



# Aquaponic Production of Ornamental Koi Carp (*Cyprinus carpio* Linn.) and Lettuce (*Lactuca sativa*) in Comparison with Traditional Fish Culture and Hydroponics System

Khushvir Singh, Vaneet Inder Kaur\*, Meera D. Ansal, Dilpreet Talwar<sup>1</sup>,  
Abhishek Srivastava and Kulbir Singh<sup>1</sup>

Department of Aquaculture, College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University  
(GADVASU), Ludhiana-141 004, India

<sup>1</sup>Department of Vegetable Science, College of Horticulture and Forestry  
Punjab Agriculture University, Ludhiana-141 004, India

\*E-mail: [vaneetinderkaur@gadvasu.in](mailto:vaneetinderkaur@gadvasu.in)

**Abstract:** The study was conducted for comparative analysis of the production of ornamental fish, koi carp (*Cyprinus carpio* Linn.) and lettuce (*Lactuca sativa*) in aquaponics and traditional culture system. The experimental fish were stocked at three stocking densities, i.e., 20 m<sup>-3</sup> (SD1), 30 m<sup>-3</sup> (SD2) and 40 m<sup>-3</sup> (SD3) in circular cemented tanks (10m<sup>-3</sup>) of the aquaculture unit and lettuce were planted (plant to plant spacing of 12 cm) in the hydroponics unit (HM) of automated aquaponics system. For comparison with the traditional system, koi carp were stocked in cemented tank of equal size (10m<sup>-3</sup>) at a standard stocking density of 2 m<sup>-3</sup> and lettuce was planted as per standard protocol i.e. plant to plant space of 30 cm in outdoor conditions in soil bed traditional system (SM) The water quality parameters in both aquaponics and traditional tanks remained in optimum range for fish culture along with >95% of nutrient removal by lettuce. The survival (%) of fish was maximum in control (93.33%) followed by SD3, SD1 and SD2. The final total body length and body weight was significantly higher in control, but the average fish yield (kg m<sup>-3</sup>) was significantly higher in all aquaponic tanks, with the maximum yield of 3.73 kg m<sup>-3</sup> (9.56 times) in SD3 (40 m<sup>-3</sup>). The lettuce yield (32.2 q acre<sup>-1</sup>) was 1.15 times higher in the hydroponic unit, with significantly higher pigment content and insignificant differences for nutrient content except fibre.

**Keywords:** Aquaponics, Koi carp, Lettuce, Hydroponics, Leafy vegetables

The depletion of water resources and increased water pollution has become a major threat throughout the world, especially in developing countries, due to rapidly progressing agricultural, aquaculture and industrial activities. In addition to this, lack of adequate wastewater treatment further acts as a limiting factor for the development of all these sectors (Morrison et al 2009). Since the last two decades, aquaculture has made enormous contribution towards livelihood/employment generation and food/nutritional security around the world. The country's total fisheries production was 17.545 million metric tonnes (MMT) during 2022-23 with a contribution to the world fish production (Handbook on Fisheries Statistics 2023). With this growth, the aquaculture sector is being looked forward to fill the gap, as the marine resources are already being overexploited and are facing many ecological imbalances.

For taking up traditional aquaculture, a large volume of water and land is required, and scarcity/limited availability of these two resources are the major challenges (FAO 2022) for expansion of inland aquaculture. Additionally, surplus organic waste in the form of ammonia, nitrate and phosphate is being added in aquaculture waste water and finally in

natural water bodies leading to water pollution. Therefore, it is essential to manage the heavy nutrient load of aquaculture waste waters, so that receiving water bodies can be protected from eutrophication for potential reuse of water (Endut et al 2009). Further, intensification of aquaculture farming with more advent techniques along with diversification of economically important species is considered one of the best way to achieve the goal of sustainable development of aquaculture sector (FAO 2022). Among intensive aquaculture technologies, aquaponics, is a closed loop system, in which the wastewater from fish farming is purified by the plants and returned to the fish production system. Thus, the cost of purification of water is reduced and profit margin increases significantly as the excreta from farming fish and other aquatic organisms is used as fertilizer for plants in a hydroponic system (Sas-Paszt et al 2023). Moreover, this synergistic combination of two systems, i.e., aquaculture and hydroponics (soilless agriculture system) is a sustainable arrangement with limited water and land (10-12% as compared to traditional practices) requirement (Shete et al 2016).

