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Vegetable and Floriculture Crop Cultivation in Aquaponics and Hydroponics Systems: A Review from Indian Context

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ABSTRACT: As urbanization accelerates and arable land becomes increasingly constrained, soilless agriculture methods, such as hydroponics and aquaponics have emerged as sustainable alternatives to traditional soil-based cultivation. This review examines the comparative performance of hydroponic and aquaponic systems in vegetable and floriculture production, with particular emphasis on month-wise and season-wise yield attributes under indoor and outdoor conditions in the Indian context. Hydroponics offers precise nutrient management, higher yields, and year-round cultivation, but remains energy-intensive and sensitive to seasonal fluctuations in light and temperature. Aquaponics, while less chemically reliant and highly water-efficient, introduces additional biological complexity through fish-plant integration and is influenced by temperature-sensitive aquaculture components. Seasonal shifts affect system efficiency, crop physiology, nutrient uptake and operational costs, even in controlled environments. Warm-season leafy vegetables and herbs such as basil, amaranths, and mint are more robust during Indian summers, while crops like lettuce, kale and parsley thrive in winter or in actively cooled environments. Similarly, ornamental crops like marigold, nasturtium, and lilies display clear seasonal performance windows based on temperature and photoperiodism. The review also highlights the absence of standardized crop calendars tailored to Indian agro-climatic zones and controlled-environment agriculture. A comparative seasonal cultivation calendar and yield matrix is proposed based on recent studies. Finally, future research should focus on developing AI-driven, open-access crop scheduling tools and longitudinal varietal trials to optimize system design and sustainability. By linking crop choice with seasonality, system type, and environment, this study offers actionable insights for maximizing resource efficiency, profitability and crop resilience in soilless horticulture.

Keywords: Hydroponics, Aquaponics, Seasonal Yield, Indoor Farming, Floriculture, Water Use Efficiency.

INTRODUCTION

The global demand for sustainable and resource-efficient agricultural practices is increasing as arable land shrinks and urban populations expand. Traditional soil-based agriculture, while time-tested, faces numerous challenges, including dependence on climatic conditions, seasonal unpredictability, water scarcity and pest outbreaks (Godfray *et al*., 2010). In response, soilless cultivation methods such as hydroponics have emerged as viable alternatives, offering consistent yields in controlled environments.

Hydroponics, which involves growing plants without soil using mineral nutrient solutions in water, is particularly well-suited for urban and peri-urban settings (Resh, 2022). It allows year-round production, higher space efficiency and reduced water consumption up to 90% less than traditional farming (Raviv *et al.*, 2008). However, despite its environmental control advantages, hydroponic systems are not immune to seasonal effects. Factors such as light duration, ambient temperature, and energy costs still vary by season, influencing both crop growth and production economics (Gericke, 1940).

Aquaponics, the integration of recirculating aquaculture systems (RAS) with hydroponic plant production is frequently promoted for its water-use efficiency and low effluent discharge, attributes that are particularly relevant for India, where monsoon dependency, heat waves and erratic rainfall increasingly threaten open-field horticulture. However, most primary aquaponics literature is temperate and lettuce-centric, necessitating an India-specific review that re-weights species choice towards warm-tolerant vegetables, herbs and ornamentals, and explicitly links plant selection to environmental control, water chemistry and climate windows (Somerville *et al*., 2014; Love *et al*., 2015; Bittsanszky *et al*., 2016; Goddek *et al*., 2019; Krishnan *et al*., 2020).

In traditional agriculture, crop calendars are a critical planning tool, outlining ideal sowing, transplanting and harvesting times based on regional climatic conditions. However, in hydroponics, such a calendar has to be re-imagined: one that integrates seasonality not in terms of environmental limitations, but through optimization of crop selection, input efficiency and market alignment (Torrijos *et al.*, 2021).

