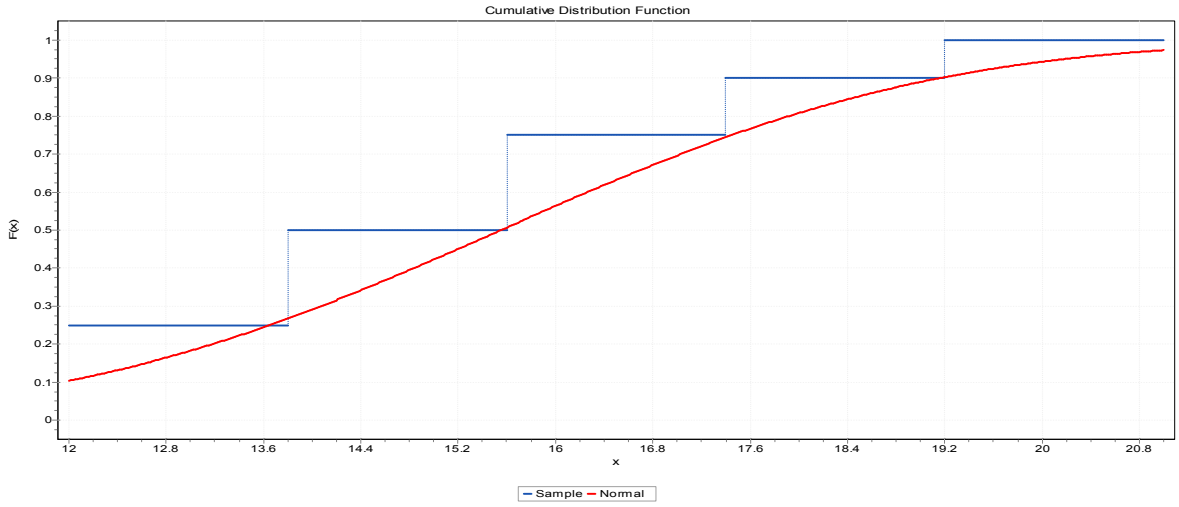


Fig. 4.75: Cumulative Distribution Function for *Ceiba pentandra* considering Modulus of Elasticity (Normal Distribution).

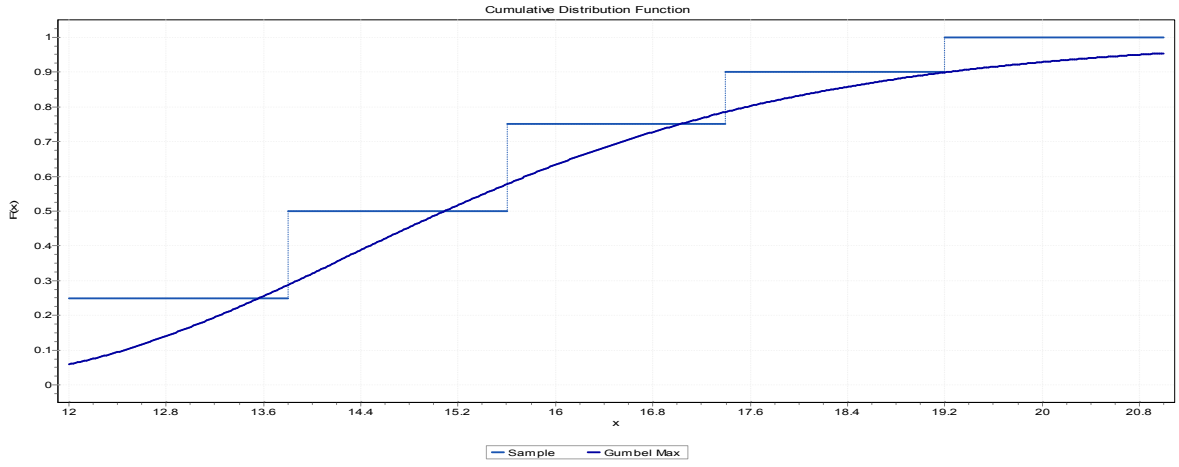


Fig. 4.76: Cumulative Distribution Function for *Ceiba pentandra* considering Modulus of Elasticity (Lognormal Distribution).

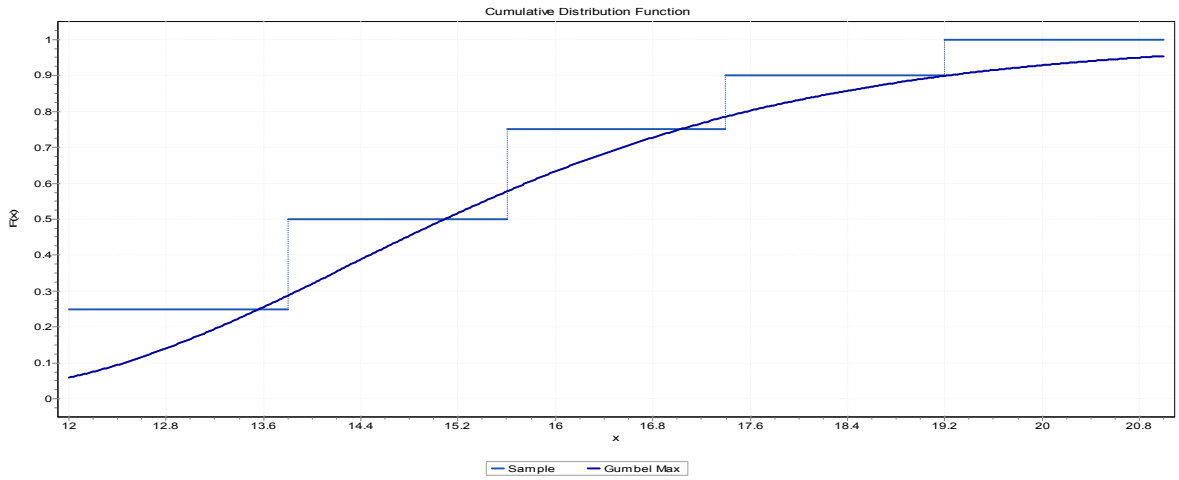


Fig. 4.77 : Cumulative Distribution Function for *Ceiba pentandra* considering Modulus of Elasticity (Gumbel Distribution).

