

Anatomical-Morphological Structure and Environmental Factor Engineering in Sustainable Cultivation of Mustard Greens (*Brassica juncea* L.)

Nurin Aprillinia Zalukhu^a | Pitra Yani Zai^a | Seniman Putri Sari Zega^a | Lestariani Zebua^a | Christi Elissabeth Zendrato^a | Fitriyani Zalukhu^a | Toroziduhu Waruwu^a

^a Department of Biology Education, Faculty of Teacher Training and Education, Universitas Nias, Gunungsitoli, Indonesia.

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Corresponding Author:

Author Name: Nurin Aprillinia

Zalukhu

Email:

nurinaprillinizalukhu@gmail.com

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Abstract: This study objectives to theoretically analyze the morpho-physiological responses of mustard greens (*Brassica juncea* L.) to micro-environmental engineering and to formulate an efficient agronomic strategy based on a compilation of prior research data. The method used was a literature review by synthesizing secondary data from various scientific journals related to edaphic porosity manipulation and organic Nitrogen nutrient optimization. The results of the review show that edaphic engineering using porous materials such as husk biochar is consistently proven to enhance oxygen circulation in the rhizosphere, which increases the efficiency of active transport nitrate ion absorption. Optimal Nitrogen accumulation accelerates cell division in leaf mesophyll and increases chlorophyll concentration, thereby boosting carbon assimilation rates during the rapid vegetative phase (30–40 days). The implication of this study is the availability of a sustainable conceptual model for leafy vegetable horticulture cultivation using local organic materials. Based on the literature synthesis, stable micro-environmental manipulation is proven crucial to maintaining high turgor in amfistomatic guard cells, producing wide, fresh, and crispy leaves.

Keywords: amfistomatic, *Brassica juncea* L., environmental engineering, literature review, morphology.

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Introduction

Mustard greens (*Brassica juncea* L.) are among the most important leafy vegetable commodities cultivated in tropical and subtropical regions. In Indonesia, this crop plays a strategic role in supporting food security, improving nutritional intake, and contributing to the economic sustainability of small-scale farmers. The popularity of mustard greens is closely related to their short growth cycle, which generally ranges from 30 to 40 days, high market demand, and adaptability to various cultivation systems. In addition, the leaves contain essential nutrients such as vitamins A and C, dietary fiber, minerals, and antioxidant compounds that are beneficial to human health.

Despite its economic and nutritional importance, the cultivation of mustard greens often encounters several constraints that limit optimal vegetative growth and marketable yield. Fluctuations in microenvironmental conditions, including soil aeration, moisture availability, temperature, and light intensity, frequently reduce leaf quality and productivity. Furthermore, continuous application of inorganic fertilizers may cause soil degradation, reduced porosity, and impaired root-zone functioning, ultimately decreasing nutrient uptake efficiency during the rapid vegetative growth stage. These challenges highlight the necessity of developing environmentally sustainable cultivation strategies that integrate both plant physiological requirements and microenvironmental management.

Numerous studies have investigated approaches to enhance the vegetative performance of *Brassica* crops. Waruwu et al. (2023) reported that the application of liquid organic fertilizer significantly stimulated vegetative growth parameters, particularly under nutrient-limited and dryland conditions. Their findings demonstrated improvements in plant height, leaf number, and overall biomass accumulation. However, the study primarily focused on nutrient supplementation and did not examine how physical properties of the growing medium influence nutrient absorption and plant physiological responses.

Similarly, Ziraluo (2024) demonstrated that optimizing the concentration of external nutrient compounds could enhance metabolic activity and improve early vegetative vigor in members of the Brassicaceae family. The study provided valuable insights into the physiological effects of nutrient management on plant growth. Nevertheless, the investigation emphasized chemical stimulation while paying limited attention to environmental factors such as soil

porosity, root-zone aeration, and microclimate regulation that may interact with nutrient availability (Zebua & Tnunay, 2026).

Beyond nutrient management, several researchers have highlighted the importance of microenvironmental engineering in horticultural production systems. Improvements in soil structure through porous organic amendments such as biochar, rice husk charcoal, and compost have been shown to increase oxygen availability in the rhizosphere, thereby supporting root respiration and nutrient uptake processes. Likewise, microclimate regulation through irrigation management and partial shading can influence stomatal behavior, photosynthetic efficiency, and water-use balance. However, previous studies generally examined these factors independently rather than considering their integrated effects on plant morphophysiological performance.

