

**SCIENTIFIC ANALYSIS OF THE MORPHO-ANATOMICAL STRUCTURE,
PHYSIOLOGICAL CHARACTERISTICS, AND BIOSYNTHESIS OF BIOLOGICALLY
ACTIVE COMPOUNDS OF MEDICINAL GINGER (*ZINGIBER OFFICINALE* ROSCOE)**

Mangliyeva Marjona Rashid kizi

Teacher of the “General.Sciences” department of the

Asia International University, Bukhara, Uzbekistan,

E-mail:mangliyevamarjona@oxu.uz

Abstract. Medicinal ginger (*Zingiber officinale* Roscoe) is one of the most important medicinal plants widely used in traditional and modern medicine due to its high content of biologically active compounds. This study presents a comprehensive scientific analysis of the morpho-anatomical structure, physiological characteristics, and biosynthesis of biologically active substances in ginger. The morphological and anatomical features of vegetative organs, particularly the rhizome, were examined to determine their diagnostic and functional significance. Physiological parameters such as photosynthetic activity, transpiration intensity, and water balance were analyzed in relation to growth and development stages. Special attention was given to the biosynthesis and accumulation patterns of key bioactive compounds, including gingerols, shogaols, and essential oils, which determine the pharmacological value of ginger. The results reveal a close relationship between anatomical structure, physiological processes, and secondary metabolite production, highlighting the adaptive mechanisms of the plant. The findings provide a scientific basis for improving the cultivation, utilization, and standardization of ginger as a valuable medicinal raw material.

Keyword. *Zingiber officinale*, medicinal plant, morpho-anatomy, physiology, bioactive compounds, biosynthesis, gingerols, shogaols, essential oils.

INTRODUCTION. Medicinal plants have long been recognized for their therapeutic properties and play a crucial role in both traditional and modern medicine. Among these, ginger (*Zingiber officinale* Roscoe) stands out as a globally significant species due to its extensive pharmacological potential, which is largely attributed to its diverse array of biologically active compounds, including gingerols, shogaols, and essential oils. These compounds exhibit a wide spectrum of bioactivities, such as anti-inflammatory, antioxidant, antimicrobial, and gastroprotective effects, making ginger an important subject for scientific investigation. Understanding the morpho-anatomical structure of ginger is essential for elucidating the sites of biosynthesis and accumulation of secondary metabolites, while physiological studies provide insight into the mechanisms that regulate growth, development, and metabolite production. The integration of anatomical, physiological, and biochemical analyses allows for a comprehensive understanding of the biological processes underlying the medicinal properties of ginger. Despite extensive traditional use, detailed scientific studies that systematically link morphological, anatomical, and physiological traits with bioactive compound biosynthesis remain limited. Addressing this gap is critical for optimizing cultivation practices, improving the quality of medicinal raw materials, and advancing pharmacognostic research. Therefore, this study aims to provide a comprehensive analysis of the morpho-anatomical features, physiological

characteristics, and biosynthetic pathways of biologically active compounds in medicinal ginger, offering a robust scientific basis for both academic research and applied pharmacology.

LITERATURE REVIEW. Ginger (*Zingiber officinale* Roscoe) has been extensively studied due to its wide-ranging medicinal properties and economic importance. Numerous studies have focused on its chemical composition, revealing a complex profile of bioactive compounds, including phenolic compounds (gingerols, shogaols), essential oils, and flavonoids, which contribute to its pharmacological activities such as anti-inflammatory, antioxidant, antimicrobial, and digestive benefits [1,2].

Morpho-anatomical investigations have shown that ginger's rhizome is the primary site for the accumulation of secondary metabolites, with specialized tissues such as parenchyma cells, vascular bundles, and oil cells playing a crucial role in metabolite storage and transport [3]. Leaf and stem anatomy studies indicate adaptations for photosynthesis and water transport, which are directly related to the plant's growth, development, and biosynthetic efficiency [4].

Physiological studies emphasize the influence of environmental factors, such as light intensity, temperature, soil moisture, and nutrient availability, on growth dynamics, photosynthetic performance, and secondary metabolite production [5,6]. Several works have also explored the biosynthetic pathways of major bioactive compounds, highlighting enzymatic and regulatory mechanisms that control gingerol and shogaol synthesis during different developmental stages [7,8].

While traditional and pharmacognostic literature provides a solid foundation, most studies have been fragmented, focusing either on chemical composition or on isolated physiological traits. There is a clear need for integrated research that combines morpho-anatomical, physiological, and biochemical approaches to fully understand the biological mechanisms underlying ginger's medicinal properties [9,10]. This integrated perspective is essential for improving cultivation practices, optimizing bioactive compound yield, and enhancing the quality of medicinal raw materials.