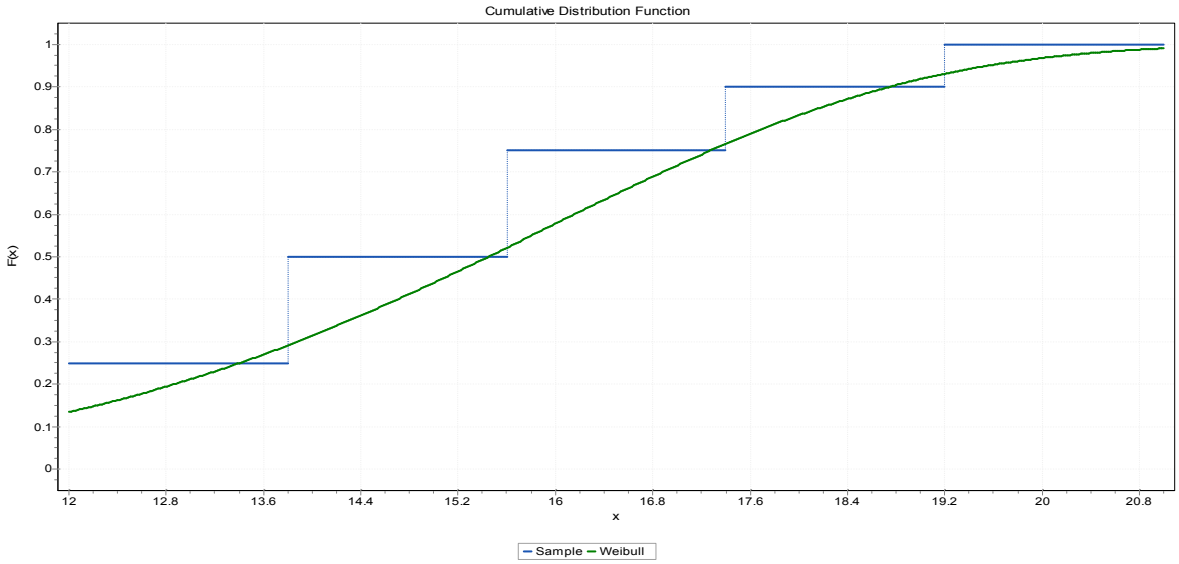


Fig .4.78: Cumulative Distribution Function for *Ceiba pentandra* considering Modulus of Elasticity (Weibull Distribution).

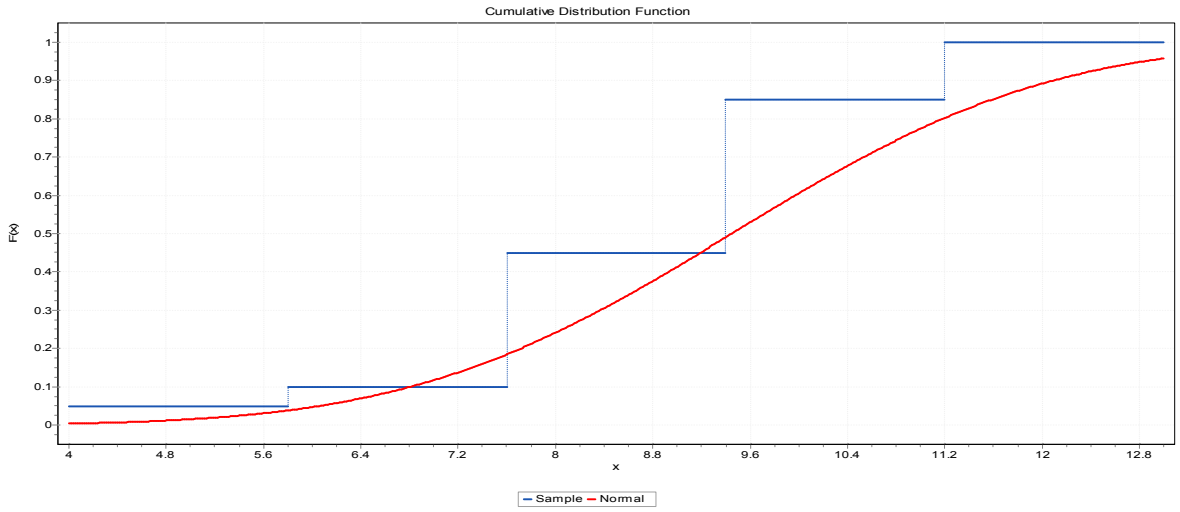


Fig .4.79: Cumulative Distribution Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Normal Distribution).

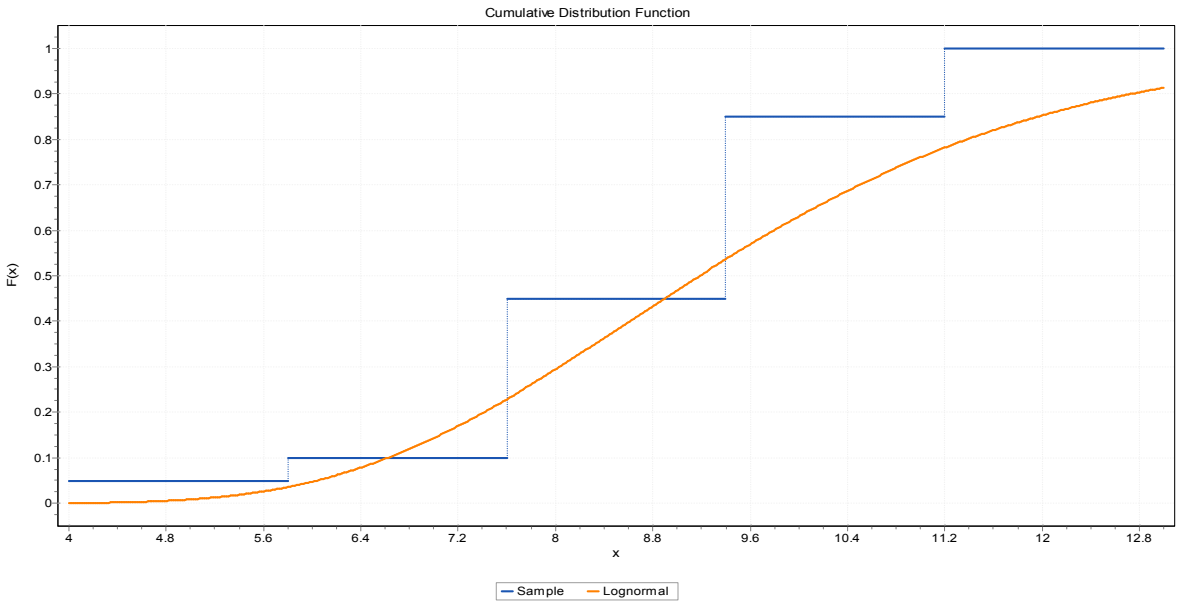


Fig. 4.80: Cumulative Distribution Function for *Chlorophora excelsa* considering Modulus of Elasticity (Lognormal Distribution).

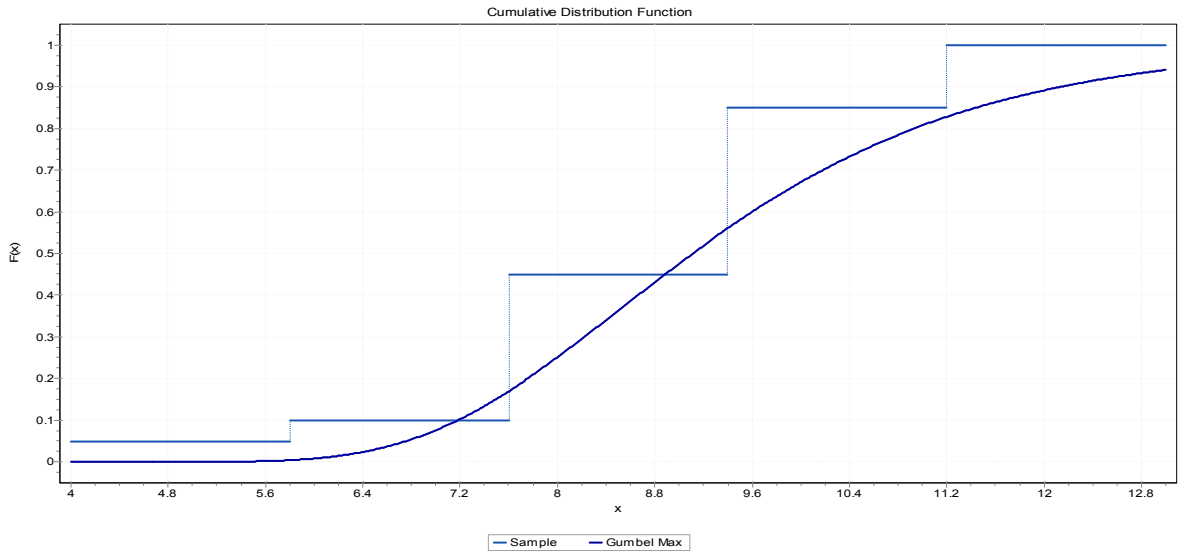


Fig .4.81: Cumulative Distribution Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Gumbel Distribution).

