

Investigation of the Morphological and Anatomical (Xeromorphic) Adaptive Features of *Jatropha curcas*

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ABSTRACT

Jatropha curcas is a drought-tolerant perennial shrub belonging to the family *Euphorbiaceae* widely cultivated in tropical and subtropical regions for biodiesel production, erosion control, and medicinal applications. Although the species is known for its adaptability to arid and semi-arid environments, limited localized anatomical evidence exists to confirm its xeromorphic adaptations under the Sudan-Sahel conditions of Maiduguri, northeastern Nigeria. This study investigated the morphological and anatomical adaptive features of *Jatropha curcas* growing within the University of Maiduguri campus.

Fresh leaf, stem, and root samples were collected and processed using standard histological techniques involving fixation in Formalin-Acetic acid-Alcohol (FAA), dehydration through graded alcohol series, paraffin embedding, microtome sectioning (10–15 µm), staining with safranin and fast green, and microscopic examination. Epidermal peels were also prepared to evaluate stomatal characteristics.

The results revealed several xeromorphic adaptations. Morphological features included a deep taproot system, thick bark, leathery lobed leaves with waxy surfaces, and seasonal leaf shedding, all contributing to water conservation. Anatomically, the leaves exhibited thick cuticles, elongated epidermal cells, compact mesophyll tissues, and sunken stomata. Stem sections showed well-developed vascular tissues and a large pith region, while root

sections displayed lignified tissues, thickened cell walls, and extensive xylem development.

These structural characteristics confirm the xeromorphic adaptability of *Jatropha curcas* to semi-arid environments and support its potential for sustainable biofuel production and environmental management in northern Nigeria.

Keywords: *Jatropha curcas*, Leaf anatomy, Stem anatomy, Xeromorphic adaptations, Morphological features, Anatomical characteristics, Semi-arid environment, Drought tolerance, Histological analysis

I. INTRODUCTION

Jatropha curcas, commonly known as physic nut, is a perennial shrub of the family Euphorbiaceae, widely cultivated in tropical and subtropical regions for its economic, medicinal, and environmental importance. The plant is valued for biodiesel production, land reclamation, and traditional medicine, and it thrives under harsh conditions, including drought-prone and nutrient-poor soils (Divakara et al., 2010; Zhou et al., 2025; Neupane et al., 2021).

Maiduguri, in northeastern Nigeria, lies within the Sudan-Sahel ecological zone, characterized by low rainfall, high temperatures, and intense evapotranspiration, exposing vegetation to severe water stress. Plants in such environments develop xeromorphic adaptations, such as thick cuticles, reduced leaf area, sunken stomata, dense mesophyll, and well-developed vascular systems that enhance water-use efficiency and structural resilience (Taiz et al., 2018; Fahn, 1982).

Although *Jatropha curcas* is recognized as drought-tolerant, detailed studies on its morphological and anatomical adaptations in northeastern Nigeria remain limited. Previous research has emphasized its biofuel potential and agronomic performance rather than localized anatomical characterization. This study aims to investigate the xeromorphic features of the leaf, stem, and root of *Jatropha*

curcas to validate its adaptive strategies in semi-arid conditions. The plant's resilience, rapid growth, and diverse applications, including fencing, erosion control, biofuel, traditional medicine, and organic fertilizer, highlight its potential for rural development and environmental sustainability in Nigeria.

1.1. Research Gap

Jatropha curcas is widely recognized for its economic value and drought tolerance, most studies have focused mainly on its biofuel potential, agronomic performance, and economic benefits. Limited research has examined the detailed morphological and anatomical mechanisms that enable the plant to survive in arid and semi-arid environments. In the Sudan-Sahel region of northeastern Nigeria, particularly Maiduguri, environmental conditions are characterized by low rainfall and high temperatures, yet localized studies on the xeromorphic adaptations of *Jatropha curcas* remain scarce. Therefore, this study investigates the morphological and anatomical features of the leaf, stem, and root of *Jatropha curcas* to provide scientific evidence of its adaptation to semi-arid conditions.

1.2. Problem Statement

Jatropha curcas is a drought-tolerant shrub valued for biodiesel production, soil conservation, and medicinal uses. Although it is adapted to arid and

semi-arid environments, there is limited localized anatomical and morphological evidence confirming its xeromorphic adaptations under the semi-arid conditions of Maiduguri, northeastern Nigeria. Most studies have focused on its agronomic and biofuel potential rather than the structural traits that enable survival under water stress. This knowledge gap limits understanding of the plant's drought tolerance mechanisms and constrains its optimized cultivation in northern Nigeria. Therefore, a detailed investigation of the morphological and anatomical features of *Jatropha curcas* is needed to validate its adaptive strategies and support sustainable use in arid environments.

1.3. Aim and Objectives

1.3.1. General Objective

The aim of the study is to investigate the morphological and anatomical (xeromorphic) adaptive features of *Jatropha curcas* in the semi-arid environment of the University of Maiduguri campus, northeastern Nigeria

1.3.2. Specific Objectives

1. To identify the xeromorphic adaptive feature of *Jatropha curcas* to arid and semi-arid environment in University of Maiduguri campus.
2. To investigate the morphology and anatomical features of leaf structures linked to xeromorphy of *Jatropha curcas* in arid and semi-arid environment of Maiduguri.
3. To determine the stem morphology and anatomical features contributing to water conservation of *Jatropha curcas* in the study area.
4. To determine stomatal density and distribution patterns of *Jatropha curcas* in arid and semi-arid environment of Maiduguri.

1.4. Significance of the Study

This study is important because it improves understanding of the structural features that enable *Jatropha curcas* to survive in the semi-arid environment of Maiduguri, northeastern Nigeria.

Despite the plant's recognized drought tolerance and economic value, limited local studies have examined its anatomical and morphological (xeromorphic) adaptive features of *Jatropha curcas*. The findings from this study will contribute to knowledge on plant adaptation to water stress and serve as useful reference material for students, researchers, and scientists in botany and environmental studies. Furthermore, the study provides scientific evidence supporting the cultivation of *Jatropha curcas* for biofuel production, erosion control, and desertification management, thereby promoting sustainable agriculture and environmental conservation in arid regions.

