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Assessment of Eco-Physiological Potential and Folia-Morpho-Anatomical Variation in *Triplochiton Scleroxcylon* K. Schum

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Abstract

This study assessed the eco-physiological growth performance and foliar morpho-anatomical characteristics of T. scleroxylon wildlings across three ecological locations in Ondo State, Nigeria: Owo (RUGIPO), Akungba-Akoko (AAUA), and Akure (FUTA). Five families (F1–F5) from Queen's plot, Akure Forest Reserve, were evaluated to determine variations in growth traits, leaf morphology, venation patterns, epidermal structure, and stomatal characteristics, as well as their relationships with climatic factors. Growth parameters measured included height, collar diameter, and number of leaves, while foliar traits included leaf area, venation density, epidermal cell density, and stomatal characteristics. Climatic variables (air temperature, rainfall, and relative humidity) were correlated with the growth variable. Wildlings at FUTA recorded the highest mean collar diameter (5.97 ± 0.05 cm), height (31.89 ± 0.16 cm), and number of leaves (14.0 ± 0.12), compared to wildlings from Owo (5.06 ± 1.20 cm, 24.95 ± 0.09 cm, and 12.18 ± 0.22) and Akungba-Akoko (4.22 ± 0.09 cm, 24.13 ± 0.22 cm, and 7.0 ± 0.24) respectively. Among families, Family 1 exhibited superior growth performance with the highest mean height (33.79 cm) and collar diameter (5.99 cm), while Family 2 recorded the highest mean leaf number (13). Strong positive correlation was recorded between height and air temperature (r = 0.93), height and rainfall (r = 0.85), and height and number of leaves (r = 0.97). Foliar analysis revealed significantly higher epidermal cell density and stomatal density in FUTA (ECD = 64.00 mm⁻²; SD = 27.50 mm⁻²). The study demonstrates that both ecological conditions significantly influence early growth and foliar characteristics of T. scleroxylon. The superior performance of wildlings from family 1 in FUTA and other locations highlights their suitability for conservation, domestication, and plantation establishment. These findings provide empirical support for the selection of site-specific, genetically superior planting materials for sustainable forest management and afforestation programs in Nigeria.

Keywords: Eco-physiology, Foliar morpho-anatomy, *Triplochiton scleroxylon*, Phenotypic plasticity, Leaf anatomical traits.

Introduction

According to Nicotra *et al.*[1] climate change alters the availability of tree species and the conditions vital for their growth and development. In nature, where environmental conditions continually vary, the individual is confronted with the challenge of taking full advantage of fitness under diverse conditions[2]. Species inhabit a large geographical array or a variety of different habitats within a limited area, or both. Phenotypic plasticity has been broadly recognised as a significant feature for plants to cope with varying environmental heterogeneity[1,3].

Plant responses to environmental variations involve a complex interaction of several morphological, anatomical, or physiological characteristics, which are responsible for adaptive success to a particular environment[4]. Climate change may directly affect the morpho-anatomical structure of leaves during their development. Leaves with different characteristics can be produced by individuals of the same species, or even by a single individual, in response to these variations[1,4]. Morphologically, leaves that developed under full sun exposure tend to be smaller and thicker, with larger leaf mass per area and higher amounts of chlorophyll compared to the leaves that developed in shade[5].

The differences in anatomical structure are mainly related to the quantity and distribution of palisade and spongy parenchyma, density of stomata, trichomes, venation, and epidermal thickness These variations are associated with the regulation of internal levels of light and CO_2, maximizing photosynthetic efficiency; they also reduce leaf heat and favor cooling, keeping internal temperatures at optimal levels for physiological processes[4]. Technically, the strategies a particular plant species develops in interacting with its environment may vary from those of a different species.

Triplochiton scleroxylon (Family: Sterculiaceae) is an environmentally and economically important tropical tree. It is a pioneer species found more frequently in secondary forests, woodlands, and farmlands[6].

T. scleroxylon is adapted to colonising secondary forests and degraded areas, although its population does not decrease rapidly after forest vegetation has been established[6]. Thus, this study aims to assess the eco-physiological potential and foliar morpho-anatomical variation in *T. scleroxylon*.

T. scleroxylon is a fast-growing, long-lived tropical hardwood native to West Africa, valued for its timber and ecological services. Decades of overexploitation in Nigeria have driven widespread deforestation and a sharp decline in wild populations. Mature, seed-bearing trees are continually removed with little reforestation, which disrupts natural regeneration and fragments remaining stands. While leaf trait plasticity is known to underpin resilience in many tropical trees, systematic data on *T. scleroxylon*'s morphological and anatomical responses to climate, soil, and light gradients are scarce. This gap limits our ability to select suitable provenances, predict performance across sites, and design effective restoration strategies.

The consequences of inaction are significant. Continued decline of *T. scleroxylon* reduces biodiversity, weakens ecosystem services like soil stabilization and carbon storage, and threatens the livelihoods of communities that depend on the species for timber and non-timber products. Pest and disease pressures, including aphids and defoliating caterpillars, further compound its vulnerability.