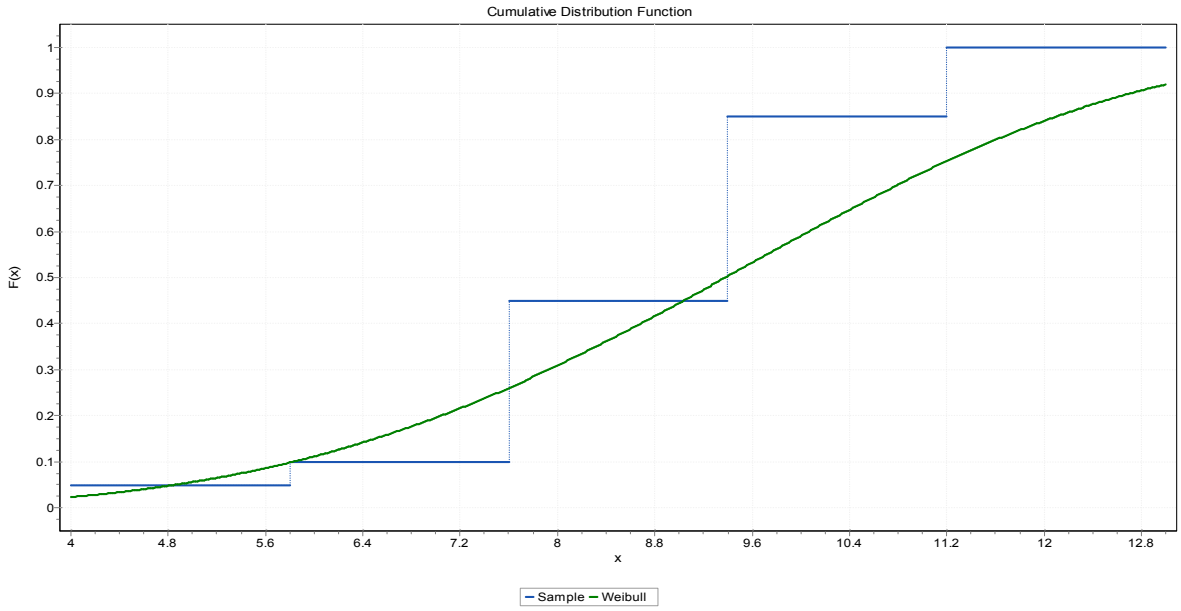


Fig. 4.82: Cumulative Distribution Function for *Chlorophoral excelsa* considering Modulus of Elasticity (Weibull Distribution).

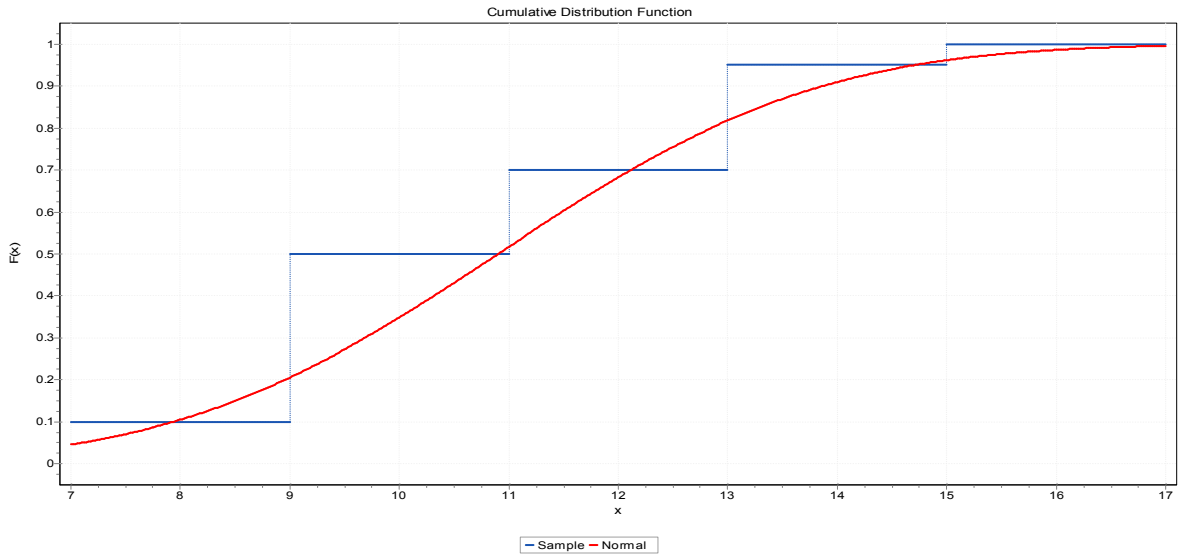


Fig .4.83: Cumulative Distribution Function for *Khaya senegalensis* considering Modulus of Elasticity (Normal Distribution).

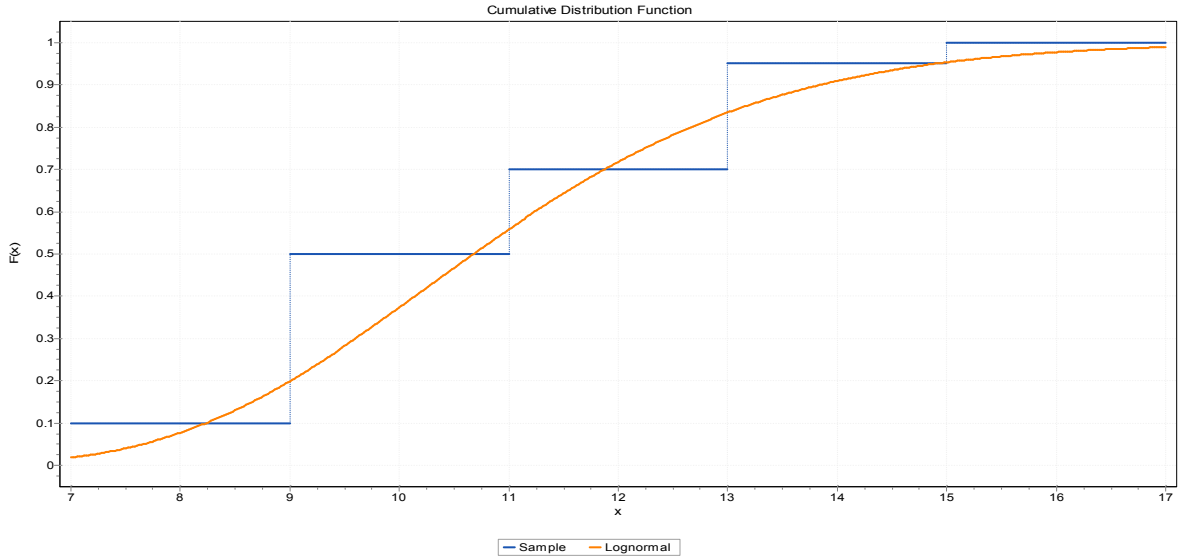


Fig. 4.84: Cumulative Distribution Function for *Khaya senegalensis* considering Modulus of Elasticity (Lognormal Distribution).