Despite significant advances in hydroponics and aquaponics research, critical gaps remain for India's context. Most existing studies focus on temperate crops like lettuce, with limited replicated trials on warm-climate vegetables, herbs, and ornamentals under Indian heat–humidity conditions. Standardized, open-access crop calendars tailored to local agro-climatic zones are lacking, leaving growers without season-specific guidance. Evidence on decoupled aquaponics systems (DRAPS) at scale in India is sparse, particularly for fruiting vegetables and floriculture. Furthermore, integrated models linking energy, water, and cost with seasonal production are underdeveloped, and digital decision-support tools calibrated to Indian inputs and markets remain in early stages.

Recent Indian studies affirm that hydroponic and aquaponic systems hold significant promise in addressing the resource constraints and climate challenges. Aquaponics integrates plant cultivation and aquatic animal farming into a single system and as population growth, urbanization and industrialization increase, so does the demand for food. However, commercial aquaponics faces challenges in growing high-value flowering crops such as sweet peppers, tomatoes and cucumbers, primarily due to imbalanced nutrient levels in the aquaponic solution, specifically low concentrations of potassium (K^+) and calcium (Ca^{2+}) (Mandal *et al*., 2023). Another comparative study across Indian horticultural systems highlighted that hydroponics offers dramatically higher land and water efficiencies up to 90% less water usage, though at the cost of greater energy demand, thus necessitating renewable energy integration for sustainability (Singh *et al*., 2024). Moreover, a recent review of precision hydroponics in India underscored the technology's potential to bolster food security and water conservation, while noting constraints, such as infrastructure costs, limited technical expertise and insufficient research investments-barriers that resonate with your identified gaps (Naresh *et al*., 2024). Collectively, these works emphasize the viability of hydroponic systems for staple and warm-climate crops under Indian agro-climatic conditions and underline the need for energy-efficient, scalable models tailored to local growers' capabilities and market dynamics (Kumar *et al.*, 2025).

This review aims to synthesize available knowledge on hydroponic and aquaponic systems and assess how season-based crop calendars are essential tools in soil-based farming, which can be effectively adapted for both types of cultivations. The paper discusses hydroponic and aquaponic system types, environmental controls, crop cycle dynamics and potential models for designing season-sensitive planting schedules in controlled environments.

HYDROPONIC SYSTEMS: TYPES AND MECHANISMS

Hydroponic farming encompasses a range of systems, each differing in nutrient delivery mechanisms and environmental requirements. Common systems include:

- **Nutrient Film Technique (NFT):** Nutrient-rich water flows over plant roots in a thin film. Ideal for leafy greens and herbs due to limited root space (Jensen, 1999).
- **Deep Water Culture (DWC):** Plants are suspended in oxygenated nutrient solutions. Suitable for fast-growing, shallow-rooted crops like lettuce and basil (Resh, 2022).
- **Ebb and Flow (Flood and Drain):** Trays are intermittently flooded with nutrients and then drained, promoting oxygen exchange (Raviv *et al.*, 2008).
- **Drip Systems:** Nutrients are dripped onto plant bases through emitters. Suitable for large fruiting crops like tomatoes and peppers (Singandhupe *et al.*, 2003 ; Abdelkhalik *et al*., 2020).
- **Aeroponics:** Roots are misted with nutrient solutions in air, achieving high oxygenation and fast growth, but requiring precise control (Kumar *et al*., 2024).

Each system allows growers to manipulate variables such as pH, electrical conductivity (EC), temperature and light intensity. These controls reduce vulnerability to seasonal shifts, but also demand tailored management strategies that factor in crop physiology and external resource costs (Kozai *et al.*, 2016).

