Domed Aquaponic Systems: Integrating Fish, Fruits, and Vegetables for Sustainable Agriculture

Abstract

Domed aquaponic systems present an advanced agricultural framework that combines aquaculture, hydroponic crop cultivation, and controlled-environment engineering to achieve year-round, pesticide-free, and resource-efficient food production. Unlike hybrid systems integrating cattle or other large livestock, these systems focus primarily on fish, fruits, and vegetables within a closed-loop nutrient cycle. By leveraging double-dome architecture, aquaponics-driven nutrient exchange, and renewable energy integration, domed aquaponic farms reduce water usage, mitigate methane emissions, and maximize productivity per unit of land. This paper expands on design principles, nutrient cycles, crop-fish symbiosis, and potential incorporation of smaller livestock species, offering a comprehensive blueprint for next-generation food systems that prioritize sustainability, scalability, and adaptability in both urban and rural contexts.

1. Introduction

Global agriculture is increasingly challenged by climate change, land scarcity, soil degradation, and unsustainable input dependencies. Traditional open-field farming requires large tracts of land, intensive irrigation, and heavy chemical use, which degrade ecosystems while providing diminishing yields in the face of extreme weather events. Aquaponics, the integration of fish farming and hydroponic plant cultivation, has emerged as a sustainable alternative capable of producing protein and produce simultaneously. When combined with the structural innovations of domed architecture, aquaponics transcends conventional limitations, creating an enclosed, self-regulating environment optimized for resource efficiency. This paper examines the domed aquaponic model with a focus on fruits, vegetables, and fish, while also exploring how certain smaller animals—such as chickens, rabbits, or ducks—could be integrated in supporting roles without necessitating the inclusion of cattle or other resource-intensive livestock.

2. Double Dome Architecture

The engineering foundation of domed aquaponic farms is a dual-dome system designed for climate resilience and energy efficiency. The outer dome acts as a shield against wind, rain, and temperature fluctuations, while the inner dome employs aerogel membranes for superior thermal insulation and light diffusion (Agriculture Report, 2024)【23†source】. Negative pressure maintained between the domes stabilizes temperature and humidity, reducing the need for artificial climate control systems. By creating a consistent microclimate, the domes enable year-round cultivation of temperature-sensitive fruits and vegetables such as tomatoes, cucumbers, peppers, and leafy greens. Compared to traditional greenhouses, domed structures offer enhanced durability, lower maintenance, and higher energy efficiency. This architecture not only conserves external inputs but also protects crops from pests, diseases, and air pollution, thereby supporting pesticide-free cultivation.

3. Aquaponic Nutrient Cycles and Crop-Fish Symbiosis

Central to domed aquaponics is the closed-loop exchange of nutrients between fish and plants. Tilapia, the preferred aquaculture species, produce wastewater rich in ammonia and organic matter. Within biofiltration systems, nitrifying bacteria convert ammonia into nitrites and subsequently into nitrates, which are readily absorbed by crops (Rakocy et al., 2006). Fruits and vegetables such as lettuce, basil, strawberries, and peppers thrive on these nutrient flows, producing rapid growth and high yields without the addition of synthetic fertilizers (Goddek et al., 2019). The plants, in turn, filter the water, which is recirculated back into the fish tanks, maintaining water clarity and fish health. This self-regulating cycle drastically reduces water consumption—by up to 90% compared to soil-based farming—while providing both plant and protein harvests. By diversifying crops within the dome, nutrient demands are balanced, and symbiotic resilience is enhanced. Over time, this creates a stable, productive ecosystem capable of sustaining multiple harvest cycles annually.

