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ARTIFICIAL INTELLIGENCE IN HYDROPONIC VEGETABLE PRODUCTION: SMART MANAGEMENT, SUSTAINABILITY AND CONSUMER-PERCEIVED VALUE

INTELIGÊNCIA ARTIFICIAL NA PRODUÇÃO HIDROPÔNICA DE HORTALIÇAS: MANEJO INTELIGENTE, SUSTENTABILIDADE E VALOR PERCEBIDO PELO CONSUMIDOR

INTELIGENCIA ARTIFICIAL EN LA PRODUCCIÓN HIDROPÓNICA DE HORTALIZAS: MANEJO INTELIGENTE, SOSTENIBILIDAD Y VALOR PERCIBIDO POR EL CONSUMIDOR

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ABSTRACT

Artificial intelligence (AI) has been incorporated into hydroponic vegetable production as a strategy to improve management, increase production efficiency, and enhance the sustainability of cultivation systems. This study aimed to analyze, through an integrative review with a systematic search, AI applications in hydroponic management, their potential environmental benefits, and their relationship with perceived value and consumer acceptance. An integrative review was conducted using an open bibliographic source, metadata verification, and complementary consultation of scientific and editorial platforms. Thirty-two published studies formed the final synthesis. The reviewed literature indicates that sensors, IoT, automation, and AI models can operate in an integrated manner in nutrient solution monitoring, environmental control, growth prediction, computer vision, irrigation, fertilization, and decision support. However, the evidence is still marked by the predominance of prototypes, heterogeneity of indicators, and few longitudinal studies at commercial scale. Sustainability benefits, such as water and nutrient savings, reduced losses, and greater production stability, are potential outcomes and depend on comparable metrics, systemic assessment, and transparency regarding energy costs, infrastructure, maintenance, and data governance. In the consumer market, the perceived value of AI-assisted hydroponic vegetables depends less on the technology itself and more on understandable and verifiable attributes, such as quality, safety, freshness, traceability, demonstrated sustainability, acceptable price, and trust. It is concluded that AI can represent a competitive advantage in hydroponics when it connects management precision, demonstrable socio-environmental performance, and transparent communication with consumers. Further Brazilian studies, life cycle analyses, economic assessments, and choice experiments are needed to validate these relationships empirically.

KEYWORDS: *Artificial intelligence. Hydroponics. Precision agriculture. Sustainability. Consumer behavior.*

RESUMO

A inteligência artificial (IA) tem sido incorporada à produção hidropônica de hortaliças como estratégia para qualificar o manejo, aumentar a eficiência produtiva e ampliar a sustentabilidade dos sistemas de cultivo. Este estudo teve como objetivo analisar, por meio de revisão integrativa com busca sistematizada, as aplicações da IA no manejo hidropônico, seus potenciais benefícios ambientais e sua relação com o valor percebido e a aceitação do consumidor. Realizou-se revisão integrativa em fonte bibliográfica aberta, com verificação de metadados e consulta complementar em plataformas científicas e editoriais. Trinta e dois estudos publicados compuseram a síntese final.

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A literatura indica que sensores, IoT, automação e modelos de IA podem atuar de forma integrada no monitoramento da solução nutritiva, controle ambiental, previsão de crescimento, visão computacional, irrigação, fertilização e apoio à decisão. Entretanto, as evidências são marcadas pela predominância de protótipos, heterogeneidade de indicadores e poucos estudos longitudinais em escala comercial. Os benefícios de sustentabilidade, como economia de água e nutrientes, redução de perdas e estabilidade produtiva, são potenciais e dependem de métricas comparáveis, avaliação sistêmica e transparência sobre custos energéticos, infraestrutura, manutenção e governança de dados. No mercado consumidor, o valor percebido depende menos da tecnologia em si e mais de atributos verificáveis, como qualidade, segurança, frescor, rastreabilidade, sustentabilidade demonstrada, preço aceitável e confiança. Conclui-se que a IA pode representar vantagem competitiva quando conecta precisão do manejo, desempenho socioambiental demonstrável e comunicação transparente. Estudos brasileiros, análises de ciclo de vida, avaliações econômicas e experimentos de escolha são necessários para validar essas relações.

PALAVRAS-CHAVE: Inteligência artificial. Hidroponia. Agricultura de precisão. Sustentabilidade. Comportamento do consumidor.

