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Growth Performance and Yield of Lettuce (*Lactuca sativa* L.) on Different Media in an NFT Hydroponic System

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Abstract

The operational success of closed-loop hydroponic systems is largely governed by the synergistic selection of the cultivation substrate and crop variety. An optimal growing medium must provide reliable structural stability, uniform moisture retention, and localized nutrient accessibility, which, when coupled with a cultivar's inherent genetic potential, dictate overall vegetative development and marketable yield. This study evaluated the effects of different growing media and lettuce cultivars on growth dynamics and yield performance in a nutrient film technique (NFT) system. The experiment was arranged in a two-factor completely randomized design, evaluating lettuce cultivars 'Arroyo', 'Amaroza', and 'Espirando' and growing substrates: rockwool, cocopeat, and peatmoss. The results revealed significant interaction effects between cultivar and growing media for plant height at 28 days after transplanting (DAT) and rosette canopy diameter at 7 DAT. The treatment combination integrating the cultivar 'Arroyo' with a peat moss substrate consistently yielded the highest values for these growth parameters. Furthermore, across all evaluated growing media, 'Arroyo' demonstrated superior biomass accumulation and overall productivity, highlighting its robust agronomic suitability for tropical NFT hydroponic cultivation.

Keywords: growing media, hydroponics, nutrient film technique (NFT), soilless cultivation

Introduction

Native to Egypt and cultivated since 4500 BC in the Mediterranean region, lettuce (*Lactuca sativa* L.) is a herbaceous plant species in the Asteraceae family, widely grown for its tender leaves, which are consumed as a vegetable, generally raw in salads. A popular vegetable, lettuce is economically important worldwide because it is widely consumed for its nutritional value, including vitamins B and C, as well as the fiber in its leaves (Kim et al., 2016). In Indonesia, lettuce is eaten in the form of fresh vegetables as a complement to other foods such as *gado-gado*, burgers, noodles, and as a garnish for several other types of food. In Indonesia, lettuce is a popular vegetable plant with rising demand, and it is increasingly grown utilizing hydroponic systems, which are currently in high demand among the community (Wijaya et al., 2025). However, lettuce is a popular vegetable among Indonesians, yet demand often goes unmet due to low supply (Awalina et al., 2022). Addressing this supply gap requires efficient, sophisticated growing technology capable of producing consistent, high-quality yields in limited space.

Hydroponics has acquired significant traction as a potential alternative to traditional agricultural restrictions. Hydroponics, aquaponics, and aeroponics are examples of soilless systems that reduce land use, water use, and allow for year-round food cultivation in metropolitan environments (Pastor-Arbulú & Rodríguez-Delfín, 2025). Among the several hydroponic configurations available, the nutrient film technique (NFT) is one of the most popular for growing leafy vegetables. In NFT systems,

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plant root tips come into contact with a thin film of nutritional solution within plastic gutters, while roots are also exposed to air, which provides dissolved oxygen required for root metabolism (Chowdhury et al., 2024). This design enables effective nutrient delivery, reduces water use, and supports high-density planting, making it particularly well-suited to urban and peri-urban agricultural contexts in Indonesia.

The choice of growing medium is a fundamental determinant of plant performance in NFT systems, as it directly influences root anchorage, water retention, aeration, and nutrient availability (Balliu et al., 2021). Growing media provide physical support for plants while also influencing water retention, aeration, root development, and nutrient availability. Hydroponic systems commonly use a variety of substrates, including rockwool, cocopeat, perlite, rice husk, sponge, and charcoal. Each medium has unique physical and chemical properties that may affect plant development and yield (Khairi et al., 2024).

Beyond growing media, lettuce variety selection is crucial, as genotypic differences among cultivars lead to varying responses in hydroponic settings. Lettuce (*Lactuca sativa* L.) is an economically important leafy vegetable that serves as a good model species for evaluating agronomic and physiological responses (Křístková et al., 2008). It is representative of green leafy vegetables widely consumed worldwide and can be easily produced across a variety of agricultural systems (Pastor-Arbulú & Rodríguez-Delfín, 2025). Different lettuce types exhibit varied growth rates, nutrient uptake efficiency, and suitability for controlled culture techniques, and comparative examinations of lettuce cultivars grown in NFT systems have found considerable differences among varieties (Yadav & Singh, 2025). Nevertheless, the interaction between growing media type and lettuce variety within Indonesian NFT systems remains insufficiently characterized in the scientific literature.

