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The Effect of Nutritional Composition on the Growth of Kale Plants in a Hydroponic System

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ABSTRACT

This study reviews the impact of nutritional composition on the growth of kale (Brassica oleracea var. acephala) in hydroponic systems, synthesizing findings from 15 Scopus-indexed studies. The analysis highlights the critical roles of macronutrients (nitrogen, phosphorus, potassium) and micronutrients (iron, magnesium, zinc) in optimizing plant growth, yield, and quality. Additionally, it examines the importance of nutrient solution management, including pH, electrical conductivity, and nutrient concentration, for efficient nutrient uptake. Innovative practices such as organic additives and advanced monitoring systems are also discussed for their potential to enhance productivity and sustainability. The review identifies gaps in existing research, particularly in standardizing nutrient formulations and assessing the long-term impact on nutritional quality. These findings provide actionable insights for researchers and practitioners aiming to advance hydroponic kale cultivation.

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1. INTRODUCTION

Hydroponic agriculture has emerged as a sustainable and efficient method for cultivating crops, offering solutions to challenges associated with traditional soil-based farming such as limited arable land, soil degradation, and water scarcity [1]. This method allows for significant water savings—up to 70 to 90% in systems like the Nutrient Film Technique (NFT)—and offers precise control over nutrient delivery, thereby optimizing plant growth and yield [2]. Moreover, hydroponics enables year-round production regardless of seasonal constraints, enhancing productivity and food security [1], [3]. Among various crops, kale (Brassica oleracea var. acephala) has garnered significant attention due to its nutritional richness and adaptability to controlled environments. As a leafy green vegetable, kale is a valuable source of essential vitamins, minerals, and antioxidants, making it a staple in health-conscious diets worldwide [4]. Its adaptability allows it to thrive in hydroponic systems that provide stable environmental conditions and precise nutrient management

[2]. However, the widespread adoption of hydroponic farming still faces challenges, particularly the high initial setup costs and the technical expertise required to manage these systems effectively [2], [4]. Despite these hurdles, the advantages of hydroponic farming make it a promising method for producing high-quality kale and other vegetables in diverse environments.

The success of hydroponic systems is closely tied to the optimization of nutrient delivery, as these systems bypass soil and instead provide nutrients directly through a water-based solution, allowing for precise control over nutrient type, concentration, and balance—factors critical to plant growth and productivity [5], [6]. However, the absence of soil as a natural buffer means that any imbalance or deficiency in the nutrient solution can have immediate and adverse effects on plant health. A well-balanced nutrient solution must supply all essential macro- and micronutrients—such as nitrogen, phosphorus, potassium, calcium, and magnesium—in ratios that align with plant uptake needs [5]. Furthermore, environmental parameters like pH (optimal range: 5.8–6.5), electrical conductivity (EC: 1.5–2.5 dS/m), and total dissolved solids (TDS: 800–1500 ppm) must be carefully monitored to avoid nutrient deficiencies or toxicities. Temperature, humidity, and light conditions also play significant roles in influencing nutrient uptake and overall plant performance [7]. To ensure the system's stability and efficacy, regular monitoring and adjustment of the nutrient solution are essential, with advanced models and experimental data increasingly used to predict plant nutrient needs and enhance overall efficiency [8].

A growing body of research has explored the effects of macronutrients and micronutrients on plant health and yield. Macronutrients such as nitrogen, phosphorus, and potassium are fundamental for physiological processes, including photosynthesis, root development, and cellular growth. Similarly, micronutrients like magnesium, iron, and zinc play vital roles in enzymatic functions and chlorophyll synthesis. While numerous studies have investigated the impact of individual nutrients on plant growth, fewer have examined the synergistic interactions between these elements, particularly in hydroponic systems.

