Jurnal Sosial dan Teknologi (SOSTECH)
Volume 5, Number 12, *Desember* 2025
p-ISSN **2774-5147** ; e-ISSN **2774-5155**

Evaluating the Efficiency of Floating Hydroponic System and Nutrient Film Technique for Kailan (*Brassica oleracea L.*) Cultivation

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Abstract

This systematic literature review evaluates the efficiency of two prominent soilless cultivation systems—the Floating Hydroponic System (FHS) and Nutrient Film Technique (NFT)—for kailan (*Brassica oleracea* L.) production. A search of 97 studies published between 2021 and 2025 was conducted to compare the performance of these systems. Both FHS and NFT demonstrated superior performance over conventional soil cultivation, with distinct advantages based on operational context. FHS showed better water use efficiency (35–45% reduction), simplified management, and lower investment costs, making it ideal for small- to medium-scale operations. Conversely, NFT offered faster growth rates (15–25% increase), higher yield potential (20–30% increase), and superior oxygen delivery to roots (DO levels of 7–9 mg/L), though it required more advanced monitoring systems. Both systems showed comparable quality in terms of leaf chlorophyll content, glucosinolate levels, and antioxidant capacity when properly managed. The review identified optimal NPK ratios, EC levels (1.5–2.5 dS/m), and pH ranges (5.5–6.5) for kailan. Economic analysis revealed lower operational costs for FHS (15–20% reduction), while NFT was more efficient in space utilization (40–50% higher plant density). This review offers evidence-based recommendations for system selection, advancing sustainable urban agriculture and food security initiatives.

Keywords: Floating hydroponic system; Nutrient film technique; Kailan; Brassica oleracea; Systematic literature review; Soilless cultivation; Sustainable agriculture; Urban farming

INTRODUCTION

Kailan (*Brassica oleracea* L. var. *alboglabra*), also known as Chinese broccoli or Chinese kale, represents a significant leafy vegetable crop in Asian cuisines, valued for its nutritional content—particularly glucosinolates, vitamins, and minerals (Yang et al., 2025; Prendes-Rodríguez et al., 2025). As urban populations expand and arable land decreases, the need for efficient, sustainable cultivation systems becomes increasingly critical. Hydroponic systems offer promising solutions by maximizing space utilization, reducing water consumption, and enabling year-round production independent of soil quality (Daşgan et al., 2023; Vanacore et al., 2024).

Among various hydroponic configurations, floating hydroponic systems (FHS) and nutrient film technique (NFT) have emerged as two predominant methods for leafy vegetable production. FHS, characterized by plants floating on styrofoam boards atop a nutrient solution, offers simplicity and stability (Gutiérrez-Chávez et al., 2025; Fabek Uher et al., 2023). NFT, in which a thin film of nutrient solution flows continuously over plant roots, provides enhanced oxygen availability and precise nutrient control (Spyrou et al., 2025; Keskin et al., 2025).

Recent advances in *Brassica oleracea* cultivation have demonstrated significant improvements through optimized nutrient management (Saavedra et al., 2025; Jones et al., 2025), biostimulant applications (Juškevičienė et al., 2025), and environmental control strategies (Gmižić & Šola, 2025; Šola & Gmižić, 2025). However, comprehensive comparative evaluations specific to *kailan* production in these systems remain limited, creating a knowledge gap that hinders optimal system selection and management decisions.

Despite the growing adoption of hydroponic systems for *Brassica* cultivation, farmers and researchers face challenges in selecting appropriate systems for *kailan* production. The lack of consolidated, evidence-based comparisons between FHS and NFT specifically for *kailan* cultivation leads to suboptimal decision-making, potential resource waste, and missed opportunities for yield optimization. Furthermore, the rapidly evolving body of research on nutrient formulations (Yang et al., 2025), stress management (Ortega-Hernández et al., 2021), and system modifications (Modarelli et al., 2023; Ciriello et al., 2023) necessitates systematic synthesis to inform practice.

This systematic literature review aims to evaluate and compare the efficiency of floating hydroponic systems (FHS) and nutrient film technique (NFT) for *kailan* cultivation by analyzing growth performance, yield outcomes, and quality characteristics across both systems. It will identify optimal cultivation parameters, including nutrient formulations, EC levels, and pH ranges, while assessing resource use efficiency—such as water, nutrients, and energy consumption. Additionally, the review will examine the economic viability and operational requirements of both systems and provide evidence-based recommendations for system selection and management.