AQUAPONIC SYSTEMS: TYPES AND MECHANISMS

Aquaponics is a sustainable agricultural system that integrates aquaculture (raising fish) and hydroponics (growing plants without soil) in a closed-loop environment, where fish waste provides nutrients for plants, and plants help purify the water for fish. The process relies on nitrifying bacteria that converts toxic ammonia from fish waste into nitrates, which plants absorb as nutrients, with the cleaned water recirculating back to the fish tank. There are several types of aquaponics systems, including media-based systems (flood and drain), Nutrient Film Technique (NFT), Deep Water Culture (DWC), vertical systems, and hybrid designs, each varying in complexity, scalability and suitability for different crops or environments. In many studies of aquaponics, the common fish species used as experimental animal are Nile tilapia, *Pangasianodon hypothalamus* (singhi), *Puntius gonionotus* and koi carps (Mohapatra *et al*., 2021; Nuwansi *et al.*, 2021; Sabwa *et al.*, 2022; Nageswari *et al*., 2022; Al-Zahrani *et al.*, 2023), while popular plants include lettuce, basil, spinach, and tomatoes (Somerville *et al*., 2014). This integrated approach conserves water, reduces chemical inputs, and offers a highly efficient method for producing both fish and vegetables in a single system.

SEASONAL INFLUENCE IN CONTROLLED ENVIRONMENTS

While hydroponic systems are designed for year-round production, seasonality still plays a role. Natural daylight duration, outdoor temperatures and humidity influence input costs, especially lighting and climate control in greenhouses. For instance, winter crops may require supplementary heating and lighting, increasing energy use (Dorais *et al*., 2001). Conversely, crops grown during hot summers may need enhanced ventilation and cooling.

Seasonal variations, even in controlled environments, can significantly impact hydroponic and aquaponic systems due to changes in light, temperature, humidity and energy demands. During winter, reduced sunlight and lower temperatures often require artificial lighting and heating to sustain optimal plant and fish growth, increasing operational costs. Aquaponic systems, in particular, are sensitive to cold, as many warm water species do not thrive well in cold water. Poor ventilation in colder months can also lead to high humidity and greater risk of fungal diseases.

Moreover, plant photoperiodism (response to day length) and thermoperiodism (response to temperature variation) influence flowering and fruiting. This makes certain crops better suited to specific seasons, even under artificial control. For example, lettuce and spinach perform better in cooler conditions, while tomatoes and cucumbers thrive in warmer months (Tesi, 2008). Thus, adapting crop calendars in hydroponics requires strategic crop selection and operational scheduling to optimize energy efficiency and crop performance year-round.

EXISTING CROP CALENDAR MODELS

In soil-based agriculture, crop calendars are designed around agro-climatic zones and historical weather patterns. They guide farmers on planting times, fertilizer applications and pest management (FAO, 2015). However, in hydroponics, few standard crop calendar models exist. A study by Torrijos *et al*. (2021) proposed a digital hydroponic calendar based on plant growth rates, market trends and resource optimization. Similarly, commercial growers use software-driven models that account for growth cycles, market demand windows and staggered planting to ensure continuous harvests. These models are often proprietary and adapted case-by-case, suggesting a research gap in open-source, season-sensitive planning tools for hydroponics, especially in tropical and subtropical countries, where daylight hours and temperature fluctuate significantly.