Punjab, one of the progressive state in North-Western

India, produced about 1.85 lakh tonnes of fish production (major contribution from freshwater carps) during 2022-23 (Handbook on Fisheries Statistics 2023). New initiatives has been taken w.r.to standardization of intensive aquaculture technologies like re-circulatory aquaculture system (RAS), biofloc aquaculture system and aquaponics in agroclimatic conditions of the region. Preliminary trials were conducted during 2020-21 to explore the possibility of combining fish with different crops/vegetables in the said system. In line with this, the present study was executed to optimize the stocking density of koi carp, one of the widely cultured ornamental fish throughout the world including India, in combination with lettuce during the winter season.

### MATERIAL AND METHODS

**Experimental layout:** The experimental study (3 months) was conducted in an automated aquaponics unit (175 m<sup>2</sup>) with aquaculture unit having 3 tanks (75 m<sup>2</sup>) and hydroponic unit (100 m<sup>2</sup>) at the Instructional cum Research Farm, College of Fisheries, GADVASU, Ludhiana. Koi carp fingerlings were stocked at three stocking densities in aquaculture unit and lettuce was planted in hydroponics (HM) unit. For comparison with the traditional system, koi carp fingerlings were stocked in cemented tanks (triplicate) at a standard stocking rate and lettuce was planted in outdoor conditions in a traditional soil bed (SM) system in completely randomized design (Table 1).

**Water quality:** Water quality parameters viz.; Temperature, pH, Dissolved Oxygen (DO), total alkalinity (TA), total

hardness (TH), ammonia (NH<sub>3</sub>-N), nitrite (NO<sub>2</sub><sup>-</sup>-N), nitrate (NO<sub>3</sub><sup>-</sup>-N) and ortho-phosphate (PO<sub>4</sub><sup>3-</sup>-P) were analyzed as per standard methods of APHA (2012) every fortnight throughout the experimental period in both control and experimental tanks.

**Nutrient removal (%):** The nutrient removal (%) of water in terms of NH<sub>3</sub>-N, NO<sub>3</sub><sup>-</sup>-N and PO<sub>4</sub><sup>3-</sup>-P in water collected from hydroponics unit was studied at fortnightly intervals.

**Fish growth:** Fish growth was observed at monthly intervals in terms of total body length, body weight and growth parameters in terms of average total length gain (TLG), average net weight gain (NWG), yield (Kg m<sup>-3</sup>), specific growth rate (SGR), condition factor (K), feed conversion ratio (FCR) and survival (%) were calculated after the completion of experiment.

**Lettuce growth, pigment analysis and nutrient composition:** Lettuce growth was assessed in terms of total plant height and root length at monthly interval. The plant height increase (PHI), root length increase (RLI), yield (Kg m<sup>2</sup>) and pigment content (chlorophyll a, chlorophyll b, total chlorophyll and carotenoids) calculated/analyzed after completion of experiment. Nutrient composition (%) in terms of protein, fat, ash, carbohydrates and fiber was analyzed (AOAC 2007).

**Statistical analysis:** The data was analyzed by software statistical package CPCS-1 (Cheema and Singh 1991).

### RESULTS AND DISCUSSION

**Water quality:** The water quality parameters viz. water temperature pH, DO, TA, TH, NH<sub>3</sub>-N, NO<sub>2</sub><sup>-</sup>-N, NO<sub>3</sub><sup>-</sup>-N and PO<sub>4</sub><sup>3-</sup>-P of control and experimental tanks remained in