II. METHODS AND MATERIALS

2.1. Study Area

The study was conducted at the University of Maiduguri located in Maiduguri, the capital of Borno State in northeastern Nigeria. Maiduguri lies within the Sudan–Sahel ecological zone, which is characterized by semi-arid climatic conditions, high temperature, low rainfall, and sparse vegetation (NiMet, 2023; Omonijo & Okogbue, 2014). The city is geographically located between Latitude 11°50'N – 11°55'N and Longitude 13°05'E – 13°15'E, with an average elevation of about 354 m above sea level (Adefolalu, 2007).

The University of Maiduguri campus is situated along the Maiduguri–Bama road and covers a large land area within the Maiduguri metropolitan region. The terrain of the study area is generally flat to gently undulating, consisting mainly of sandy to sandy-loam soils, which are typical of the Sudan–Sahel savannah environment (Olofin, 2008). The area is part of the Lake Chad Basin, which is characterized by sedimentary deposits and extensive sandy plains (Moussa et al., 2016).

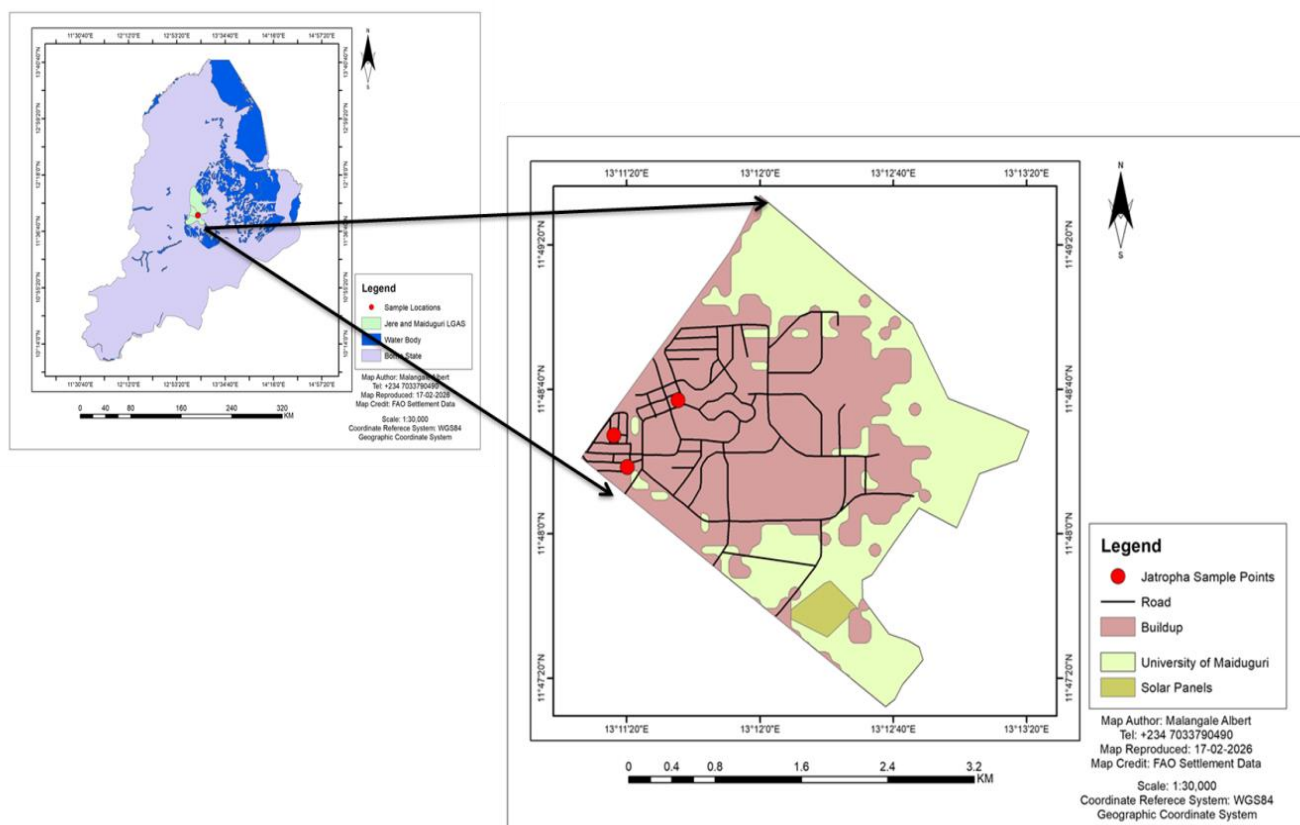


Figure 1: The map of Borno State showing University of Maiduguri and *Jatropha curcas* sample location (source: Malangale, 2026)

2.2. Climate, Geology and Vegetation

The climate of Maiduguri is classified as tropical semi-arid, characterized by two distinct seasons: the rainy season, which occurs between June and September, and the dry season, which lasts from October to May (NiMet, 2023). The mean annual rainfall ranges between 500 mm and 650 mm, with the highest rainfall usually recorded in August (Ojo, 1977). Temperatures are generally high throughout the year, with mean annual temperatures ranging between 28°C and 32°C, while maximum temperatures may exceed 40°C during the hot dry season between March and May (Adefolalu, 2007). Vegetation in the study area is typical of the Sudan savanna, dominated by drought-resistant grasses, shrubs, and scattered trees adapted to arid and semi-arid conditions. Common plant species include *Acacia spp.*, *Azadirachta indica*, and *Calotropis procera*, which exhibit xeromorphic characteristics

that enable them to survive under conditions of water stress and high evapotranspiration (Keay, 1989). The semi-arid environmental conditions of Maiduguri therefore provide a suitable ecological setting for investigating the morphological and anatomical adaptive features of *Jatropha curcas*.

2.3. Data Sampled

The materials used in this study consisted of the leaf, stem, and root tissues of young seedlings of *Jatropha curcas* plant. The samples for the study were collected from the campus of the University of Maiduguri in Maiduguri, Borno State, Nigeria, and were subsequently transported to the Histology Laboratory of the Department of Biological Sciences, University of Maiduguri, where they were processed for anatomical analysis.

2.4. Procedure

2.4.1. Tissue Fixation

This is the first requirement in the preservation of tissue, by using free hand sections (i.e. transverse about 5mm of fresh stems, leaves and roots of *Jatropha curcas*) was obtained or cut using new razorblade with free hand, then the fresh tissue was fixed in 70% F.A.A. (Formal Acetic acid and Alcohol), for about 24hrs to preserve the structures (Díaz, 2019; Ruzin, 1999; Criswell, et al., 2025).

