International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 23-01-2023, Accepted: 07-02-2023, Published: 25-02-2023
Volume 5, Issue 1, 2023, Page No. 22-26

Non-destructive estimation of leaf area of white teak (*Gmelina arborea* Roxb.) from leaf length and width

Titus Fondo Ambebe[1*], Forba Gillian Zee[2]
[1] Department of Forestry and Wildlife Technology, The University of Bamenda, Bambili, North West Region, Cameroon
[2] Department of Development Studies, Pan African Institute for Development, West Africa, Buea, South West Region, Cameroon

Abstract

Mathematical models constitute a simple and accurate tool for non-destructive determination of leaf area. They have proven to be important in experimental situations where leaf area meters are unaffordable and unavailable. The purpose of this study was to develop a model for predicting leaf area of *Gmelina arborea* from leaf linear dimensions. Intact leaves were collected from trees in the Tubah Upland Forest of the Bamenda Highlands forest in northwest Cameroon. The length (L) and width (W) of each leaf were measured. Leaf area (LA) was determined by counting the number of cells and squares that fell within the boundary of the leaf margin traced on a graph paper. The measurements were subjected to regression analysis with LA as dependent variable and L, W, L×W as independent variable, while adjusting for linear, quadratic, and cubic equations. Goodness-of-fit was evaluated from the coefficient of determination (R^2) and model accuracy was assessed from Relative Root Mean Square Error (RRMSE). Of the three variables and types of polynomial tested, the quadratic regression with W resulted in the highest R^2, indicating that 96% of variation in leaf area is explained by this function. Model accuracy was generally good as demonstrated by values of RRMSE that ranged from 10.22 to 12.40. A plot between predicted and observed leaf areas resulted in a strong significant highly positive fit ($R^2 = 0.92$, $p = 0.00$). It is therefore concluded that the model $LA = -498.47+56.33(W)+1.53(W)^2$ can be applied for an estimation of leaf area in *Gmelina arborea*.

Keywords: *Gmelina arborea*, leaf area, leaf area meter, leaf dimensions, polynomial regression

Introduction

Gmelina arborea Roxb. (Family Verbenaceae) is a deciduous medium-sized pioneer tree that attains a height of 40 m and diameter of 140 cm. The trunk is crooked and branchless for 6-9 m (Adebayo *et al*., 2018). The bark is thin and gray. Leaves are simple, opposite with petiole length 5-15 cm and a more or less heart-shaped blade measuring 10-25 × 5-20 cm (length × width). Its yellowish or grayish-white wood is solicited for crafts work, fuelwood, charcoal as well as for the manufacture of furniture, musical instruments, plywood, matches and agricultural implements (Adam and Krampah, 2005). Flowers are producers of abundant nectar for high-quality honey while the leaves present cattle with fodder. There are also medicinal properties associated with the plant as evident from activity of extracts against inflammation, bacteria, and diabetes (Audipudi and Chakicherla, 2010; Nayak *et al*., 2012; Kulkarni *et al*., 2013) [5, 15, 10]. The tree grows best in climates with a mean annual temperature of 21 - 28°C and rainfall of 1800 - 2300 mm (Adam and Krampah, 2005; Orwa *et al*., 2009) [1, 17]. Although found on a variety of soils, it prefers deep moist soils of pH 5-6 with an ample supply of nutrients. Under poor conditions, trees are often stunted or slightly in excess of a shrub (Tropical Plant Database). Native to Pakistan, Sri Lanka, Myanmar, Thailand, Vietnam and southern China (Lauridsen and Kjaer, 2002) [13], Gmelina arborea has become naturalized in many African countries including Cameroon where it is an important constituent of the western highlands forest. Most of the forest that once covered the landscape has been lost due conversion and changing environmental conditions driven by anthropogenic factors.