RESUMEN
La inteligencia artificial (IA) se ha incorporado a la producción hidropónica de hortalizas como estrategia para mejorar la gestión, aumentar la eficiencia productiva y ampliar la sostenibilidad de los sistemas de cultivo. Este estudio analizó, mediante revisión integradora con búsqueda sistematizada, las aplicaciones de la IA en la gestión hidropónica, sus beneficios ambientales potenciales y su relación con el valor percibido y la aceptación del consumidor. Se realizó una revisión integradora en fuente bibliográfica abierta, con verificación de metadatos y consulta complementaria en plataformas científicas y editoriales. Treinta y dos estudios compusieron la síntesis final. La literatura indica que sensores, IoT, automatización y modelos de IA pueden actuar de forma integrada en el monitoreo de la solución nutritiva, control ambiental, predicción del crecimiento, visión artificial, riego, fertilización y apoyo a decisiones. Sin embargo, la evidencia está marcada por prototipos, indicadores heterogéneos y pocos estudios longitudinales comerciales. Los beneficios de sostenibilidad, como ahorro de agua y nutrientes, reducción de pérdidas y estabilidad productiva, son potenciales y dependen de métricas comparables, evaluación sistémica y transparencia sobre costos energéticos, infraestructura, mantenimiento y gobernanza de datos. En el mercado, el valor percibido depende menos de la tecnología en sí y más de atributos verificables, como calidad, seguridad, frescura, trazabilidad, sostenibilidad demostrada, precio aceptable y confianza. Se concluye que la IA representa ventaja competitiva cuando conecta precisión de la gestión, desempeño socioambiental demostrable y comunicación transparente. Estudios brasileños, análisis de ciclo de vida, evaluaciones económicas y experimentos de elección son necesarios para validar estas relaciones.

PALABRAS CLAVE: *Inteligencia artificial. Hidroponía. Agricultura de precisión. Sostenibilidad. Comportamiento del consumidor.*

1. INTRODUCTION

Vegetable production faces simultaneous constraints regarding the availability of water, soil, and labor, as well as climate stability. Hydroponic systems address some of these pressures by enabling plant cultivation in nutrient solutions or soil-free substrates, allowing for greater control over growing conditions. While this setup can boost productivity per unit area and facilitate the recirculation of water and nutrients, it is not inherently sustainable; its outcomes depend on system

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design, energy sources, nutrient solution formulation and disposal, available infrastructure, and technical operational capacity (SAMBO *et al.*, 2019; FUSSY; PAPENBROCK, 2022; GONNELLA; RENNA, 2021).

Digitalization introduces sensors, connectivity, automation, and analytical models to the hydroponic environment. Sensors measure pH, electrical conductivity, temperature, dissolved oxygen, solution levels, light intensity, humidity, and plant variables; the Internet of Things (IoT) transmits and integrates this data; automation executes predefined commands; and AI identifies patterns, estimates future states, or optimizes decisions. This distinction is crucial, as a connected or automated system does not necessarily constitute AI. The specific contribution of artificial intelligence emerges when machine learning algorithms, computer vision, fuzzy logic, or predictive control transform data into diagnoses, forecasts, or adaptive decisions (MARAVEAS, 2022; MOHYUDDIN *et al.*, 2024; MUHAMMED *et al.*, 2024).

In hydroponics, the most promising applications of AI involve diagnosing nutritional deficiencies and diseases, forecasting growth and yield, adjusting nutrients, and managing the environment and energy use. However, recent reviews indicate a prevalence of custom-built prototypes, low interoperability, and insufficient validation at a commercial scale. Thus, claims regarding resource savings or increased yields must be interpreted in light of the cultivation type, time horizon, comparison metric, and system energy consumption (CATOTA-OCAPANA *et al.*, 2025; REZA *et al.*, 2025; SPORTELLI *et al.*, 2025).

The adoption of these technologies also depends on the consumer market. Consumers may value attributes associated with controlled-environment production—such as safety, consistency, perceived sustainability, and traceability—yet they may also view enclosed environments, artificial lighting, robotics, and algorithms as signs of artificiality or a lack of naturalness. Evidence indicates that perceived sustainability, knowledge, and trust foster the acceptance of soil-less systems and vertical farming, whereas technological neophobia, perceived risk, and negative expectations regarding naturalness, flavor, nutrition, and safety can reduce purchase intention (JÜRKENBECK; HEUMANN; SPILLER, 2019; YANO *et al.*, 2021; ZHOU; ASIOLI; JÜRKENBECK, 2025).