**Table 1.** Details of experimental layout & design

Particulars	Details
Preparation of experimental & control tanks	<ul style="list-style-type: none"> <li>Before stocking of fish, experimental and control tanks were completely sun dried (10 days) for disinfection, which were further disinfected with limestone applied @ 300kg/ha. Tube well water was used for filling and maintaining the water in the experimental and control tanks. After one week of liming and filling of water, the water quality parameters of all the tanks were analyzed before stocking the fish.</li> </ul>
Tank capacity & water volume	<ul style="list-style-type: none"> <li>Aquaponics Tanks Circular cemented &amp; Circular – 11m<sup>3</sup>, with water volume of 10,000 liters</li> <li>Control tanks (Rectangular cemented &amp; rectangular – 10m<sup>3</sup>)</li> </ul>
Fish acclimatization	<ul style="list-style-type: none"> <li>10-15 days under indoor conditions (fed <i>Ad libitum</i> with commercial diet)</li> </ul>
Fish stocking density (SD)	<ul style="list-style-type: none"> <li>Experimental stocking densities (SD) – (3) i.e. 20m<sup>-3</sup> (SD1), 30m<sup>-3</sup> (SD2), 40m<sup>-3</sup> (SD3)</li> <li>Control (C) Stocking density - 2m<sup>3</sup></li> </ul>
Fish Size	<ul style="list-style-type: none"> <li>Average total body length 3.39±0.06 cm</li> <li>Av. body weight 3.32±0.06 g</li> </ul>
Fish feeding	<ul style="list-style-type: none"> <li>5% of fish body weight, twice daily (10:00 and 16:00 h). Amount of feed was adjusted after each sampling (monthly) according to increase in fish weight</li> </ul>
Crop plantation	<ul style="list-style-type: none"> <li>Plantation of Lettuce (<i>Lactuca sativa</i>) procured from local nursery of Ludhiana following completely randomized design.</li> <li>Plant to plant space - 12 cm, planted in eight stands [9 pipes having 29 cups each (24 cups planted) in one stand] in hydroponics (HM) unit - (Vertical Farming). Water from aquaculture units was circulated into the hydroponic unit at fixed intervals through a biological filter, resulting in nutrient uptake by the lettuce plants</li> <li>Plant to plant space - 30 cm, planted in 100 m<sup>2</sup> plot area with 8 beds in traditional soil bed (SM) system - (horizontal farming). Standard management practices were followed</li> </ul>

optimum range (Table 2) for koi carp (*C. carpio*) with significant higher pH and significant lower values for NH<sub>3</sub>-N, NO<sub>3</sub>-N and PO<sub>4</sub><sup>3-</sup>-P in control as compared to all the treatments. The values for water quality parameters remained in optimum range for fish culture and are in agreement with the previous studies by different researchers (Da Silva Cerozi and Fitzsimmons 2016, Nuwansi et al 2017 and Nuwansi et al 2020).

**Nutrient removal (%):** During experimental period, the nutrient removal (%) in terms of NH<sub>3</sub>-N, NO<sub>3</sub>-N and PO<sub>4</sub><sup>3-</sup>-P (Table 3) revealed that with the progress of experiment, nutrient removal (%) increased with maximum removal of NH<sub>3</sub> N (98.22%) followed by NO<sub>3</sub>-N (97.53%) and PO<sub>4</sub><sup>3-</sup>-P (96.41%). Lin et al (2002) reported 86-98% removal of ammonium nitrogen (NH<sub>4</sub><sup>+</sup>-N) from constructed wetlands system receiving aquaculture waste water. Endut et al (2009) found total phosphorus removal rates of 43 to 53% in aquaponic systems, lesser than observed in present experiment.

**Fish survival and growth:** Fish survival (%) in C, SD1, SD2 and SD3 after completion of experiment was 93.33, 82.00, 78.33 and 83.25, respectively. Significantly higher fish survival (%) was observed in C as compared to all the treatments (Table 4).

At the completion of the experiment, treatment with low stocking density (C) resulted in the higher fish growth. Furthermore, there was a negative correlation between the

stocking density and length and/or weight increase of the fish. Similar findings were observed in terms of impact of increasing stocking density on the growth and survival rate of different fish species in different aquaculture systems (Wang et al 2017, Haridas et al 2017, Nuwansi et al 2021) by previous researchers. The biomass of Koi carp significantly increased with increasing stocking density of fish. At the end of experimental period, the average yield (kgm<sup>-3</sup>) was significantly higher in all the treatments, with the maximum yield (9.417 times) recorded in SD3 followed by SD2, SD1 and C. The results in terms of total fish biomass/yield coincide with stocking density of fish. The findings of the study are consistent with those of Nuwansi et al. (2021) for Koi carp (*C. carpio* var. koi) in aquaponic system. Feed efficiency in terms of FCR was significantly higher (in all aquaponic treatments with the maximum 4.24 in SD2 followed by SD1, SD3 and control (2.85). Previous studies also revealed higher values for FCR (Shete et al 2013, Hussain et al 2014, Nuwansi et al 2020, Nuwansi et al 2021) for Koi carp in aquaponic systems.