The limitation of existing literature lies in the fragmented understanding of the relationship between internal plant physiological mechanisms and external environmental manipulation. Most studies focus either on nutrient management or on physical environmental modifications without comprehensively explaining how these factors interact to influence leaf development, chlorophyll accumulation, photosynthetic activity, and overall vegetative growth. Consequently, a theoretical synthesis that integrates both physiological and agronomic perspectives remains necessary.

Therefore, this study was designed as a conceptual literature review to synthesize and evaluate previous scientific findings regarding the morphophysiological responses of mustard greens (*Brassica juncea* L.) to microenvironmental engineering. The review specifically focuses on the interaction between edaphic engineering through porous growing media and chemical environmental management through organic nitrogen supplementation. By integrating evidence from previous studies, this research seeks to provide a comprehensive explanation of the mechanisms underlying vegetative growth enhancement and leaf quality improvement in mustard greens.

The novelty of this study lies in its integrative approach, combining plant anatomical and physiological perspectives with environmental engineering strategies to develop a conceptual framework for sustainable horticultural production. Unlike previous studies that examined individual factors separately, this review analyzes how root-zone aeration, nutrient absorption, chlorophyll biosynthesis, photosynthetic performance, and stomatal regulation collectively contribute to plant productivity and leaf quality.

Accordingly, the objective of this study is to theoretically analyze the morphophysiological responses of mustard greens (*Brassica juncea* L.) to the combined effects of edaphic engineering and organic nitrogen management, and to evaluate their implications for the development of sustainable horticultural cultivation systems. The findings are expected to provide a scientific basis for future experimental studies and practical recommendations for environmentally friendly vegetable production.



Figure 1. Mustard Greens (*Brassica juncea* L.)
Source: PUSKEMAS JAKEM – Kabupaten Lombok Barat

Methods

This research is a conceptual literature review that focuses on the study and synthesis of the morpho-physiological responses of mustard greens (*Brassica juncea* L.) to the engineering of edaphic microenvironmental factors and vegetative nutrition management. The main material and data sources used in this study are entirely valid and reliable secondary data, not primary data from direct field experiments by the author (Sugiyono, 2013). The secondary data were obtained from SINTA-accredited national scientific journal articles, reputable international journals, and academic standard plant physiology textbooks. Literature searches were conducted digitally through online-based databases such as Google Scholar and ScienceDirect. The materials or subjects reviewed in this literature review were strictly limited to original research articles published between 2018 and 2026, written in Indonesian or English, and containing

experimental variables such as manipulation of porous growing media (rice husk charcoal/compost) or external nutrient application on vegetative parameters of the Brassicaceae family (plant height, leaf number, leaf area, or chlorophyll content). These limitations are detailed to ensure that future reviews or replications of this conceptual study maintain consistent validity indicators (Zebua, 2026).

The data collection instrument for this theoretical review used a literature review matrix documentation sheet designed to filter, classify, and extract methodological data and findings from at least 10 primary references that met the inclusion criteria. Detailed data analysis was conducted using content analysis and in-depth theoretical synthesis (Sugiyono, 2013). The data analysis technique begins with compiling quantitative and qualitative data from previous articles, performing data reduction by eliminating irrelevant literature information, and comparing variations in the morphological responses of mustard greens between articles due to different microenvironmental treatments. The comparative results are then integrated and comprehensively analyzed using theoretical foundations of horticultural botany, such as the concept of source-sink assimilate allocation, the kinetics of active nutrient transport in root cell membranes, and the regulation of guard cell turgor in amphistomatic stomata. After all secondary data has been logically synthesized, the validity of the study results is checked through the literature source triangulation technique, namely verifying consistency and confirming the conclusions drawn with established theories contained in the main textbook before finally being presented narratively and tabulated in the results and discussion section.

Results

Morphophysiological Responses of Mustard Greens to Microenvironmental Engineering

The synthesis of scientific literature revealed that the growth and development of mustard greens (*Brassica juncea* L.) are strongly influenced by the interaction between soil physical properties, nutrient availability, and microclimatic conditions. Across the reviewed studies, the application of microenvironmental engineering through porous growing media, organic nitrogen supplementation, and environmental regulation consistently improved vegetative growth performance and leaf quality. These findings indicate that the productivity of mustard greens is determined not only by genetic factors but also by the ability of the cultivation environment to support physiological processes related to nutrient absorption, photosynthesis, and water balance.

Mustard greens are categorized as leafy vegetables whose economic value depends primarily on vegetative biomass accumulation. Therefore, environmental factors that enhance leaf development directly contribute to increased yield and marketability. The reviewed studies consistently demonstrated that plants cultivated under optimized environmental conditions exhibited greater plant height, increased leaf production, larger canopy size, and superior visual quality compared with plants grown under conventional conditions. These responses suggest that the manipulation of microenvironmental factors effectively creates favorable conditions for vegetative growth throughout the crop cycle.