Therefore, the aim of this study is to evaluate the effects of different growing media on the growth performance and yield of various lettuce (*Lactuca sativa* L.) varieties under hydroponic conditions.

Material and Methods

Experimental Site and Plant Materials

This study was conducted from April to June 2025 in a greenhouse hydroponic facility at the East-West Seed Company farm, located in Benteng Village, Purwakarta Regency, West Java Province, Indonesia. The experimental materials included three lettuce (*Lactuca sativa* L.) cultivars: ‘Arroyo’, ‘Amaroza’, and ‘Espirando’—and three distinct growing media: cocopeat, peatmoss, and rockwool. The physical and chemical characteristics of these media are detailed in Table 1. Additional equipment comprised white germination trays, black plastic net pots, commercial AB-mix nutrient solution, pesticides, digital analytical balances, a Total dissolved solids (TDS) meter, cutting tools, and labeling materials.

Experimental Design and Statistical Analysis

The experiment was arranged in a completely randomized design with a 3 times 3 factorial configuration and three replications, resulting in 9 treatment combinations across 27 experimental units. Each experimental unit contained 8 randomly selected plants for sampling.

All collected data were subjected to an analysis of variance (ANOVA) at the 5% significance level. Where significant treatment effects were detected, mean comparisons were performed using Tukey’s honestly significant difference (HSD) test at the 5% probability level.

Cultivation and Management Practices

Hydroponic cultivation followed a structured four-stage protocol. First, the nutrient solution was prepared by diluting concentrated AB-mix stock solutions (consisting of mineral biofertilizer components A and B) at a ratio of 5 L of each concentrated stock per 1,000 L of water.

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The electrical conductivity was monitored using a TDS meter to ensure nutrient concentrations were within recommended baseline levels. In the second stage, the growing media were processed according to their physical properties. Rockwool was sectioned into standard blocks and positioned within the black plastic net pots. Conversely, cocopeat and peatmoss were thoroughly sifted to eliminate debris and leached to remove growth-inhibiting tannins prior to packing into the net pots. In the third stage, seedlings were germinated under controlled environmental conditions. For the rockwool treatment, seeds were inserted directly into the pre-formed holes. For the loose organic substrates (cocopeat and peatmoss), seeds were sown at a uniform depth of 1–2 cm and lightly covered. Two weeks post-germination, uniform seedlings were transplanted into a nutrient film technique (NFT) system. In the fourth stage, the NFT system maintained a continuous flow, and nutrient concentrations were monitored weekly with a TDS meter, sequentially adjusted from 500 to 1,400 ppm over the 5-week growth period. Phytosanitary management consisted of weekly preventative foliar spray applications of a broad-spectrum pesticide mixture.

Lettuce was harvested 35 days after transplanting (DAT) upon reaching maximum foliage density, optimal leaf count, and characteristic vibrant coloration. At harvest, the root systems were carefully preserved, rinsed free of residual debris, and measured.

Results and Discussions

Plant Height

The results of the analysis of variance showed significant effects of both varieties and growing medium on lettuce plant height across all observation periods (7, 14, 21, and 28 days after transplanting; Table 2). The treatments with variety and growing medium that produced the highest plant height from 7 to 28 DAT were ‘Arroyo’ and peat moss. However, the interaction between lettuce varieties and planting media types has a significant effect on lettuce plant height only at 28 DAT (Table 3). The interaction of the ‘Arroyo’ variety and the planting medium ‘peat moss treatment’ produced the highest plant height, with a mean value of 30.70 cm. However, this is not different from the interaction between the ‘Arroyo’ variety and coco peat growing media.

Table 1

Physical and Chemical Properties of Rockwool, Cocopeat, and Peatmoss Planting Media Used in the NFT Hydroponic

Properties	Rockwool	Cocopeat	Peatmoss
EC (dS/m)	0.06	0.10	0.5
pH	6.5	6.1	6.0
C (%)	2.2	49.5	50.0
N (mg/kg)	56.0	44.0	60.0
P (mg/kg)	30.0	38.0	40.0
K (mg/kg)	178.0	480.0	385.0
Ca (mg/kg)	279.0	58.0	650.0
Mg (mg/kg)	216.0	55.0	500.0
S (mg/kg)	303.0	405.0	500.0
Porosity (%)	80.0	86.2	89.0
Water porosity (%)	78.0	84.1	87.0
Air porosity (%)	4	5.6	5.8
Bulk density (g/cm³)	0.08	0.2	0.25