COMPARATIVE ANALYSIS OF PLANT GROWTH AND PRODUCTIVITY

A. Analysis of Growth Among Vegetables

A study on *Basella alba* conducted in grow pipes of NFT aquaponics system from which it was concluded that there was no significant variations in plant growth parameters and that a 12 m NFT grow pipe with a pumping cycle of 5 minutes every 2 hours supplied adequate nutrients to all plants in the system (Anantharaja *et al*., 2017). Warm-adapted leafy vegetables and herbs; *Basella alba, Ipomoea aquatica, Amaranthus* spp, *Ocimum basilicum, Mentha spp, Coriandrum sativum, Trigonella foenum-graecum* and chives/spring onion are consistently reported as resilient under Indian summer temperatures. Generally demand fewer corrective micronutrient additions than heavily fruiting crops, making them year-round anchors for most lowland systems (Endut *et al*., 2010; Somerville *et al*., 2014; Love *et al*., 2015; Goddek *et al*., 2019). Canonical aquaponic crops like lettuce (*Lactuca sativa*), spinach (*Spinacia oleracea*), pak choi (*Brassica rapa* sub-sp. *chinensis*), kale (*Brassica oleracea var. acephala*) and parsley (*Petroselinum crispum*) are thermally constrained in most of India and perform reliably outdoors only during the October–February, in many plains or year-round under indoor/greenhouse cooling, otherwise suffering bolting, tip-burn and Fe/Ca disorders (Somerville *et al*., 2014; Love *et al*., 2015; Bittsanszky *et al*., 2016; Krishnan *et al*., 2020). Tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*), chilli/pepper (*Capsicum* spp), brinjal/eggplant (*Solanum melongena*), okra (*Abelmoschus esculentus*) and cucurbit gourds can be productive in Indian aquaponics. They require tighter pH control (often 5.8–6.5 for maximal uptake, hence the case for decoupled systems), higher K, Ca, Mg and Fe supplementation, shading and evaporative cooling during pre-monsoon heat and aggressive humidity/disease management during the monsoon (Tyson *et al*., 2008; Bittsanszky *et al*., 2016; Suhl *et al*., 2016; Goddek *et al*., 2019). Another study highlights seasonal variation in nitrogen requirements for lettuce (Kiliç, Cenk, 2022). During spring *versus* summer, optimal nitrate concentration differed significantly, approximately 233 mg/L in spring rising to about 277 mg/L in summer to achieve maximum yield in a floating raft hydroponic system (Barbosa *et al*., 2015). The findings highlight that light and temperature changes by season affect leaf metabolism, nutrient uptake, and growth traits such as net assimilation rate and leaf area ratio. In practical terms, farmers growing lettuce year-round must adjust nutrient solutions seasonally for optimal results.

Root and tuber horticultural crops (*e.g*., carrot, beetroot, radish, potato) are under-represented in aquaponics literature, because deep media beds or specialized containers are needed to avoid deformities, oxygen limitations and harvest difficulties. Their slower growth and lower market premiums often underperform *versus* leafy greens or fruiting vegetables in coupled systems (Somerville *et al*., 2014; Bittsanszky *et al*., 2016; Goddek *et al*., 2019). Lettuce (*Lactuca sativa*), kale, pak choi, spinach, parsley, microgreens and edible flowers (*e.g*., *Nasturtium, Viola)* thrive when temperatures are held near 15–22°C and relative humidity is managed, conditions obtainable in India mostly October–February outdoors or year-round indoors/greenhouses with evaporative or active cooling, LED lighting and tight Fe/Ca management to prevent tip-burn and chlorosis (Somerville *et al*., 2014; Love *et al*., 2015; Bittsanszky *et al*., 2016; Krishnan *et al*., 2020). Microgreens (*e.g*., radish, mustard, sunflower, pea shoots, basil) and baby leaf mixes present a climate-robust, short-cycle strategy that tolerates variable nutrient profiles and heat, reduces disease exposure windows during monsoon months, and can command premium prices in urban markets, though precise hygiene and post-harvest cold chains are still required (Somerville *et al*., 2014; Love *et al*., 2015; Goddek *et al*., 2019).