Therefore, this study addresses the urgent need to evaluate *T. scleroxylon*'s adaptive potential across contrasting environments, providing evidence to guide conservation, sustainable management, and large-scale restoration of degraded tropical landscapes in Nigeria. Few researchers have investigated the adaptive potential of *T. scleroxylon*, a valuable tropical hardwood, to varying environmental conditions across large geographical scales. Prior studies remain limited to local-scale foliar anatomy within single reserves or early growth trials, leaving unclear whether leaflet morphological traits (e.g., size, shape) and anatomical features (e.g., stomatal density, mesophyll thickness) exhibit systematic variations linked to environmental adaptation. This knowledge gap is critical, as such plasticity could underpin the species' resilience amid deforestation and climate shifts in Nigerian rainforests, yet no work has tested it across climatically distinct sites like those in Ondo State.

The three study locations (Owo, Akure, and Akungba Akoko) differ clearly in climatic conditions due to their north-south gradient in Ondo State, Nigeria. These differences in temperature, rainfall patterns, and topography creates varying heat and water stresses that likely drive leaflet trait plasticity, such as stomatal adjustments or mesophyll adaptations, yet remain untested at this scale. Investigating *T. scleroxylon*'s responses across these sites justifies the research need, as it reveals the species' adaptive capacity for conservation amid deforestation and climate shifts in Nigerian rainforests.

Methodology

Description of the Study: This research covers three different zones in Ondo State of Nigeria. Five trees of *Triplochiton scleroxylon* in the three different zones covering Rainforest Zone, Derived Savanna Zone and Transition Zone between rainforest and derived savanna were considered for this study. The zones were: The Federal University of Technology, Akure (Rainforest Zone), Adekunle Ajasin University, Akungba-Akoko (Derived Savanna Zone), and Rufus Giwa Polytechnic, Owo (Transition Zone between Rainforest and Derived Savanna).

Method of Data Collection: Experimental Procedure: *Triplochiton scleroxylon* wildings were collected from Queen's plot, Akure Forest Reserve, Aponmu, Ondo State, Nigeria. This forest was purposefully selected owing to the abundance of this species. Five mother trees of *Triplochiton scleroxylon*, not less than 50 meters apart were randomly selected for this study. Seventy-five (75) tree weddings were collected under each mother tree, which amounted to a total of three hundred and seventy-five (375) wildlings from all the mother trees. Twenty-five (25) uniform weddings from each mother tree were randomly assigned to these three locations: Adekunle Ajashin Akungba Akungba-Akoko, The Federal University of Technology, Akure, and Rufus Giwa Polytechnic Owo for eco-physiological evaluation. The study lasted for 6 months. Map of Akure Forest Reserve with the location of the five mother trees is presented in Figure-1.

Eco-physiological Assessment: The number of leaves and leaflets on each seedling were counted and recorded fortnightly for six months. Also, seedling height and collar diameter were measured and recorded. At the end of the experiment, mature leaves of five different trees from each of the zones (Rainforest Zone, Derived Savanna Zone and Transition Zone between rainforest and derived Savanna) were harvested for qualitative and quantitative leaf macro-morphological studies, Variables such as leaf surface area (LSA), leaf length (LL), and leaf width (LW) were measured with leaf area meter. More so, three leaves were randomly selected from each studied location for anatomical study.

For leaf epidermal study, standard median portions (midway between the tip and the base) were taken from each sample. The portions were put into Nitric Acid, in glass Petri-dishes, and kept in an oven at 60ºC for 20 minutes. Each sample was washed thoroughly in 4-5 changes of water. The abaxial and the adaxial epidermis were separated using fine forceps and a dissecting needle. The epidermis were then stained in Safranin-O, and counter-stained in Toluedene blue for five minutes, washed with 4-5 changes of water to remove excess stain, and then mounted in 25% glycerol.