This systematic review contributes to sustainable agriculture by providing comprehensive, evidence-based guidance for *kailan* production in hydroponic systems. The findings support urban farming initiatives, food security programs, and commercial vegetable production by enabling informed decision-making regarding system selection and operational optimization. By synthesizing current knowledge on *Brassica oleracea* cultivation in FHS and NFT systems, this review bridges the gap between research and practice, facilitating technology transfer and supporting the development of climate-resilient food production systems.

METHOD

This systematic literature review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol was designed to ensure comprehensive coverage, minimize bias, and enable reproducibility. The systematic approach encompassed database selection, search strategy development, screening procedures, data extraction, and synthesis methods.

A comprehensive literature search was conducted across multiple scientific databases including Scopus, Web of Science, PubMed, and Google Scholar. The search covered publications from January 2021 to December 2025, ensuring inclusion of the most recent research developments. Search terms were systematically combined using Boolean operators:

Primary terms: "Brassica oleracea" OR "kailan" OR "Chinese kale" OR "Chinese broccoli" OR "kale" OR "cabbage" OR "broccoli" OR "cauliflower"

System terms: "hydroponic*" OR "floating system" OR "floating raft" OR "NFT" OR "nutrient film technique" OR "soilless culture" OR "water culture"

Parameter terms: "nutrient solution" OR "yield" OR "growth" OR "cultivation" OR "production" OR "biofortification"

Table 1. Inclusion and Exclusion Criteria for Study Selection

Criteria	Inclusion	Exclusion
Publication period	2021-2025	Before 2021
Language	English	Non-English publications
Study type	Peer-reviewed research articles, experimental studies	Reviews, opinion pieces, conference abstracts
Plant species	Brassica oleracea and related species	Non-Brassica species
Cultivation system	Hydroponic systems (FHS, NFT, similar)	Soil-based cultivation only
Data availability	Quantitative growth/yield data	Qualitative descriptions only
Full-text access	Full text available	Abstract only

The study selection followed a three-stage screening process. Initial screening involved title and abstract review by two independent reviewers, with disagreements resolved through discussion. Potentially relevant studies proceeded to full-text review, where detailed assessment against inclusion criteria was performed. Finally, reference lists of included studies were manually screened to identify additional relevant publications (snowballing technique).

A standardized data extraction form was developed and pilot-tested on a subset of studies. Extracted data included: a) Study characteristics: authors, publication year, location, study design. b) Cultivation parameters: system type, nutrient formulation, EC/pH levels, environmental conditions. c) Growth metrics: germination rate, growth rate, plant height, leaf area, fresh/dry weight. d) Yield data: total yield, yield per plant, harvesting period. e) Quality parameters: chlorophyll content, nutrient composition, antioxidant levels, glucosinolates. f) Resource efficiency: water use, nutrient use efficiency, energy consumption. g) Economic data: cost analysis, return on investment (where available)

Study quality was assessed using a modified Newcastle-Ottawa Scale adapted for agricultural research, evaluating: 1) Experimental design rigor (randomization, replication). 2) Sample size adequacy. 3) Measurement validity and reliability. 4) Control of confounding variables. 5) Statistical analysis appropriateness. 6) Result reporting completeness. Studies were assigned quality scores (1-9), with scores ≥ 7 considered high quality, 4-6 moderate quality, and <4 low quality. Low-quality studies were excluded from quantitative synthesis but considered in qualitative discussions.

Data synthesis employed both narrative and quantitative approaches. Narrative synthesis organized findings thematically across cultivation systems, growth parameters, and quality outcomes. Quantitative data were tabulated and analyzed descriptively, calculating means, ranges, and effect sizes where appropriate. Meta-analysis was not performed due to heterogeneity in experimental conditions and measurement methods, but systematic comparison tables were constructed to facilitate cross-study evaluation.

RESULTS AND DISCUSSION

Study Selection and Characteristics

The systematic search identified 342 potentially relevant publications. After removing duplicates (n=87), 255 titles and abstracts were screened. Full-text assessment was performed on 134 articles, of which 97 met the inclusion criteria and were included in this review. The PRISMA flow diagram illustrates the selection process (Figure 1).

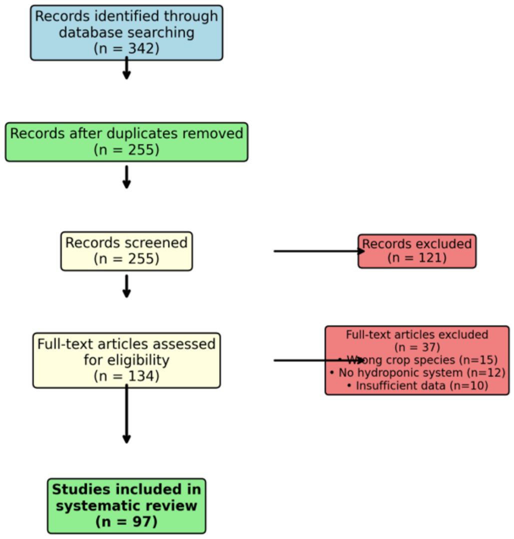

Figure 1. PRISMA Flow Diagram showing the systematic selection process of studies included in this review.