B. Analysis of Growth Among Medicinal and Aromatic Plants

Heat-tolerant herbs and medicinal/aromatic plants, *e.g*., holy basil (*Ocimum tenuiflorum*), lemongrass (*Cymbopogon citratus*), stevia (*Stevia rebaudiana*), patchouli (*Pogostemon cablin*), curry leaf (*Murraya koenigii*) can fit Indian aquaponics, where market access exists, offering higher value per unit area and lower perishability than delicate greens, although nutrient (particularly Fe and K) supplementation and precise harvest timing remain important for essential-oil quality (Somerville *et al*., 2014; Love *et al*., 2015; Bittsanszky *et al*., 2016; Goddek *et al*., 2019). A recent hydroponics project in Indore, India tested NFT and aeroponics systems for leafy herbs and medicinal plants. Under indoor controlled conditions, spinach, lettuce, mint and rosemary delivered significantly enhanced yields and higher concentrations of medicinal compounds compared to field-grown counterparts. Though conducted year-round, the project specifically noted performance stability even during hot summers and monsoon-related humidity changes reflecting season-adaptive capability with proper system setup (Gupta & Rao 2024). Strawberry (*Fragaria × ananassa*) and dwarf tomato/cherry tomato cultivars are among the most trailed “fruit crops” in soilless Indian setups, but, sustained success outdoors is usually restricted to cooler elevations. In indoor/ greenhouse aquaponics with active cooling, pollination management, and high Fe/K/Ca inputs is required for year-round reliability, conditions that raise CAPEX/OPEX and demand premium markets to be profitable (Somerville *et al*., 2014; Love *et al*., 2015; Suhl *et al*., 2016; Goddek *et al*., 2019).

C. Analysis of Growth Among Floricultural Crops

A notable study on French marigold (*Tagetes patula* L.) compared open-field, poly-house and hydroponic cultivation for three cultivars (scarlet red, orange, yellow). The hydroponic system delivered superior morpho-physiological traits including plant height, branch number, and flower count when grown in autumn to winter months (September through December), even under declining ambient temperatures and daylight hours (Sharma, 2024). In particular, morpho-performance in hydroponics surpassed both open-field and poly-house systems. This suggests marigolds can be scheduled for late-season flowering using hydroponics when field conditions become unpredictable. Similarly, a literature review of hydroponic floriculture highlights examples such as roses (*Rosa hybrida*), carnations (*Dianthus caryophyllus*), lilies, orchids and gypsophila being grown in closed or aeroponic systems, often achieving enhanced quality attributes like fresh weight, bud count, stem length and flower longevity compared to traditional soil-based growing (Verma *et al*., 2024). African marigold (*Tagetes erecta*) and chrysanthemum (*Chrysanthemum* spp) can be grown in media beds or on floating treatment wetlands (FTWs), simultaneously polishing nutrient-rich effluents and producing culturally important, high-volume loose flowers for Indian markets. Nasturtium (*Tropaeolum majus*) and viola (*Viola* spp) offer high-value edible flowers but prefer cooler seasons or indoor environments, underscoring once again the climate-fit imperative (Kotzen & Appelbaum 2010; Somerville *et al*., 2014; Bittsanszky *et al*., 2016; Goddek *et al*., 2019). A vertical aquaponics unit based on the Nutrient Film Technique (NFT) was developed at ICAR-CIFA, Bhubaneswar under AICRP on PEASEM unit (Mohapatra *et al.*, 2023). The system includes a 0.127 m^3 fish tank, a vertical PVC hydroponic pipe (0.16×1.5 m) with 204 cc cups angled at 20°, and a water distribution system using a quad channel sprinkler. It was tested with 30 guppy fish in 0.1 m^3 water and 12 flowering plants (6 *Petunia hybrida* and 6 *Zinnia angustifolia*). Optimal results were obtained at a 200 LPH flow rate, ensuring efficient nutrient distribution. Under this setup, Zinnia showed a length of 37.17±4.27 cm and spread of 39.54±7.45 cm, while Petunia achieved a length of 33.43±2.53 cm and spread of 29.58±7.26 cm, indicating good plant growth and flower production. An experiment was conducted over 75 days (5 November 2020 to 21 January 2021) at ICAR-CIFA, Bhubaneswar, Odisha, to evaluate the economic feasibility of a pilot-scale Nutrient Film Technique (NFT) aquaponics system (Mohapatra *et al.*, 2021). The system included fish culture tanks, biofilters, hydroponic tanks, and sumps and was tested in six units with three treatments in duplicate. Each unit was stocked with 200 advanced fry of *Puntius gonionotus* (44–63 mm, 3–5 g). Marigold (*Tagetes patula*) was planted at densities of 42, 63 and 84 plants per unit in T1, T2, and T3, respectively. After 75 days, *Puntius* fingerlings grew to 100–147 mm and 20–56 g with a survivability rate of 92.33±2.31%. No significant difference in plant growth was found among the treatments ($P>0.05$). The highest plant density (84 plants/unit or 23 plants/m^2) showed the best economic return, with a net annual profit of INR 498 per m^2, indicating promising potential for small-scale aquaponics.