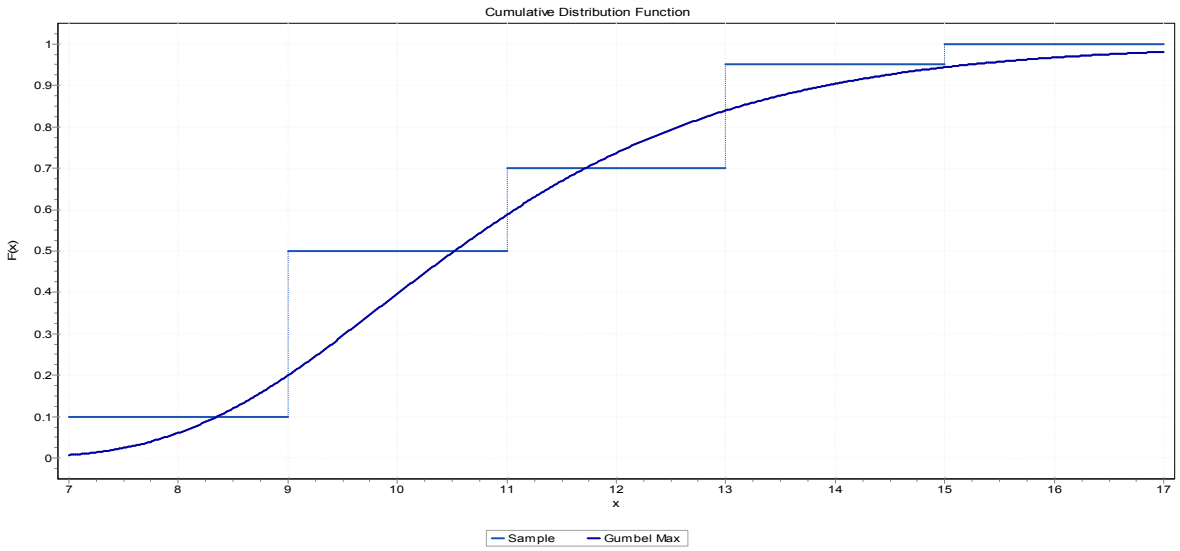


Fig. 4.85: Cumulative Distribution Function for *Khaya senegalensis* considering Modulus of Elasticity (Gumbel Distribution).

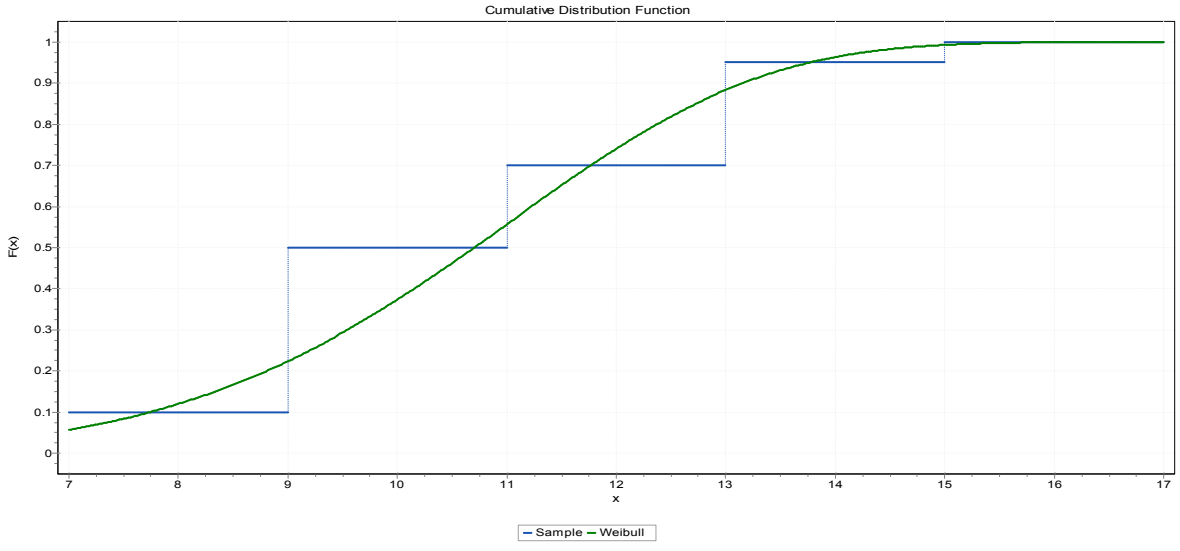


Fig .4.86: Cumulative Distribution Function for *Khaya senegalensis* considering Modulus of Elasticity (Weibull Distribution).

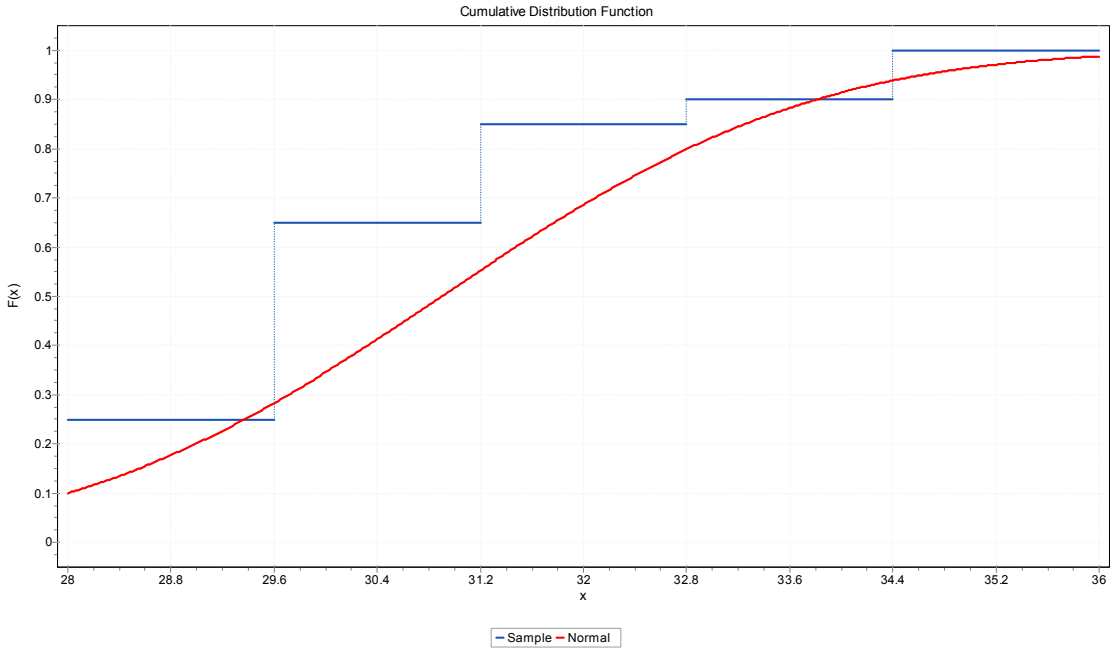


Fig. 4.87: Cumulative Distribution Function for *Daniellia oliveri* considering Modulus of Elasticity (Normal Distribution).