Leaf area is a key variable for assessing the competitive ability and fitness of forest plants. It is a routine measurement in Eco physiological studies where light interception, photosynthesis, fertilization, and irrigation are of interest (Ghoreishi *et al*., 2012) [8]. Furthermore, the vital role that leaf area plays in explaining variations in relative growth rate has been demonstrated (Lambers *et al*., 2008) [12]. Thus, it is a crucial factor for predicting the growth potential of plants under various environmental conditions in anticipation for management decisions. Leaf area measurements are performed with the use of automated leaf area meters, planimeters, scanners, and image processing softwares (Easlon and Bloom, 2014) [7]. However, high costs of procurement and maintenance, lack of technical competence, and unavailability have undermined the universal utilization of some of the equipment so that determination of leaf area using leaf linear dimensions is becoming increasingly popular. Linear measurements for leaf area prediction are hinged on the relationship of area with length and width of the leaf. The measurements are used to develop mathematical models that may be conveniently used for leaf area estimation. To this end, models have been adopted for several plant species following various forms of regression. Apart from their simplicity and accuracy, the use of regression models does not require defoliation.

In a previous study, $LA = -972.63 + 110.90W$ was found to be the preferred equation for non-destructive determination of leaf area of Gmelina arborea (Ambebe *et al*., 2018) [4]. Building on the aforementioned, the present study analyzed the efficacy of models from linear, quadratic, and cubic regression with the objective of highlighting a single model for leaf area estimation in the species.

Materials and Methods

Study area

Leaves of Gmelina arborea were collected from the Tubah Upland Forest. Tubah is one of the five Sub-divisions that make up Mezam Division in northwestern Cameroon. It is located between latitudes 4°50' and 5°20'N of the equator and longitudes 10°35' and 11°59'E of the Greenwich meridian at an altitudinal range of 950 to 1500 m. Tubah is made up of four main villages namely Bambili, Bambui, Kedjom-Keku, and Kedjom-Ketinguh. Its vegetation is a mixture of montane grassland, montane forest and remnants of forest patches along streams. The samples were collected from Kedjom-Keku located in the northern part of the Sub-division where the forest is mainly concentrated (Figure 1). Characterized by two seasons, the dry season starts in November while the rainy commences in April (Melle *et al.*, 2016) [14]. A slight shift in the start date of the season is not unusual. With a mean annual rainfall of 1780 to 2290 mm and temperature of 20.67 °C, most precipitation occurs between July and September (Yuninui, 1990; Ndenecho, 2010) [20, 16]. In the course of the year, the temperature ranges from 13 to 22 °C (Kiteh, 2011) [9].