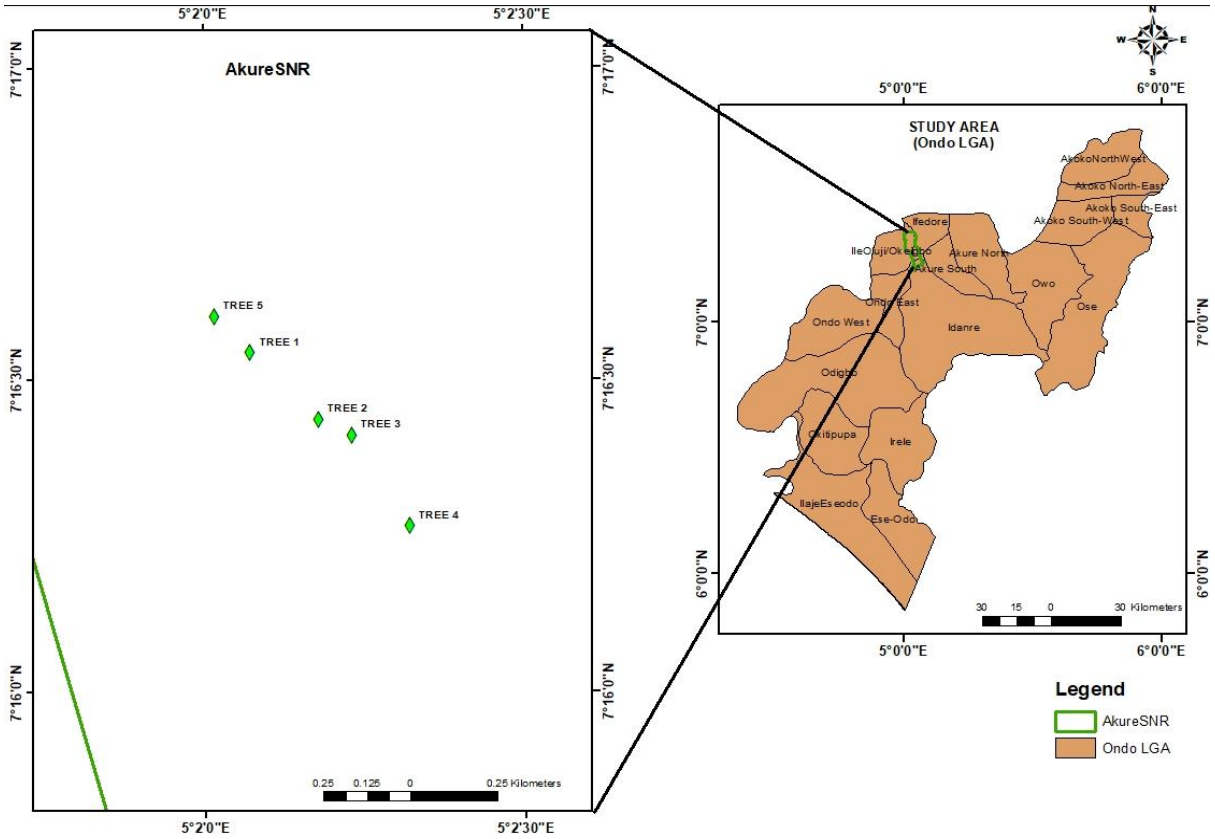


Figure-1: Map of Akure Forest Reserve with the location of the five mother trees.

The scraping method of Metcalfe was utilized in getting the epidermal peeled off. The entire leaflets were placed face down on a slide and flooded with a commercial bleaching agent (containing Sodium Hypochlorate). The material was then carefully scraped with a new razor blade until the epidermis was reached. The bleaching agent acted as a lubricant and at the same time help to soften the cell layers as they were scraped off. After scraping, the scraped portion was carefully cut, and the peels were stained in Safranin-O and then mounted in 25% glycerol for examination under the light microscope. Photomicrographs of the epidermis were made for both the adaxial and abaxial surfaces (Figure-2 and 3). Photomicrographs of the venation architecture were taken to show the arrangement of the main vein (MV), areoles (AR), and veinlet endings (VE). These are presented in Figure-4 (A–C). Trichome type(s), crystal type(s), shapes of the epidermal cells, numbers of epidermal cells, stomata types, and stomata frequency were all noted for both leaflet surfaces. Also, stomata frequency per square millimetre and stomata index (I) were estimated for the two leaflet surfaces using the formula below as proposed by Wilkinson[7]:

$$SI = \frac{S}{(S+E)} \times 100$$

Where: S = number of stomata per unit area, E = number of ordinary epidermal cells in the same area, SI = stomata index. The length and breadth of the stomata was measured using an ocular micrometer and the measurements were converted to microns using the stage micrometer.

Foliar Mopho-anatomical Assessment: The anatomy of sampled leaflets was studied by cutting transverse sections of the leaflet. All sections were made with the aid of Reichert Sliding Microtome at a thickness of 8 - 10 mi. The sections were stained in Alcian blue for 3-5 minutes, rinsed thoroughly in water to remove excess stain, and counterstained in Safranin O solution for 3-5 minutes. The sections were again washed with water and treated in a series of ethanol dilutions: 50%, 70%, 80%, 90%, and 100% to enhance the dehydration process. The dehydrated sections were transferred into absolute xylene to remove any remaining trace of water and ethanol. These made the sections clear and prevented cloudiness of the slide, as well as the drying of the slide. Sections were therefore mounted in 25% glycerol.

Photomicrographs of all anatomical features were made with the aid of an Accu-scope Trinocular Microscope (Accu-scope 33001 LED Trinocular Microscope with 3.2 MPCMOS digital camera). All measurements were made with the aid of an ocular micrometer and final figures were derived with an ocular constant. For the determination of the cuticle thickness of the leaflets, transverse sections of the leaves were cut at a thickness

of 20 m using a Reichert sliding microtome. Specimens were processed using standard anatomical procedures as described previously[8]. All microscopic measurements were made with the aid of an ocular micrometre inserted in the eyepiece of the microscope. These measurements were later multiplied by the ocular constant for the objectives under which they were carried out.

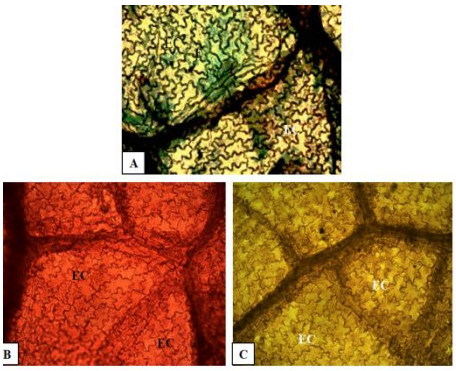


Figure-2: Photomicrographs of adaxial surfaces, A: Adaxial surface in rainforest, B: Adaxial surface in derived savanna, C: Adaxial surface in transition zone between rainforest and derived savanna, EC: Epidermal cell.