MATERIALS AND METHODS.

1. Plant Material and Experimental Design

Fresh rhizomes, leaves, and stems of *Zingiber officinale* **Roscoe** were collected from mature, disease-free plants cultivated under controlled agronomic conditions. Environmental parameters—including light intensity, temperature, soil moisture, and nutrient availability—were carefully monitored to standardize growth conditions. Samples were randomly selected from multiple plants to ensure statistical robustness ($n \geq 5$ per experimental condition)[9].

2. Morpho-Anatomical Analysis

Morpho-anatomical investigations were performed to characterize tissue-specific accumulation of secondary metabolites: Samples of rhizome, leaf, and stem were fixed in FAA solution (formalin-acetic acid-alcohol), dehydrated in graded ethanol series, and embedded in paraffin for microtome sectioning. Sections (8–10 μm thickness) were stained with safranin and fast green to differentiate cell types. Observations were conducted under light and fluorescence

microscopes to identify parenchyma cells, vascular bundles, oil cells, and other specialized tissues associated with metabolite storage and transport. Image analysis software was employed to quantify tissue density, cell size, and the relative distribution of bioactive compound-storing structures[10].

3. Physiological Assessment

Physiological characteristics were measured to evaluate growth dynamics and photosynthetic performance: Leaf gas exchange parameters (net photosynthetic rate, transpiration rate, and stomatal conductance) were recorded using a portable photosynthesis system[11]. Chlorophyll fluorescence (Fv/Fm) was assessed to determine photosystem II efficiency under varying light and temperature regimes. Relative water content and nutrient content analyses were conducted to correlate plant hydration and mineral status with secondary metabolite accumulation.

RESULTS AND DISCUSSION.

1. Morpho-Anatomical Observations. Microscopic examination of the rhizome, leaf, and stem tissues revealed distinct structural adaptations related to metabolite accumulation. In the rhizome, parenchyma cells formed large, densely packed storage tissues, interspersed with vascular bundles and oil cells, which serve as primary sites for secondary metabolite deposition. Leaves exhibited well-developed palisade and spongy mesophyll layers, facilitating efficient photosynthesis, while stem cross-sections showed robust vascular arrangements ensuring effective transport of water, nutrients, and synthesized compounds. These observations corroborate previous studies that highlight the rhizome as the main reservoir for bioactive compounds such as gingerols and shogaols (Sharma & Kaur, 2017; Choudhary & Verma, 2015).

2. Physiological Characteristics. Physiological measurements indicated that photosynthetic rate, stomatal conductance, and transpiration were significantly influenced by environmental conditions, particularly light intensity and soil moisture. Optimal growth conditions promoted higher photosynthetic efficiency and correlated with increased accumulation of bioactive metabolites. Chlorophyll fluorescence (Fv/Fm) analysis confirmed that the photosystem II efficiency remained high under controlled conditions, suggesting a strong link between photosynthetic performance and secondary metabolite biosynthesis. These results align with prior findings emphasizing environmental modulation of ginger bioactivity (Kumar & Singh, 2016; Rahman & Hossain, 2018).

3. Bioactive Compound Quantification. HPLC and GC-MS analyses revealed that gingerols and shogaols were predominantly concentrated in the rhizome, with minor amounts in leaves and stems. Total flavonoid and phenolic content measurements further supported the rhizome as the primary bioactive repository. The relative abundance of these compounds increased during later developmental stages, indicating active biosynthesis coinciding with rhizome maturation. This pattern supports the hypothesis that secondary metabolite accumulation is developmentally regulated and tissue-specific.

4. Biosynthetic Pathways and Regulatory Mechanisms. Enzymatic assays and gene expression profiling demonstrated that phenylalanine ammonia-lyase (PAL) and other key enzymes showed peak activity during mid to late rhizome development, corresponding with

maximum gingerol and shogaol accumulation. qRT-PCR analysis revealed upregulation of genes involved in the gingerol biosynthetic pathway, confirming a tight regulatory network coordinating metabolite synthesis. These findings are consistent with previously reported biosynthetic models, highlighting the importance of both developmental stage and tissue type in regulating bioactive compound production (Li & Chen, 2014; Zhang & Wang, 2013).

5. Integrated Analysis. Integration of morpho-anatomical, physiological, and biochemical data revealed a clear correlation between tissue structure, photosynthetic performance, and secondary metabolite accumulation. Rhizome anatomical features, combined with optimal physiological conditions, facilitate the biosynthesis and storage of gingerols and shogaols. This integrated approach underscores the significance of considering multiple plant traits to optimize cultivation practices and enhance the yield of medicinally valuable compounds. The study demonstrates that ginger's medicinal value is intricately linked to its rhizome anatomy, physiological performance, and tightly regulated biosynthetic pathways. Effective manipulation of growth conditions and developmental timing can maximize bioactive compound yield, providing a scientific basis for improving ginger cultivation for pharmaceutical and nutraceutical applications.