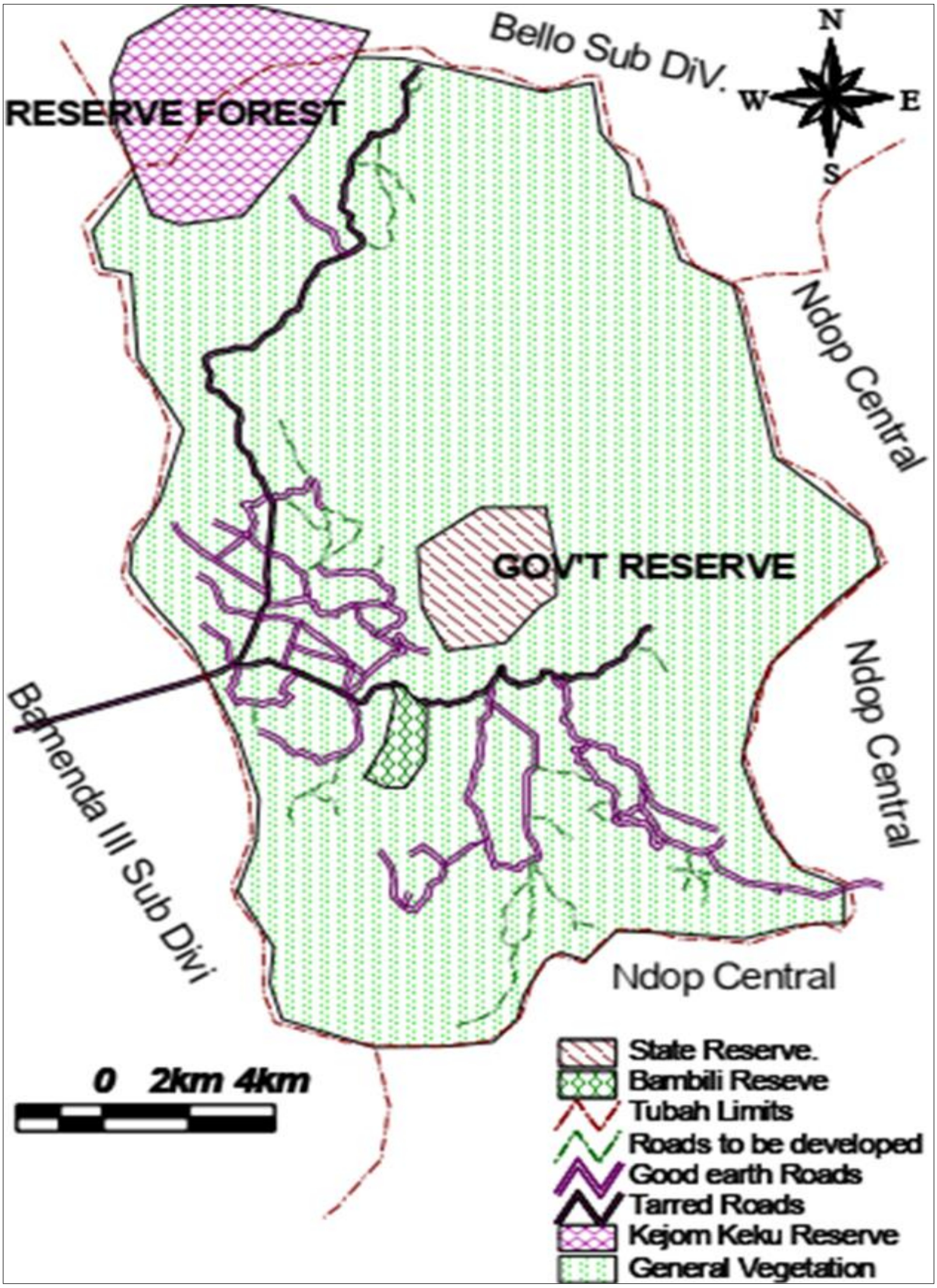


Fig 1: Vegetation distribution in Tubah Sub-division (CDP, 2012)

Experimental design

Leaves were collected from five randomly chosen mature trees of Gmelina arborea. To capture as much morphological variability as possible, the vertical axis of the canopy was partitioned into four fractions. After visual inspection, a leaf within the largest category was harvested from each fraction. Only leaves that had their edges preserved and had not suffered herbivore or insect damage were harvested. After the collection, the twenty leaves were immediately sealed in an air-tight polythene bag and transported for 15 km to Bamenda, the regional headquarter of the northwest region, where the leaf linear dimensions were measured at the Pan African Institute for Development – West Africa Learning Support Centre.

Values of the leaf area were obtained with the use of a graph paper. The graph paper was made up of 1 cm2 cells which were each subdivided into twenty-five 0.04 cm2 cells.

The leaf was fully spread out on the graph sheet and its margin traced. The observed leaf area was determined from the number of 1 cm2 and 0.04 cm2 cells that fell within the boundary of traced region. Leaf length (L) was measured as the distance from upper edge to the lowest point of the lamina along the midrib while leaf width (W) was considered to be the widest distance across the lamina perpendicular to the length (Figure 2). The measurements of the leaf dimensions were determined with a meter rule.