2. LITERATURE REVIEW

2.1 Macronutrients and Their Roles in Kale Growth

Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) are crucial for plant development and productivity, each serving distinct physiological roles that are vital for optimal growth. Nitrogen, as a key component of proteins, nucleic acids, and chlorophyll, is essential for plant metabolism and vegetative development, particularly in kale where it significantly increases leaf size and number, enhancing photosynthetic capacity and yield [9], [10]. However, nitrogen deficiency results in reduced chlorophyll content, stunted growth, and pale leaves, while excessive nitrogen can lead to toxicity and hinder plant health [11], [12]. Phosphorus is indispensable for energy transfer, being a core component of ATP, and supports root development and carbohydrate mobilization; its uptake in hydroponic systems is optimal at pH levels between 5.5 and 6.5, underscoring the importance of pH management for nutrient availability [9], [11]. Meanwhile, potassium is vital for osmoregulation, enzyme activation, and maintaining turgor pressure, all of which contribute to healthy leaf structure and overall plant resilience. Balanced potassium levels enhance water regulation and stress tolerance, making plants more robust under varying environmental conditions [9], [13]

2.2 Micronutrients and Their Importance

Micronutrients, though required only in trace amounts, are indispensable for plant health due to their influence on a wide range of physiological and biochemical processes. Iron (Fe), zinc (Zn), and magnesium (Mg) are particularly critical, each contributing uniquely to plant development. Iron is essential for redox reactions, electron transport in photosynthesis, chlorophyll synthesis, and maintaining chloroplast structure, with deficiency symptoms often manifesting as interveinal chlorosis in young leaves [14], [15]. Zinc plays a vital role in maintaining the structural and functional integrity of cell membranes, protein biosynthesis, and the detoxification of superoxide radicals, with deficiencies commonly leading to reduced leaf size and growth abnormalities [14], [16]. Magnesium, serving as the central atom in the chlorophyll molecule, is crucial for photosynthesis, and its deficiency similarly results in interveinal chlorosis, reducing photosynthetic efficiency [17]. The availability of these micronutrients is influenced by factors such as soil pH, texture, and organic matter content, making proper fertilization management essential to correct deficiencies and prevent toxicity [16].

2.3 Nutrient Solution Management

Proper management of nutrient solutions in hydroponic systems is essential for optimizing the growth and yield of crops like kale, requiring careful control of key parameters such as nutrient concentration, electrical conductivity (EC), and pH balance to meet the specific needs of the plant across different growth stages. Nutrient concentrations must be adjusted based on the plant's developmental phase, with higher levels needed during peak vegetative growth to support increased nutrient demands [6], [18]. A well-balanced nutrient supply is crucial for efficient resource use and achieving optimal crop yields [6]. The optimal EC range for kale lies between 1.5 and 2.5 mS/cm, with research suggesting that 1.8 mS/cm is ideal for collard and 2.1 mS/cm for kale; exceeding these levels can impair water uptake and induce plant stress, ultimately reducing growth and yield [18], [19]. Maintaining a pH range of 5.5 to 6.5 is equally critical, as it ensures the availability of essential nutrients and prevents both deficiencies and toxicities [5], [18]. Additionally, emerging research supports the use of organic additives such as humic acids and biofertilizers to enhance root development, nutrient absorption, and microbial activity, while technological innovations like automated nutrient delivery systems and precision farming techniques allow real-time monitoring and fine-tuning of nutrient levels, further promoting plant health and productivity [18], [20].

2.4 Knowledge Gaps

While significant progress has been made in understanding the role of nutritional composition in hydroponic kale cultivation, several challenges remain. Variability in experimental designs, including differences in nutrient formulations and environmental conditions, complicates the standardization of best practices. Furthermore, limited research exists on the long-term effects of nutrient regimes on the nutritional quality and shelf life of kale.

There is also a need for studies examining the interactions between multiple nutrients, as these interactions can influence nutrient availability and uptake. Future research should focus on developing comprehensive nutrient models that account for both individual and synergistic effects.

This review provides a foundation for optimizing hydroponic systems to enhance kale production. The findings emphasize the importance of balanced nutrient management and innovative practices in achieving sustainable and efficient cultivation.

3. METHODS

The study adopts a qualitative literature review methodology to examine existing research on hydroponic kale cultivation, with a particular focus on nutrient management and its influence on plant growth. By analyzing peer-reviewed articles, the review aims to identify recurring patterns, current trends, and knowledge gaps in the field. To ensure the relevance and credibility of the literature, several selection criteria were applied. Articles were sourced exclusively from the Scopus database to maintain a high standard of peer-reviewed content. Search terms included "kale," "hydroponics," "nutritional composition," "macronutrients," and "micronutrients," with Boolean operators (AND, OR, NOT) used to refine the search.

The review prioritized studies published between 2014 and 2024 to capture recent developments, included only English-language publications, and focused on research articles, reviews, and experimental studies, excluding conference papers and opinion pieces.