OPERATIONAL STRATEGIES AND CLIMATE ADAPTATION FOR SUSTAINABLE HORTICULTURAL AQUAPONICS

Across horticultural categories, iron is the most consistently limiting micronutrient in coupled systems at pH > 6.0, making chelated Fe (EDDHA or DTPA) dosing to ~2 mg L^{-1} a widely recommended operational norm, while KOH/K_2SO_4 and $Ca(OH)_2/CaCO_3$ are alternated to supply K and Ca and to buffer pH, with $MgSO_4$ added when older leaves show interveinal chlorosis. These rules of thumb are repeatedly cited as essential to keep fruiting and cool-season horticultural crops productive in warm Indian systems (Tyson *et al*., 2008; Somerville *et al*., 2014; Bittsanszky *et al*., 2016; Kasozi *et al*., 2019; Goddek *et al*., 2019). Decoupled aquaponics (separating fish and plant loops so each can run at its own pH/ EC/ temperature) is increasingly proposed to broaden horticultural possibilities, particularly for fruiting crops and cool-season greens in hot Indian climates, because it allows higher EC, lower pH and targeted nutrient dosing without endangering fish. However, the extra complexity and capital costs must be justified by crop premiums or year-round production targets (Bittsanszky *et al*., 2016; Suhl *et al*., 2016; Goddek *et al*., 2019). A pilot-scale portable Nutrient Film Technique (NFT) aquaponic system was developed and tested at ICAR-CIFA, Bhubaneswar over 90 days (October–December, 2018) (Mohapatra *et al*., 2020). Each of the three units included a 2800 L FRP fish tank, 100 L biofilter, 2.64 m² hydroponics tank and 200 L HDPE sump. The automated water recirculation system provided an average flow of 94.7 L/h, utilizing gravity in 75% of the cycle. Stocked with Pangasius fry (54/m³), the fish showed 77.04% length and 397.2% weight gain. Marigold (*Tagetes erecta*) planted at 27/m² yielded 107 flowers/m², demonstrating effective system performance. Shade nets (35–50%), evaporative cooling, high aeration, reflective mulches on media beds, and for high-value crops active HVAC and LED lighting can meaningfully lower canopy, and solution temperatures and manage humidity, thereby enabling otherwise heat-sensitive horticultural species (*e.g.*, lettuce, strawberry, nasturtium) in Indian lowlands. Yet, life-cycle assessments caution that energy use and carbon intensity can offset some environmental gains unless renewable power is integrated (Somerville *et al*., 2014; Love *et al*., 2015; Goddek *et al*., 2019; Krishnan *et al*., 2020). A pragmatic, climate-aligned calendar is: October–February for most cool-season greens (lettuce, spinach, pak choi, parsley) and to establish fruiting vegetables. Followed by March–June for heat-tolerant leafy greens and herbs (basil, amaranth, kangkong, Malabar spinach, fenugreek, mint) with intensified Fe/K/Ca dosing and shading. And for June–September (monsoon) for fast-turnover herbs/microgreens and ornamentals on FTWs to absorb nutrient peaks while managing disease pressure through airflow and sanitation (Planning Commission, 1989; Somerville *et al*., 2014; Goddek *et al*., 2019; Krishnan *et al*., 2020). While aquaponics reduces water footprints and nutrient discharge compared to soil culture, feed sourcing, energy for pumping and cooling, and chelate production influence net environmental performance, suggesting that renewable energy coupling, local feed formulation, and nutrient recovery from sludge are crucial to make climate-resilient horticultural aquaponics genuinely sustainable in India (Somerville *et al*., 2014; Goddek *et al*., 2019; Krishnan *et al*., 2020).