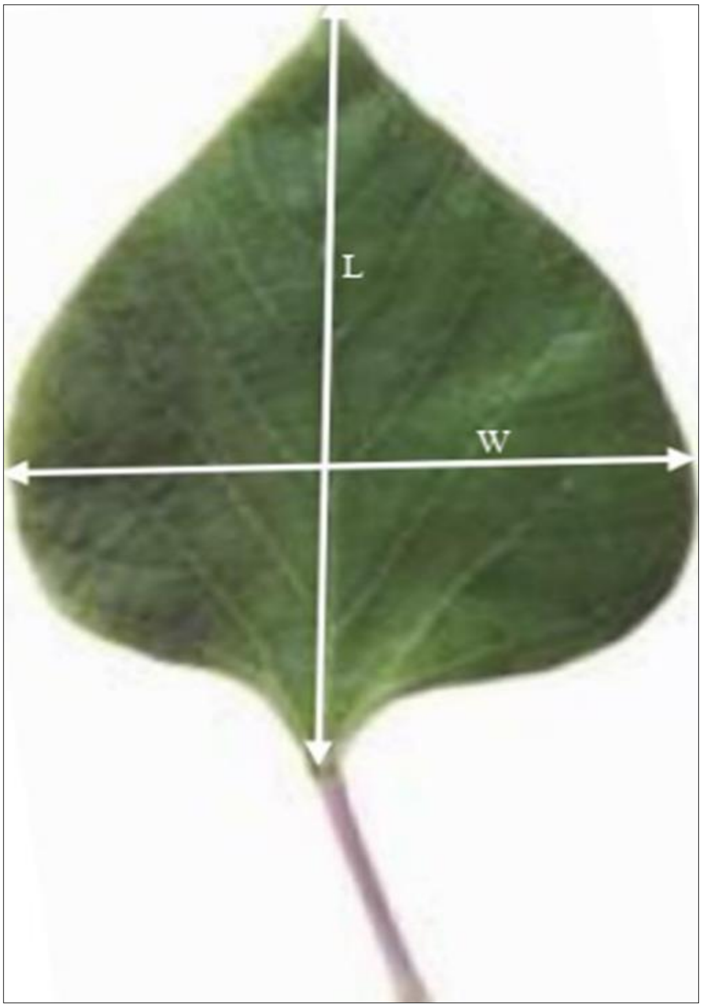


Fig 2: Leaf of Gmelina arborea

Data analysis

Regression analyses were performed between the leaf area as dependent variables and L, W, L× W as independent variables, adjusting for the linear (Eq. 1), quadratic (Eq. 2), and cubic (Eq. 3) equations. Data for the linear model were obtained from Ambebe *et al.* (2018) [4]. The adjustments were made in Sigma Plot 14.0.

LA = y0 + ax 1
LA = y0 + ax + bx2 2
LA = y0 + ax + bx2 + cx3 3

Where
LA = leaf area (cm2); y0, a, b, c = coefficients; x = L, W, L×W (cm)

Goodness-of-fit was evaluated from the Coefficient of Determination (R2).

Model accuracy was determined with Relative Root Mean Square Error (RRMSE, %) (Eq. 4).It was obtained by dividing the Root Mean Square Error (RMSE) by the mean of the measured leaf areas, and multiplying the resulting value by 100 (Richardson *et al*., 2002). In accordance with Lalic *et al*. (2018), model accuracy was rated as excellent if RRMSE < 10%, good if 10% < RRMSE < 20%, fair if 20% < RRMSE < 30%, and poor if RRMSE > 30%. The validation of the model was achieved by plotting the values of predicted leaf area against those of observed leaf area.