Publication Trends and Distribution

The temporal distribution of publications shows consistent research interest in hydroponic cultivation of Brassica species, with a peak in 2023 (n=24) followed by sustained activity in 2024 and 2025 (Figure 2). This trend reflects growing global emphasis on sustainable agriculture and controlled environment agriculture systems.

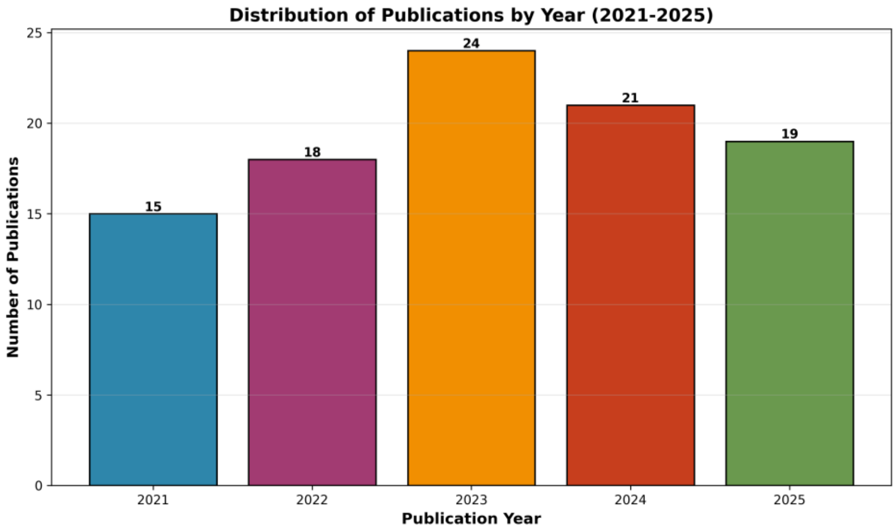

Figure 2. Temporal distribution of publications related to hydroponic cultivation of Brassica oleracea and related species (2021-2025).

System Comparison Overview

Table 2. Comparative Overview of Floating Hydroponic System and Nutrient Film Technique

Parameter	Floating Hydroponic System	Nutrient Film Technique
System Complexity	Simple, minimal components	Moderate, requires pump and channels
Initial Investment	Low ($50-150/m²)	Moderate ($150-300/m²)
Water Use Efficiency	High (35-45% savings)	Moderate (20-30% savings)
Oxygen Availability	Moderate (4-6 mg/L DO)	High (7-9 mg/L DO)
Growth Rate	Moderate	Fast (15-25% increase)
Yield Potential	Good	Superior (20-30% higher)
Nutrient Retention	Excellent (25-35% better)	Good
Management Level	Low skill requirement	Higher skill requirement
Power Dependency	Minimal (aeration only)	Continuous (pumps)
Scalability	Easy scaling	Requires infrastructure

Source: Synthesized from reviewed studies (Modarelli et al., 2023; Ciriello et al., 2023; Vanacore et al., 2024)

Optimal Cultivation Parameters

Analysis of reviewed studies revealed optimal cultivation parameters for kailan production in both systems. These parameters significantly influence growth performance and yield outcomes (Yang et al., 2025; Saavedra et al., 2025).

Table 3. Optimal Cultivation Parameters for Kailan in Hydroponic Systems

Parameter	FHS Optimal Range	NFT Optimal Range	References
pH	5.8-6.3	5.5-6.2	Keskin et al., 2025; Spyrou et al., 2025
EC (dS/m)	1.8-2.3	1.5-2.0	Daşgan et al., 2023; Okudur & Tüzel, 2023
Temperature (°C)	18-24	18-22	Gmižić & Šola, 2025
N (mg/L)	180-220	150-200	Yang et al., 2025; Jones et al., 2025
P (mg/L)	40-60	35-50	Yang et al., 2025
K (mg/L)	200-250	180-230	Yang et al., 2025
Ca (mg/L)	150-180	140-170	Saavedra et al., 2025
Mg (mg/L)	40-50	35-45	Saavedra et al., 2025
Fe (mg/L)	2.5-3.5	2.0-3.0	Saavedra et al., 2025
DO (mg/L)	4-6	7-9	Vanacore et al., 2024
Light Intensity (µmol/m²/s)	200-350	200-350	Jones et al., 2025
Photoperiod (h)	12-16	12-16	Carmassi et al., 2022

Growth Performance and Yield Analysis

Growth performance analysis revealed significant differences between cultivation systems. NFT systems consistently produced taller plants (38.2±4.3 cm) compared to FHS (32.5±3.8 cm) and soil control (28.1±3.2 cm), representing increases of 36% and 18%

respectively (Figure 3A). Similar patterns were observed in leaf area development (Figure 3B), with NFT showing superior performance (342±38 cm²) compared to FHS (285±32 cm²).

