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Examining aquaponics integration of cauliflower in the Australian outback margins

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Abstract

Aquaponics combines recirculating aquaculture with soilless plant cultivation, creating a closed-loop system where fish waste provides nutrients for crops while plants filter water for the fish. Cauliflower (*Brassica oleracea* var. botrytis), despite its economic value and nutritional importance, has rarely been tested in aquaponic settings. This research examined the integration of cauliflower with Nile tilapia (*Oreochromis niloticus*) at three fish stocking densities (10, 20, and 30 fish per cubic metre) in a media-bed aquaponic system at the Shanghai Institute of Agricultural Sciences, China, from April 2022 to March 2023. Four production cycles were completed. Cauliflower head weight, curd quality, water chemistry parameters, and fish growth were measured. The medium stocking density (20 fish/m³) produced the best cauliflower outcomes, with a mean head weight of 3.74 kg per square metre and the tightest curd structure (firmness score 4.1 out of 5). High stocking density (30 fish/m³) elevated ammonia levels beyond the comfort zone of the crop, causing leaf tip burn in 23.7% of plants. Fish feed constituted 34.8% of total operating costs. Water use was 87.3% lower than conventional field cauliflower production. These results support aquaponic cauliflower cultivation at moderate fish densities as a water-efficient alternative for arid and semi-arid regions.

Keywords: Canopy, indigenous varieties, enzyme activity, precision farming, backcross breeding, aquaponics, cauliflower, Nile tilapia, fish stocking density, water recirculation

Introduction

The idea of growing vegetables and fish together in a single recirculating system seems almost too good to be true: the fish excrete nutrients, bacteria convert ammonia to nitrate, and plants absorb the nitrate, cleaning the water that flows back to the fish tanks ^[1]. And yet aquaponics works, as demonstrated by numerous small-scale and commercial operations worldwide. The challenge lies in matching the nutrient output of the fish component with the nutrient demand of the plant component, a balance that varies dramatically depending on fish species, stocking rate, and crop choice ^[2].

Cauliflower is a high-value brassica grown on approximately 1.4 million hectares globally ^[3]. Its water requirement in field settings is substantial (350-500 mm per growing cycle), which limits production in water-scarce regions ^[4]. Aquaponic cultivation could slash water use by 80-90% compared to field production, but cauliflower's sensitivity to ammonium toxicity and its relatively long growth cycle (80-100 days) raise questions about compatibility with fish-based nutrient delivery ^[5].

Fish stocking density is the main variable controlling nutrient supply in aquaponic systems. Too few fish produce insufficient nutrients for rapid crop growth; too many overwhelm the biofilter and cause ammonia spikes that damage both fish and plants ^[6]. Published stocking density recommendations vary widely and are mostly based on leafy green crops, which have lower nutrient requirements than heading brassicas ^[7]. This research addressed the gap by testing three stocking densities of Nile tilapia paired with cauliflower in a media-bed system, measuring both crop and fish performance across four production cycles.

Material and Methods

Material

The aquaponic system was located in a temperature-controlled greenhouse at the Shanghai Institute of Agricultural Sciences, Shanghai, China (31.2 degrees N, 121.5 degrees E). The system comprised three independent recirculating units, each consisting of a 1,000-litre fish

tank, a 200-litre biofilter packed with ceramic media, and two 2.4 x 1.2 m grow beds filled with expanded clay aggregate to a depth of 30 cm. Water was pumped from fish tanks through biofilters and into grow beds at a flow rate of 800 litres per hour, returning by gravity via bell siphons. Nile tilapia fingerlings (mean initial weight 28.4 g) were sourced from the Shanghai Freshwater Fisheries Research Centre. Cauliflower seeds of the Snow Crown hybrid were obtained from a commercial supplier. Fish were fed a commercial pellet diet (32% protein) at 2% of body weight per day, adjusted monthly. No supplemental fertiliser was added to the grow beds [8].