CONCLUSIONS AND RECOMMENDATIONS

1. The study confirms that *Zingiber officinale* rhizome serves as the primary site for accumulation of bioactive compounds, particularly gingerols and shogaols, supported by specialized parenchyma cells, vascular bundles, and oil cells.

2. Physiological performance, including photosynthetic efficiency, stomatal conductance, and water/nutrient transport, is closely linked to metabolite biosynthesis, demonstrating the importance of environmental factors in optimizing secondary metabolite yield.

3. Biosynthetic pathway analysis revealed a coordinated regulation of key enzymes and genes controlling gingerol and shogaol synthesis, highlighting developmental stage-specific accumulation patterns.

4. Integrated morpho-anatomical, physiological, and biochemical analyses provide a comprehensive understanding of the factors influencing medicinal quality, demonstrating that the plant's structural and functional traits are interdependent in determining bioactive compound content.

5. Cultivation Practices: Optimize light, temperature, soil moisture, and nutrient availability to enhance photosynthesis and secondary metabolite accumulation in the rhizome.

6. Harvest Timing: Collect rhizomes at peak developmental stages when bioactive compound content is maximal to improve medicinal efficacy.

7. Breeding and Selection: Focus on genotypes with superior anatomical features (larger parenchyma, oil cells) and higher enzymatic activity to maximize gingerol and shogaol content.

8. Further Research: Investigate the molecular regulatory networks controlling secondary metabolite synthesis and explore potential elicitors or stress treatments to boost bioactive compound production.

9. Industrial Application: Use the integrated knowledge of anatomy, physiology, and biosynthesis to guide pharmaceutical, nutraceutical, and functional food industries for producing high-quality ginger extracts.

REFERENCES

1. Patel, R., & Joshi, V. (2020). *Integrated approaches to improve medicinal quality of Zingiber officinale*. *Journal of Integrative Plant Biology*, 62(11), 1602–1615.
2. Devi, S., & Singh, P. (2021). *Future perspectives on ginger research: Combining anatomy, physiology, and biochemistry*. *Current Medicinal Chemistry*, 28(9), 1830–1845.
3. Jumaboyeva, F. R. (2024). *Zanjabil – Zingiber officinale O‘siminigining dorivor xususiyatlari va kimyoviy tarkibi*. *Tadqiqotlar.UZ Journal*, 41(2), 127–129. Retrieved from <https://tadqiqotlar.uz/new/article/view/4089>
4. Narziyeva, F. N., & Babamuratov, B. E. (2025). *Zanjabilning shifobaxsh xususiyatlari va uning xalq tabobatidagi o‘rni*. *Journal of Universal Science Research*, 3(5), 375–378. Retrieved from <https://inlibrary.uz/index.php/universal-scientific-research/article/view/115662>
5. Gapparova, F., & Xudoynazarov, S. (2025). *Zanjabil (Zingiber officinale) ildizidan 6-Gingerolning olinishi va kimyoviy tahlili*. *Ilmiy xabarlar jurnali*. Retrieved from <https://ilmiyxabarlar.kspi.uz/index.php/journal/article/view/5465>
6. Teshaboyev, J. A. (2025). *Kurkuma va zanjabil asosidagi fitoterapevtik vositalarning yurak-qon tomir kasalliklarida qo‘llanilishi*. Retrieved from <https://journalss.org/index.php/obr/article/view/4009>
7. Umaraliyeva, M. (2024). *Imbir (Zanjabil)ning foydali hususiyatlari*. *Modern Education and Development*, 13(4), 32- 36. Retrieved from <https://scientific-jl.org/mod/article/view/2315>
8. Siddiqova, Y. X., & O‘sarov, R. R. (2025). *Zanjabil o‘simligining foydali xususiyatlari*. *Innovate Conferences*. Retrieved from <https://innovateconferences.org/index.php/ic/article/view/103>
9. Ahmed, A. A., & Jogdand, S. (2021). *Medicinal properties of Zingiber officinale*. *Journal of Pharmaceutical Research International*, 33(60B), 3341-3347. Retrieved from <https://journaljpri.com/index.php/JPRI/article/view/7001>
10. Paudel, K. R., Orent, J., & Penela, O. G. (2025). *Pharmacological properties of ginger (Zingiber officinale): what do meta-analyses say?* *Frontiers in Pharmacology*. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/40808693>