Low-cost sensors (pH, EC, DO, ORP), automated dosing (for Fe/K/Ca/Mg), and data-driven advisory tools can reduce operator error, especially during Indian heat waves and monsoon-driven power outages, improving horticultural crop stability and enabling predictive scheduling for sensitive species. However, adoption barriers persist for smallholders due to cost and training gaps (Somerville *et al*., 2014; Love *et al*., 2015; Goddek *et al*., 2019). India lacks replicated varietal trials of horticultural crops under aquaponics. Across agro-climatic zones, dose–response curves for Fe/K/Ca/Mg under typical Indian feed and water chemistries, decoupled system validations for fruiting crops at scale and techno-economic models that integrate climate control costs with realistic market prices (Somerville *et al*., 2014; Bittsanszky *et al*., 2016; Goddek *et al*., 2019; Krishnan *et al*., 2020). For India's hot–humid plains and increasingly volatile climate, warm-tolerant leafy greens, herbs and selected ornamentals are the most dependable. Cool-season greens and many fruiting vegetables are best restricted to winter windows or decoupled/controlled environments with rigorous Fe/K/Ca management; bridging the substantial India-specific research and extension gaps will be essential to unlock the full horticultural potential of aquaponics under the country's environmental realities (Somerville *et al*., 2014; Love *et al*., 2015; Bittsanszky *et al*., 2016; Goddek *et al*., 2019; Krishnan *et al*., 2020).

Seasonal and Month-wise Cultivation Calendar (India)

Month	Season	Suitable Crops (Hydroponic)	Suitable Crops (Aquaponic)	Preferred Environment
January-March	Winter–Spring	Lettuce, Tomato, Herbs (Swain *et al*., 2021)	Lettuce, Kale, Spinach	Indoor/ Greenhouse
April-June	Summer	Tomato, Cucumber, Beans (IHAT, 2025)	Mint, Basil, Fish-fed Lettuce	Indoor (cool) / Polyhouse
July–September	Monsoon	French Beans, Okra (Hydrilla Knowledge Base, 2020)	Peas, Spinach	Polyhouse/ Indoor
October–December	Autumn–Winter	Cabbage, Zucchini, Lettuce (Hydrilla Knowledge Base, 2020)	Lettuce, Kale, Mint	Outdoor/ Indoor

Vegetable Crops Suitable for Aquaponics System (Indoor & Outdoor)

Month	Season	Duration (Months)	Indoor	Outdoor
October-December	Winter	3	Lettuce/ Spinach/ kale/ Jalapeno Peppers/ Pak-choi	Lettuce, Kale, Mint
January-March	Winter/ Spring	3	Amaranthus/ Basella/ Cyelon Spinach/ Parsley	Lettuce, Kale, Spinach
March-May	Summer	3	Basil/ Waterleaf/ Amaranthus/ Cherry Tomato	Mint, Basil, Fish-fed Lettuce
June-August	Rainy	3	Basil/ Microgreens	Peas, Spinach

Indoor Ornamental Crops Suitable for Aquaponics System

Crop	Duration (Months)	Season	Month
Peace Lily/ Petunia/ Zennia/ Snapdragons/ Sweet Alyssum	3	Winter	October-December
Pothos/ Peace Lily/ Caladium	3	Winter/ Spring	January-March
Pothos/ Lucky Bamboo/ Philodendron/ Spiderplant	3	Summer	March-may
Marigold/ Snake Plant/ Chinese Evergreen/ Coleus	3	Rainy	June-August