2.4.2. Dehydration of the Tissues

Dehydration simply means the removal of water from the plant tissue. The water content hinders subsequent processing like infiltration within an embedding medium such as molten wax (Ruzin, 1999). After the preservation process, the tissues were dehydrated by passing the tissue through serial dilution of alcohol as follows:- The tissue was kept in 70% alcohol for 24hrs. The tissue was then transferred into 80% alcohol for 6hrs. The tissue was also transferred into 95% alcohol for 3hrs x 2 and finally the tissue was transferred into absolute alcohol for 6hrs (Díaz, 2019; Ruzin, 1999).

The tissues were subsequently cleared by transferring them through a graded series of absolute alcohol and xylene mixtures as follows: a ratio of 3:1 (absolute alcohol : xylene) for 2 hours, followed by 1:3 (absolute alcohol : xylene) for 3 hours, and finally pure xylene for 2 hours to ensure complete removal of alcohol from the tissues. Thereafter, the plant materials were placed in a container containing a small amount of paraffin wax mixed with xylene and kept in an oven at approximately 25°C for one week to facilitate infiltration.

2.4.3. Embedding the Tissue

Embedding was done in order to prevent the collapse and distortion of the tissue during sectioning. This was done by infiltrating or impregnating and surrounded by hard wax or solid for support (Ruzin, 1999). The tissues were embedded in 'L'-block, the 'L'-blocks were cleaned

and smeared with glycerol and then the blocks were set according to the size needed, in rectangular shape, then pure melted paraffin wax was poured to fill the blocks, the tissues were picked with a flamed forceps from the wax medium in oven and was placed in L-block and they were cooled in cold water where it solidifies, then the L-blocks were removed, the plant part was indicated by labeling and the block of paraffin containing the tissue was kept in refrigerator for some times (Diaz, 2019).

Mounting the block on chock was done by a knife flamed on a spirit lamp. Trim the block to obtain equal shape and size, this was done by flaming the knife and was passed between the block and chock, it made the block to stick on the chock and was put into water for solidification and was fridge for cooling (Ruzin, 1999; Diaz, 2019).

2.4.4. Sectioning of Tissue

Sectioning is the making thin slice cut from the tissue using microtone. After mounting the paraffin wax block on chock, then the blocks were placed on the microtone, block hold and the knife-edge of the rotatory microtone was set at the angle 3° to enable the knife to easily cut the tissues (Kiernan, 2015). About 15-20 µm, was used to trim the excess paraffin wax and then fine section was gotten by adjusting to 10µm, section come out in ribbon like a manner containing slice cut from the tissue (Bancroft & Gamble, 2008). By using a blunted forceps the sectioned tissue was picked and was placed on a paper then was carefully separated by a surgical blade.

2.4.5. Staining Slides

Staining of slides is the exposing of section to the action of dye to enable a clear view of the morphology of the cellular, structure; the cell constituents of the tissue using saffranin and fat-green dyes for permanent staining (Bancroft & Gamble, 2008). Even permanent staining may lose their colour if exposed to sunlight, so the slide should be stored in the dark (Kiernan, 2015).

2.4.6. Mounting of Slide

The plain slide was cleaned and smeared with egg albumen (Bancroft & Gamble, 2008). A drop of boiled distilled water was placed in the center of the slide (Kiernan, 2015). The sections were then placed on the slide and excess water was drained, making sure that the specimens were at the center of the slide and placed on a controlled hot plate for the slide to dry. Mounting gives protection to section, because it is anti-infectant, and it increases the refractive index. Canada balsam was dropped on the center of slide; cleaned cover slide was gently placed on slide avoiding air, the air then dried on drying plate at a regulated temperature (Presnell, et al., 1997).

2.4.7. Observations and Labeling of Slide

The section was observed under a research microscope, under various magnifications. The name of the plant; the tissue type; and surface of sections cut, were written on each slide, given full information about the material on the slide. The images of the tissues were drawn.

2.4.8. Removal of the Leaf Epidermal Tissue

The portion of the leaf was put in a test-tube and 40% of Nitric acid was added on it and was partially boiled. The content in the test-tube was poured in the Petri-dish containing water. With the help of forceps the epidermis was easily removed and then it was stained with Saffranin. Some distilled water was used to drain the excess staining, after which the specimen was covered with cover slip and then was observed under microscope.

III. RESULTS AND DISCUSSION

3.1. Results

This section of the study, present the results. Detailed observations were carried out on the morphological and anatomical characteristics of the stem, leaf, and root of *Jatropha curcas*. *Jatropha curcas* is a small tree or shrub characterized by smooth grey bark that exudes whitish, watery latex when injured. The plant develops a prominent taproot system that penetrates deeply into the subsoil, enabling it to access moisture under dry conditions. It also possesses large green to pale-green leaves and a distinctly erect stem, which contribute to its overall structural appearance and adaptation to semi-arid environments.

3.2. Morphological Features of *Jatropha curcas*

The leaves of the plant are alternately arranged on the stem, glabrous, and pentagonal in shape, usually possessing three to five shallow lobes with a spiral phyllotaxis. The leaf venation is reticulate, specifically palmate and prominent, consisting of five basal veins and four to five pairs of lateral veins. The plant develops a long taproot system that penetrates deeply into the soil, enabling it to absorb moisture during dry conditions. The stem is covered with thick grey bark, which helps reduce the rate of transpiration. In addition, the leaves possess a shiny, leathery surface that reflects sunlight. The plant also sheds its leaves during severe dry conditions, a strategy that further minimizes water loss through transpiration.



Plate 1: 3.2. Morphological Features of *Jatropha curcas* plant

3.3. Anatomical Features of the Leaves

The transverse section (T.S.) of the leaf reveals several anatomical adaptive features of *Jatropha curcas* plant (Plate 2 and Plate 3):

3.3.1. Epidermis

The leaf possesses an epidermal layer on both the upper and lower surfaces, forming the boundary between the atmosphere and the internal tissues. The epidermis is covered by a thin cuticle, while the outer walls of the epidermal cells are thicker than the inner walls. The epidermal cells are elongated and arranged in well-defined rows, contributing to structural protection.

3.3.2. Sunken Stomata and Compact Cells

Sunken stomata occur within depressions or grooves and are often protected by trichomes. These trichomes shield the stomata from excessive sunlight and strong winds, thereby reducing the rate of transpiration. The cells between the

epidermal layers are closely packed and compactly arranged, which prevents the collapse of the mesophyll tissue and enables the leaf to remain functional under severe arid conditions.