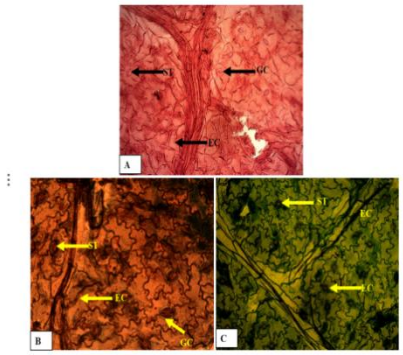


Figure-3: Photomicrograph of abaxial surfaces, *A: Adaxial surface in rainforest, B: Adaxial surface in derived savanna, C: Adaxial surface in transition zone between rainforest and derived savanna, EC: Epidermal cell, ST: Stomata, GC: Guard cell, TR: Trichome.*

Weather data: Weather data were obtained from the Department of Meteorology and Climate Science within the School of Earth and Mineral Sciences at the Federal University of Technology Akure (FUTA), Nigeria**.**

Method of Data Analysis: The data obtained was subjected to One-way Analysis of Variance in a complete randomised design (CRD) using Statistical Package for Social Sciences (SPSS) version 21 to test for significant differences among the variables measured across the ecological zones. Where significant differences exist, Duncan's New Multiple Range Test (DMRT) follow-up procedure was carried out.

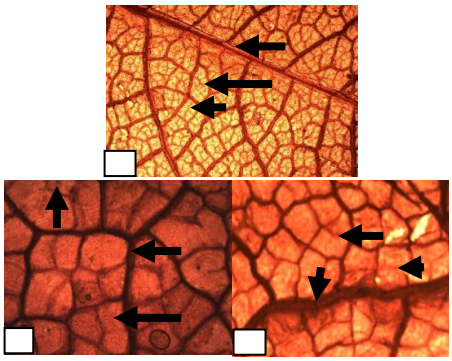


Figure-4: Photomicrographs of venation pattern in the three zones, A: Venation pattern in the rainforest zone, B: Venation pattern in the derived savanna zone, C: Venation pattern in the transition zone between the rainforest and derived savanna, AR: Areole, VE: Veinlet ending, MV: Main vein.

Results and Discussion

Eco-physiological study of *Triplochiton scleroxylon:* The performances of each tree families in each studied location are presented in Figure-2, 3 and 4. In RUGIPO, Family 1 consistently had the highest mean height (30.44 cm), collar diameter (5.74 mm) and number of leaves (15). Although inconsistent variation exists in the performance of other families, Family 4 recorded the least performance in all the studied variables, as presented in Figure-2. In FUTA, Family 1 had the highest mean height (40.33 cm) and collar diameter (7.12 mm) but was penultimate for mean number of leaves. Family 2 had the highest mean number of leaves (17) but was second to Family 1 in mean collar diameter (7.12 and 6.84 mm) and mean height (40.33 and 37.36 cm). In all the studied variables, Family 3 recorded the least performance as presented in Figure-3. Similar to the growth characteristics of wildlings in FUTA, family 1 in AAUA had the highest mean height (30.60cm) and mean collar diameter (5.10cm), but second to Family 2 in terms of the mean number of leaves (11, 9). Moreover, Family 3 had the least mean height (18.32cm), number of leaves (6), but penultimate in terms of mean collar diameter (3.51cm) in AAUA as presented in Figure-4.

The result for comparing the growth characteristics of the s wildlings among the studied locations is presented in Table-1. Mean Collar diameter (5.97cm) was significantly higher in FUTA, followed by RUGIPO (5.06) and AAUA (4.22), respectively. Mean wildling height was significantly higher in FUTA (31.89cm) than in RUGIPO (24.95) and AAUA (24.13cm). Also, the number of leaf was significantly higher in FUTA than in any of the other two locations. However, no significant difference was found in the number of leaves for wildlings in FUTA (13.71) and RUGIPO (12.18) as presented in Table-1. Generally, wildlings in FUTA recorded the best growth characteristics, followed by wildlings raised in RUGIPO and AAUA, respectively. This revealed the response of this species to different environmental conditions.