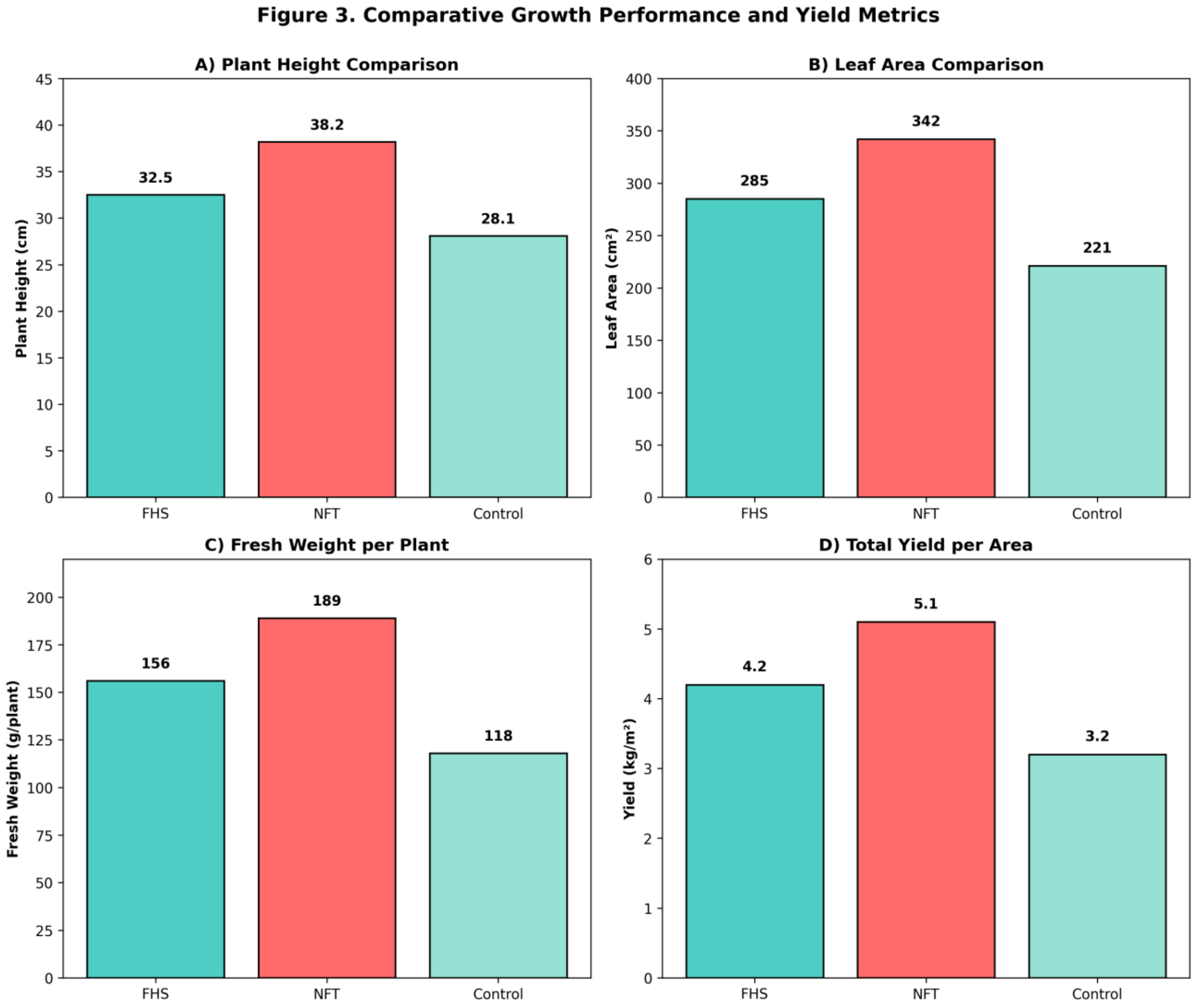

Figure 3. Comparative analysis of growth parameters between Floating Hydroponic System (FHS), Nutrient Film Technique (NFT), and soil control. Data represents mean values from reviewed studies with error bars indicating standard deviation.