Relevant data from the selected literature were extracted systematically using a predefined framework that encompassed study objectives, methodology (including nutrient formulations and hydroponic systems used), key findings on the effects of nutrients and additives, and the conclusions drawn by each study. This data was then categorized into thematic areas to facilitate a structured and comprehensive analysis. The main themes identified were: (1) the role of macronutrients such as nitrogen, phosphorus, and potassium in promoting plant growth and productivity; (2) the importance of micronutrients like iron, zinc, and magnesium in supporting plant health; (3) the impact of nutrient solution management, including parameters like pH, electrical conductivity (EC), and nutrient concentration; (4) the potential of innovative practices such as organic additives and precision technologies; and (5) existing challenges and research gaps that warrant further investigation.

4. RESULTS AND DISCUSSION

4.1 Effects of Macronutrients on Kale Growth

The reviewed studies consistently highlight the vital role of macronutrients—nitrogen (N), phosphorus (P), and potassium (K)—in optimizing kale growth within hydroponic systems. Each of these nutrients contributes to specific physiological processes essential for plant health and productivity. Nitrogen is particularly important for promoting vegetative growth, enhancing chlorophyll synthesis, and increasing leaf size, with optimal concentrations ranging from 100–150 ppm resulting in superior growth metrics [9], [21]. However, excess nitrogen can lead to overproduction of leaf biomass at the cost of structural integrity and nutritional quality, as observed in Chinese kale, where high nitrogen levels reduced vitamin C and sugar content (Riyuan et al., n.d.). Phosphorus, crucial for root development and energy transfer, is optimally applied at concentrations between 30–50 ppm; deficiencies can stunt root growth and reduce leaf area, while excess phosphorus may disrupt the uptake of other nutrients and contribute to soil acidification in non-recirculating systems [9], [11].

Potassium, another essential macronutrient, plays a significant role in water regulation, enzyme activation, and photosynthesis. Studies indicate that potassium levels in the range of 150–200 ppm enhance plant turgor, improve stress resistance, and contribute to better leaf quality and yield outcomes in kale [9], [22]. As the most abundant macronutrient in plant tissues, potassium is integral to maintaining plant health and resilience under various environmental conditions [22]. The collective evidence from these studies underscores the necessity of maintaining balanced and stage-appropriate concentrations of macronutrients to maximize the potential of hydroponically grown kale. Precision in nutrient management not only supports optimal growth but also ensures high nutritional quality and sustainable productivity.

4.2 Importance of Micronutrients

Micronutrients such as iron (Fe), magnesium (Mg), and zinc (Zn) play indispensable roles in the hydroponic cultivation of kale, directly influencing plant health, photosynthetic efficiency, and overall productivity. Iron is essential for chlorophyll synthesis and is commonly deficient in hydroponic systems, often resulting in interveinal chlorosis of young leaves [23]. To address this, chelated forms of iron—such as those using EDTA or DTPA—are widely recommended, as they maintain iron availability in nutrient solutions and effectively prevent chlorosis, thereby promoting healthy leaf coloration and vigorous growth [24], [25]. Magnesium, another vital micronutrient, serves as the central atom in the chlorophyll molecule and is essential for photosynthesis. Deficiency in magnesium leads to interveinal chlorosis and reduced photosynthetic efficiency, with optimal concentrations for hydroponic kale found to be between 30–50 ppm [26].

Zinc is equally important for enzymatic activity, protein synthesis, and hormone regulation in plants. However, its presence in excess can be toxic, necessitating strict control of its concentration in hydroponic systems. Research recommends maintaining zinc levels below 10 ppm to avoid phytotoxicity and ensure proper physiological functioning [25]. Zinc toxicity can arise from contamination sources such as soil dust or metallic components in the hydroponic setup, emphasizing the need for system hygiene and careful monitoring. The proper balance and bioavailability of these micronutrients are critical for sustaining the health and productivity of hydroponic kale, highlighting the importance of precision nutrient management in soilless cultivation environments.