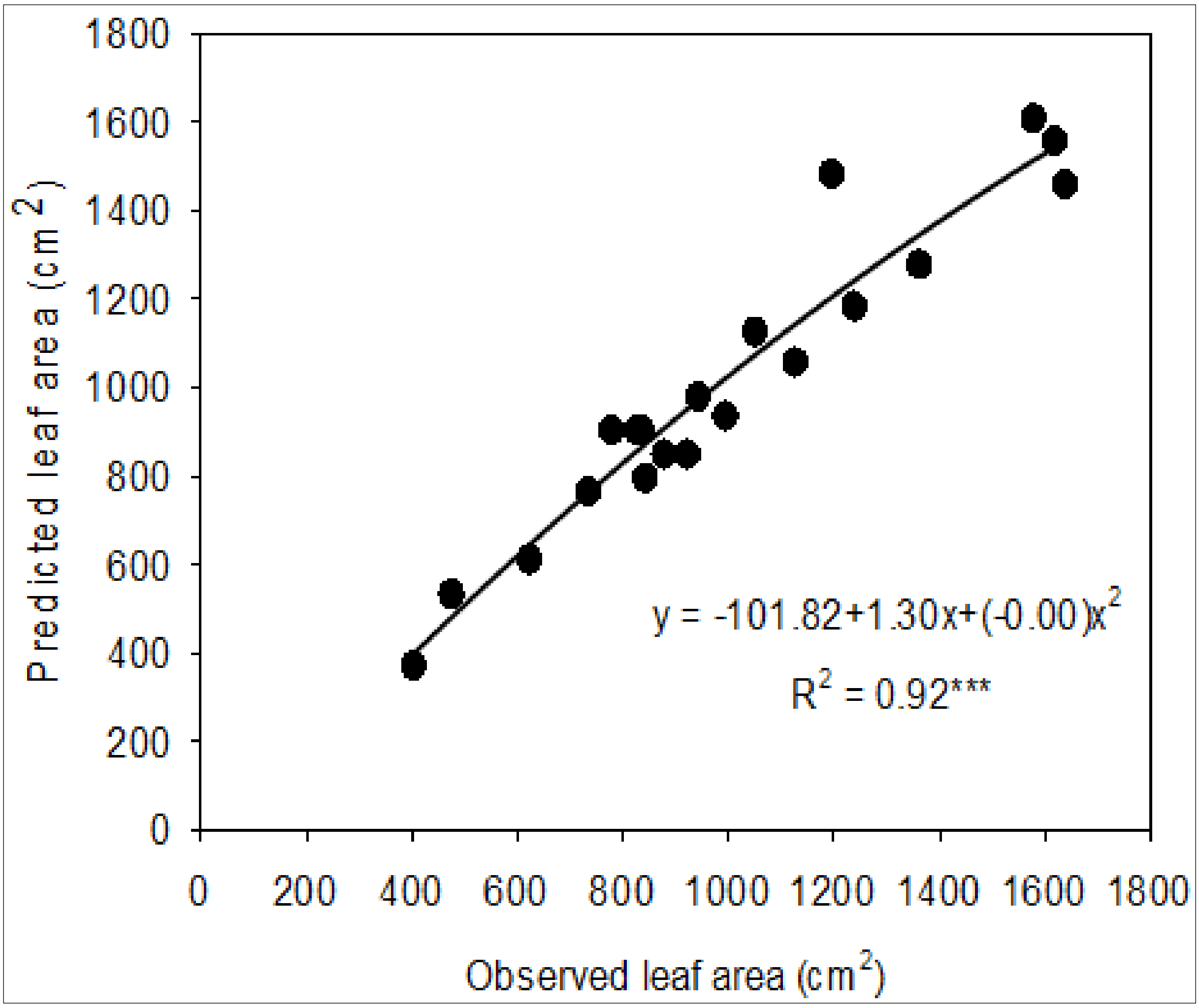
Results and discussion

The relationships between observed leaf area and the three leaf functions were highly significant for each of the models tested (Table 1). Generally, the R2 values were ca 0.90 and above, indicating that 89 to 96% of the variance of the LA is explained by the variance of its dimensions and their product. A further evaluation of the goodness-of-fit revealed that model accuracy was generally good with values 10.22 ≤ RRMSE ≤ 12.40 (Table 1). The most interesting finding of this study, however, was that the quadratic regression between LA and W resulted in the highest R2. Consequently the model LA = -498.47 + 56.33(W) + 1.53(W)2 was found to be most suitable for estimation of leaf area of Gmelina arborea.

Table 1: Regression analysis between leaf area and dimensions

Model	Variable	Equation	R^2	p	RRMSE
Linear	L	LA = -401.09 + 66.82(L)	0.89	0.00	11.90
	W	LA = -972.63 + 110.90(W)	0.92	0.00	10.22
	L×W	LA = 162.52 + 2.17(LW)	0.91	0.00	10.86
Quadratic	L	LA = -605.98 + 86.68(L) + (-0.45) (L)^2	0.89	0.00	12.18
	W	LA = -498.47 + 56.33(W) + 1.53(W)^2	0.96	0.00	10.37
	L×W	LA = -131.47 + 3.74(LW) + (-0.00) (LW)^2	0.92	0.00	10.29
Cubic	L	LA = 677.77 + (-117.81) (L) + 9.92(L)^2 + (-0.17) (L)^3	0.90	0.00	12.40
	W	LA = 1830.10 + (-366.69) (W) + 26.48(W)^2 + (-0.48) (W)^3	0.92	0.00	10.59
	L×W	LA = 6.53 + 2.43(LW) + 0.00(LW)^2 + (-0.00) (LW)^3	0.92	0.00	10.56

Regression analysis for the relationship between observed leaf area and that predicted by the model of choice showed a highly significant R2 (Figure 3). The strength of the latter relationship is in further support of the model's ability to reliably predict the leaf area of the species.