Given this context, the research problem is: how can AI applied to hydroponic vegetable management contribute to sustainable outcomes and translate them into value perceived by the consumer? The study is justified by the fragmentation of literature across the fields of agricultural engineering, sustainability, and consumer behavior. The general objective was to analyze, in an integrative manner, the relationships between smart management, socio-environmental performance, and consumer perception in AI-assisted hydroponic vegetable production.

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2. METHODOLOGY

An integrative review approach was adopted, suitable for combining experimental studies, reviews, and research on consumer behavior. The methodological process followed the stages of problem definition, search, selection, extraction, critical appraisal, and thematic synthesis proposed by Whittemore and Knafl (2005) and Souza, Silva, and Carvalho (2010), with the identification and selection flow documented based on PRISMA 2020 (Page *et al.*, 2021). The review is described as having a “systematized search” because it employed a reproducible strategy using open sources, without claiming the comprehensiveness of a systematic review based on all available commercial databases.

The primary search was conducted in May 2026 on OpenAlex, with DOI and metadata verification performed via Crossref. Additionally, scientific databases and publishing platforms were consulted for supplementation, cross-checking, and locating full texts; these included Google Scholar, ScienceDirect, IEEE Xplore, MDPI, Frontiers, Wiley Online Library, SpringerLink, Emerald Insight, BMJ, and SciELO. Publications from 2019 to 2026 in Portuguese, English, or Spanish were considered. Eleven English search terms were used, combining the following blocks: (a) “hydroponics,” “hydroponic vegetables,” “soilless,” “vertical farming,” and “controlled environment agriculture”; (b) “artificial intelligence,” “machine learning,” “deep learning,” “IoT,” “sensors,” and “smart control”; (c) “sustainability,” “nutrient,” “water,” and “energy”; and (d) “consumer acceptance,” “perceived value,” “willingness to pay,” “trust,” “naturalness,” and “purchase intention.” For each term, up to one hundred records ranked as most relevant by the search source itself were retrieved.

Peer-reviewed articles addressing at least one of the following themes were included: AI, sensing, IoT, or control systems applied to hydroponics, soilless horticulture, or controlled-environment agriculture; and the productive or environmental sustainability of these systems; or consumer perceptions regarding hydroponic products, vertical farming, indoor production, and agricultural digitalization. Exclusions included duplicates, preprints, texts lacking abstracts or verifiable content, studies focused exclusively on soil-based farming, aquaculture, or automation not transferable to horticulture, as well as publications unrelated to the review's core themes.

The search yielded 1,100 records, supplemented by 50 "seed references" identified from the reference lists of selected studies and relevant reviews. Following deduplication, 845 unique records were screened by title and abstract. Of these, 801 were excluded due to a lack of thematic or document-type alignment. Forty-four texts proceeded to the eligibility assessment, and 12 were excluded due to tangential focus, methodological shortcomings, or a lack of specific contribution. The final corpus comprised 32 studies: 19 addressing technologies and sustainability, and 13 focusing on consumer perception, acceptance, or value (Figure 1).