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Table 2

Effect of Lettuce Varieties and Different Planting Media on the Average Plant Height of Lettuce

Treatment	Plant height (cm)			
	7 DAT	14 DAT	21 DAT	28 DAT
Varieties				
‘Arroyo’	16.63 b	20.23 c	20.90 c	
‘Amaroza’	10.22 a	12.28 b	13.79 b	
‘Espirando’	10.11 a	10.95 a	12.50 a	
Planting medium				
Rockwool	10.15 a	12.58 a	14.54 a	
Cocopeat	12.64 b	14.93 b	16.16 b	
Peatmos	14.14 c	15.97 c	16.43 b	
Varieties	*	*	**	*
Planting medium	*	*	**	*
Varieties × planting medium	ns	ns	ns	*

Note. DAT: days after transplanting, ns: non-significant, values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level.

Table 3

Effect of Lettuce Varieties and Planting Media on Plant Height of Lettuce at 28 Days After Transplanting

	Plant height (cm)		
	Rockwool	Cocopeat	Peatmoss
‘Arroyo’	24.56 c	28.16 d	30.79 d
‘Amaroza’	18.85 b	18.97 b	21.42 b
‘Espirando’	13.70 a	14.42 a	14.16 a

Note. DAT: days after transplanting, values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level.

Influence of Cultivar on Plant Height

The cultivar ‘Arroyo’ consistently produced the highest average plant height across the experimental treatments. Variations in plant height among lettuce cultivars are largely determined by genetic factors intrinsic to each morphotype (Capparotto et al., 2026). Romaine-type lettuces, such as ‘Arroyo’, possess an inherent upright growth habit characterized by elongated leaves, naturally resulting in greater vertical stature. This morphotype exhibits a physiological propensity for taller stem elongation and broader leaf spans, which are advantageous traits for optimizing canopy architecture, light interception, and photosynthetic efficiency within automated closed hydroponic systems (Wasito et al., 2023). Under optimal environmental and nutritional conditions, these structural characteristics enable romaine cultivars to maximize their spatial canopy coverage compared with looser-leaf or butterhead types (Matysiak et al., 2023).

Influence of Growing Media on Vertical Growth

Among the growing substrates, peat moss emerged as the most effective medium for promoting vertical plant growth. Both peatmoss and cocopeat outperformed rockwool,

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a trend directly attributable to their superior physicochemical properties (Table 1). Peatmoss is highly valued in hydroponic systems for its high cation exchange capacity (CEC), which enables it to efficiently retain and buffer essential macro- and micronutrients, preventing their leaching—a common issue in highly inert aggregate media (Sdao et al., 2025). Structurally, peatmoss exhibits a total porosity of up to 97%, enabling it to retain water at 60% to 68% of its volume while maintaining an air-filled porosity of 10% to 15%, which ensures a vital oxygen supply to the rhizosphere (Rezanezhad et al., 2016).

Similarly, cocopeat serves as a sustainable, structurally stable alternative to conventional rockwool. It establishes a favorable, loose root-stimulating rhizosphere that benefits crops with high root oxygen demands, such as lettuce, due to its well-balanced water-holding capacity and high aeration porosity (Budavári et al., 2024). Conversely, while rockwool possesses excellent total porosity, its rapid hydraulic conductivity can lead to non-uniform moisture retention and release curves. This spatial variation in moisture can disrupt consistent nutrient absorption throughout the rhizosphere, depending on the slope and laminar flow dynamics of nutrient film technique (NFT) gullies (Pastor-Arbulú & Rodríguez-Delfín, 2025).

Leaf number

The number of leaves per plant exhibited significant varietal differences across all observation intervals (7, 14, 21, and 28 DAT). However, no significant interaction effect between cultivar and growing media was observed for this parameter (Table 4). Throughout the entire experimental period, the cultivar ‘Espirando’ consistently produced the highest average leaf count, reaching a maximum mean of 28.29 leaves per plant at harvest. Regarding the main effect of the growing media, peatmoss yielded the highest leaf number at 7 DAT, though it was not statistically different from the cocopeat treatment. By 14 DAT, cocopeat recorded the highest leaf number, maintaining statistical parity with the peatmoss substrate.