3.3.3. Sclerenchyma:

The leaf contains a considerable proportion of sclerenchyma cells with lignified walls, including fibres, sclereids, and fibre-sclereids. The sclerenchymatous sheath helps limit excessive transpiration and also provides mechanical support to the leaf structure.

3.3.4. Mesophyll

The mesophyll consists of thin-walled parenchymatous cells. Some of these cells contain chloroplasts and are referred to as chlorenchyma, which are responsible for photosynthesis. The remaining thin-walled cells function mainly in the storage of water, food materials, and metabolic waste products.

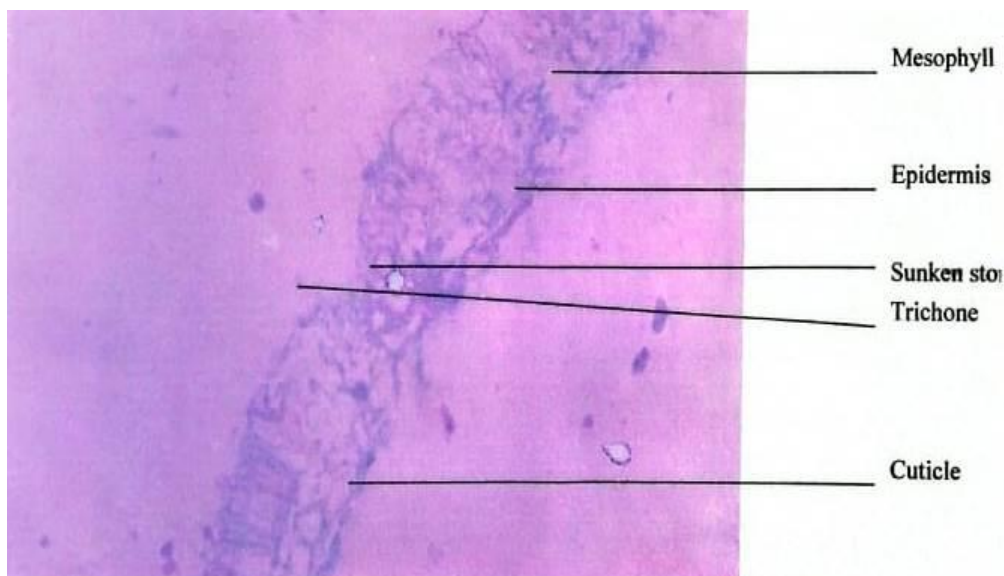


Plate 2: Transverse Section of a *Jatropha curcas* leaf showing the sunken stomata and mesophyll

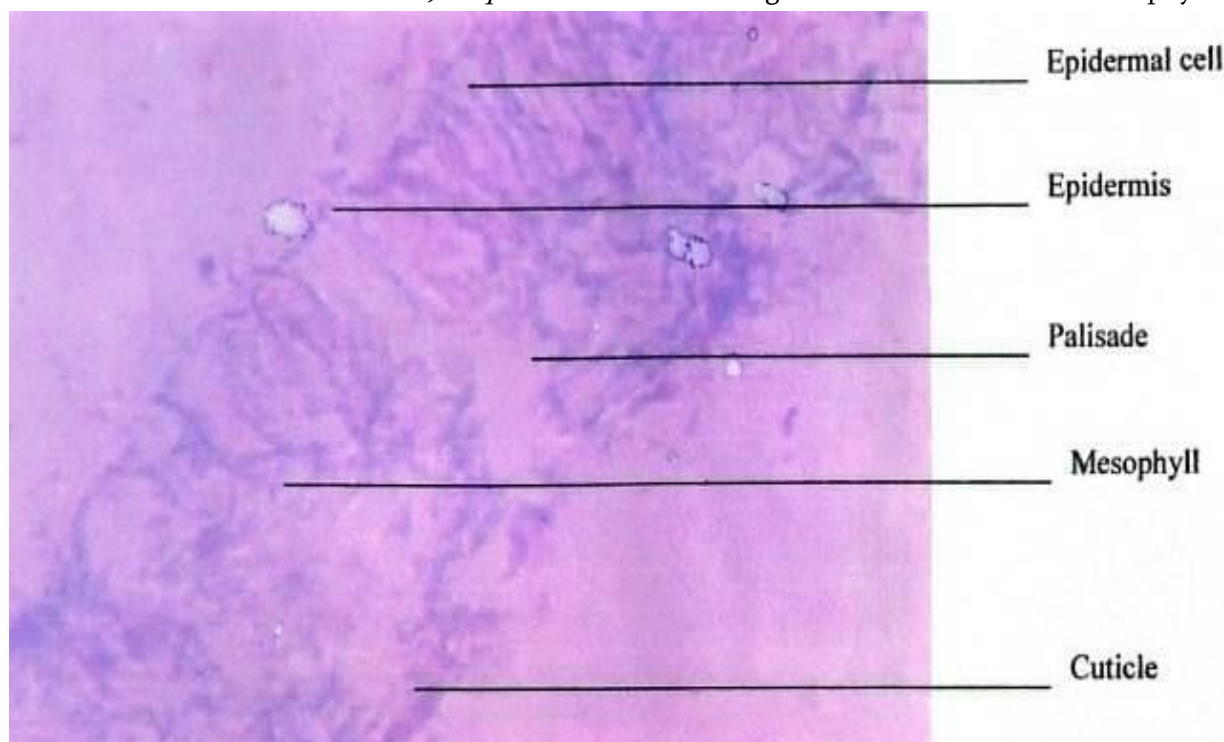


Plate 3: Transverse Section of a *Jatropha curcas* leaf showing different tissue regions

3.4. Anatomical Features of the Stem

The anatomical features of the stem are illustrated in Plate 4 and Plate 5. The transverse section (T.S.) of the stem reveals several adaptive anatomical characteristics.

The stem of *Jatropha curcas* possesses a compact and well-developed epidermal layer. Beneath the epidermis lies the cortex, which represents the

ground tissue located between the epidermis and the vascular cylinder.

Following the cortex is the vascular cylinder, which is prominently composed of primary and secondary xylem tissues (protoxylem and metaxylem) as well as phloem elements. The protoxylem and metaxylem are arranged in strands that gradually

decrease in size from the cortex toward the pith, an arrangement referred to as the endarch condition.

At the center of the stem is a large ground tissue region known as the pith. The pith consists of loosely arranged cells forming a hollow central region where water can accumulate, thereby serving as a reservoir for water storage during dry conditions.