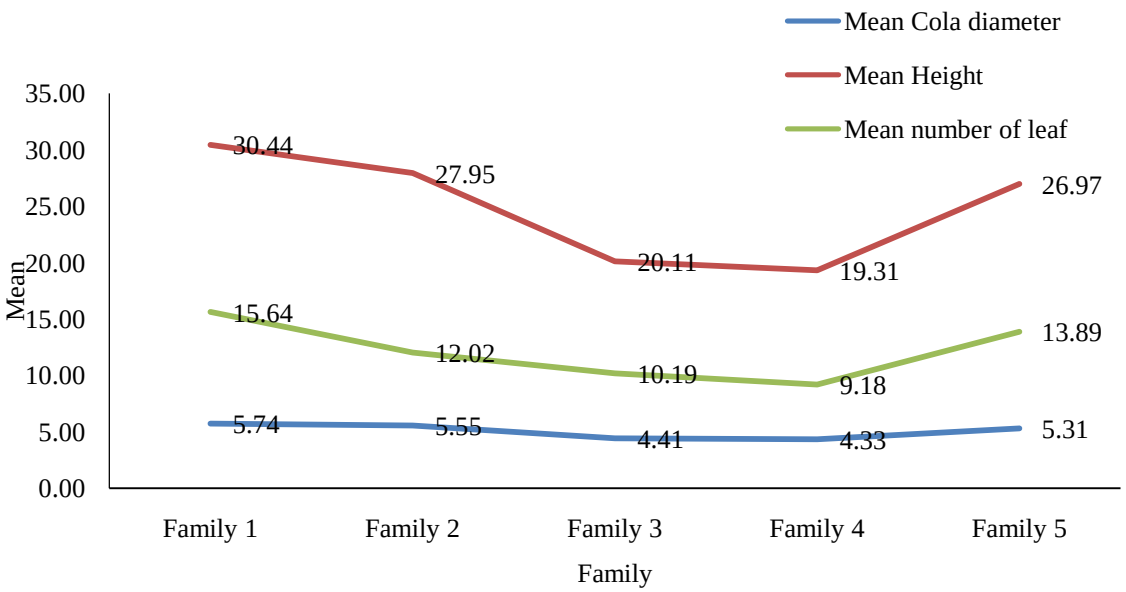


Figure-2: Performance of tree families in terms of wildlings collar diameter, height and number of leaves in RUGIPO.

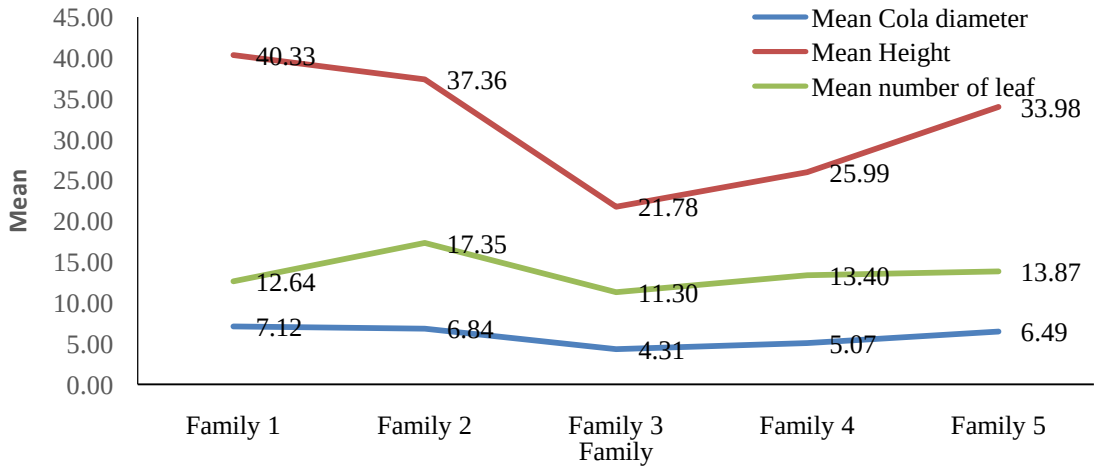


Figure-3: Performance of tree families in terms of wildlings collar diameter, height and number of leaves in FUTA.

Table-1: Comparison of wildlings' growth characteristics in the study areas.

Locations	Collar Diameter(cm)	Height (cm)	Number of Leaf
RUGIPO	5.06 ± 1.20^{b}	24.95 ± 0.09^{b}	12.18 ± 0.22^{a}
AAUA	4.22 ± 0.09^{c}	24.13 ± 0.22^{b}	7.56 ± 0.24^{b}
FUTA	5.97 ± 0.05^{a}	31.89 ± 0.16^{a}	13.71 ± 0.12^{a}

The result for comparing the wildlings growth characteristics from different families across the study locations is presented in Table-2. Collar diameter was significantly higher in family 1 (5.99 cm), but no significant difference ($p>0.05$) from family 2 (5.72cm) and family 5 (5.36cm). Similarly, no significant difference was recorded in the wildlings' collar diameter ($p>0.05$) between Family 3(4.08cm) and Family 4 (4.29cm). Similar trends were observed in mean wildling height and mean number of leaves per wildling. Wildlings from Family 1 were observed to perform best in all the morphological characteristics investigated. This was followed by wildlings from families 2 and 5, respectively. Wildings from Family 3 and Family 4 were not significantly different from each other in all the traits investigated, as presented in Table-2.

Table-2: Comparison of wildling' growth characteristics among the tree families across the study areas.

Families	Collar diameter (cm)	Height (cm)	Number of Leaf
Family 1	5.99^{a}	33.79^{a}	12.27^{a}
Family 2	5.72^{a}	30.81^{ab}	12.96^{a}
Family 3	4.08^{b}	20.07^{c}	9.25^{b}
Family 4	4.29^{b}	21.27^{c}	9.76^{b}
Family 5	5.36^{a}	28.92^{b}	11.33^{ab}

Table-3 shows the comparison of leaf traits from different locations. All the leaf traits (leaf length, breadth and area) were significantly higher ($p<0.05$) in RUGIPO (31.364cm, 21.230cm and 333.384cm^2) than in AAUA (7.99cm, 5.670cm, and 56.32cm). There was no significant difference ($p>0.05$) in leaf length and leaf breadth in wildlings from AAUA (7.990, 5.670) and FUTA (10.593, 7.680). However, the leaf area among three locations was in this order: RUGIPO>FUTA>AAUA as presented in Table-3.