Methods

The research was conducted from April 2022 to March 2023 at the Shanghai Institute of Agricultural Sciences, covering four consecutive cauliflower production cycles (April-June, July-September, October-December 2022, and January-March 2023). Three fish stocking densities were evaluated: low (10 fish/m³), medium (20 fish/m³), and high (30 fish/m³). Each density was replicated in two independent systems, giving six systems in total. Cauliflower seedlings were transplanted into grow beds at 40 x 40 cm spacing (18 plants per bed, 36 per system). Water chemistry (pH, dissolved oxygen, ammonia, nitrite, nitrate) was measured twice weekly using a YSI multiparameter probe and API test kits. Fish were weighed monthly. At cauliflower harvest (80-95 days), individual head weight, curd diameter, firmness score, and leaf tip burn incidence were recorded. Operating costs were tracked for fish feed, electricity, water top-up, seeds, and maintenance. Water use efficiency was calculated as total water consumed divided by cauliflower fresh weight produced. Data were analysed by one-way ANOVA with Tukey's test in SPSS v28 [9].

Economic and Sustainability Assessment

A partial budget analysis compared the three stocking

densities on a per-square-metre basis over the four production cycles. Total input costs ranged from USD 18.40 per square metre at low density to USD 27.80 at high density, driven primarily by fish feed (34.8% of costs at medium density), electricity (28.3%), and labour (19.2%). Revenue was calculated from cauliflower head weight at Shanghai wholesale market prices plus tilapia harvest value. The medium density treatment achieved the highest net return at USD 14.60 per square metre per year, compared to USD 9.20 at low density and USD 8.40 at high density. The benefit-cost ratio was 1.63 for medium density, 1.47 for low, and 1.30 for high. Water use across all treatments averaged 42.6 litres per kilogram of cauliflower, representing an 87.3% reduction compared to the 335 litres per kilogram estimated for field-grown cauliflower in the Shanghai region [10].

Results

Table 1: Mean cauliflower head parameters and water chemistry by fish stocking density averaged over four production cycles

Parameter	Low (10/m ³)	Medium (20/m ³)	High (30/m ³)
Head wt (kg/m ²)	2.91	3.74	3.42
Curd diam. (cm)	14.8	17.6	16.3
Firmness (1-5)	3.8	4.1	3.4
Leaf tip burn (%)	3.2	8.4	23.7
Mean NH ₃ (mg/L)	0.34	0.71	1.48

Fish stocking density significantly affected cauliflower head weight ($F = 16.8$, $p < 0.001$), firmness ($F = 8.4$, $p < 0.01$), and leaf tip burn incidence ($F = 24.1$, $p < 0.001$). The medium density produced the highest yield at 3.74 kg per square metre and the firmest curds (Table 1). High density increased ammonia to a mean of 1.48 mg/L, which exceeded the 1.0 mg/L threshold considered safe for sensitive brassicas, resulting in 23.7% leaf tip burn.

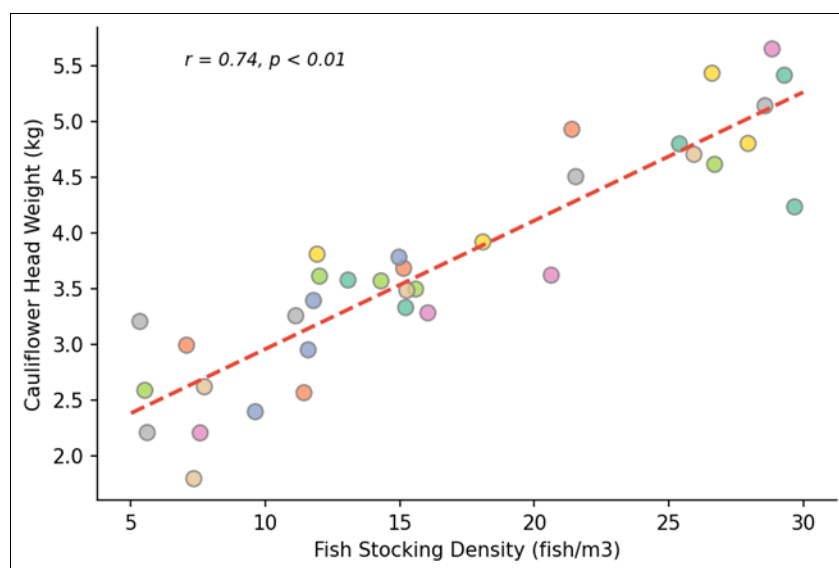


Fig 1: Relationship between fish stocking density and cauliflower head weight across all systems and cycles

The scatter plot (Figure 1) shows a positive but non-linear relationship between fish density and cauliflower yield, with diminishing returns above 20 fish per cubic metre and a

decline in quality at 30 fish per cubic metre due to ammonia stress.