In addition, latex tubes (laticiferous canals) are present within the stem tissues. These specialized

cells contain latex, whose viscous nature may contribute to reducing

transpiration to some extent. The latex produced by *Jatropha curcas* is known to be irritating to the skin. Furthermore, the stem possesses a thick cuticular layer on the bark, which helps to minimize excessive water loss through transpiration.

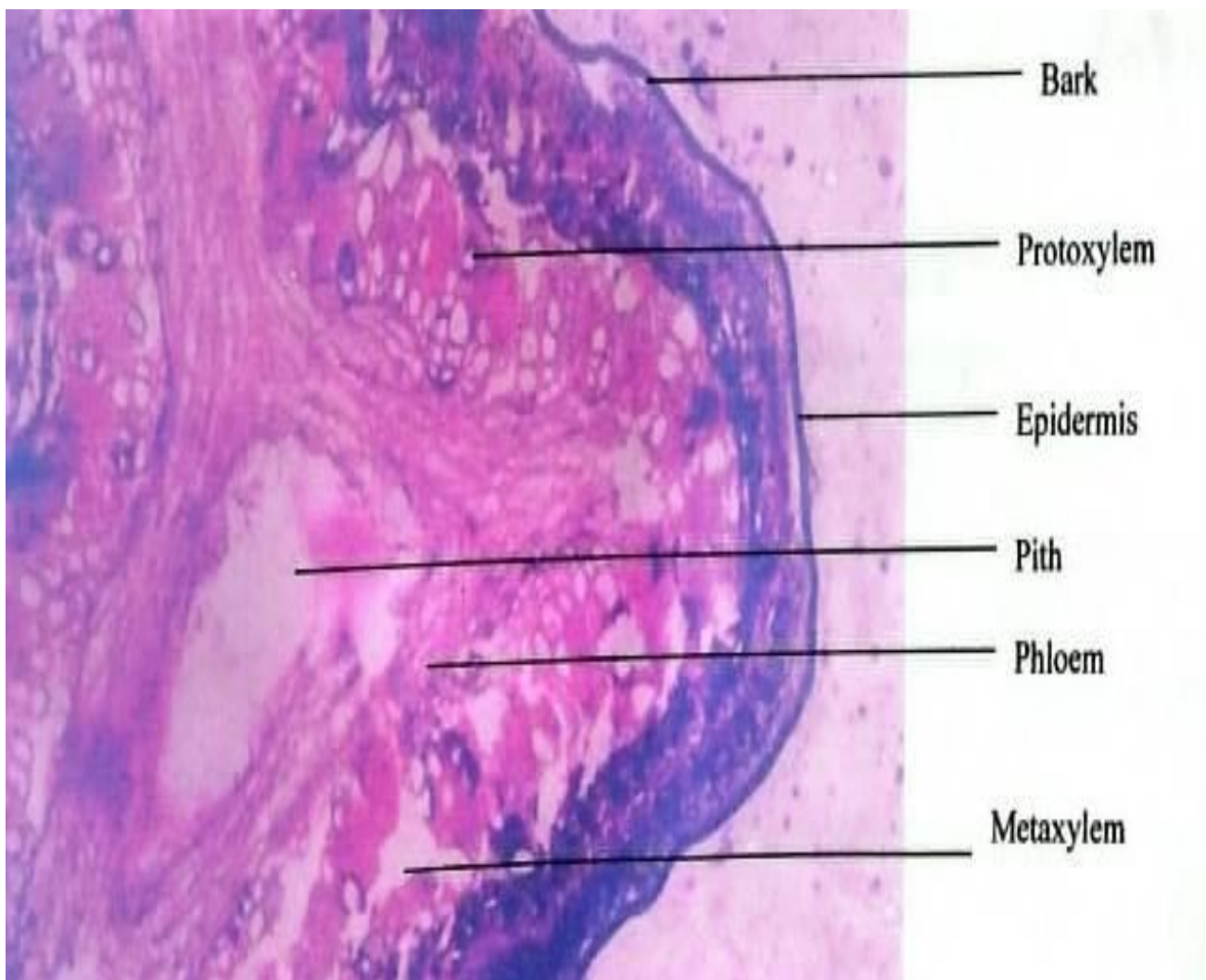


Plate 4: Transverse Section of a *Jatropha curcas* stem showing the enlarge tissue of the pith