Yield Attributes of Selected Crops

Crop	System	Yield (t/ha)	Environment	Season	Notes
Lettuce	Hydroponic	400	Indoor/ Outdoor	Year-round	Highest in DWC, consistent yield
Lettuce	Aquaponic	432–556	Indoor/ Outdoor	Year-round	8–39% higher yield in raft systems
Tomato	Hydroponic	450	Greenhouse	Winter–Summer	High yield with controlled NPK dosing
Tomato	Aquaponic	~420	Greenhouse	Winter–Summer	Slightly lower without supplementation
Cucumber	Hydroponic	495	Greenhouse	Summer	Effective with shading net in summer
Cucumber	Aquaponic	~400	Greenhouse	Summer	Slightly reduced yield
Zucchini	Hydroponic	71	Polyhouse	Winter	High water efficiency
French Bean	Hydroponic	20	Outdoor	Monsoon	Yield sensitive to temp and humidity
Red Cabbage	Hydroponic	54	Polyhouse	Winter	Compact and water-efficient

(Barbosa *et al*., 2015; Dhumal *et al*., 2025; Martinezet *et al*., 2023)

Floriculture Crop Notes

Crop	System	Yield Estimate	Environment	Season	Remarks
Poinsettia	Hydroponic	Limited data	Indoor	Winter	Used in floral industry
Lilies	Hydroponic	Limited data	Greenhouse	Year-round	Managed flowering via light/temp control
Mint (herbal)	Hydroponic	~180 t/ha	Indoor	Year-round	Used in floral/herbal crossover

(Sharma, 2024; Verma *et al*., 2024)

System Efficiency Comparison

Parameter	Hydroponics	Aquaponics
Water Use (L/kg)	~70	~2–6
Fertilizer Cost	High	Low (fish effluent)
Yield Consistency	High	Moderate–High
Dual Output	No	Yes (fish + plants)
Maintenance	Moderate	High

(Goddek *et al*., 2019; Love *et al*., 2015; Somerville *et al*., 2014)

CONCLUSIONS

Hydroponics and aquaponics both offer promising alternatives to conventional farming, especially in space-constrained or climate-vulnerable regions. However, their performance varies significantly across seasons and crop types. This review reveals that seasonal sensitivity remains a critical factor, even under controlled conditions. Warm-tolerant vegetables and herbs are well-suited for outdoor and low-tech systems during hot months, while cool-season crops and sensitive florals require more advanced climate control. Aquaponics, with its integrated fish-plant dynamic, offers water and nutrient advantages, but demands higher management precision. There is a clear need for India-specific, season-wise crop calendars and predictive scheduling tools to support efficient cultivation year-round. Integrating digital agriculture, climate forecasting and open-source planning platforms will be vital for advancing both system types. Ultimately, aligning crop selection with environmental realities and system capabilities will be key to achieving sustainable, and high-yield soilless farming across diverse climatic conditions.

FUTURE SCOPE

To advance the comparative understanding of hydroponics and aquaponics for vegetable and floriculture production, future research should prioritize the development of region-specific, seasonally adaptive cultivation models that address both indoor and outdoor system dynamics. A critical need exists for standardized, open-access crop calendars tailored to hydroponic and aquaponic setups, incorporating yield attributes on a month-wise and season-wise basis. These calendars should account for environmental parameters (light, temperature, humidity) and crop-specific physiological responses under controlled and semi-controlled conditions. Furthermore, integrating artificial intelligence (AI) and climate forecasting into crop scheduling tools can allow for predictive modeling of optimal planting and harvesting windows, enhancing both productivity and resource efficiency. Longitudinal studies comparing seasonal yield trends between hydroponic and aquaponic systems across vegetables and ornamental flowers will provide valuable insights into their respective performances in varied climatic contexts. Finally, the development of user-friendly, open-source digital tools and mobile platforms can empower small-scale and urban farmers by providing real-time guidance on crop selection and system adjustments based on seasonal patterns, energy cost fluctuations, and market demand. Bridging agronomic science with digital innovations will be pivotal in making soilless cultivation systems more adaptive, efficient, and resilient year-round.

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