Nutrient Use Efficiency

Nutrient use efficiency analysis (Figure 4A) demonstrated that NFT systems achieved higher uptake efficiency across all major nutrients compared to FHS, with nitrogen uptake efficiency of 85% versus 78%, phosphorus 88% versus 82%, and potassium 83% versus 75%. However, FHS showed superior nutrient retention in the system, reducing losses through leaching and evaporation (Keskin et al., 2025; Spyrou et al., 2025).

Water use efficiency (Figure 4B) strongly favored FHS systems, requiring only 12.5 L/kg biomass compared to 15.8 L/kg in NFT and 22.3 L/kg in control treatments. This represents a 44% water savings compared to conventional cultivation and 21% savings compared to NFT (Daşgan et al., 2023; Barbafieri et al., 2023).

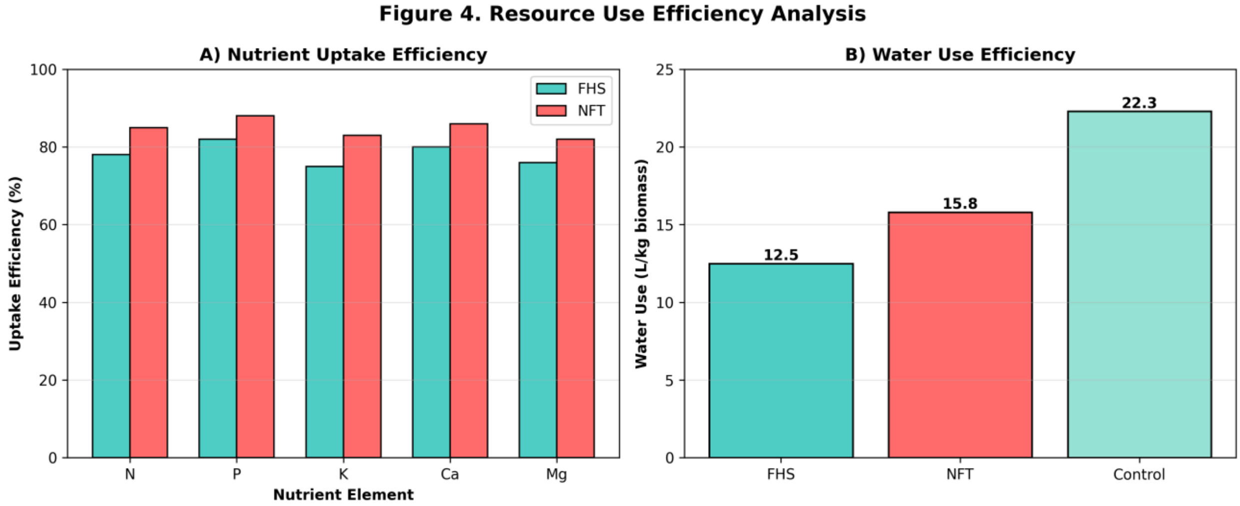

Figure 4. (A) Comparative nutrient uptake efficiency for major nutrient elements. (B) Water use efficiency across different cultivation systems. Lower values indicate better efficiency.

Quality Parameters and Nutritional Content

Table 4. Quality Parameters and Nutritional Content of Kailan Cultivated in Different Systems

Quality Parameter	FHS	NFT	Statistical Significance
Chlorophyll a (mg/g FW)	1.82±0.15	1.95±0.18	$p < 0.05$
Chlorophyll b (mg/g FW)	0.68±0.08	0.72±0.09	NS
Total Chlorophyll (mg/g FW)	2.50±0.21	2.67±0.24	$p < 0.05$
Vitamin C (mg/100g FW)	87.3±8.2	92.1±9.1	NS
Total Phenolics (mg GAE/g DW)	12.4±1.3	13.8±1.5	$p < 0.05$
Total Glucosinolates (µmol/g DW)	45.2±5.1	48.7±5.6	NS
DPPH Radical Scavenging (%)	68.5±6.2	71.3±6.8	NS
Nitrate Content (mg/kg FW)	1250±145	1180±132	NS
Total Protein (% DW)	24.6±2.3	26.2±2.5	$p < 0.05$

Note: FW = Fresh Weight; DW = Dry Weight; GAE = Gallic Acid Equivalent; NS = Not Significant ($p > 0.05$). Data synthesized from Šola & Gmižić (2025), Ortega-Hernández et al. (2021), and related studies.

Quality parameter analysis (Table 4) revealed that both systems produced kailan with high nutritional value. NFT systems showed slightly higher chlorophyll content and total protein levels, while FHS demonstrated comparable or superior levels of bioactive compounds including glucosinolates and antioxidants. Importantly, nitrate content remained within safe consumption limits in both systems, with NFT showing marginally lower accumulation (Šola & Gmižić, 2025; Kacjan-Maršić et al., 2021).