*** = significant at p ≤ 0.001

Fig 3: Relationship between predicted and observed leaf areas

Conclusion

The quadratic regression between LA and W resulted in the highest R2. In addition, the resulting model accuracy was as good as was the case for all other models developed in the study. With an ability to explain 96% of variation in leaf area in Gmelina arborea, LA = -498.47 + 56.33(W) + 1.53(W)2 is the recommended model for non-destructive determination of leaf area of the species.

References

1. Adam KA, Krampah E. Gmelina arborea Roxb.ex Sm. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa, 2005.
2. Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Accessed 23 January 2023,
3. Adebayo MA, Avoseh ON, Openiyi IO, Lawal OA, Ogunwande IA. Anti-nociceptive and Anti-inflammatory Effects of Gmelina arborea Roxb. ex. Sm. Investigational Medicinal Chemistry and Pharmacology,2018:1(2):13.
4. Ambebe TF, Zee FG, Shu AM. Modeling of leaf area of three Afromontane-forest tree species through linear measurements. Journal of Research in Ecology,2018:6(2):2364-2371.
5. Audipudi AV, Chakicherla BVS. Antioxidative and antimicrobial activity of methanol and chloroform extracts of Gmelina arborea Roxb. International Journal of Biotechnology and Biochemistry,2010:6(1):139-144.
6. CDP. Tubah Council Development Plan. Tubah Council, North West Region, Cameroon, 2012.
7. Easlon MH, Bloom AJ. Easy Leaf Area: Automated digital image analysis for rapid and accurate measurement of leaf area. Application in Plant Sciences,2014:2(7):1400033
8. Ghoreishi M, Hossini Y, Maftoon M. Simple models for predicting leaf area of mango (Mangifera indica L.). Journal of Biology and Earth Science,2012:2(2):B45-B53
9. Kiteh CC. Stakeholders participation: Myth or reality? A case study of community water supply management in Bambui-Tubah village in Cameroon. Master Thesis Institutionen för geovetenskaper, Uppsala Universitet, Sweden, 2011, 79.
10. Kulkarni YA, Ritesh P, Vishvas P, Aditi T, Alok G. Effect of Gmelina arborea Roxb in experimentally induced inflammation and nociception. Journal of Ayurveda and Integrative Medicine,2013:4(3):152-157.
11. Lalic B, Eitzinger J, Marta AD, Orlandini S, Sremac AF *et al*. Agricultural Meteorology and Climatology. Firenze University Press, 2018.
12. Lambers H, Chapin FS III, Pons TL. Plant physiological ecology. Springer, New York, 2008, 604.
13. Lauridsen EB, Kjaer ED. Provenance research in Gmelina arborea Linn., Roxb. A summary of results from three decades of research and a discussion of how to use them. International Forestry Review,2002:4(1):20-29.
14. Melle EM, Nkwatoh AF, Achiri AB, Hele TN. The unsustainable exploitation of wildlife-habitat resources in Tubah Sub-division, North West Region, Cameroon. International Journal of Current Research in Biosciences and Plant Biology,2016:3(8):32-38.
15. Nayak BS, Ellaiah P, Dinda SC. Antibacterial, antioxidant and antidiabetic activities of Gmelina arborea Roxb fruit extracts. International Journal of Green Pharmarcy,2012:6(3):224-230.
16. Ndenecho EN. Implications of fuel wood yield, availability and harvest in Tubah Mountain Forest, Cameroon. Global Journal of Human Social Science,2010:10(3):49-55.
17. Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S. Agroforestry Database: A Tree Reference and Selection Guide version 4.0. World Agroforestry Centre, Kenya, 2009.
18. Richardson AD, Duigan SP, Berlyn GP. An evaluation of noninvasive methods to estimate foliar chlorophyll content. The New Phytologist,2002:153(1):185-194.
19. Tropical Plants Database, Ken Fern. tropical.theferns.info. <tropical.theferns.info/viewtropical.php?id=Gmelina+arborea>. Accessed 23 January 2023.
20. Yuninui NM. Initiation practical report on Bambui village. A Research Report, Regional College ofAgriculture, Bambili, Cameroon, 1990.