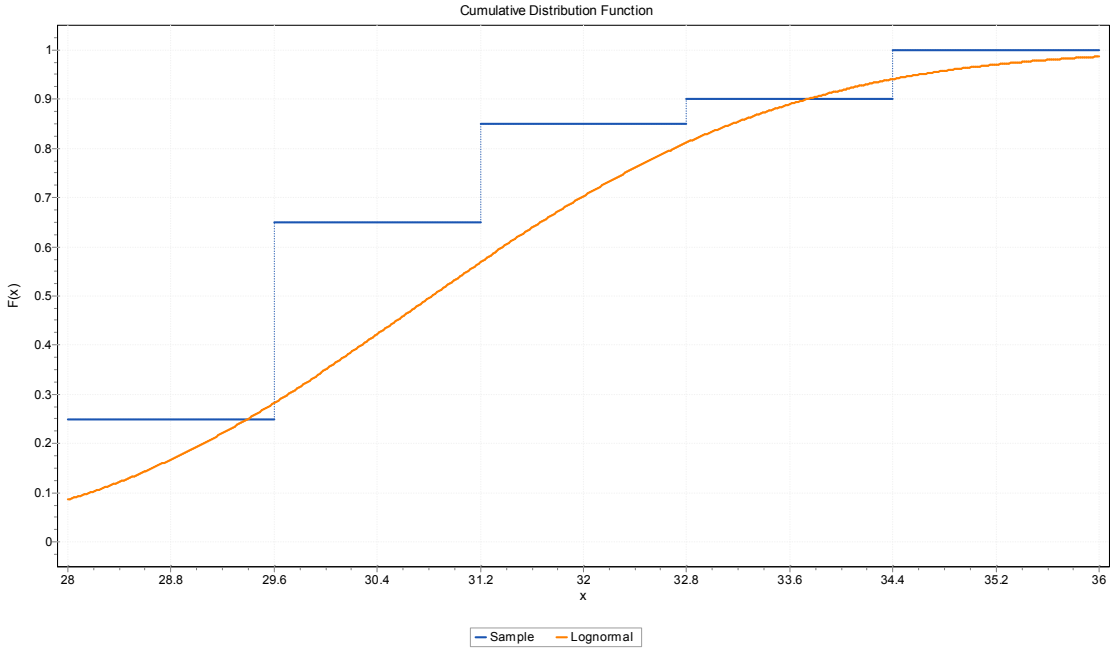


Fig. 4.88: Cumulative Distribution Function for *Daniellia oliveri* considering Modulus of Elasticity *(*Lognormal Distribution)

4.3 STRENGTH CLASSIFICATION OF THE SPECIES

The strength grade classification identified in BS5268 part 2 (2002) Structural use of timber classified timber into two groups

a. C14 to C40 for coniferous - soft wood
b. D30 to D70 for deciduous - hard wood

The strength classification conducted in the current work is in accordance with EN384 (2008)

Table 1 of the EN384 was used in conjunction with results presented in Table 4.5. The following is the classification of the species:

Chlorophoral ecxelsa with the mean modulus of elasticity of 9,899.32 N/mm^2, mean bending strength of 74.76N/mm^2 $and\ density\ of 474.95 kg/m^3$ was assigned to strength Class D70.

Khaya senegalensis with the mean modulus of elasticity of 8,944.01N/mm^2, mean bending strength of 80.64$N/mm^2 and\ density\ of\ 800.21 kg/m^3$ was assigned to strength Class D70 .

Daniellia oliveri with the mean modulus of elasticity of 6,865.87 N/mm^2, mean bending strength of 57.6N/mm^2 and density of 509.01kg/m^3 was assigned to strength Class D50.

Ceiba pentandra was assigned to strength class C40 with modulus of elasticity 4,423.64 N/mm^2, bType equation here.ending strength of 41.16N/mm^2 $and\ density$ of 300.78 kg/m^3.

The European strength classification system EN338 (2008), defines the minimum characteristic bending strength for each strength class. The bending strength of solid timber obtained through equation 5 given by (Ranta Maurus, et al, 2001; EN384 1995).

$$f_{m,k} = 1.12\, f_{0.05} \qquad (4.6)$$

Where $f_{m,k}$ is the characteristic value of bending strength. $f_{0.05}$ is the 5% fractile value of bending strength.

The 5% fractile values (Engineering statistic, 2006) and the characteristic values of bending strength are presented in table 4.7

From Table 4.7: Bending strength is calculated from the result obtained from the laboratory by applying the formula for example Chlorophoral excelsa

Bending strength = $\frac{afmax}{2z}$

$$= \frac{300*15.575*1000}{2*81,260}$$

$$= 74.76 \text{ N}/mm^2$$

From equation (4.6)

$F_{mk} = 1.12F_{0.05}$

$F_{0.05} = F_{mk/1.12}$

$F_{0.05} = \frac{74.76}{1.12}$

$F_{0.05} = 66.75 \text{ N}/mm^2$

Table 4.7 : 5% fractile values and characteristic strength of bending strength

Test Method	*Clorophoral excelsa*		*Khaya senegalensis*		*Ceiba pentandra*		*Daniellia oliveri*	
	$f_{0.05}$ N/mm^2	f_k N/mm^2	$f_{0.05}$ N/mm^2	f_k N/mm^2	$f_{0.05}$ N/mm^2	f_k N/mm^2	$f_{0.05}$ N/mm^2	f_k N/mm^2
4 point Bending	66.75	74.76	72.00	80.64	36.75	41.16	51.43	57.6

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSSION

The statistical models of the grade determining properties (density , modulus of elasticity and bending strength) of four selected Nigerian timber species: *Chlorophoral excelsa, Khaya senegalensis, Ceiba pentandra and Daniellia oliveri* were generated from three- point and four - point bending tests as well as the oven dry method for the density and moisture content.

The generated statistical models include the means, standard deviations, coefficient of variations and theoretical distributions. These are the necessary inputs for the reliability analysis and design of engineering structures.

Chlorophoral ecxelsa, was assigned to strength class D70, *Khaya senegalensis* was assigned to strength class D70, *Daniellia oliveri* was assigned to strength class D50 and *Ceiba pentandra* was assigned to strength class C40.

5.2 RECOMMENDATIONS

Based on the finding of this research work, the following recommendation can be made.

1. The four (4) classified Nigerian timber species are reliable structural materials that can be used based for structural design using Eurocode 5 (2004).
2. NCP2 (1973) is recommended for revision in order to adopt the recent timber design methodology for all Nigerian timbers.