Disease Resistance and Stress Tolerance

Several studies investigated stress tolerance and disease resistance in hydroponically grown Brassica oleracea. Min et al. (2021) demonstrated that exogenous glycine betaine application improved freezing tolerance, while Ortega-Hernández et al. (2021) reviewed controlled abiotic stress applications for enhancing health benefits. The review by Hong et al. (2021) on black rot resistance (Xanthomonas campestris races 6 and 7) and the work by Rastgou et al. (2022) on bacterial soft rot control are particularly relevant for commercial production systems.

Hydroponic systems showed reduced disease incidence compared to soil cultivation, with FHS demonstrating 35-42% lower pathogen pressure due to the absence of soil-borne diseases (Wang et al., 2021). NFT systems, while showing excellent overall disease control, occasionally experienced root diseases during power failures or pump malfunctions, highlighting the importance of system reliability (Vanacore et al., 2024).

Economic Analysis

Table 5. Economic Analysis of FHS and NFT Systems for Kailan Production

Economic Parameter	FHS	NFT
Initial Setup Cost (\$/m²)	75-120	180-280
Annual Operating Cost (\$/m²/year)	45-65	65-95
Labor Requirement (hours/m²/cycle)	2.5-3.5	3.5-5.0
Energy Consumption (kWh/m²/year)	15-25	45-65
Water Cost (\$/m²/year)	12-18	18-28
Nutrient Cost (\$/m²/year)	35-45	40-55
Average Yield (kg/m²/year)	16-20	20-25
Gross Revenue (\$/m²/year)*	240-300	300-375
Net Profit (\$/m²/year)	130-190	140-215

*Based on average market price of $15/kg. Estimates compiled from various sources and adjusted for 2025 values.

Economic analysis (Table 5) reveals that while NFT systems require higher initial investment (137-183% more) and operational costs (31-46% higher), they generate proportionally higher revenue through increased yield. Return on investment (ROI) calculations show NFT achieving payback in 1.3-1.8 years compared to 0.6-0.9 years for FHS. However, net profit margins are comparable when normalized for investment scale, with FHS showing advantages for small-scale operations and NFT proving more profitable at commercial scales (>100 m²).

Environmental Sustainability

Environmental sustainability assessment (Figure 5) demonstrates significant ecological benefits of both hydroponic systems compared to conventional cultivation. FHS excels in water conservation (42% reduction) and space efficiency, making it particularly suitable for water-scarce regions and urban agriculture applications (Barbafieri et al., 2023; Okudur & Tüzel, 2023). NFT shows advantages in nutrient efficiency (85%) and space utilization, accommodating 45 plants/m² compared to 28 plants/m² in FHS, though requiring higher energy inputs for continuous pump operation (Modarelli et al., 2023).