Table-3: Comparison of leaf traits from wildlings in different locations.

Locations	Leaf length	Leaf breadth	Leaf Area
AAUA	7.9896^b	5.670^b	56.322^c
FUTA	10.593^b	7.680^b	120.114^b
RUGIPO	31.364^a	21.230^a	333.384^a

Table-4 shows the relationship between the wildlings growth traits and weather parameters in AAUA. A strong positive and strong correlation (0.932) was found between air temperature and wildling's height. Rainfall exhibits strong positive correlations with RDS (0.928) and collar diameter (0.877). The number of leaves showed a strong and positive correlation with wilding's height (0.971), suggesting a close association between plant height and leaf abundance. Relative Humidity also had a strong correlation of 0.753 with collar diameter. Similarly, a correlation coefficient of 0.724 was found between the number of leaves and rainfall, as shown in Table-4.

Table-5 shows the relationship between the wildings' growth characteristics and weather parameters in AAUA. The correlation coefficient between Air Temperature and Relative Humidity was 0.735, suggesting a strong positive correlation. The correlation coefficient between rainfall and RDS was 0.965, indicating a very strong positive correlation. Collar diameter showed a strong and positive correlation with RDS (0.712), Height (0.929), and rainfall (0.669). Height showed a positive correlation with temperature (0.828), relative humidity (0.706), and Rainfall (0.903). Number of leaves showed a positive correlation with Rainfall (0.743) as presented in Table-5.

Table-6 shows the relationship between the growth characteristics and weather parameters in RUGIPO. There was a negative correlation between air temperature and collar diameter (-0.42231) and air temperature and wildling height (-0.79498). Wildling's number of Leaves was positively correlated with temperature (0.90172) and relative humidity (0.763325) as presented in Table-6.

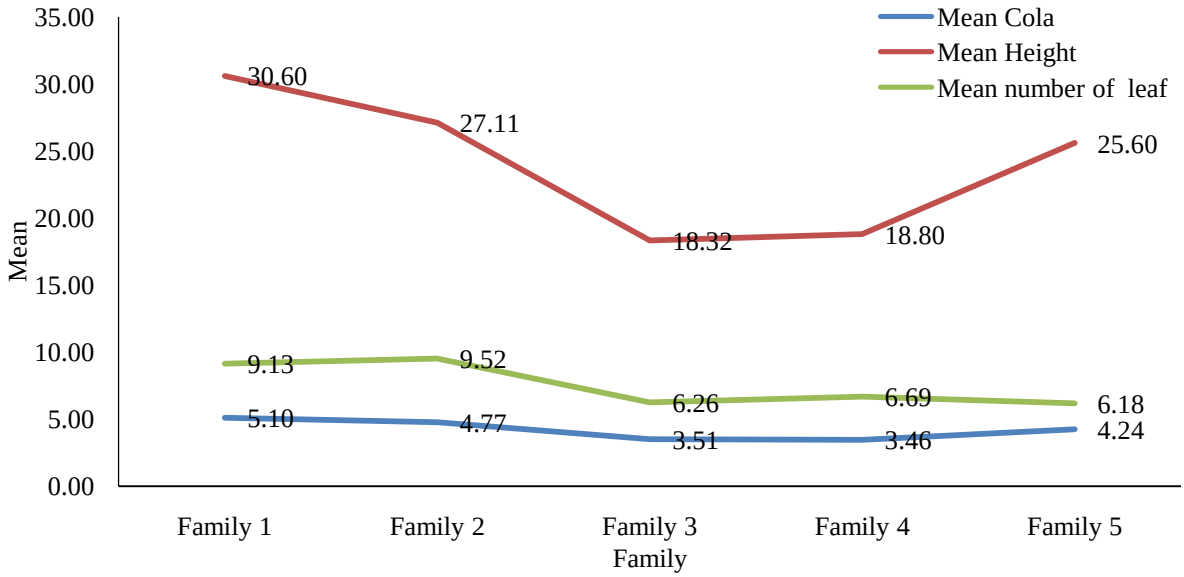


Figure-4: Performance of tree families in terms of wildlings collar diameter, height and number of leaves in AAUA.

Table-4: Correlation Matrix for Growth Characteristics and Weather Parameters in Akure.

	Air Temperature	Relative humidity	Rainfall	RDS	Collar diameter	Height	Number of Leaf
Air Temperature	1						
Relative humidity	0.623	1					
Rainfall	0.757	0.865	1				
RDS	0.648	0.944	0.928	1			
CollarDiameter (cm)	0.787	0.753	0.877	0.926	1		
Height	0.932	0.618	0.846	0.961	0.737	1	
Number of Leaf	0.714	0.623	0.724	0.826	0.564	0.971	1

Table-6: Correlation Matrix for Growth Characteristics and Weather Parameters in Owo.

	Air Temperature	Relative humidity	Rainfall	RDS	Collar diameter	Height	Number of Leaf
Air Temperature	1						
Relative Humidity	0.95718	1					
Rainfall	0.94873	0.94609	1				
RDS	0.83679	0.90399	0.859435	1			
Collar diameter	-0.42231	0.816779	0.640859	0.953533	1		
Height	-0.79498	0.707075	0.833832	0.868077	0.98282	1	
Number of Leaves	0.90172	0.763325	0.045984	0.552059	0.464717	0.949562	1

Table-7: Foliar Venation and Morphological Characteristics of *Triplochiton scleroxylon* among the Study Areas.