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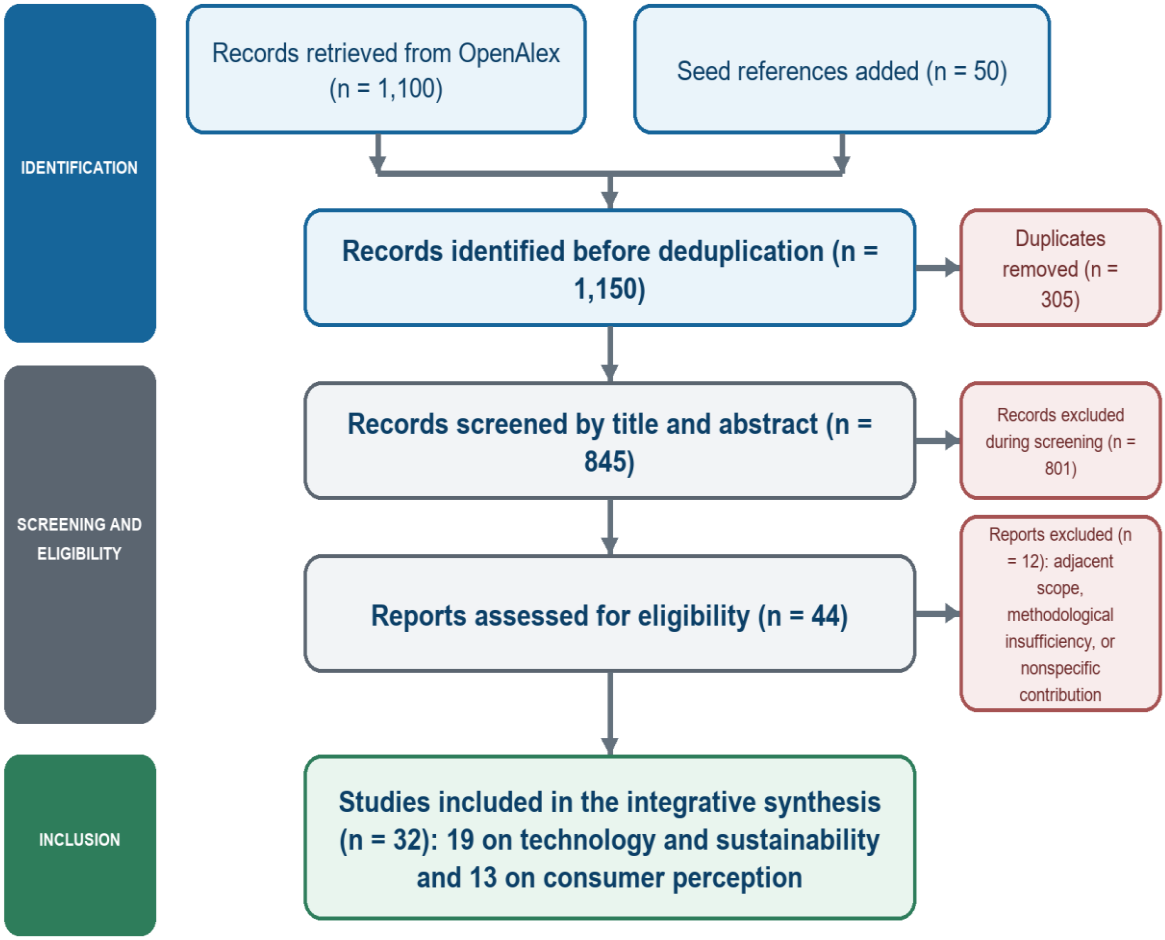
Figure 1. Study identification, screening, and inclusion flow



Source: prepared by the authors (2026), with a flow inspired by PRISMA 2020.

The data extraction matrix covered authorship, year, subject, study design, technology analyzed, management variables, production and environmental effects, acceptance factors, and limitations. The synthesis was narrative and thematic, organized into four categories: smart management architecture; sustainability and commitments; consumer-perceived value; and the integration of technical performance and market legitimacy. No meta-analysis was conducted due to the heterogeneity of crops, metrics, methodological designs, and scales of analysis.

The critical appraisal of the selected studies considered the clarity of objectives, adequacy of the methodological design, description of the technologies or variables analyzed, presence of productive, environmental, economic, or behavioral indicators, scale of application, declared limitations, and adherence to the review problem. This appraisal was not used as an exclusionary

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scoring system, but guided the interpretation of the weight and robustness of the evidence in the narrative synthesis.

To increase transparency regarding the composition of the review corpus, Table 1 summarizes the 32 studies included in the integrative synthesis according to review axis, study type, context, and main contribution.

Table 1. Characterization of the 32 studies included in the review

Author(s)/year	Review axis	Type of study	Context/object	Main contribution to the review
Abu Sneineh and Shabaneh (2023)	Technology and management	Applied/prototype study	Smart hydroponic system using ESP32, sensors, IoT, and pumps	Demonstrates the feasibility of automated monitoring and correction of nutrient solution parameters
Ahmed *et al.* (2024)	Technology and sustainability	Review	Evolution of vegetable cultivation toward protected and high-tech systems	Positions hydroponics and protected cultivation as alternatives for productive resilience
Catota-Ocapana *et al.* (2025)	Technology and management	Systematic review	Smart control models for nutrient management in hydroponics	Maps fuzzy logic, AI, and computer vision applied to nutrient control
Chowdhury *et al.* (2020)	Technology and management	Experimental /prototype study	IoT-based indoor vertical hydroponics test bed	Shows the integration of sensors, connectivity, and automation in controlled environments
Fuentes-Penailillo *et al.* (2024)	Technology and management	Review	IoT, remote sensing, and AI for smart crop management	Supports the understanding of digital architecture in layers: data, connectivity, analytics, and decision-making
Fussy and Papenbrock (2022)	Sustainability	Review	Soil-based and soilless cultivation techniques	Discusses sustainability opportunities and challenges in soilless systems
Gonnella and Renna (2021)	Sustainability	Review	Soilless systems, circularity, and the relationship with organic agriculture	Contributes to the discussion of recirculation, reuse, and circular economy in hydroponics