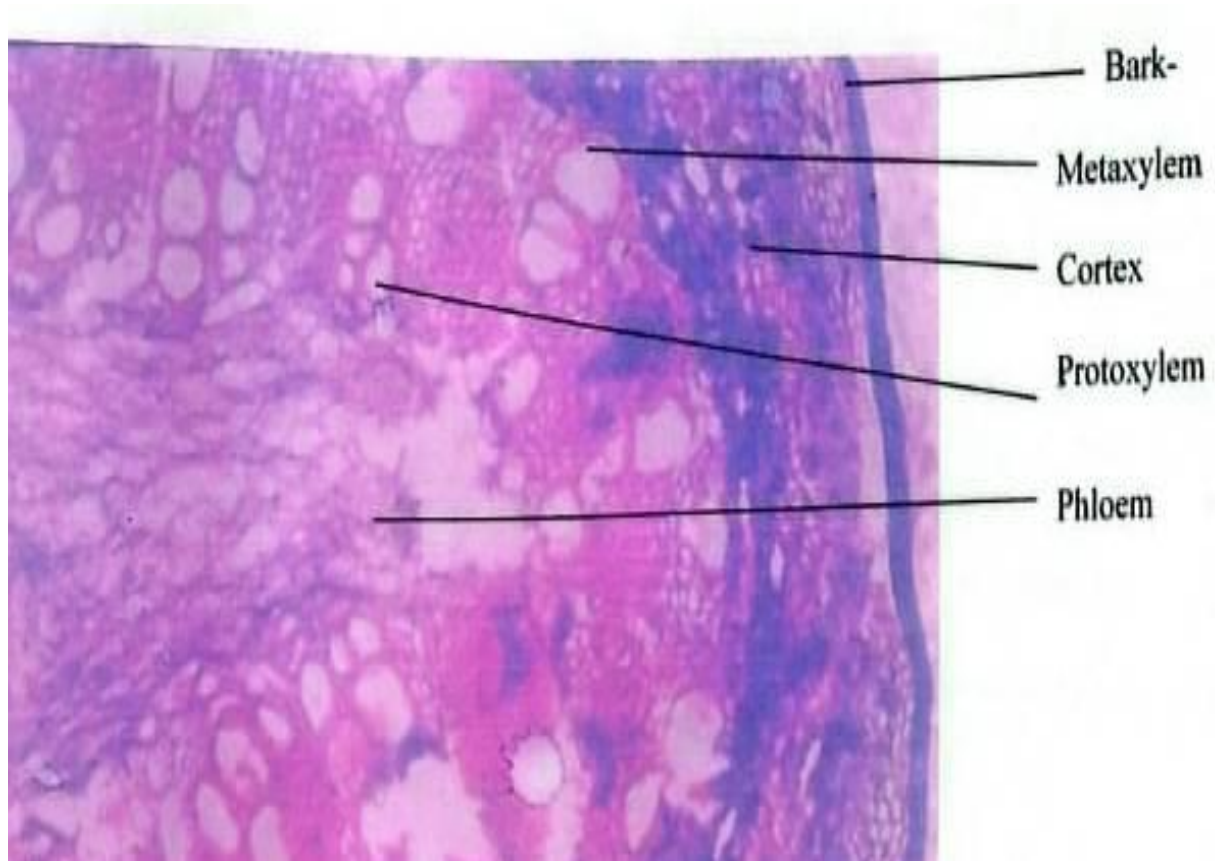


Plate 5: Transverse Section of a *Jatropa curcas* stem showing different tissues from the bark to protoxylem

3.5. Anatomical Features of the Root

The vascular bundles in the root exhibit an endarch arrangement, in which the metaxylem is oriented toward the cortex while the protoxylem is directed toward the pith region. This vascular configuration is characteristic of the endarch condition (Plate 6).

The transverse section of the root shows that the epidermis consists of a single layer of epidermal cells, followed by layers of parenchymatous cells forming the cortex. Beneath this region, a boundary of reddish-coloured cells is observed, which is associated with secondary growth within the cortex. The cell walls in this region are thickened and lignified, providing structural strength and possibly enhancing the plant's ability to withstand severe arid conditions.

Below the secondary cortex, the vascular tissues phloem and xylem are distributed within the

vascular cylinder. The phloem functions in the transport of food materials, whereas the xylem is responsible for the conduction of water and mineral salts. A large portion of the root region is occupied by xylem elements, which may also serve as a reservoir for water storage during periods of drought, thereby supporting the plant's survival in dry environments. The pith is either very small or nearly absent in the root structure.

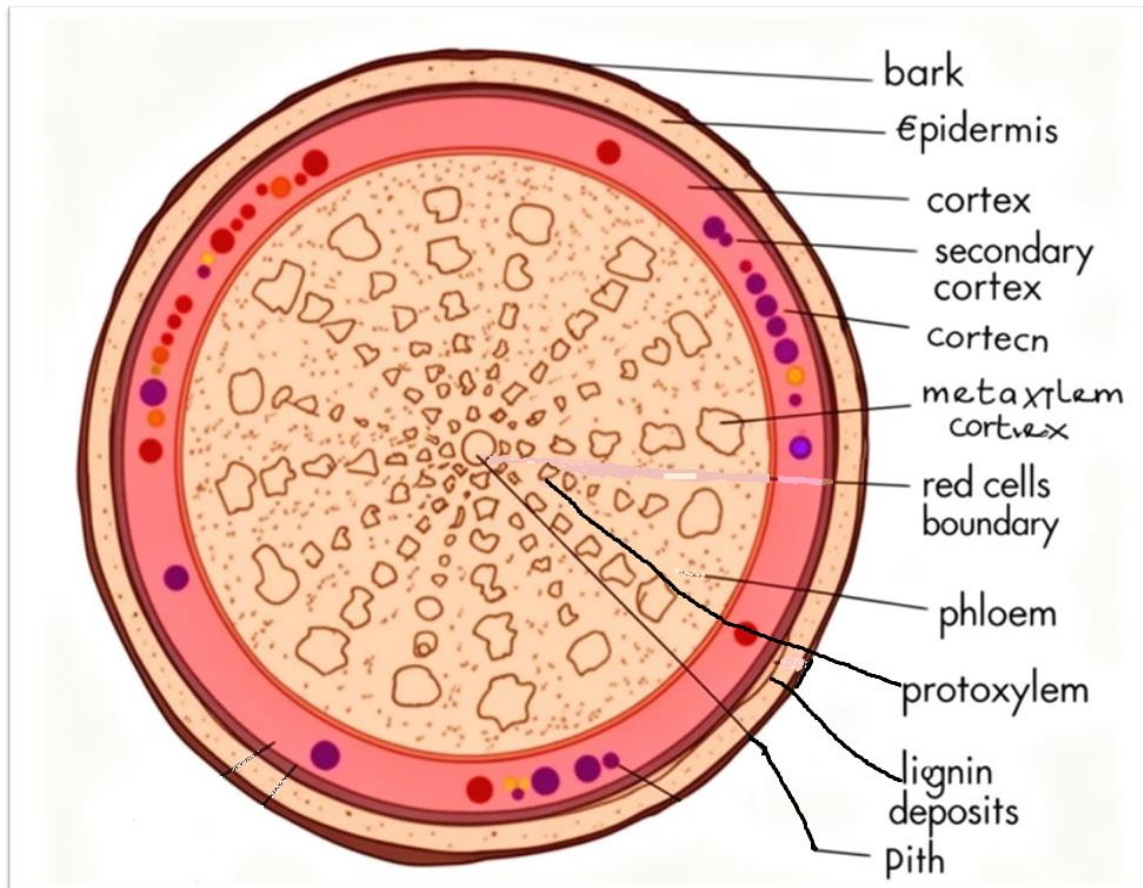


Plate 6: T-section of *Jatropa curcas* root showing different tissue regions from the bark to pith

3.6. Discussions

The results obtained in this study demonstrate several morphological and anatomical characteristics that support the adaptation of *Jatropa curcas* to arid and semi-arid environments. These findings are largely consistent with earlier studies, although some variations in structural features have been reported depending on environmental conditions and plant age (Hsie et al., 2015; Nunes, et al., 2017).

3.6.1. Morphological Features

The present study observed that *Jatropa curcas* is a small tree or shrub with smooth grey bark that exudes whitish latex when injured, along with large lobed leaves and an erect stem. These characteristics agree with the descriptions reported by Moniruzzaman et al., 2015, Achten et al. (2008) and Divakara et al. (2010), who noted that *Jatropa*

curcas typically grows as a drought-resistant shrub with a well-developed canopy and latex-producing tissues.