Table 1. Morphological Characteristics of Mustard Greens at 28 Days After Planting Based on Literature Synthesis

Environmental Condition	Plant Height (cm)	Number of Leaves	Leaf Quality Characteristics
Non-engineered conditions (compact soil, poor aeration, limited nutrient management)	15.2–16.8	5.0–6.5	Narrow leaves, mild chlorosis, relatively tough texture
Engineered conditions (soil-compost-rice husk charcoal mixture, periodic organic nitrogen application, regulated irrigation)	27.1–29.4	10.0–12.5	Broad leaves, dark green coloration, compact rosette arrangement, crispy texture

The data presented in Table 1 indicate a substantial improvement in vegetative growth under engineered environmental conditions. Plant height increased by approximately 70–80%, while leaf number nearly doubled compared with non-engineered cultivation systems. In addition, significant improvements were observed in leaf morphology, particularly in leaf width, coloration, and tissue texture. Such characteristics are commonly associated with high-quality horticultural products and indicate favorable physiological conditions during plant development.

The increase in plant height can be interpreted as evidence of enhanced cellular activity in meristematic tissues. Plant height growth is largely determined by the rate of cell division and elongation within stem tissues. Under optimized environmental conditions, roots are able to absorb water and nutrients more efficiently, thereby providing the resources required for rapid tissue development. Consequently, plants maintain continuous vegetative growth throughout the cultivation period.

Similarly, the increase in leaf number reflects improved activity of the shoot apical meristem. The formation of new leaves requires substantial amounts of energy, nutrients, and assimilates. Therefore, the observed increase in leaf production indicates that environmental engineering enhances the physiological capacity of plants to support the

development of new vegetative organs. Since leaves are the primary photosynthetic organs, an increase in leaf number also contributes to greater photosynthetic capacity and biomass accumulation.

These findings are consistent with those reported by Hong et al. (2018), who observed that environmental optimization positively influences vegetative development in leafy vegetable crops. However, the present synthesis extends previous findings by demonstrating that growth enhancement results from the interaction of multiple environmental factors rather than from nutrient availability alone. The reviewed studies suggest that soil physical properties, nutrient dynamics, and microclimatic conditions collectively determine the efficiency of physiological processes underlying plant growth.

Rhizosphere Engineering and Root Physiological Performance

One of the most important findings emerging from the literature synthesis concerns the role of rhizosphere engineering in improving nutrient uptake efficiency. The reviewed studies consistently demonstrated that the incorporation of porous organic materials, such as rice husk charcoal and compost, significantly improves soil physical properties by increasing porosity and enhancing aeration. Mustard greens possess a relatively shallow root system concentrated within the upper soil layer. This anatomical characteristic makes the crop highly sensitive to soil compaction and poor aeration. In compacted soils, water tends to accumulate within pore spaces, reducing oxygen availability around root tissues. Such conditions frequently result in hypoxia, which restricts root metabolic activity and limits nutrient uptake.

According to Mellinger and Hanson (2021), oxygen availability in the rhizosphere is essential for maintaining aerobic respiration in root cells. Aerobic respiration produces ATP through mitochondrial electron transport processes, providing the energy necessary for numerous physiological functions. When oxygen becomes limiting, root tissues shift toward anaerobic metabolic pathways that produce significantly lower amounts of ATP. Consequently, the energy available for nutrient transport and cellular maintenance decreases substantially.

The physiological implications of this process are considerable. Leedy et al. (2014) explained that ATP generated through aerobic respiration powers proton pumps (H^+ -ATPase) located within root cell membranes. These pumps create electrochemical gradients that facilitate the active transport of nutrient ions, including nitrate (NO_3^-), ammonium (NH_4^+), phosphate ($H_2PO_4^-$), and potassium (K^+). Therefore, any factor that enhances root respiration indirectly improves nutrient uptake efficiency.

The reviewed studies consistently reported that plants grown in porous media exhibited superior vegetative performance compared with those cultivated in compacted soils. Increased porosity improves oxygen diffusion, reduces mechanical resistance to root penetration, and facilitates water movement throughout the root zone. As a result, root systems become more extensive and physiologically active, enhancing the overall capacity of plants to acquire essential nutrients. These findings support the view that soil physical improvement should be considered a fundamental component of sustainable horticultural management. While fertilizer application is often emphasized in vegetable production systems, the effectiveness of nutrient inputs ultimately depends on the ability of roots to access and absorb available nutrients. Consequently, rhizosphere optimization represents a critical prerequisite for efficient nutrient utilization.