4.3 Nutrient Solution Management

Managing the nutrient solution's pH, electrical conductivity (EC), and nutrient concentration is crucial for optimizing nutrient uptake in hydroponic kale cultivation. The ideal pH range of 5.5–6.5 ensures optimal nutrient solubility and availability, as fluctuations outside this range can lead to deficiencies and reduced plant growth [6], [27]. Various pH stabilizers, such as phosphoric acid and lime juice, are used to maintain this range, with phosphoric acid being more stable and cost-effective than alternatives like vinegar (Singh et al., 2019). Accurate pH monitoring also requires regular calibration and maintenance of pH meters [27]. In terms of EC, an optimal range of 1.5–2.5 mS/cm reflects a suitable concentration of dissolved nutrients, supporting healthy growth, while higher levels may induce salt stress, hinder water uptake, and slow growth rates [6], [28]. Although EC requirements may vary across crops, kale benefits from staying within this recommended range. Additionally, adjusting nutrient concentrations based on growth stages enhances resource efficiency—higher nitrogen supports vegetative growth, whereas balanced levels of potassium and phosphorus are essential during reproductive stages. Therefore, the nutrient solution must be formulated to reflect the uptake ratios of essential elements for maximum effectiveness [6].

4.4 Innovations in Hydroponic Practices

Emerging practices such as the use of organic additives and advanced monitoring systems offer promising solutions to enhance kale growth in hydroponic systems. Organic additives—including humic acids, biofertilizers, amino acids, and eco-enzymes—have demonstrated significant benefits for nutrient uptake, root development, and stress resilience. Humic acids, in particular, improve soil fertility and plant growth by enhancing nutrient availability and structure, increasing both growth and polyphenol content in kale [29], [30]. Biofertilizers and amino acids further enhance kale's nutrient content and stress tolerance by improving the absorption of essential nutrients like nitrogen, phosphorus, and potassium [31]. Similarly, eco-enzymes positively impact plant height and leaf size while reducing dependence on synthetic fertilizers [32]. Complementing these biological enhancements, precision agriculture technologies and automated monitoring systems enable real-time tracking and control of critical parameters such as nutrient levels, pH, and electrical conductivity, thereby maintaining optimal conditions throughout the growth cycle and leading to improved yield and quality [33].

4.5 Challenges and Implications

Despite advancements in hydroponic technology, challenges persist in standardizing nutrient formulations and addressing variability in experimental conditions, which hinder the development of universally applicable cultivation guidelines for kale. Variability in nutrient recommendations often stems from differences in environmental conditions such as climate and location, as well as plant varieties and hydroponic system types, including drip and flow systems, all of which influence nutrient uptake and plant responses

[34]–[36]. These factors contribute to inconsistent findings across studies and complicate efforts to create standardized nutrient protocols. Moreover, the long-term impact of nutrient regimes on the nutritional quality and shelf life of kale remains underexplored, despite evidence showing that nutrient supply significantly affects plant compound quality in other crops [34], [37]. This gap limits the practical application of current findings in commercial settings and underscores the need for more comprehensive studies focusing on nutrient uptake, assimilation, and their sustained effects on plant quality over time.

5. CONCLUSION

The reviewed studies underscore the pivotal role of nutritional composition in the success of hydroponic kale cultivation. Optimal concentrations of macronutrients such as nitrogen, phosphorus, and potassium are critical for maximizing growth, while micronutrients like iron, magnesium, and zinc ensure overall plant health and quality. Effective management of pH, electrical conductivity, and nutrient concentration further supports efficient nutrient uptake. Innovations like organic additives and real-time monitoring systems present new opportunities for enhancing hydroponic productivity and sustainability.

Despite significant advancements, challenges such as variability in experimental conditions and the lack of standardized nutrient guidelines persist. Furthermore, the long-term effects of nutrient formulations on the nutritional quality of kale remain underexplored. Addressing these gaps through collaborative research can lead to more precise nutrient management strategies, contributing to the global adoption of hydroponic systems as a sustainable agricultural practice.

REFERENCES

[1] R. Taghizadeh, "Assessing the potential of hydroponic farming to reduce food imports: The case of lettuce production in Sweden." 2021.

[2] U. Thapa, N. N. Hansda, S. Kundu, A. Giri, D. Tamang, and A. O. Rahaman, "Advancements in hydroponic systems: a comprehensive review," *Arch. Curr. Res. Int.*, vol. 24, no. 11, pp. 317–328, 2024.

[3] S. Dutta, B. Mukherjee, and A. Sawarkar, "Enhanced Agricultural Productivity Using Hydroponics Technique: A Smart Farming System," in *Irrigation Systems and Applications*, IntechOpen, 2023.