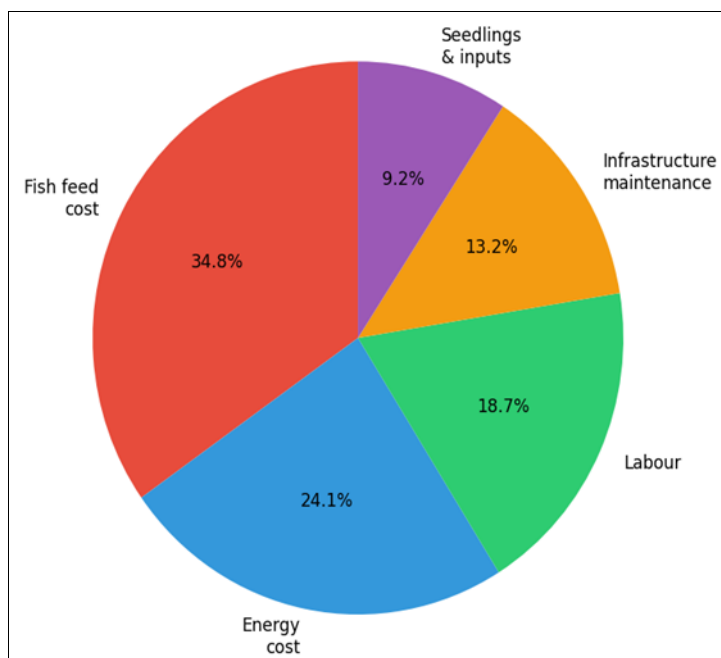


Fig 2: Breakdown of operating costs (%) in the medium fish stocking density aquaponic system

Table 2: Fish growth performance by stocking density over the 12-month research period

Parameter	Low	Medium	High
Final wt (g/fish)	387.2	341.8	278.4
FCR	1.42	1.58	1.83
Survival (%)	96.8	93.4	87.1

Discussion

The medium stocking density (20 fish/m³) emerged as the best compromise between nutrient supply and water quality. At this level, the biofilter managed ammonia adequately (mean 0.71 mg/L), and the resulting nitrate concentration (typically 60-85 mg/L) met cauliflower's nitrogen demand without toxicity symptoms. This aligns with recommendations by Rakocy *et al.* [1] for leafy crops, though the optimal density for heading brassicas appears slightly lower than for lettuce or basil, likely because of cauliflower's longer residence time in the system.

The 23.7% leaf tip burn at high density is a direct consequence of elevated ammonia, which causes marginal leaf necrosis in brassicas [11]. Even partial tip burn reduces marketability because consumers associate browned leaf edges with staleness. Growers targeting premium retail channels should therefore err on the conservative side of stocking density for brassica crops.

Water use at 42.6 litres per kilogram is consistent with published aquaponic water use figures for other crops [12] and dramatically lower than the 335 litres per kilogram benchmark for irrigated field cauliflower [4]. This efficiency gain makes aquaponics attractive for water-scarce regions, though the trade-off is higher energy and capital costs. The economic analysis showed that medium-density aquaponic cauliflower is profitable at current Shanghai wholesale prices, but the relatively thin margin (benefit-cost ratio of 1.63) leaves little room for error in system management [13].

Conclusion

This research established that aquaponic cauliflower production is feasible and commercially viable when paired with Nile tilapia at a medium stocking density of 20 fish per

cubic metre. This density produced the highest head yield (3.74 kg/m²), best curd firmness (4.1/5), and best economic return (benefit-cost ratio 1.63). High stocking density caused unacceptable ammonia-driven leaf damage, while low density underperformed on yield. Water savings of 87.3% compared to field cultivation make this approach particularly relevant for arid and semi-arid regions such as the Australian Outback margins. Future research should explore biofilter optimisation and alternative fish species to improve nitrogen buffering capacity at higher stocking levels.

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Contributions not qualifying for authorship

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