3. Assigned statistical distribution models are also recommended for use in timber structural reliability analysis.

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APPENDIX A

Table 1 MOISTURE CONTENT FOR *Chlorophoral excelsa.*

Dimension of timber specimen = 60 mm X 40 mm X 40 mm

S/N0	Identification Mark	Initial Weight (g)	Oven Dried Weight (g)	Weight of Moisture (g)	Moisture content (%)
1	Iroko B1	54	46.1	7.9	17.14
2	Iroko B2	54	46.0	8.0	17.39
3	Iroko B3	55	47.0	8.0	17.22
4	Iroko B4	54	46.1	7.9	17.14
5	Iroko B5	51	43.0	8.0	18.60
6	Iroko B6	51	43.0	8.0	18.60
7	Iroko B7	51	43.0	8.0	18.60
8	Iroko B8	54	46.1	7.9	17.14
9	Iroko B9	52	43.9	8.1	18.45
10	Iroko B10	57	48.1	8.9	18.50
11	Iroko B11	55	47.0	8.0	17.02
12	Iroko B12	54	46.0	8.0	17.39
13	Iroko B13	55	46.8	8.2	17.52
14	Iroko B14	55	46.9	8.1	17.27
15	Iroko B15	55	46.9	8.1	17.27
16	Iroko B16	54	46.0	8.0	17.39
17	Iroko B17	55	46.8	8.2	17.52

18	Iroko B18	54	46.0	8.0	17.39
19	Iroko B19	51	43.0	8.0	18.60
20	Iroko B20	54	45.9	8.1	17.65

Table 2 MOISTURE CONTENT FOR *Khaya senegalensis.*

Dimension of timber specimen = 60 mm X 40 mm X 40 mm

S/N0	Identification Mark	Initial Weight (g)	Oven Dried Weight (g)	Weight of Moisture (g)	Moisture content (%)
1	Mahogany A1	85	70.4	14.6	20.74
2	Mahogany A2	90	75.2	14.8	19.68
3	Mahogany A3	87	73.2	13.8	18.85
4	Mahogany A4	98	81.8	16.2	19.80
5	Mahogany A5	85	70.6	14.4	20.40
6	Mahogany A6	80	66.2	13.8	20.85
7	Mahogany A7	80	66.9	13.1	19.58
8	Mahogany A8	100	83.3	16.7	20.05
9	Mahogany A9	95	79.4	15.6	19.65
10	Mahogany A10	95	79.2	15.8	19.95
11	Mahogany A11	85	70.9s	14.1	19.89
12	Mahogany A12	90	75.2	14.8	19.68
13	Mahogany A13	97	81.1	15.9	19.61
14	Mahogany A14	87	72.2	14.8	20.50
15	Mahogany A15	91	76.9	14.1	18.34
16	Mahogany A16	90	75.4	14.6	19.36
17	Mahogany A17	95	78.3	16.7	21.33
18	Mahogany A18	92	75.8	16.2	21.37
19	Mahogany A19	96	79.3	16.7	21.06
20	Mahogany A20	92	75.8	16.2	21.37

Table 3 MOISTURE CONTENT FOR *Ceiba pentandra*.

Dimension of timber specimen = 60 mm X 40 mm X 40 mm

S/N0	Identification Mark	Initial Weight (g)	Oven Dried Weight (g)	Weight of Moisture (g)	Moisture content (%)
1	Araba C1	31	25.8	5.2	20.16
2	Araba C2	37	30.8	6.2	20.13
3	Araba C3	37	30.9	6.1	19.74
4	Araba C4	38	31.5	6.5	20.63
5	Araba C5	32	26.5	5.4	20.30
6	Araba C6	31	25.9	5.1	19.61
7	Araba C7	35	29.4	5.6	19.25
8	Araba C8	31	25.8	5.2	20.16
9	Araba C9	35	29.5	5.5	18.64
10	Araba C10	35	29.4	5.6	19.05
11	Araba C11	35	29.6	5.4	18.24
12	Araba C12	35	29.5	5.5	18.64
13	Araba C13	35	29.5	5.5	18.64
14	Araba C14	36	30.3	5.7	18.81
15	Araba C15	36	30.2	5.8	19.21
16	Araba C16	36	30.2	5.8	19.21
17	Araba C17	35	29.5	5.5	18.64

18	Araba C18	31	25.9	5.1	19.69
19	Araba C19	32	26.8	5.2	19.40
20	Araba C20	35	29.6	5.4	18.24

Table 4 MOISTURE CONTENT FOR *Daniellia oliveri*.

Dimension of timber specimen = 60 mm X 40 mm X 40 mm

S/N0	Identification Mark	Initial Weight (g)	Oven Dried Weight (g)	Weight of Moisture (g)	Moisture content (%)
1	Maje D1	54.6	45.4	9.2	20.26
2	Maje D2	61.3	50.9	10.4	20.43
3	Maje D3	53.6	44.6	9.0	20.18
4	Maje D4	55.6	46.2	9.4	20.35
5	Maje D5	66.2	55.1	11.10	20.15
6	Maje D6	57.7	48.3	9.4	19.46
7	Maje D7	54.9	45.7	9.2	20.13
8	Maje D8	55.0	45.7	9.3	20.35
9	Maje D9	59.9	49.8	10.1	20.28
10	Maje D10	58.2	48.4	9.8	20.25
11	Maje D11	67.0	55.8	11.2	20.07
12	Maje D12	55.6	46.3	9.3	20.09
13	Maje D13	59.4	49.4	10.0	20.24
14	Maje D14	60.2	50.0	10.2	20.40
15	Maje D15	50.0	41.5	8.5	20.48
16	Maje D16	58.8	49.0	9.8	20.00
17	Maje D17	66.7	55.5	11.2	20.18
18	Maje D18	51.0	42.4	8.6	20.28
19	Maje D19	53.2	44.3	8.9	20.09
20	Maje D20	56.8	47.2	9.6	20.34

Table 5 DENSITY *(Chlorophoral excelsa* 60 mm X 40 mm X 40 mm)

S/NO	IDENTIFICATION MARK	INITIAL WEIGHT (g)	OVEN DRIED WEIGHT (g)	VOLUME OF SPECIMEN cm^3	DENSITY Kg/m^3
1	Iroko B1	57	48.3	96000	503.13
2	Iroko B2	55	47.2	96000	491.67
3	Iroko B3	54	46.1	96000	480.21
4	Iroko B4	54	46.0	96000	479.17
5	Iroko B5	51	43.0	96000	447.92
6	Irloko B6	51	42.9	96000	446.88
7	Iroko B7	51	43.0	96000	446.88
8	Iroko B8	52	43.8	96000	456.25
9	Iroko B9	55	47.0	96000	489.58
10	Iroko B10	54	46.1	96000	480.21
11	Iroko B11	52	43.9	96000	457.29
12	Iroko B12	53	45.1	96000	469.79
13	Iroko B13	55	47.1	96000	490.63
14	Iroko 14	55	47.2	96000	491.67
15	Iroko B15	54	46.0	96000	479.17
16	Iroko B16	51	43.1	96000	448.96
17	Iroko B17	54	46.0	96000	479.17
18	Iroko B18	54	46.1	96000	480.21
19	Iroko B19	55	47.0	96000	489.58
20	Iroko B20	55	47.1	96000	490.63

Table 6 DENSITY *(Khaya senegalensis* 60 mm X 40 mm X 40 mm)