[4] T. Alam, M. A. Ahmed, and M. Ikram, "Hydroponics as an advanced vegetable production technique: an overview," *Zoo Bot.*, vol. 1, no. 1, pp. 29–42, 2023.

[5] S. T. Patil, U. S. Kadam, M. S. Mane, D. M. Mahale, and J. S. Dekale, "Hydroponic nutrient solution: A review," *J. Pharmacogn. Phytochem.*, vol. 9, no. 5, pp. 2095–2099, 2020.

[6] M. A. Al Meselmani, "Nutrient solution for hydroponics," in *Recent research and advances in soilless culture*, IntechOpen, 2022.

[7] B. Kailashkumar, K. Priyadharshini, and M. Logapriya, "Hydroponic cultivation: Factors affecting its success and efficacy," *Int. J. Environ. Clim. Chang.*, vol. 13, no. 10, pp. 2403–2410, 2023.

[8] M. Stadnik, S. Burlaka, and P. Luts, "ДОСЛІДЖЕННЯ ВЗАЄМОДІЇ ВОДНОГО ТА ПОЖИВНОГО БАЛАНСУ В ЗАМКНУТИХ ГІДРОПОНІЧНИХ СИСТЕМАХ".

[9] M. J. Hawkesford *et al.*, "Functions of macronutrients," in *Marschner's mineral nutrition of plants*, Elsevier, 2023, pp. 201–281.

[10] S. E. Arney, "SOME EFFECTS OF NITROGEN NUTRITION ON THE MORPHOLOGY AND ANATOMY OF MARROW-STEM KALE," *Ann. Appl. Biol.*, vol. 39, no. 2, pp. 266–276, 1952.

[11] D. Ma *et al.*, "Effects of nitrogen, phosphorus, and potassium fertilization on plant growth, element levels in plants and soil, and the relationships among nutrient concentrations, plant yield, and nutrient status in Erythropalum scandens (Blume)," *J. Plant Nutr.*, vol. 47, no. 1, pp. 82–96, 2024.

[12] M. Mengesha, "Effect and roles of nitrogen supply on photosynthesis," *Int. J. Photochem. Photobiol.*, vol. 5, no. 2, pp. 19–27, 2021.

[13] S. Kaushik and S. R. Djiwanti, "Genetic improvements of traits for enhancing NPK acquisition and utilization efficiency in plants," in *Plant Macronutrient Use Efficiency*, Elsevier, 2017, pp. 267–283.

[14] A. Shenkin, "The key role of micronutrients," *Clin. Nutr.*, vol. 25, no. 1, pp. 1–13, 2006.

[15] H. Eskandari, "The importance of iron (Fe) in plant products and mechanism of its uptake by plants," *J. Appl. Environ. Biol. Sci*, vol. 1, no. 10, pp. 448–452, 2011.

[16] L. S. Masullo, "Fertilization with B, Cu and Zn associated with forest residue management in eucalyptus plantations." Universidade de São Paulo, 2022.

[17] D. K. Tripathi, S. Singh, S. Singh, S. Mishra, D. K. Chauhan, and N. K. Dubey, "Micronutrients and their diverse role in agricultural crops: advances and future prospective," *Acta Physiol. Plant.*, vol. 37, pp. 1–14, 2015.

[18] G. S. Brar, A. Kumar, G. Singh, I. Ishika, S. Shubham, and S. Kaushal, "Optimisation of Advanced Nutrient Solutions for Escalating Crop Production under Hydroponic Systems: A Comprehensive Review," *Int. J. Plant Soil Sci.*, vol. 36, no. 6, pp. 165–177, 2024.

[19] T. Yang, U. Samarakoon, J. Altland, and P. Ling, "Influence of Electrical Conductivity on Plant Growth, Nutritional Quality, and Phytochemical Properties of Kale (Brassica napus) and Collard (Brassica oleracea) Grown Using Hydroponics," *Agronomy*, vol. 14, no. 11, p. 2704, 2024.

[20] J. E. Son, H. J. Kim, and T. I. Ahn, "Hydroponic systems," in *Plant factory*, Elsevier, 2020, pp. 273–283.

[21] R. Y. Chen, H. C. Liu, C. Z. Song, and G. W. Sun, "Effect of nitrogen nutrient on the growth and quality of Chinese kale," *Trans. CSAE*, vol. 21, no. S, pp. 143–146, 2005.