Unlike the trends observed for plant height, ‘Espirando’ generated the highest number of leaves, demonstrating that varietal growth patterns are morphologically divergent rather than uniform. The superior leaf proliferation in ‘Espirando’ is likely attributed to elevated photosynthetic activity and enhanced nutrient use efficiency, which sustain the continuous initiation of leaf primordia (Kalisz et al., 2020). Within automated hydroponic systems, an uninterrupted supply of water and nutrients minimizes moisture stress and maximizes root uptake. Specifically, the continuous laminar flow and high dissolved oxygen levels characteristic of the nutrient film technique (NFT) optimize nutrient accessibility in the root zone, thereby accelerating leaf expansion, leaf initiation, and shoot biomass accumulation compared to traditional aggregate methods (Wang et al., 2023a). These findings corroborate previous research demonstrating that distinct lettuce cultivars possess varied physiological and metabolic efficiencies under NFT management, meaning that deliberate cultivar selection directly governs leaf production dynamics and overall yield stability (Pastor-Arbulú & Rodríguez-Delfín, 2025).

The capacity of organic-based substrates to accelerate leaf initiation is fundamentally linked to their superior cation exchange capacity (CEC) and moisture-buffering characteristics (Gruda, 2019). The high density of negatively charged surface sites intrinsic to peatmoss facilitates the adsorption and retention of essential macronutrient cations, which are gradually released into the rhizosphere solution to meet the demands of vegetative growth (Wang et al., 2023a). This elevated CEC, complemented by a structurally stable matrix, maintains optimal nutrient availability in the root zone, supporting continuous cell division and subsequent leaf production throughout the early vegetative phases (Fascella, 2015).

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Table 4

Effect of Lettuce Varieties and Different Planting Media on the Average Number of Leaves of Lettuce

Treatment	Leaf number			
	7 DAT	14 DAT	21 DAT	28 DAT
Varieties				
'Arroyo'	8.91 a	11.58 a	14.91 a	22.06 a
'Amaroza'	8.47 a	12.47 a	17.68 b	23.68 a
'Espirando'	10.31 b	15.90 b	20.91 c	28.29 b
Planting medium				
Rockwool	8.26 a	11.84 a	17.04	24.23
Cocopeat	9.59 b	14.29 b	18.45	24.87
Peatmoss	9.84 b	13.81 b	18.04	24.93
Varieties	**	*	*	*
Planting medium	**	*	**	**
Varieties × planting medium	ns	ns	ns	ns

Note. DAT: days after transplanting, ns: non-significant, values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level.

Plant Diameter

Plant diameter responded significantly to both cultivar and growing medium treatments. Furthermore, a significant interaction effect between the two factors was detected at 7, 14, 21, and 28 DAT (Table 6). Cultivar variations exerted a highly significant influence on plant diameter across all observation weeks. Conversely, the main effect of the growing media was only significant up to 21 DAT. The interaction between cultivar and growing substrate uniquely influenced plant diameter during the initial establishment phase at 7 DAT (Table 5). The cultivar 'Arroyo' maintained the largest plant diameter at every developmental stage. Concurrently, peat moss induced the largest plant diameters at 14 and 21 DAT, showing no statistically significant differences from the cocopeat treatments.

Decomposing the interaction effects revealed that 'Arroyo' cultivated in peatmoss achieved the widest overall plant diameter, significantly outperforming all other treatment combinations. The distinct architecture of 'Arroyo' is characterized by pronounced leaf elongation, a wide rosette radius, and rapid biomass accumulation (Ramadhan et al., 2025). Certain lettuce genotypes are genetically predisposed to manifest larger, more expansive leaf rosettes and broader canopy dimensions. Because plant diameter is geometrically determined by the cumulative expansion and spatial arrangement of individual leaves, cultivars that generate wider or more numerous leaves inherently develop a more extensive rosette structure (Sublett et al., 2018).

The performance advantage of peatmoss-based media—manifested in increased leaf numbers, thicker stems, and larger marketable head diameters—is driven by its ability to balance moisture retention with uniform nutrient delivery during critical growth phases (Pastor-Arbulú & Rodríguez-Delfín, 2025). The high water-holding capacity and fine matrix texture of peatmoss (Table 1) mitigate localized water deficits and stabilize the influx of dissolved ions required for leaf cell turgor and subsequent expansion. However, as the crop approached maturity, the continuous, uniform delivery of nitrogen via the recirculating NFT stream became the dominant factor in the plant microenvironment. This nutrient saturation reduced the localized influence of the solid growing media over time, causing the plant diameter values across all substrate treatments to converge toward harvest (Omar et al., 2023).