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Kaya (2025)	Technology and management	Review	Intelligent environmental control in plant factories	Synthesizes the role of sensors, automation, and AI in controlling light, temperature, humidity, CO2, and nutrients
Linaza *et al.* (2021)	Technology and sustainability	Review	Data-driven AI applications for sustainable precision agriculture	Links AI, resource-use efficiency, and sustainability in precision agriculture
Mansoor *et al.* (2025)	Technology and management	Review	Smart sensors and IoT in precision agriculture	Supports the discussion of sensor integration, connectivity, interoperability, and trends
Maraveas (2022)	Technology and sustainability	Review	AI in smart greenhouses	Discusses irrigation, energy, robotics, and renewable energy integration in protected environments
Mohyuddin *et al.* (2024)	Technology and management	Comprehensive review	Machine learning in smart agriculture systems	Contributes to the discussion of algorithmic performance, validation, and explainability
Muhammed *et al.* (2024)	Technology and management	Review	AIoT for smart agriculture	Grounds the integration of AI, IoT, data architectures, and smart solutions
Qin *et al.* (2025)	Technology and management	Systematic review	Deep learning applied to lettuce cultivation	Maps diagnosis, growth classification, yield prediction, irrigation, and fertilization
Rajendran *et al.* (2024)	Sustainability	Review	Hydroponics and sustainable technologies, with emphasis on potato mini-tubers	Broadens the discussion of productive uses of hydroponics and sustainable technologies
Ramakrishnam Raju *et al.* (2022)	Technology and management	Applied/prototype study	Smart hydroponics system with AI-based controller, IoT, and mobile application	Illustrates the integration of control, remote monitoring, and decision support

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Reza *et al.* (2025)	Technology and management	Review	Nutrient sensors for open-field and hydroponic cultivation	Details advances in electrochemical and optical sensors for nutrient solutions
Sambo *et al.* (2019)	Technology and sustainability	Review	Nutrient solutions for soilless systems from a smart agriculture perspective	Supports the discussion of pH, electrical conductivity, ionic composition, and root interactions
Sportelli *et al.* (2025)	Technology and management	Review	IoT-enabled hydroponic platforms	Highlights gaps between prototypes and commercial systems: interoperability, connectivity, and standardization
Balqiah *et al.* (2020)	Consumer perception	Empirical study/survey	Attractiveness of hydroponic products	Identifies antecedents of purchase intention, such as attitude, subjective norm, quality, price, availability, and knowledge
Califano, Crichton-Fock, and Spence (2024)	Consumer perception	Empirical study	Preferences for urban farming, hydroponics, and robotic cultivation	Shows that technology neophobia can reduce acceptance of more technologically intensive systems
D'Amico *et al.* (2024)	Consumer perception	Empirical study	Willingness to pay for hydroponic tomatoes	Relates familiarity, sustainability, income, education, and perceived safety to price premiums
Gan, Soukoutou, and Conroy (2022)	Consumer perception	Review	Sustainability framing in controlled-environment agriculture	Shows that communication often emphasizes environmental and economic dimensions while neglecting social and cultural aspects
Jaeger (2024)	Consumer perception	Review/consumer insights	Vertical farming products with artificial lighting	Discusses how sensory experience can contradict negative expectations about indoor systems