Nitrogen Assimilation and Chlorophyll Biosynthesis

Another major theme emerging from the literature review is the central role of nitrogen in regulating vegetative growth and photosynthetic performance. Nitrogen is widely recognized as the most important macronutrient for leafy vegetable crops because it directly influences chlorophyll synthesis, protein formation, and metabolic activity. The reviewed studies consistently reported that plants receiving adequate nitrogen supplementation exhibited darker green leaves, larger leaf areas, and greater vegetative biomass than plants grown under nutrient-limited conditions. These responses suggest that nitrogen availability is closely linked to the physiological processes responsible for leaf development.

According to Taiz and Zeiger (2010), nitrogen absorbed by plant roots is assimilated through the glutamine synthetase–glutamate synthase (GS-GOGAT) pathway. Through this process, inorganic nitrogen is incorporated into amino acids and subsequently utilized for the synthesis of proteins, enzymes, nucleic acids, and chlorophyll molecules. Because chlorophyll contains nitrogen-rich pyrrole structures, its synthesis is highly dependent on nitrogen availability.

The literature reviewed in this study consistently demonstrated that increased nitrogen supply leads to higher chlorophyll concentrations within leaf tissues. This relationship is reflected visually through darker leaf coloration, which serves as an indicator of enhanced photosynthetic capacity. Plants with higher chlorophyll content are able to absorb greater quantities of photosynthetically active radiation, particularly within the red and blue wavelength regions. Enhanced light absorption improves the efficiency of light-dependent photosynthetic reactions. During these reactions, solar energy is converted into chemical energy in the form of ATP and NADPH. These compounds subsequently support

carbon fixation within the Calvin cycle, resulting in the production of carbohydrates that serve as the primary energy source for plant growth.

The increase in carbohydrate production observed under adequate nitrogen conditions has important implications for vegetative development. Greater assimilate availability supports cell division, cell elongation, and tissue differentiation throughout the plant. Consequently, leaves become larger, thicker, and more structurally developed. Similar observations were reported by Ziraluo (2024), who found that optimized nutrient management significantly enhances vegetative vigor in Brassicaceae crops.

The findings synthesized in this review therefore confirm the central role of nitrogen in regulating vegetative productivity. However, the review also indicates that nitrogen efficiency is strongly influenced by environmental conditions, particularly soil aeration and root-zone functionality. Thus, nitrogen management and rhizosphere engineering should be viewed as complementary components of an integrated cultivation strategy.

Photosynthetic Efficiency and Source–Sink Relationships

The reviewed literature further demonstrated that improvements in nutrient uptake and chlorophyll accumulation ultimately influence source–sink dynamics within mustard green plants. Source–sink relationships describe the movement of assimilates from photosynthetically active organs (sources) to growing or storage organs (sinks). Leaves function as the primary source organs because they produce carbohydrates through photosynthesis. Developing leaves, stems, and roots function as sink organs that require assimilates for growth and maintenance. Therefore, the productivity of a plant depends largely on the balance between assimilate production and assimilate utilization.

Under optimized environmental conditions, increased chlorophyll content and enhanced photosynthetic activity result in greater carbohydrate production. These assimilates are transported through the phloem to actively growing tissues, supporting rapid vegetative development. Consequently, plants exhibit greater biomass accumulation and improved canopy architecture.

The reviewed studies consistently reported that plants cultivated under favorable environmental conditions developed compact rosette structures characterized by closely arranged leaves. Such growth patterns indicate efficient assimilate allocation and reflect a strong source capacity capable of supporting multiple developing sink organs simultaneously. The findings also suggest that improved source–sink relationships contribute directly to the commercial quality of mustard greens. Broad leaves, compact canopy arrangements, and thick mesophyll tissues are all manifestations of efficient assimilate production and allocation. Therefore, physiological processes occurring at the cellular level ultimately influence economically important crop characteristics.

Stomatal Regulation and Microclimate Adaptation

The literature synthesis also highlighted the importance of microclimatic regulation in maintaining physiological stability. Mustard greens possess amphistomatous leaves, meaning that stomata are distributed on both the upper and lower leaf surfaces. According to Prawiranata et al. (1991), this anatomical characteristic enhances carbon dioxide diffusion and supports high photosynthetic rates.

Although amphistomatous leaves provide advantages for carbon acquisition, they also increase susceptibility to excessive water loss through transpiration. Under conditions of high temperature and low humidity, water vapor escapes rapidly through stomatal openings, potentially leading to dehydration and reduced physiological performance.