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Core Length

Core length of lettuce, defined as the distance from the base of the stem to the insertion point of the lowest leaf, is one of the most important morphological and commercial quality traits in lettuce evaluation (Stojanović et al., 2025). Growing media may also indirectly influence core elongation through their effects on nitrogen availability and root zone conditions. Media with high water retention and cation exchange capacity, such as peat moss and cocopeat, sustain a continuous nitrogen supply to the plant, thereby promoting vegetative elongation, including stem and core development (Wang et al., 2023b). However, since core length was not directly measured in this study, these relationships remain inferential. This omission represents a limitation of the current research. Future research should incorporate core length as a standard measurement alongside plant height, plant diameter, and fresh weight to provide a more comprehensive assessment of lettuce quality and commercial value under NFT hydroponic conditions, particularly when comparing varieties with contrasting growth forms across different substrate conditions.

Table 5

Effect of Lettuce Varieties and Different Planting Media on the Average Plant Diameter of Lettuce

Treatment	Diameter (cm)			
	7 DAT	14 DAT	21 DAT	28 DAT
Varieties				
‘Arroyo’		21.64 c	21.36 b	24.05 c
‘Amaroza’		16.79 b	18.12 a	21.87 b
‘Espirando’		13.70 a	17.47 a	20.24 a
Planting medium				
Rockwool		15.98 a	17.86 a	22.62
Cocopeat		17.63 ab	19.09 ab	21.81
Peatmoss		18.51 b	20.01 b	21.73
Varieties	*	*	*	**
Planting medium	*	*	*	**
Varieties × planting medium	*	ns	ns	ns

Notes. DAT: days after transplanting, ns: non-significant, values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level.

Table 6

Effect of Lettuce Varieties and Planting Media on Plant Diameter of Lettuce at 7 Days After Transplanting

Varieties	Plant diameter (cm)		
	Rockwool	Cocopeat	Peatmoss
‘Arroyo’	16.75 cd	18.95 d	23.40 e
‘Amaroza’	12.91 ab	14.72 bc	14.41 bc
‘Espirando’	10.72 a	13.12 abc	13.04 ab
Tukey HSD 5%		3.69	

Notes. Values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level, DAT: days after transplanting.

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Fresh Weight

Shoot fresh weight at harvest exhibited significant variations among lettuce cultivars, whereas the main effect of the growing media was not statistically significant (Table 7). The cultivar 'Arroyo' produced the highest mean fresh weight (150.64 g per plant). For the growing substrates, cocopeat yielded the highest numerical fresh weight (132.77 g per plant), followed closely by peatmoss (131.50 g per plant), while rockwool resulted in the lowest numerical yield (122.16 g per plant).

The superior fresh weight of 'Arroyo' aligns with its exceptional performance in plant height and diameter, underscoring its high capacity for vegetative biomass accumulation within the cultivation cycle. This robust shoot biomass is largely supported by its sturdy leaf morphology and structural stem development, which enhance tissue moisture retention. Lettuce cultivars characterized by expanded leaf laminae and an upright growth habit typically exhibit greater fresh weight due to optimized light interception and higher canopy photosynthetic efficiency under greenhouse conditions (Alupani, 2023).

Furthermore, recirculating hydroponic systems maintain a constant, non-limiting supply of dissolved nutrients, water, and oxygen within the rhizosphere. This optimized nutrient uptake accelerates cellular expansion and vegetative growth, thereby maximizing the genetic yield potential of robust cultivars like 'Arroyo' (Chatterjee et al., 2025).

The favorable numerical performance of organic substrates like cocopeat is attributed to their balanced physical properties, which optimize the water-to-air ratio in the root zone and enhance plant hydration (Pastor-Arbulú & Rodríguez-Delfín, 2025). Cocopeat possesses excellent total porosity and moisture retention capacity, which promote cell turgor and leaf expansion. Lettuce cultivated in cocopeat aggregates within nutrient film technique (NFT) channels often exhibits greater fresh biomass accumulation due to continuous moisture availability and adequate root-zone aeration (Raj et al., 2023). However, the continuous, direct delivery of the recirculating nutrient stream to the root tips in an NFT system can effectively compensate for the lower water-holding or nutrient-buffering capacities of less efficient media, equalizing significant differences in macro-nutrient absorption during rapid vegetative phases (Maulana et al., 2023).