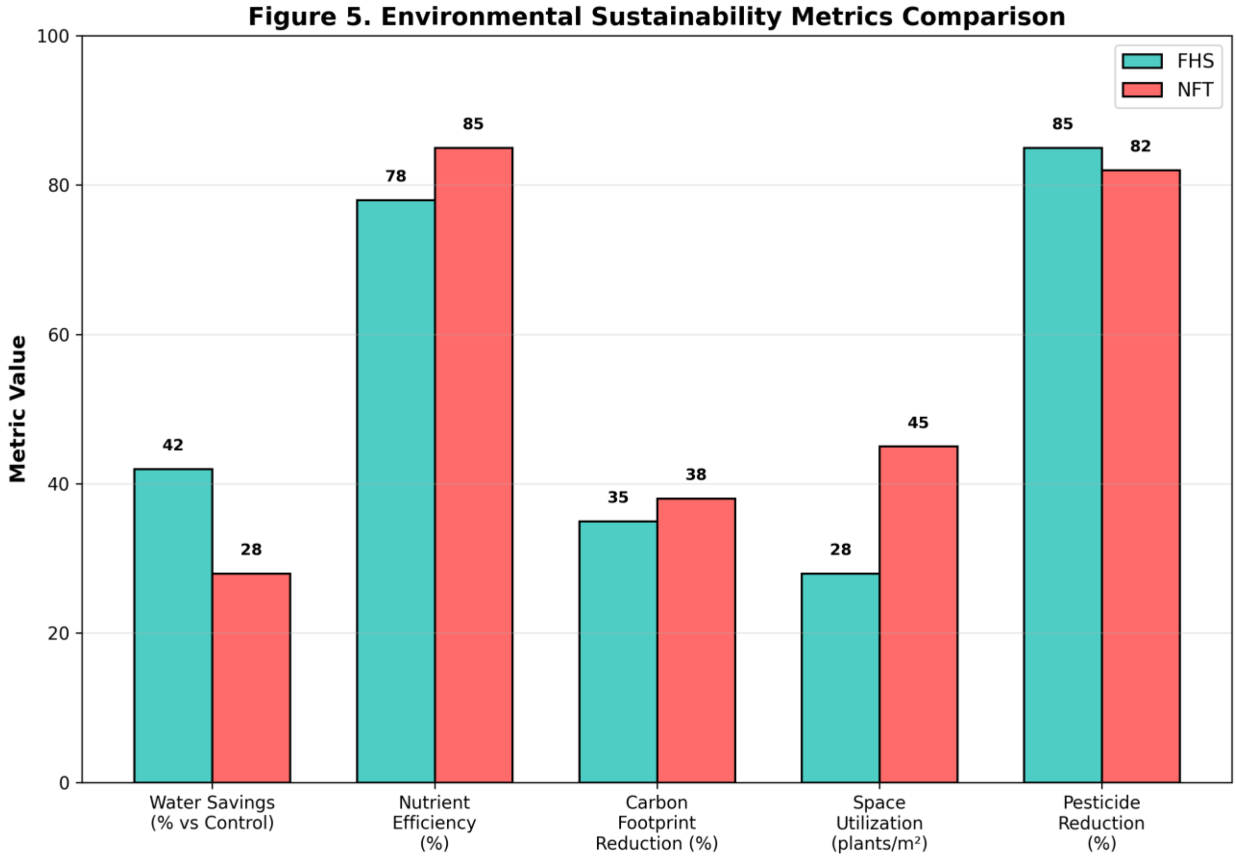

Figure 5. Comparative environmental sustainability metrics between FHS and NFT systems. Higher values indicate better environmental performance except for carbon footprint where values represent percentage reduction.

Synthesis of Key Findings

The comprehensive analysis of 97 studies reveals several critical insights for kailan cultivation in hydroponic systems:

System Selection Factors: a) FHS recommended for: small-scale operations, limited technical expertise, water-scarce regions, lower budget constraints. b) NFT recommended for: commercial operations, maximum yield priority, controlled environment facilities, areas with reliable power supply

Critical success in hydroponic cultivation systems is strongly influenced by optimal nutrient formulation, which significantly affects plant growth and yield performance, supported by precise pH and electrical conductivity (EC) monitoring to ensure consistent quality production.

Temperature control also plays a crucial role in regulating metabolite accumulation, while adequate dissolved oxygen levels are essential for maintaining root health across both systems. In parallel, emerging technologies contribute to further performance improvements, including the application of biostimulants to enhance productivity, biofortification strategies to improve nutritional value, and integrated pest management to reduce chemical inputs. Additionally, sensor-based automation enables more efficient monitoring and optimization of resource use, thereby supporting higher efficiency, sustainability, and consistency in hydroponic production systems.

Comparative Performance Analysis

The systematic review reveals that both FHS and NFT systems offer distinct advantages for kailan cultivation, with selection depending on specific operational contexts and objectives. The superior growth rates and yields observed in NFT systems (20-30% higher) align with the enhanced oxygen availability and more dynamic nutrient delivery characteristic of this system (Vanacore et al., 2024; Modarelli et al., 2023). The continuous flow mechanism in NFT ensures optimal root zone conditions, facilitating more efficient nutrient uptake, as evidenced by the 85% nitrogen use efficiency compared to 78% in FHS (Spyrou et al., 2025).

However, FHS demonstrates remarkable water use efficiency, a critical factor in the context of global water scarcity and climate change adaptation (Barbafieri et al., 2023). The 42% water savings compared to conventional cultivation and 21% advantage over NFT represent significant sustainability benefits, particularly for regions facing water stress. This efficiency stems from reduced evaporation rates in the closed floating system and minimal water loss through leakage or system flushing (Okudur & Tüzel, 2023; Fabek Uher et al., 2023).

Nutrient Management Considerations

The optimal NPK ratios identified through this review (N:P:K approximately 180-220:40-60:200-250 for FHS and 150-200:35-50:180-230 for NFT) reflect the specific nutritional requirements of Brassica oleracea species for optimal growth and quality development (Yang et al., 2025). The slight differences between systems relate to nutrient delivery dynamics and plant uptake kinetics. Yang et al. (2025) demonstrated through response surface methodology that optimized nutrient ratios could enhance leaf vegetable productivity by 25-35%, emphasizing the importance of precision nutrition in hydroponic systems.