	Venation Characteristics		Morphological Characteristics			
Locations	AL (mm)	Araole width (mm)	Vein density (mm)	LL (cm)	LWt (gram)	Petiole length (cm)
RUGIPO	74.250[a]	42.000[b]	2.000[a]	26.30[a]	13.90[a]	1.480[b]
FUTA	75.250[a]	48.500[a]	2.100[a]	17.80[b]	13.10[a]	2.400[a]
AAUA	78.250[a]	48.750[a]	2.200[a]	12.80[c]	8.80[b]	2.020[a]

Table-8: Foliar adaxial characteristics of *Triplochiton scleroxcylon* among the study areas.

Locations	Epidermal Cell Density (mm^{-2})	Epidermal Cell Length (µm)	Epidermal Cell Width (µm)
RUGIPO	127.70[a]	42.67[a]	24.25[a]
FUTA	130.10[a]	43.50[a]	25.08[a]
AAUA	109.07[b]	42.42[a]	23.42[a]

Foliar Venation and Epidermal Studies: Table-7 presents venation (areole width, venation density) and morphological characteristics (petiole length) of the leaf samples collected from three different locations (RUGIPO, FUTA, and AAUA). Generally, the venation characteristics were the same in the three studied locations. However, petiole length was significantly higher in FUTA (2.4cm), followed by AAUA (2.02cm) and RUGIPO (1.48cm), respectively. Table-8 presents adaxial leaf characteristics (Epidermal Cell Density, Epidermal Cell Length, Epidermal Cell Width) of sampled leaves from the studied locations. The result revealed that Epidermal Cell Density was significantly higher in FUTA and RUGIPO. However, no significant difference was found in the epidermal cell length and epidermal cell width among the three locations.

Table-9 is on abaxial characteristics of leaf samples collected from three distinct locations (RUGIPO, FUTA, and AAUA). In RUGIPO, the leaf samples exhibited an Epidermal Cell Density (ECD) of 61.70, Epidermal Cell Length (ECL) of 65.000, Epidermal Cell Width (ECW) of 31.417, Stomata Density (SD) of 25.167, Stomata Length (SL) of 11.00, and Stomata Width (SW) of 8.00. In FUTA, values of 64.000, 67.500, 32.500, 27.50, 13.250 and 8.50 were recorded for Epidermal Cell Density (ECD), Epidermal Cell Length (ECL), Epidermal Cell Width (ECW), Stomata Density (SD), Stomata Length (SL), and Stomata Width (SW). Leaf samples from Akungba-Akoko (AAUA) demonstrated slightly lower values for most characteristics compared to those in RUGIPO and FUTA. The

Epidermal Cell Density (ECD) was (59.267), Epidermal Cell Length (ECL) was (60.333), Epidermal Cell Width (ECW) was (30.417), Stomata Density (SD) was (26.63), Stomata Length (SL) was (12.583), and Stomata Width (SW) was (7.50). All leaf abaxial characteristics showed significant differences among locations, with FUTA having significantly higher values in most of the characteristics investigated, as presented in Table-10. The photomicrographs of adaxial surfaces are presented in Figure-1,3.

Discussion: Eco-Physiological studies of *Triplochiton scleroxylon:* Adapting to different climates often drives strong variation in growth characteristics, as plants adjust their structure to optimize resource use under local conditions[9]. There were significant differences in the growth characteristics (collar diameter, height and number of leaves) of *T. scleroxylon* wildlings in the three different locations. The significant results observed in collar diameter, height and number of leaves among the sites confirm the existence of climatic variations among the sites and the potential ability of the study species to adapt to different environments. Based on the findings of the study, collar diameter, height, and number of *T. scleroxylon* were significantly higher in FUTA. Overall, the higher growth of *T. scleroxylon* in FUTA compared to other areas could be attributed to a combination of favourable site nutrients, weather parameters, and other growth conditions that provide a conducive environment for this species to thrive[1].

The existence of variation among these wildlings in different locations was substantiated by the significant difference found for the studied morpho-anatomical characteristics. The findings of this study were consistent with the report of Violle et al.[10], that different individuals of the same species may

Table-9: Foliar abaxial characteristics of *Triplochiton scleroxylon* among the study areas.

Locations	ECD	Epidermal Cell Length	Epidermal Cell Width	Stomata Density	Stomata Length,	Stomata Width
Owo	61.70^{ab}	65.000^{ab}	31.417^{a}	25.167^{b}	11.00^{b}	8.00^{ab}
FUTA	64.000^{a}	67.500^{a}	32.500^{a}	27.50^{a}	13.250^{a}	8.50^{a}
AAUA	59.267^{b}	60.333^{b}	30.417_{a}	26.63^{ab}	12.583^{a}	7.50^{b}

present a variation in their morphology either naturally or in connection with local adaptations. Also, it corroborates the study of Ehlers *et al.*[11] on intraspecific variation in the same species. Umaña and Swenson[12] supported the theory that the height, collar diameter and number of leaves might be the dynamic factors in tree breeding and silvicultural technology to be taken into account.