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Joo and Hwang (2023)	Consumer perception	Empirical study	Restaurants using indoor smart farms	Shows the effects of psychological risk, quality risk, and novelty seeking on consumer attitudes
Jurkenbeck, Heumann, and Spiller (2019)	Consumer perception	Empirical study	Acceptance of vertical farming systems	Identifies perceived sustainability as a relevant antecedent of acceptance
Pfeiffer, Gabriel, and Gandorfer (2021)	Consumer perception	National survey	Public acceptance of digital farming technologies	Shows the importance of environmental benefits and trust in farmers for public acceptance
Schnack *et al.* (2024)	Consumer perception	Empirical/segmentation study	Sustainable agricultural technologies and controlled-environment agriculture	Identifies consumer groups with different levels of adoption readiness
Torres *et al.* (2025)	Consumer perception	Empirical study with explicit and implicit methods	Perception of lettuce production systems	Shows appreciation for small-scale local production and possible negative associations with high technology
Yano *et al.* (2021)	Consumer perception	Empirical study	Russian consumer attitudes toward vertically farmed produce	Relates negative evaluations to expectations of lower naturalness, nutrition, taste, or safety
Yano *et al.* (2023)	Consumer perception	Survey/information experiment	Reaction to indoor farming using LED lighting in Japan	Shows that explanations of plant growth mechanisms can improve perceptions
Zhou, Asioli, and Jurkenbeck (2025)	Consumer perception	Review	Consumer views on foods from soilless farming systems	Systematizes factors such as sensory properties, growing conditions, sustainability, knowledge, technological affinity, and neophobia

This characterization supported the thematic synthesis by distinguishing studies focused on technological and sustainability aspects from those addressing consumer perception, acceptance, and perceived value.

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3. RESULTS AND DISCUSSION

3.1. Characteristics of the scientific literature

The corpus focused on recent years: nine studies were published in 2024, eight in 2025, four in 2022, four in 2023, three in 2021, and two in each of the years 2019 and 2020. This distribution highlights the topic's rapid expansion but also its limited longitudinal maturity. Among the 19 technology-focused studies, reviews and experimental architectures predominated; among the 13 consumer-focused studies, reviews and cross-sectional surveys were observed in countries such as Germany, Italy, Japan, Russia, Spain, Australia, and New Zealand. All 32 selected studies were indexed in OpenAlex. Of these, 22 (68.8%) were published in outlets listed in the Directory of Open Access Journals (DOAJ). The corpus also included journals and conference proceedings indexed in Scopus and Web of Science, such as Frontiers in Plant Science, Agriculture and Human Values, British Food Journal, and E3S Web of Conferences.

Geographic heterogeneity broadens the range of perceptions but limits direct applicability to Brazil. Price, familiarity, institutional trust, and the cultural meaning of "naturalness" vary across markets. Likewise, technical results obtained for lettuce, basil, tomatoes, parsley, or potatoes should not be automatically generalized to all vegetables. The synthesis, therefore, identifies recurring mechanisms rather than universal coefficients, as summarized in Table 2.

Table 2. Synthesis of the analytical categories
Source: prepared by the authors based on the review corpus (2026).

Category	Recurring evidence	Implication
Data and connectivity	Sensors for pH, EC, temperature, level, light, and plant variables; IoT integration.	Decision quality depends on calibration, frequency, and data reliability.
AI and control	Prediction, computer vision, fuzzy logic, diagnosis, and adaptive optimization.	AI must be distinguished from monitoring and rule-based automation.
Sustainability	Potential water and nutrient efficiency, smaller land footprint, and greater consistency.	Energy, materials, disposal, cost, and scale may shift impacts.
Perceived value	Quality, safety, freshness, sustainability, familiarity, and information.	Naturalness, risk, and technology neophobia condition acceptance and price.

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3.2 Smart management architecture

Smart management can be understood in four layers. The first is physical: sensors and actuators. The second is communicational: IoT, protocols, and storage. The third is analytical: AI models that recognize patterns, estimate states, and recommend actions. The fourth is decisional: automatic execution or evidence-supported human decision-making. Fuentes-Peñailillo *et al.* (2024), Mansoor *et al.* (2025), and Muhammed *et al.* (2024) show that the value of the architecture emerges from integration rather than from the isolated presence of devices.

In the nutrient solution, pH and electrical conductivity are central operational indicators, but they do not individually describe the availability of each ion. Reza *et al.* (2025) highlight advances in electrochemical and optical sensors, whereas Sambo *et al.* (2019) note that precipitation, antagonism, chemical form, and root interactions affect nutrition. Intelligent models can combine signals, phenological stage, and historical data to adjust dosing, but they remain dependent on reliable sensors and models calibrated for the species and environment.

The systematic review by Catota-Ocapana *et al.* (2025) identified fuzzy logic, AI, and computer vision in nutrient control, with potential efficiency and productivity benefits. For lettuce, Qin *et al.* (2025) mapped deep learning applications for diagnosis, growth classification, yield prediction, irrigation, and fertilization. Mohyuddin *et al.* (2024) and Elbasi *et al.* (2023) reinforce that algorithmic performance should be evaluated using external data, comparable metrics, and explainability, rather than only accuracy obtained from the training set.