S/NO	IDENTIFICATION MARK	INITIAL WEIGHT (g)	OVEN DRIED WEIGHT (g)	VOLUME OF SPECIMEN cm^3	DENSITY Kg/m^3
1	Mahogany A1	86	72.9	96000	759.38
2	Mahogany A2	89	75.9	96000	790.63
3	Mahogany A3	87	73.6	96000	766.67
4	Mahogany A4	90	76.9	96000	801.04
5	Mahogany A5	85	71.9	96000	748.96
6	Mahogany A6	80	66.9	96000	696.88
7	Mahogany A7	86	72.9	96000	759.38
8	Mahogany A8	95	81.4	96000	847.92
9	Mahogany A9	95	81.0	96000	843.75
10	Mahogany A10	95	81.5	96000	848.96
11	Mahogany A11	86	73.9	96000	769.79
12	Mahogany A12	89	75.8	96000	789.58
13	Mahogany A13	95	80.1	96000	834.38
14	Mahogany A14	88	74.2	96000	772.92
15	Mahogany A15	90	77.9	96000	811.45
16	Mahogany A16	90	76.2	96000	793.75
17	Mahogany A17	94	82.3	96000	857.29
18	Mahogany A18	92	78.7	96000	819.79
19	Mahogany A19	96	82.3	96000	857.29
20	Mahogany A20	93	80.1	96000	834.38

Table 7 DENSITY *(Ceiba pentandra* 60mm X 40mm X 40mm)

S/NO	IDENTIFICATION MARK	INITIAL WEIGHT (GRAMS)	OVEN DRIED WEIGHT (GRAMS)	VOLOME OF SPECIMEN cm^3	DENSITY Kg/m^3
1	Araba C1	31	28.8	96000	300.00
2	Araba C2	37	32.4	96000	337.50
3	Araba C3	37	33.9	96000	353.13
4	Araba C4	38	33.4	96000	347.92
5	Araba C5	32	28.8	96000	300.00
6	Araba C6	31	28.0	96000	291.67
7	Araba C7	35	30.7	96000	319.79
8	Araba C8	31	28.3	96000	294.79
9	Araba C9	35	31.0	96000	322.92
10	Araba C10	35	31.7	96000	330.21
11	Araba C11	35	30.6	96000	318.75
12	Araba C12	35	32.0	96000	333.33
13	Araba C13	35	32.7	96000	340.63
14	Araba C14	36	32.3	96000	336.46
15	Araba C15	36	32.2	96000	335.42
16	Araba C16	36	32.0	96000	333.33
17	Araba C17	35	30.0	96000	312.50
18	Araba C18	31	29.7	96000	309.38
19	Araba C19	32	29.8	96000	310.42
20	Araba C20	35	29.7	96000	309.38

Table 8 DENSITY (*Daniellia oliveri* 60mm X 40mm X 40mm)

S/NO	IDENTIFICATION MARK	INITIAL WEIGHT (GRAMS)	OVEN DRIED WEIGHT (GRAMS)	VOLOME OF SPECIMEN cm^3	DENSITY Kg/m^3
1	Maje D1	74	42.7	96000	444.79
2	Maje D2	94	52.5	96000	546.88
3	Maje D3	95	54.4	96000	566.67
4	Maje D4	84	48.2	96000	502.08
5	Maje D5	83	46.7	96000	486.46
6	Maje D6	94	52.3	96000	544.79
7	Maje D7	85	46.8	96000	487.50
8	Maje D8	90	44.9	96000	467.71
9	Maje D9	95	56.1	96000	584.38
10	Maje D10	92	48.5	96000	505.21
11	Maje D11	81	48.3	96000	503.13
12	Maje D12	82	44.7	96000	465.63
13	Maje D13	88	46.3	96000	482.29
14	Maje D14	92	50.2	96000	522.92
15	Maje D15	96	53.1	96000	553.13
16	Maje D16	100	50.8	96000	529.17
17	Maje D17	90	50.3	96000	523.96
18	Maje D18	95	50.4	96000	525.00
19	Maje D19	84	48.1	96000	500.00
20	Maje D20	68	42.1	96000	438.54

Table 9 THREE - POINT BENDING TEST (*Chlorophoral excelsa)*

S/N0	Identification Mark	Failure Load (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Iroko B1	10	12	20	30	2	4	6
2	Iroko B2	11	16	26	36	2	4	6
3	Iroko B3	11	14	22	29	2	4	6
4	Iroko B4	11	9	16	26	2	4	6
5	Iroko B5	10	12	20	30	2	4	6
6	Iroko B6	10	12	19	29	2	4	6
7	Iroko B7	9.5	9	16	24	2	4	6
8	Iroko B8	13.5	10	15	22	2	4	6
9	Iroko B9	8.5	12	20	28	2	4	6
10	Iroko B10	11	9	17	26	2	4	6
11	Iroko B11	10	12	17	25	2	4	6
12	Iroko B12	10	12	20	30	2	4	6
13	Iroko B13	11	13	22	29	2	4	6
14	Iroko B14	13.5	10	15	20	2	4	6
15	Iroko B15	10	12	19	28	2	4	6
16	Iroko B16	9.5	13	22	34	2	4	6
17	Iroko B17	8.5	12	22	31	2	4	6
18	Iroko	11	11	19	27	2	4	6

	B18							
19	Iroko B19	13.5	10	15	23	2	4	6
20	Iroko B20	10	13	20	30	2	4	6

Table 10 THREE - POINT BENDING TEST *(Khaya senegalensis)*

S/N0	Identification Mark	Failure Load (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Mahogany A1	12	11	18	24	2	4	6
2	Mahogany A2	10	13	22	31	2	4	6
3	Mahogany A3	10	13	24	33	2	4	6
4	Mahogany A4	11	10	19	25	2	4	6
5	Mahogany A5	16	7	13	20	2	4	6
6	Mahogany A6	12	12	18	23	2	4	6
7	Mahogany A7	12.5	8	13	19	2	4	6
8	Mahogany A8	10	13	23	32	2	4	6
9	Mahogany A9	8	17	26	.33	2	4	6
10	Mahogany A10	10	14	24	36	2	4	6
11	Mahogany A11	11	10	17	22	2	4	6
12	Mahogany A12	8	20	33	43	2	4	6
13	Mahogany A13	13	10	16	22	2	4	6
14	Mahogany A14	12	13	19	25	2	4	6
15	Mahogany A15	9	15	24	32	2	4	6
16	Mahogany A16	9	16	26	34	2	4	6
17	Mahogany A17	12	13	20	28	2	4	6
18	Mahogany A18	10	12	20	29	2	4	6
19	Mahogany A19	11	10	18	23	2	4	6
20	Mahogany A20	12.5	10	19	28	2	4	6

Table 11 THREE - POINT BENDING TEST (*Ceiba Pentandra)*

S/N0	Identification Mark	Failure Load (kN)	Deflection1 1 (mm)	Deflection 2 (mm)	Deflectio 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Araba C1	8	16	22	34	2	4	6
2	Araba C2	6	20	34	57	2	4	6
3	Araba C3	6	19	33	56	2	4	6
4	Araba C4	5	16	27	-	2	4	
5	Araba C5	7	16	24	34	2	4	6
6	Araba C6	5	18	29	-	2	4	
7	Araba C7	8	16	23	34	2	4	6
8	Araba C8	6	17	32	52	2	4	6
9	Araba C9	5	18	29	-	2	4	
10	Araba C10	8	14	25	36	2	4	6
11	Araba C11	5	16	34	-	2	4	
12	Araba C12	4.5	15	30	-	2	4	
13	Araba C13	5	19	33	-	2	4	
14	Araba C14	8	14	20	34	2	4	6
15	Araba C15	7	16	24	34	2	4	6
16	Araba C16	8	20	33	43	2	4	6