Studies have shown that an increase in plant collar diameter is positively associated with an increase in seedling height[13]. Collar diameter is related to various morphological features of seedling sprouts, indicating its importance in seedling growth. Additionally, collar diameter is a practical and species-specific index of potential survival for wildlings, with larger diameters increasing the probability of survival[14]. These findings suggest that monitoring and promoting collar diameter growth can contribute to the production of high-quality seedlings in nurseries and improve the success of outplanting efforts in reforestation projects.

The marked differences in leaf length, breadth and area across locations reflect the strong influence of local environmental conditions on seedling development. Larger leaves in RUGIPO suggest favourable moisture and nutrient conditions that support greater photosynthetic investment[15]. Smaller leaves in AAUA and FUTA likely indicate environmental stress, which commonly restricts leaf expansion as a protective response[16]. Leaf morphology is known to be highly plastic and responsive to site-specific resource availability[1]. These findings confirm that microenvironmental variation plays a central role in shaping early growth performance among wildlings[17].

Positive and strong correlation was discovered between the growth characteristics and weather parameters. These results are consistent with quantitative genetic theory, which holds that strong correlations between growth-related traits can arise when shared genetic factors or pleiotropic genes influence both characters[18]. They recorded a high correlation coefficient for height and root collar diameter. In this study, the high correlation coefficient obtained for two variables (collar diameter and height) is probably also due to inherent factors. However, it showed a low negative correlation between the number of leaves and relative humidity. This could be attributed to adaptation to the study site. Trees often have adaptations to conserve water. Some species may have smaller leaves, fewer leaves, or modified leaf structures (such as thick cuticles or sunken stomata) to reduce water loss through transpiration. These adaptations can result in a negative correlation between leaf number and humidity. Also, in areas with low humidity, trees may prioritise allocating resources to essential functions such as root growth or reproductive efforts rather than leaf production[19]. As a result, they may produce fewer leaves to conserve resources for survival and reproduction.

Morpho-Anatomical Disparity: Foliar Venation Studies: The venation pattern is an essential component of leaf morphology, which influences the overall appearance and structure of the plant. Observing the venation pattern alongside other leaf characteristics can aid in species classification[20]. The findings of the study show that the venation characteristics (areola width and vein density) in the three study sites vary significantly. The leaf surface area varied among the three study sites. These findings were consistent with Xu *et al.*,[21] who reported that leaf surface area is an important parameter which dictates growth rate; the larger the specific leaf area, the larger the area for capturing light per unit of previously captured mass. Although contradicting the report of Tain *et al.*[22], who reported that leaf area has no apparent trend with the changing environmental factors. It is widely recognised that a large leaf area can enhance solar energy capture, but also increases evapotranspiration. Therefore, findings from this study imply that *T. scleroxylon* could perform well in any harsh condition. Findings from this study are supported by Bonan[17], who reported that leaves growing in sunny environments are smaller than leaves growing in shaded environments. Xu et al.[21] emphasized that leaf size was clearly limited when there was a scarcity of water.

Epidermal Studies: The epidermal cell length (ECL) and epidermal cell width (ECW) showed no significant difference among locations at $p>0.05$, but a significant difference was found in epidermal cell density among the three study sites. The difference in the epidermal density among the studied locations could be attributed to a reaction to alterations in their surroundings, as foliage may open, close, or display enduring modifications in its structure. These findings could also be attributed to variations during leaf maturation, as supported by James and Bell[23] that significant variations in leaf type can also occur within species. During a plant's maturation, leaf growth is constrained by the amount of light available; certain trees, however, typically have erect or horizontal dorsiventral leaves.

This study clearly identified leaf abaxial characteristics and revealed a significant difference among the locations. The stomata length and density slightly vary in the region and were significantly higher in FUTA, which could be a result of the higher temperature in Akure and the environment. This was consistent with the report of Luomala *et al.*[24] that stomatal length decreased and stomatal density increased with increasing maximum monthly temperature.

Stomata density, frequency and distribution are inherently hereditary or genetically controlled traits, but sometimes, there may be ecotypes. It was discovered in this study. Higher stomata density and consequent stomata index observed on the abaxial surfaces of *T. scleroxylon* from FUTA (the rainforest zone) suggest that CO_2 was more taken up, probably due to the annual rainfall, which is presumably higher in the rainforest than in the other two locations. The more stomata per unit area (stomata density), the more CO_2 can be taken up and the more water can be released. This, however, agrees with the previous findings by Bertolino[25]. However, the reduced stomata densities observed in RUGIPO and AAUA further emphasised that stomata distribution varies but can be greatly affected by seasonal variations and mild dry conditions.

Conclusion

Significant differences were found when growth characteristics from different study sites were evaluated, underscoring the impact of genetic diversity and environmental conditions on the growth and development of *T. scleroxylon*. Interestingly, family 1 showed better growth characteristics across the study sites, its intrinsic potential to adapt to different environmental conditions suggesting Foliar venation and epidermal provided succinct information on the morphological characteristics from the study sites. Variations in environmental conditions and plant responses were indicated by the significant differences found in leaf area, areola width, vein density, epidermal cell density, length, and breadth, as well as stomata density among the sites. Conservation efforts should be raised to support the population of this species and prevent it from becoming extinct.

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