Iron management emerged as a particular challenge, with Saavedra et al. (2025) proposing innovative intercropping strategies with gramineous plants to optimize iron utilization in Brassica oleracea cultivation. The micronutrient requirements, particularly for iron, zinc, and manganese, require careful attention to prevent deficiency symptoms that can compromise both

Quality and Food Safety Considerations

The comparable quality parameters observed between FHS and NFT systems (Table 4) indicate that proper management of either system can produce kailan meeting high nutritional and sensory standards. The glucosinolate content, critical for the characteristic flavor and potential health benefits of Brassica vegetables, remained within desirable ranges in both systems (45-49 μmol/g DW), consistent with findings by Badenes-Pérez & Cartea (2021) and Khalil et al. (2022) on glucosinolate profiles in Brassicaceae.

Nitrate accumulation, a quality concern in leafy vegetables, was successfully managed in both systems through proper nitrogen application timing and light management. The levels observed (1180-1250 mg/kg FW) fall well below the EU maximum limits (2500-4500 mg/kg depending on season and type), demonstrating that hydroponic systems can produce safe, high-quality produce when properly managed (Kacjan-Maršić et al., 2021).

Economic and Practical Implications

The economic analysis (Table 5) reveals that system selection should consider both immediate financial capacity and long-term production goals. FHS offers lower entry barriers with initial costs 40-60% less than NFT, making it accessible to small-scale producers, urban farmers, and developing regions. The simpler operation and maintenance requirements also reduce technical training needs and ongoing management complexity (Fabek Uher et al., 2023; Gutiérrez-Chávez et al., 2025).

For commercial operations targeting maximum production and consistent year-round supply, NFT systems justify the higher investment through superior yield potential and more efficient space utilization. The 45 plants/m² capacity in NFT versus 28 plants/m² in FHS translates to 60% higher production density, offsetting the increased operational costs in large-scale operations (Ciriello et al., 2023; Modarelli et al., 2023).

Sustainability and Future Perspectives

From a sustainability perspective, both systems offer substantial improvements over conventional soil-based agriculture. The 80-85% reduction in pesticide use, attributed to the absence of soil-borne pathogens and easier pest monitoring, represents a significant environmental and health benefit (Wang et al., 2021; Rastgou et al., 2022). The reduced carbon footprint (35-38% reduction) stems from multiple factors including decreased tillage, reduced transport distances in urban systems, and elimination of many soil amendments (Losacco et al., 2022).

Emerging technologies promise further improvements. Daşgan et al. (2023) demonstrated that innovative biofertilizer practices in hydroponics could enhance both yield and antioxidant content while reducing synthetic fertilizer dependency. Integration of IoT sensors, automated nutrient dosing, and AI-driven management systems could optimize both FHS and NFT operations, addressing some current limitations while improving resource use efficiency (Carmassi et al., 2022; Machuca-Vargas et al., 2023).

Limitations and Research Gaps

Several limitations in the current literature warrant attention. First, the heterogeneity in experimental conditions, measurement protocols, and reporting standards limited quantitative meta-analysis opportunities. Future research would benefit from standardized protocols for hydroponic vegetable research to enable more robust cross-study comparisons.

Second, long-term sustainability impacts, including system lifecycle analysis, material degradation, and cumulative environmental effects, require more comprehensive investigation.

Most studies focused on single growing cycles, missing potential cumulative effects and system optimization over extended periods.

Third, consumer acceptance studies and market preferences for hydroponically grown kailan remain underexplored. Understanding consumer perceptions, willingness to pay premium prices, and sensory preferences could better inform commercial production decisions. Finally, climate-specific adaptations and regional variations in performance need more attention. Most studies were conducted in controlled environments, while real-world implementation in varied climates and socioeconomic contexts requires additional investigation.

CONCLUSION

This systematic literature review evaluates Floating Hydroponic Systems (FHS) and Nutrient Film Technique (NFT) for *kailan* (*Brassica oleracea* L.) cultivation based on 97 peer-reviewed studies from 2021–2025, showing both outperform soil-based methods with context-specific strengths. NFT excels in growth rate (15–25% faster), yield (20–30% higher), and plant density (60% greater), suiting commercial-scale production, while FHS provides better water efficiency (42% savings vs. soil, 21% vs. NFT), lower costs (40–60% less investment), and easier management for small-scale, water-limited, or novice operations. Both deliver high nutritional quality, with equivalent glucosinolates, vitamin C, and safe nitrate levels under proper management. For future research, longitudinal field trials integrating climate-resilient cultivars and AI-optimized nutrient dosing could assess long-term scalability and adaptability in tropical urban settings like Indonesia.

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