The alternate leaf arrangement, pentagonal leaf shape, and 3–5 shallow lobes with palmate venation observed in this study are also consistent with the findings of Heller (1996) and Openshaw (2000), who described the leaves of *Jatropa curcas* as palmately veined and variably lobed. These leaf structures enhance light interception and photosynthetic efficiency, which is important for plants growing in regions with intense solar radiation.

Furthermore, the presence of a deep taproot system observed in this study supports previous reports by Fairless (2007) and Divakara et al. (2010), who emphasized that *Jatropa curcas* develops an extensive root system that allows the plant to access

deep soil moisture, thereby improving drought tolerance. The leaf shedding during extreme dry conditions, also recorded in this study, is a known xerophytic strategy reported by Achten et al. (2008) for reducing water loss.

3.6.2. Leaf Anatomical Features

The anatomical examination of the leaf revealed the presence of a double epidermal layer with a cuticular covering, sunken stomata, trichomes, compact mesophyll cells, and abundant sclerenchyma tissues, this study agrees with the study reported by Šantrůček, (2022). These features correspond with xeromorphic adaptations previously reported by Esau (1977) and Fahn (1982) in plants adapted to dry environments.

The sunken stomata protected by trichomes, observed in this study, are particularly important in reducing transpiration rates. Similar observations were reported by Dickison (2000) and Šantrůček, (2022) in xerophytic plants, where stomata located in depressions help reduce direct exposure to dry air and strong winds. The compact mesophyll arrangement observed in this study also agrees with findings by Fahn (1982), who noted that tightly packed mesophyll cells help prevent tissue collapse under water stress.

However, some studies have reported thicker cuticular layers and more pronounced palisade mesophyll in *Jatropha curcas* leaves growing in extremely arid environments. Achten et al. (2010) noted that environmental stress may increase cuticle thickness and leaf structural rigidity. The relatively thin cuticle observed in the present study may therefore reflect local environmental conditions or the developmental stage of the plant.

3.6.3. Stem Anatomical Features

The stem anatomy observed in this study showed a well-developed epidermis, cortex, vascular cylinder, large pith region, and the presence of laticiferous canals. These observations correspond with the findings of Metcalfe and Chalk (1983), who described members of the family Euphorbiaceae as

possessing laticiferous tissues and well-developed vascular systems.

The presence of protoxylem and metaxylem arranged in an endarch pattern is typical of dicotyledonous stems and has also been reported in *Jatropha curcas* by Dickison (2000). The large pith region observed in this study may function as a temporary water storage tissue, which is beneficial for plants growing in semi-arid environments.

The laticiferous canals containing latex, observed in the stem tissues, are another characteristic feature of *Jatropha curcas*. According to Heller (1996), latex production in this species plays roles in defense against herbivores, wound sealing, and reduction of water loss. As reported by Boithias (2012), agrees with the current findings that latex may contribute to limiting transpiration.

3.6.4. Root Anatomical Features

The root anatomical structure observed in this study revealed a single-layered epidermis, parenchymatous cortex, lignified cells associated with secondary growth, and well-developed xylem tissues occupying a large portion of the root. These results are consistent with the observations of Fahn (1982), who reported that xerophytic plants often possess well-developed xylem tissues to facilitate efficient water transport.

The extensive xylem development observed in the present study may enhance the plant's capacity for water conduction and storage, which supports its survival in water-limited environments. Similar findings were reported by Divakara et al. (2010), who noted that *Jatropha curcas* roots are adapted to efficient water absorption and transport.

However, some studies have reported a more pronounced pith region in younger roots, whereas the present study observed a very small or nearly absent pith. This difference may be attributed to plant maturity, environmental conditions, or methodological differences during anatomical observation, as reported by Abe (2019).

IV. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusions

This study has demonstrated that *Jatropha curcas* possesses well-developed morphological and anatomical (xeromorphic) features that enable its survival and adaptation to the semi-arid conditions of Maiduguri in northeastern Nigeria. The plant exhibits several drought-resistant morphological traits, including a deep taproot system, thick bark, leathery lobed leaves with waxy surfaces, and the ability to shed leaves during extreme dry periods. These features collectively reduce water loss and enhance water acquisition from deeper soil layers.

Anatomically, the study revealed significant xeromorphic characteristics such as thick cuticles, elongated epidermal cells, sunken stomata, compact mesophyll tissues, and the presence of sclerenchyma in the leaves, all of which contribute to minimizing transpiration and maintaining structural integrity under water stress. The stem showed well-developed vascular tissues, a large pith region for possible water storage, and laticiferous canals that may aid in protection and water conservation. Similarly, the root structure exhibited extensive xylem development, lignified tissues, and reduced or absent pith, which enhance efficient water transport and mechanical strength.

Findings from the study confirm that *Jatropha curcas* is highly adapted to semi-arid environments through a combination of structural and physiological strategies. The study also provides localized anatomical evidence supporting its drought tolerance under Sudan–Sahel conditions, thereby filling an important research gap. These adaptive features make the plant a suitable candidate for sustainable biofuel production, land reclamation, and environmental management in arid and semi-arid regions of Nigeria.

4.2. Implication

The study shows that *Jatropha curcas* is highly adapted to semi-arid conditions, confirming its drought tolerance and ecological resilience. These adaptations make it suitable for sustainable cultivation, biofuel production, erosion control, and desertification management. Additionally, the findings provide a foundation for further research and large-scale environmental monitoring using modern tools such as GIS and remote sensing.

4.3. Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Promotion of Cultivation in Arid Regions:** *Jatropha curcas* should be widely cultivated in semi-arid and arid regions of northern Nigeria due to its strong drought tolerance and adaptability, especially for biofuel production and land restoration.
2. **Use in Environmental Management:** The plant should be integrated into afforestation, desertification control, and erosion management programs, particularly in the Sudan–Sahel zone, to improve environmental sustainability.
3. **Further Anatomical and Physiological Studies:** Future research should investigate physiological responses such as water-use efficiency, transpiration rates, and photosynthetic activity to complement the anatomical findings.
4. **Comparative Studies Across Ecological Zones:** Similar studies should be conducted in different ecological zones to compare structural variations and better understand the phenotypic plasticity of *Jatropha curcas*.
5. **Application of Advanced Techniques:** The use of modern tools such as scanning electron microscopy (SEM),

6. GIS, and remote sensing (e.g., Google Earth Engine) is recommended for more detailed analysis and large-scale monitoring of the plant's distribution and performance.
7. **Improved Agronomic Practices:** Research should focus on optimizing planting techniques, spacing, and soil management practices to enhance growth and yield under semi-arid conditions.