Prototypes demonstrate operational feasibility. Chowdhury *et al.* (2020) built an automated vertical hydroponic test bed; Ramakrishnam Raju *et al.* (2022) integrated an AI controller, IoT, and a mobile application; and Abu Sneineh and Shabaneh (2023) used an ESP32, sensors, and pumps to monitor and correct parameters. The latter illustrates the conceptual boundary: threshold-based automation is useful but should not be presented as machine learning. Calling every form of automation AI inflates novelty and hinders scientific evaluation.

The gap between prototypes and commercial production is recurrent. In a review of 74 studies, Sportelli *et al.* (2025) identified customized solutions, dependence on open-source microcontrollers, Wi-Fi connectivity, and limited use of interoperable protocols; machine learning applications were still incipient. Kaya (2025) adds that environmental control requires harmonizing light, temperature, humidity, CO2, nutrients, and energy. Consequently, the optimal system is not the one that maximizes a single variable, but the one that balances growth, quality, cost, risk, and resource consumption.

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3.3. Sustainability: benefits and trade-offs

The literature associates hydroponics with water recirculation, precise nutrient application, intensive use of space, production close to markets, and reduced exposure to climatic events. Ahmed *et al.* (2024) and Rajendran *et al.* (2024) position soilless systems as components of resilient horticulture. Fussy and Papenbrock (2022), however, warn that comparisons depend on the adopted boundaries: water efficiency does not eliminate impacts from electricity, infrastructure, substrates, fertilizers, and effluent treatment.

AI can improve efficiency by anticipating needs and reducing preventive or delayed corrective applications. Linaza *et al.* (2021) associate data-driven applications with reduced water and input use, whereas Maraveas (2022) discusses irrigation, energy, robotics, and renewable energy integration in greenhouses. Nevertheless, theoretical gains must be confirmed through indicators such as water per kilogram, energy per kilogram, marketable yield, losses, nutrient discharge, emissions, and total cost. Without a comparable baseline, “sustainable” remains a promotional claim.

Circularity provides a more demanding criterion. Gonnella and Renna (2021) discuss recirculation, reuse, and waste reduction while acknowledging tensions between highly technological systems and expectations of natural or organic production. Sensor failures, cyberattacks, unstable connectivity, and poorly generalizable models can also produce incorrect dosing and losses. Reliability, maintenance, data governance, and human capability are therefore components of environmental performance.

The synthesis suggests four conditions for attributing sustainability to hydroponic AI: comparison with a baseline; joint measurement of water, nutrients, energy, and losses; assessment over representative cycles and scales; and transparency regarding uncertainty. Technology is a management tool, not an automatic sustainability certificate.

3.4. Consumer-perceived value and acceptance

Perceived value results from the comparison between benefits and sacrifices. For hydroponic foods, benefits may include freshness, appearance, safety, consistency, local production, absence of residues, and environmental attributes; sacrifices include price, distrust, limited familiarity, and perceived artificiality. The review of 56 studies by Zhou, Asioli, and Jürkenbeck (2025) identified sensory properties, growing conditions, sustainability, income, education, knowledge, technological affinity, and neophobia as recurring factors.

Empirical studies confirm that acceptance is heterogeneous. Califano, Crichton-Fock, and Spence (2024), studying 148 British consumers, found a preference for urban farming, followed by hydroponics and, lastly, robotic cultivation; technology neophobia impaired acceptance. Schnack *et al.* (2024), using samples from Australia and New Zealand, identified segments with different

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levels of readiness for controlled environment agriculture and automation. A single communication strategy is therefore likely to fail: environmentally engaged consumers respond to benefits that differ from those prioritized by skeptical or quality-oriented consumers.

Perceived sustainability is an important but insufficient driver. Jürkenbeck, Heumann, and Spiller (2019) found it to be the main antecedent of vertical farming acceptance. Gan, Soukoutou, and Conroy (2022), however, show that communication tends to privilege environmental and economic dimensions while neglecting social and cultural aspects. When discourse ignores energy, scale, labor, and naturalness, it may appear selective and reduce trust.