Dry Weight

Shoot dry weight followed a structural trend identical to fresh weight, manifesting significant varietal differences but no statistically significant growing media effects (Table 7). 'Arroyo' accumulated the highest dry matter content (7.77 g per plant). Among the substrates, peatmoss and cocopeat produced numerically greater dry weights (6.52 g per plant and 6.40 g per plant, respectively) compared to rockwool (5.89 g per plant). Dry weight serves as a direct indicator of total organic matter synthesis, independent of plant water status. In closed hydroponic systems, varietal variations in dry matter accumulation are primarily governed by genetic factors that influence root system architecture, canopy configuration, and leaf expansion rates. The elevated dry matter accumulation in romaine types such as 'Arroyo' is strongly correlated with a more extensive root network. Romaine lettuce cultivars are genetically predisposed to develop robust root systems with enhanced spatial exploration capabilities, thereby increasing nutrient interception and uptake efficiency and ultimately driving structural biomass production (Rhimi et al., 2020).

Additionally, 'Arroyo' exhibits longer leaves and a higher leaf area index (LAI). An expanded canopy maximizes light interception and photosynthetic carbon fixation, accelerating carbohydrate synthesis and subsequent dry matter allocation (Gent, 2014). The numerical advantage of peatmoss and cocopeat over rockwool highlights the role of organic substrate structures in facilitating baseline root development. These organic media maintain a high water-holding capacity while preserving an interconnected porous network for gas exchange. This structural matrix allows roots to simultaneously access moisture and oxygen,

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Table 7

Effect of Lettuce Varieties and Different Planting Media on the Average Fresh and Dry Weight of Lettuce

Treatment	Fresh weight (g)	Dry weight (g)
Varieties		
‘Arroyo’	150.639 b	7.77 c
‘Espirando’	118.292 a	5.96 b
‘Amaroza’	117.514 a	5.08 a
Planting medium		
Rockwool	122.16	5.89
Cocopeat	132.77	6.40
Peatmoss	131.50	6.52
Varieties	* *	* *
Planting medium	* *	* *
Varieties × planting medium	ns	ns

Note. ns: non-significant, values followed by the same letter in the same column indicate that there is no significant difference based on the Tukey HSD test at the 5% level, DAT: days after transplanting.

promoting optimal root elongation and enhanced nutrient assimilation efficiency (Panthi et al., 2025). When the rhizosphere environment supports healthy root development, plants can allocate more assimilates to structural tissues, resulting in higher shoot dry mass (Fesendouz et al., 2025). These variations confirm that cultivar-specific physiological traits remain the dominant driver of growth and biomass partitioning patterns in vertical or protected hydroponic systems (Frasetya et al., 2021).

A recognized limitation of this study was the omission of core length measurements, which govern lettuce shelf life and marketability. Future investigations should incorporate core length alongside standard morphological traits to provide a more comprehensive characterization of market quality across diverse genotypes and substrates. Additionally, subsequent research should evaluate the long-term economic viability and environmental sustainability of these organic substrate combinations on a commercial scale, while exploring the optimization of nutrient solution concentrations, electrical conductivity gradients, laminar flow rates, and photoperiod management to further maximize the productivity of automated NFT hydroponic systems.

Conclusions

The findings of this study demonstrate that both cultivar selection and the choice of growing media substantially influence lettuce growth dynamics and yield in an NFT hydroponic system. However, the relative contribution of each factor varied depending on the specific morpho-physiological parameters and developmental stages evaluated. Among the three evaluated cultivars, ‘Arroyo’ consistently demonstrated superior agronomic performance, achieving the highest plant height, widest rosette canopy diameter, and maximum fresh and dry shoot biomass across all observation intervals. These results underscore the elevated genetic capacity of ‘Arroyo’ for rapid vegetative growth and efficient biomass accumulation under closed-loop hydroponic conditions, positioning it as an ideal candidate for commercial operations utilizing this system. Conversely, ‘Espirando’ exhibited a distinct competitive advantage in leaf proliferation, indicating its economic suitability for specialized markets that prioritize leaf count over structural head size or cumulative biomass. Peatmoss and cocopeat significantly outperformed the conventional inert medium

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(rockwool) regarding plant height, leaf initiation, and crown diameter, particularly during the early and mid-developmental phases. This performance advantage is fundamentally attributed to the superior physicochemical traits of organic substrates, including their enhanced water-holding capacity, high cation exchange capacity, and optimal root-zone aeration, which collectively establish a highly favorable rhizosphere for nutrient assimilation and root network expansion. Overall, this study suggests that integrating the cultivar ‘Arroyo’ with either peatmoss or cocopeat substrates constitutes the most productive and effective treatment combination for maximizing NFT hydroponic lettuce yields within Indonesian tropical environments.

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