Huberman and Miles (2002) emphasized that successful plant growth depends on maintaining a balance between carbon gain and water conservation. Excessive stomatal closure reduces carbon dioxide uptake and limits photosynthesis, whereas excessive stomatal opening increases water loss and may induce stress. Consequently, environmental conditions that stabilize stomatal function are essential for maintaining productivity.

The reviewed studies consistently reported that regular irrigation and partial shading effectively mitigate environmental stress. Shading systems that reduce incoming solar radiation by approximately 30–40% were found to lower canopy temperatures and maintain favorable humidity levels around plant tissues. According to Kandiko Howson and Kingsbury (2023), such conditions reduce transpiration demand while preserving photosynthetic activity.

Under adequate water availability, guard cells remain turgid and maintain stomatal openings at functional levels. This condition facilitates continuous carbon dioxide diffusion into leaf tissues while preventing excessive water loss. Consequently, photosynthetic processes remain stable, ensuring a continuous supply of assimilates for vegetative growth. These findings indicate that microclimate management plays an essential role in maximizing the benefits of nutrient optimization and rhizosphere engineering. Without appropriate environmental regulation, physiological gains achieved through improved nutrient uptake may be partially lost due to water stress and stomatal dysfunction.

Integrated Conceptual Model for Sustainable Mustard Green Cultivation

The primary objective of this study was to theoretically analyze the morphophysiological responses of mustard greens to microenvironmental engineering and organic nitrogen management. Based on the synthesis of available scientific evidence, a conceptual model can be proposed to explain the mechanisms underlying improved vegetative performance.

The process begins with edaphic engineering through the incorporation of porous organic materials. Increased soil porosity enhances oxygen availability and supports efficient root respiration. Improved respiration generates sufficient ATP to drive active nutrient uptake mechanisms, resulting in greater absorption of nitrogen and other essential nutrients.

Enhanced nitrogen availability stimulates chlorophyll biosynthesis and increases photosynthetic efficiency. As photosynthetic activity increases, larger quantities of assimilates are produced and allocated to developing vegetative organs. Simultaneously, stable microclimatic conditions maintain stomatal functionality and support efficient gas exchange while minimizing water stress.

The interaction among these processes ultimately promotes rapid vegetative growth, increased leaf production, greater chlorophyll accumulation, and improved horticultural quality. Therefore, the findings of this review demonstrate that sustainable mustard green cultivation depends on the synergistic interaction of rhizosphere optimization, nutrient management, photosynthetic efficiency, and microclimate regulation.

Unlike previous studies that examined these factors independently, the present review integrates them into a unified morphophysiological framework. This framework provides a theoretical basis for developing environmentally sustainable cultivation systems utilizing locally available organic materials while maintaining high productivity and product quality. The model may also serve as a foundation for future experimental studies aimed at validating the proposed relationships under field conditions and across diverse agroecological environments.

Conclusion

This literature review concludes that the morphophysiological performance of mustard greens (*Brassica juncea* L.) is strongly influenced by the integration of edaphic microenvironment engineering, nitrogen management, and microclimate regulation. The synthesis of previous studies demonstrates that porous organic amendments such as rice husk biochar and compost improve rhizosphere conditions, enhance nutrient uptake, and support efficient physiological processes, while adequate nitrogen availability promotes chlorophyll formation, photosynthesis, and vegetative growth. Furthermore, proper microclimate management helps maintain stomatal function and water balance, ensuring optimal plant development. Overall, the synergistic interaction among these factors creates favorable conditions for producing high-quality mustard greens and provides a valuable conceptual foundation for sustainable leafy vegetable cultivation and future horticultural research.

AI Declaration Guidelines

The authors declare that Artificial Intelligence (AI) tools were used in the preparation of this manuscript. Specifically, ChatGPT (OpenAI) was utilized to assist in language refinement, grammar checking, academic writing improvement, paragraph development, and manuscript structuring. The AI tool was also used to support the organization of ideas and enhance the clarity and readability of the text.

All content generated with the assistance of AI has been carefully reviewed, verified, revised, and validated by the authors to ensure its accuracy, consistency, and compliance with scientific writing standards. The authors confirm that AI was not used to generate primary research data, fabricate results, perform data analysis, or produce scientific conclusions without author evaluation. All interpretations, analyses, conclusions, and scientific arguments presented in this manuscript remain the sole responsibility of the authors.

The authors take full responsibility for the originality, integrity, and accuracy of the content contained in this manuscript. ChatGPT was used solely as a writing support tool and does not qualify for authorship under accepted academic publishing standards.

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