Information can correct expectations. In a survey of 961 Japanese respondents, Yano *et al.* (2023) found a limited effect of LED light color but improved perceptions after the plant growth mechanism was explained; trust in safety, familiarity, and resistance to technology were relevant. In Russia, Yano *et al.* (2021) observed that negative evaluations were associated with expectations of food being less natural, nutritious, tasty, or safe. Jaeger (2024) notes that actual experience with vertically farmed products may contradict negative expectations because sensory quality can be high.

Willingness to pay depends on concrete attributes. D'Amico *et al.* (2024), studying 292 Italian consumers, showed that familiarity, environmental sustainability, income, education, and perceived safety influenced the premium for certified hydroponic tomatoes. Balqiah *et al.* (2020), using 981 respondents, identified attitude, subjective norm, perceived behavioral control, quality, price, availability, health consciousness, and knowledge as antecedents of purchase intention; environmental concern alone was not significant. Environmental benefits must therefore coexist with quality, availability, and an acceptable price.

Image-related risks also exist. Torres *et al.* (2025), comparing lettuce production systems through explicit and implicit methods, found greater appreciation for small-scale local production; vertical systems and high-technology greenhouses were associated with lower taste, healthiness, or sustainability, although greenhouse production was perceived as safer. Pfeiffer, Gabriel, and Gandorfer (2021) showed that environmental benefits and trust in farmers favor public acceptance of digital agriculture, but technological images can activate negative associations. In indoor smart farm restaurants, psychological and quality risks reduced attitudes, whereas novelty seeking moderated responses (JOO; HWANG, 2023).

These findings indicate that the term "AI-produced" does not automatically create value. For part of the market, AI is invisible and only the outcome matters; for others, it may signal precision and traceability; for technology-neophobic consumers, it may reinforce artificiality. Communication should prioritize verifiable evidence—measured water savings, residue control, traceability, freshness, and safety—and explain the role of human oversight.

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3.5. Integrative model: from data to value

The integrative contribution of the review is a five-stage chain. First, sensors generate valid data. Second, AI converts these data into diagnosis, prediction, or optimization. Third, decisions modify nutrient, water, climate, plant health, and energy management. Fourth, effects are measured through productive, environmental, and economic indicators. Fifth, results are communicated to and evaluated by consumers. Each link can interrupt value creation: poor data degrade the model; opaque models reduce trust; automation without measured benefits does not prove sustainability; and poorly communicated technical advantages do not become preferences.

This model also avoids two reductionisms. Technological reductionism assumes that operational precision produces social legitimacy; marketing reductionism assumes that green claims are sufficient to generate willingness to pay. The evidence indicates a need to align measured performance, certification or traceability, sensory experience, and segmented communication. In this arrangement, explainable AI and human oversight can support trust, while traceability connects cultivation data to product attributes.

Future research should combine hydroponic trials and consumer studies. A promising design would compare conventional and AI-assisted management in terms of water, nutrients, energy, losses, productivity, and quality, followed by a choice experiment with different information treatments: no technological information; information about AI; information about verified benefits; and certification. Such a design would test whether consumers value the technology itself or the proven outcomes it enables.

4. FINAL CONSIDERATIONS

The review demonstrates that AI can improve hydroponic management by adding prediction, diagnosis, and adaptive optimization to sensor, IoT, and automation infrastructure. The most consistent applications concern nutrient solution control, environmental monitoring, computer vision, growth prediction, and decision support. However, the literature still contains many prototypes, few longitudinal tests at commercial scale, and heterogeneous indicators.

Sustainability benefits are potential and conditional. Water and nutrient efficiency, production stability, and a reduced need for intervention may coexist with high energy consumption, investment requirements, technological dependence, and data risks. Sustainability must therefore be demonstrated through comparable metrics and system-level assessment rather than inferred from the presence of AI or hydroponics.

In the market, perceived value is primarily constructed through quality, safety, freshness, verifiable sustainability, knowledge, and trust. Perceived artificiality, neophobia, risk, price, and limited familiarity are barriers. Effective communication does not celebrate the algorithm in the

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abstract; it translates results into auditable benefits and preserves the perception of human oversight.

The competitive advantage of AI in hydroponics therefore depends on coherence among three dimensions: management precision, demonstrable socioenvironmental performance, and the meaning attributed by consumers. As limitations, the search used an open scholarly index and the 100 most relevant records for each expression, while the corpus encompassed heterogeneous national contexts and production systems. Brazilian studies, life-cycle assessments, economic evaluations, and choice experiments involving AI-assisted hydroponic vegetables are needed to test the proposed model.

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