4. Fruits and Vegetables in Controlled Domes

One of the unique strengths of domed aquaponic systems lies in their ability to support diverse fruit and vegetable cultivation under controlled conditions. Tropical fruits such as bananas, papayas, and pineapples can be grown alongside temperate crops like tomatoes, spinach, and cucumbers, thanks to the thermal regulation of the dome. Nutrient partitioning between leafy greens, fruiting plants, and root vegetables prevents competition and maximizes productivity per cubic meter of space. Vertical farming racks can be integrated into dome walls to further optimize land use and increase plant density (Somerville et al., 2014). By tailoring light spectra and humidity to the needs of specific crops, domed aquaponics can surpass the yields of both traditional greenhouses and open-field farms. The pesticide-free environment also enhances the nutritional value and safety of produce, meeting growing consumer demand for clean and organic foods.

5. Optional Animal Integration in Domed Aquaponics

While cattle are unnecessary in domed aquaponic farms, smaller livestock species may play supportive roles in maintaining ecological balance. Chickens, for example, can be housed in peripheral sections of the dome, where their waste can be composted into organic fertilizer for supplementary crops (Love et al., 2015). Rabbits, which produce easily compostable manure, may also be integrated without significant methane emissions. Ducks can serve as pest control agents within aquatic sections, feeding on insects and algae while providing additional protein sources. Tilapia remain the essential aquaculture species due to their tolerance for variable water quality and compatibility with plant nutrient needs. The optional integration of these smaller animals adds diversity to food outputs and strengthens system resilience without the resource burdens associated with cattle-based agriculture.

6. Methane Capture and Renewable Energy Integration

Although methane emissions are relatively low in aquaponic-focused domes compared to cattle-based systems, organic waste decomposition still generates trace methane. Strategically placed ventilation systems capture this gas, which can be filtered and repurposed as a supplementary energy source for powering water pumps, lighting, and ventilation (Agriculture Report, 2024)【23†source】. Solar panels mounted on dome exteriors complement methane-based energy recovery, creating hybrid renewable energy farms. By achieving partial or full energy self-sufficiency, domed aquaponic systems lower operational costs and reduce dependence on external utilities. Energy recycling ensures that the system remains not only carbon-neutral but potentially carbon-negative, as it offsets emissions associated with traditional farming.

7. Environmental and Economic Benefits

The domed aquaponic approach delivers substantial environmental benefits, including water conservation, soil restoration through compost integration, and elimination of synthetic fertilizers and pesticides. By maintaining closed-loop nutrient flows, pollution from agricultural runoff is nearly eliminated, protecting rivers and oceans from eutrophication (Somerville et al., 2014). Economically, initial setup costs are offset by long-term reductions in external inputs and the ability to grow premium, organic produce for urban and export markets. Space optimization through vertical farming and crop layering maximizes yield per square meter, making domed aquaponics viable even in land-scarce urban centers. Socially, these systems promote food sovereignty by enabling communities to produce protein and produce locally, reducing reliance on imports and global supply chains.

8. Applications and Scalability

Domed aquaponic systems are adaptable across diverse contexts. In urban areas, modular domes can be installed on rooftops, vacant lots, and community centers to provide fresh produce and fish protein within city limits. In rural contexts, larger domes can serve as climate-resilient farms capable of withstanding droughts, floods, and temperature swings. Their modular design allows scalability from small family units to industrial complexes. Governments and NGOs can employ these systems for food security programs in developing regions, while private investors may pursue them as part of sustainable agribusiness models (Goddek et al., 2019). By integrating aquaponics with renewable energy, these domes represent one of the most versatile tools for addressing global food and climate challenges.

9. Conclusion

The domed aquaponic system redefines agriculture by prioritizing efficiency, resilience, and sustainability. By centering on fish, fruits, and vegetables, it eliminates the need for resource-intensive cattle farming while still allowing optional integration of smaller livestock for system diversity. Double-dome architecture ensures climate control and durability, while aquaponic nutrient cycles optimize food output per unit of land and water. Energy recycling through methane capture and solar integration further enhances sustainability. As a holistic farming model, domed aquaponics offers a scalable, climate-resilient alternative to industrial agriculture, capable of ensuring food security in a rapidly changing world.

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