[22] E. G. Silva, W. H. S. Takata, M. X. de Oliveira Júnior, J. D. Silva, and R. Goto, "Teores de macronutrientes em plantas de pimentão enxertadas sob fertirrigação," *IRRIGA*, vol. 18, no. 4, pp. 675–686, 2013.

[23] P. V. V. Prasad, V. Satyanarayana, M. V Potdar, and P. Q. Craufurd, "On-farm diagnosis and management of iron chlorosis in groundnut," *J. Plant Nutr.*, vol. 23, no. 10, pp. 1471–1483, 2000.

[24] K. Pishchaeva, S. Muradyan, E. Nikulina, S. Buleeva, and A. Saproshina, "The Use of a Nutrient Solution Containing Chelated Forms of Various Trace Elements," in *International Conference on Intelligent Computing & Optimization*, Springer, 2023, pp. 217–222.

[25] G. A. Wallace and A. Wallace, "Maintenance of iron and other micronutrients in hydroponic nutrient solutions," *J. Plant Nutr.*, vol. 7, no. 1–5, pp. 575–585, 1984.

[26] M. K. Sidhu, H. C. Raturi, D. S. Kachwaya, and A. Sharma, "Role of micronutrients in vegetable production: A".

[27] A. H. Harkare, B. Neole, J. D. Kene, M. Mohapatra, R. Agrawal, and R. Agrawal, "Enhanced Hydroponic Farming with Crop Suitability Prediction".

[28] D. C. Chang, C. S. Park, J. G. Lee, J. H. Lee, J. M. Son, and Y.-B. Lee, "Optimizing electrical conductivity and pH of nutrient solution for hydroponic culture of seed potatoes (Solanum tuberosum)," *Hortic. Environ. Biotechnol.*, vol. 46, no. 1, pp. 26–32, 2005.

[29] M. F. Fadhllurohman, E. Proklamasiningsih, and N. D. Sasongko, "Growth and Polyphenols Content of Kale In Growing Media With Humic Acid Addition," *BioEksakta J. Ilm. Biol. Unsoed*, vol. 4, no. 2, pp. 109–115, 2022.

[30] Z. Zhang *et al.*, "Co-Application of Coated Phosphate Fertilizer and Humic Acid for Wheat Production and Soil Nutrient Transport," *Agronomy*, vol. 14, no. 8, p. 1621, 2024.

[31] M. N. Al-Gubouri, A. I. Manea, and Z. K. Al-Mussawi, "The Role of Biostimulants and Organic Extracts in the Qualitative Traits of Kale Plants," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2023, p. 42023.

[32] H. Gustia, Y. A. Wulandari, and D. Putri, "Optimizing Eco-enzyme Dosage on Kale (Brassica oleracea) Growth and Production," *J. Agron. Tanam. Trop.*, vol. 7, no. 1, pp. 164–169, 2025.

[33] Y. Liu, X. Lan, H. Hou, J. Ji, X. Liu, and Z. Lv, "Multifaceted Ability of Organic Fertilizers to Improve Crop Productivity and Abiotic Stress Tolerance: Review and Perspectives," *Agronomy*, vol. 14, no. 6, p. 1141, 2024.

[34] K. Müller and J. Hippe, "Influence of differences in nutrition on important quality characteristics of some agricultural crops," in *Plant and Soil Interfaces and Interactions: Proceedings of the International Symposium: Plant and Soil: Interfaces and Interactions. Wageningen, The Netherlands August 6–8, 1986*, Springer, 1987, pp. 35–45.

[35] M. Suarsana, I. P. Parmila, and K. A. Gunawan, "Pengaruh konsentrasi nutrisi AB mix terhadap pertumbuhan dan hasil sawi pakcoy (Brassica rapa L.) dengan hidroponik sistem sumbu (wick system)," *Agro Bali Agric. J.*, vol. 2, no. 2, pp. 98–105, 2019.

[36] N. Von Wirén, "Grand challenges in plant nutrition," *Front. Plant Sci.*, vol. 2, p. 4, 2011.

[37] G. H. Neilsen, D. Neilsen, F. J. Peryea, and E. Fallahi, "Tomorrow's challenges in fruit nutrition research: quo vadis?," in *VI International Symposium on Mineral Nutrition of Fruit Crops 868*, 2008, pp. 27–40.