V. REFERENCES

- [1]. Abe, J. (2019). Root Anatomical Structure of *Jatropha curcas* Seedlings—A Short Report. *American Journal of Plant Sciences*, 10(3), 491-495.
- [2]. Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008) *Jatropha* bio-diesel production and use. *Biomass Bioenergy* 32:1063–1084
- [3]. Adefolalu, D. O. (2007). Climate change and economic sustainability in Nigeria. In *International Conference on Climate Change and Economic Sustainability held at Nnamdi Azikiwe University, Enugu, Nigeria* (pp. 12-14).
- [4]. Bancroft, J. D., & Gamble, M. (Eds.). (2008). *Theory and practice of histological techniques*. Elsevier health sciences.
- [5]. Boithias, L., Do, F. C., Ayutthaya, S. I. N., Junjittakarn, J., Siltecho, S., & Hammecker, C. (2012). Transpiration, growth and latex production of a *Hevea brasiliensis* stand facing drought in Northeast Thailand: the use of the WaNuLCAS model as an exploratory tool. *Experimental agriculture*, 48(1), 49-63.
- [6]. Criswell, S., Gaylord, B., & Pitzer, C. R. (2025). Histological methods for plant tissues. *Journal of Histotechnology*, 48(1), 58-67.
- [7]. Díaz, K. V. L. (2019). Formalin-acetoalcohol (FAA) solution for killing, fixing, and pickling botanical specimen. *Laguna, Philippines: Institute of Biological Sciences, University of the Philippines Los Baños*.
- [8]. Dickison, W. C. (2000). *Integrative plant anatomy*. Elsevier.
- [9]. Divakara, B. N., Upadhyaya, H. D., Wani, S. P., & Gowda, C. L. (2010). Biology and genetic improvement of *Jatropha curcas* L.: a review. *Applied Energy*, 87(3), 732-742.
- [10]. Esau, K. (1977). Anatomy of seed plants. 550-pp.
- [11]. Fahn, A. (1982). *Plant Anatomy*. 3rd Edition. Pergamon Press, Oxford.(p. 544pp).
- [12]. Fairless, D. (2007). Biofuel: the little shrub that could-maybe.
- [13]. Heller, J. (1996). *Physic nut, Jatropha curcas L* (Vol. 1). Bioversity international.
- [14]. Hsie, B. S., Mendes, K. R., Antunes, W. C., Endres, L., Campos, M. L., Souza, F. C., ... & Pompelli, M. F. (2015). *Jatropha curcas* L.(Euphorbiaceae) modulates stomatal traits in response to leaf-to-air vapor pressure deficit. *Biomass and Bioenergy*, 81, 273-281.
- [15]. Keay, R. W. J. (1989). *Trees of Nigeria* Oxford Press.
- [16]. Kiernan, J. (2015). *Histological and histochemical methods*. Scion publishing ltd.
- [17]. Metcalfe, C. R., & Chalk, L. (1983). *Anatomy of the dicotyledons: Wood structure and conclusion of the general introduction* (Vol. 2). Clarendon Press New York.
- [18]. Moniruzzaman, M. A., Yaakob, Z., & Aminul Islam, A. K. M. (2015). Potential uses of *Jatropha curcas*. *Jatropha curcas: Biology, Cultivation and Potential Uses*, 45-96.
- [19]. Moussa, A., Novello, A., Lebatard, A. E., Decarreau, A., Fontaine, C., Barboni, D., ...

- & Brunet, M. (2016). Lake Chad sedimentation and environments during the late Miocene and Pliocene: New evidence from mineralogy and chemistry of the Bol core sediments. *Journal of African Earth Sciences*, 118, 192-204.
- [20]. Neupane, D., Bhattarai, D., Ahmed, Z., Das, B., Pandey, S., Solomon, J. K., ... & Adhikari, P. (2021). Growing *Jatropha curcas* L.) as a potential second-generation biodiesel feedstock. *Inventions*, 6(4), 60.
- [21]. Nigerian Meteorological Agency (NiMet). (2023). *Agrometeorological Bulletin (March 2023 Edition)*. Abuja, Nigeria.
- [22]. Nunes, C. F., Dos Santos, D. N., Valente, T. C. T., Pasqual, M., Soares, J. D. R., Ferreira, K. S., & de CASTRO, E. M. (2017). Leaf morpho-anatomy of *Jatropha curcas* in vitro: response to light conditions and temperature.
- [23]. Ojo, O. (1977). *The climates of West Africa* (p. 219pp).
- [24]. Olofin, E. A. (2008). The physical setting. *Wudil within Kano Region: A Geographical Synthesis*, Adamu Joji Publishers, Kano City, 5-34.
- [25]. Omonijo, T. O., & Okogbue, E. C. (2014). Trend analysis of drought in the Guinea and Sudano-Sahelian climatic zones of Northern Nigeria (1907-2006). *Atmospheric and Climate Sciences*, 4(04), 483-507.
- [26]. Openshaw, K. (2000). A review of *Jatropha curcas*: an oil plant of unfulfilled promise. *Biomass and bioenergy*, 19 (1), 1-15.
- [27]. Presnell, J. K., Schreibman, M. P., & Humason, G. L. (1997). Humason's animal tissue techniques. (*No Title*).
- [28]. Ruzin, S. E. (1999). *Plant microtechnique and microscopy* (Vol. 198, p. 322). New York: Oxford University Press.
- [29]. Kanthakhoo, N. (2024). Exosomal Immune Checkpoint Molecules as Liquid Biopsy Markers. Available at SSRN 6466858.
- [30]. Šantrůček, J. (2022). The why and how of sunken stomata: does the behaviour of encrypted stomata and the leaf cuticle matter?. *Annals of Botany*, 130(3), 285-300.
- [31]. Taiz, L., Zeiger, E., Møller, I. M. 1., & Murphy, A. S. (2018). *Fundamentals of plant physiology*. Oxford University Press.
- [32]. Zhou, Y., Fan, P., Chen, S., & Wang, Z. (2025). Future Prospects for *Jatropha curcas* L. as a Bioenergy Crop: Assessing Land Suitability under Varying Climate Scenarios. *Energy Nexus*, 100628.