17	Araba C17	5	17	38	-	2	4	
18	Araba C18	4.5	21	37	-	2	4	
19	Araba C19	5	19	34	-	2	4	
20	Araba C20	8	20	32	41	2	4	6

Table 12 THREE - POINT BENDING TEST (*Daniellia oliveri)*

S/N0	Identification Mark	Failure Load (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Maje D1	15	14	22	33	2	4	6
2	Maje D2	9	16	26	36	2	4	6
3	Maje D3	11	14	22	32	2	4	6
4	Maje D4	15	13	22	29	2	4	6
5	Maje D5	9	16	26	36	2	4	6
6	Maje D6	11	14	22	32	2	4	6
7	Maje D7	15	12	19	28	2	4	6
8	Maje D8	9	16	26	36	2	4	6
9	Maje D9	11	13	21	30	2	4	6
10	Maje D!0	15	11	19	29	2	4	6
11	Maje D11	9	16	26	32	2	4	6
12	Maje D12	11	14	22	32	2	4	6
13	Maje D13	15	14	22	30	2	4	6
14	Maje D14	9	16	21	34	2	4	6
15	Maje D15	11	14	22	31	2	4	6
16	Maje D16	15	11	18	27	2	4	6
17	Maje D17	9	16	23	32	2	4	6
18	Maje D18	11	14	22	32	2	4	6
19	Maje D19	11	13	19	30	2	4	6
20	Maje D20	15	12	19	29	2	4	6

Table 13 FOUR - POINT BENDING TEST (*Chlorophoral excelsa)*

S/N0	Identification Mark	FailureLoad (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Iroko B1	18.5	9	15	20	2	4	6
2	Iroko B2	16.5	10	16	23	2	4	6
3	Iroko B3	16	10	15	22	2	4	6
4	Iroko B4	16	8	16	23	2	4	6
5	Iroko B5	14	10	18	24	2	4	6
6	Iroko B6	18	13	20	23	2	4	6
7	Iroko B7	16	10	15	23	2	4	6
8	Iroko B8	13	12	17	24	2	4	6
9	Iroko B9	18	12	18	22	2	4	6
10	Iroko B10	16	11	16	23	2	4	6
11	Iroko B11	18.5	9	15	20	2	4	6
12	Iroko B12	16.5	9	18	25	2	4	6
13	Iroko B13	16	10	18	25	2	4	6
14	Iroko B14	13	8	16	25	2	4	6
15	Iroko B15	16	10	18	26	2	4	6
16	Iroko B16	14	10	17	24	2	4	6

17	Iroko B17	16	11	19	25	2	4	6
18	Iroko B18	18.5	9	14	20	2	4	6
19	Iroko B19	13	8	16	23	2	4	6
20	Iroko B20	16	10	18	25	2	4	6

Table 14 FOUR - POINT BENDING TEST (*Khaya senegalensis)*

S/N0	Identification Mark	Failure Load (KN)	Deflection1 (0.1) Mm	Deflection2 (0.1) Mm	Deflection3 (0.1) mm	Load 1 (KN)	Load 2 (KN)	Load 3 (KN)
1	Mahogany A1	13	13	21	29	2	4	6
2	Mahogany A2	16	12	20	30	2	4	6
3	Mahogany A3	14	11	15	20	2	4	6
4	Mahogany A4	22	10	18	24	2	4	6
5	Mahogany A5	14	9	14	20	2	4	6
6	Mahogany A6	12	13	19	27	2	4	6
7	Mahogany A7	22	17	25	29	2	4	6
8	Mahogany A8	14	11	20	28	2	4	6
9	Mahogany A9	19	10	20	.30	2	4	6
10	Mahogany A10	22	10	18	25	2	4	6
11	Mahogany A11	21	9	17	24	2	4	6
12	Mahogany A12	14	11	15	20	2	4	6
13	Mahogany A13	22	7	12	29	2	4	6
14	Mahogany A14	13	13	21	29	2	4	6
15	Mahogany A15	21	8	15	20	2	4	6
16	Mahogany A16	19	9	18	26	2	4	6

17	Mahogany A17	12	13	19	.27	2	4	6
18	Mahogany A18	14	9	14	20	2	4	6
19	Mahogany A19	13	13	21	29	2	4	6
20	Mahogany A20	19	10	19	28	2	4	6

Table 15 FOUR - POINT BENDING TEST (*Ceiba pentandra)*

S/N0	Identification Mark	Failure Load (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Araba C1	8	13	25	34	2	4	6
2	Araba C2	9	12	26	36	2	4	6
3	Araba C3	8	19	36	50	2	4	6
4	Araba C4	6	21	40	51	2	4	6
5	Araba C5	10.5	16	32	43	2	4	6
6	Araba C6	11	16	31	38	2	4	6
7	Araba C7	8	14	29	39	2	4	6
8	Araba C8	9	12	27	36	2	4	6
9	Araba C9	8	14	28	37	2	4	6
10	Araba C10	8	14	25	39	2	4	6
11	Araba C11	9	13	25	35	2	4	6
12	Araba C12	8.5	18	34	41	2	4	6
13	Araba C13	8	17	30	43	2	4	6
14	Araba C14	8	18	34	41	2	4	6
15	Araba C15	11	14	27	35	2	4	6

16	Araba C16	8	14	29	. 39	2	4	6
17	Araba C17	10.5	16	32	43	2	4	6
18	Araba C18	6	21	40	51	2	4	6
19	Araba C19	8	17	33	41	2	4	6
20	Araba C20	9	12	26	36	2	4	6

Table 16 FOUR - POINT BENDING TEST (*Daniellia oliveri)*

S/N0	Identification Mark	Failure Load (kN)	Deflection 1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)	Load 1 (kN)	Load 2 (kN)	Load 3 (kN)
1	Maje D1	9	13	21	29	2	4	6
2	Maje D2	12	14	23	35	2	4	6
3	Maje D3	15	13	.22	36	2	4	6
4	Maje D4	12	14	22	34	2	4	6
5	Maje D5	9	13	21	32	2	4	6
6	Maje D6	12	12	21	30	2	4	6
7	Maje D7	15	11	19	28	2	4	6
8	Maje D8	12	14	21	32	2	4	6
9	Maje D9	9	12	20	31	2	4	6
10	Maje D10	12	11	21	30	2	4	6
11	Maje D11	15	11	19	28	2	4	6
12	Maje D12	12	13	22	31	2	4	6
13	Maje D13	9	13	21	32	2	4	6
14	Maje D14	12	12	21	30	2	4	6
15	Maje D15	15	11	19	28	2	4	6
16	Maje D16	12	14	21	32	2	4	6
17	Maje D17	9	12	20	31	2	4	6
18	Maje D18	12	11	21	30	2	4	6
19	Maje D19	15	11	19	28	2	4	6

20	Maje D20	12	13	22	31	2	4	6