**Lettuce growth:** Lettuce growth in terms of plant height (cm) and plant root length (cm) was significantly higher in HM as compared to SM (Table 5). Plant height and root length increase (%) in HM was 1.42 and 1.28 times higher as compared to SM. Similarly, significantly (P<0.05) higher (1.15 times) total yield/biomass (32.20 Qt acre<sup>-1</sup>) was in HM as compared to SM (27.90 Qt acre<sup>-1</sup>). Sabwa et al (2022) also revealed similar results in terms of biomass of lettuce and root length in aquaponics system. Purwandari et al (2017) reported that romaine lettuce grown in hydroponic system was characterized by better growth compared to plants grown in an aquaponic system fed only with wastewater coming from giant gourami (*Osphronemus goramy*) culture system. Hairani et al (2022), observed that among three plants i.e. kailan (*Brassica oleracea* L.), lettuce (*Lactuca sativa* L.) and pakcoy (*Brassica rapa* L.), lettuce showed best growth in combination with striped catfish (*Pangasianodon hypophthalmus*) in aquaponic system, due to presence of maximum number of leaves with wider leaf width. However, contrary to this, Rana et al (2018) revealed 1.14 times higher lettuce growth in traditional soil beds as compared to aquaponics grown crop along with other growth parameters like plant height, leaf number, and plant and root weight. The aquaponics grown lettuce showed significantly higher yield compared to soil based system, and is attributed to availability of nutrients from aquaponic fish tanks through water recirculation and excessive water nutrients uptake by the lettuce in the hydroponic unit.

**Pigment analysis:** The significantly higher pigment content i.e. chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content (mg g<sup>-1</sup>) was observed in lettuce grown in

**Table 2.** Mean water quality parameters in control and treatments during the experimental period

Parameters	C	SD1	SD2	SD3
Temperature (°C)	18.93 <sup>a</sup>	18.61 <sup>a</sup>	18.59 <sup>a</sup>	18.58 <sup>a</sup>
pH	8.45 <sup>a</sup>	7.75 <sup>b</sup>	7.73 <sup>b</sup>	7.75 <sup>b</sup>
D.O. (mg l <sup>-1</sup> )	8.52 <sup>b</sup>	9.26 <sup>ab</sup>	9.32 <sup>a</sup>	9.38 <sup>a</sup>
TA (CaCO <sub>3</sub> mg l <sup>-1</sup> )	172.57 <sup>a</sup>	173.43 <sup>a</sup>	174.28 <sup>a</sup>	174.48 <sup>a</sup>
TH (CaCO <sub>3</sub> mg l <sup>-1</sup> )	187.71 <sup>a</sup>	185.33 <sup>a</sup>	184.62 <sup>a</sup>	184.95 <sup>a</sup>
NH <sub>3</sub> -N (mg l <sup>-1</sup> )	0.044 <sup>b</sup>	0.194 <sup>a</sup>	0.197 <sup>a</sup>	0.184 <sup>a</sup>
NO <sub>2</sub> -N (mg l <sup>-1</sup> )	0.022 <sup>a</sup>	0.044 <sup>a</sup>	0.044 <sup>a</sup>	0.044 <sup>a</sup>
NO <sub>3</sub> -N (mg l <sup>-1</sup> )	0.331 <sup>b</sup>	2.035 <sup>a</sup>	2.037 <sup>a</sup>	2.030 <sup>a</sup>
PO <sub>4</sub> <sup>3-</sup> -P (mg l <sup>-1</sup> )	0.047 <sup>b</sup>	0.86 <sup>a</sup>	0.861 <sup>a</sup>	0.862 <sup>a</sup>

Values with same superscript in row do not differ significantly (p<0.05)

**Table 3.** Nutrient removal in water collected from hydroponics unit (%)

Nutrient removal (%)	Number of days			
	15	45	75	90
Ammonia-N	86.2	91.72	97.23	98.22
Nitrate-N	65.45	86.07	96.34	97.53
Ortho-phosphate	66.38	79.99	94.04	96.41

**Table 4.** Comparative growth of koi carp in control and experimental tanks

Parameters	C	SD1	SD2	SD3
Average initial body length (cm)	3.35 <sup>a</sup>	3.42 <sup>a</sup>	3.43 <sup>a</sup>	3.35 <sup>a</sup>
Average final body length (cm)	11.35 <sup>a</sup>	9.54 <sup>c</sup>	9.75 <sup>c</sup>	10.45 <sup>b</sup>
TLG (cm)	7.99 <sup>a</sup>	6.12 <sup>c</sup>	6.32 <sup>c</sup>	7.11 <sup>b</sup>
Average initial body weight (g)	3.27 <sup>a</sup>	3.33 <sup>a</sup>	3.33 <sup>a</sup>	3.33 <sup>a</sup>
Average final body weight (g)	21.20 <sup>a</sup>	10.53 <sup>b</sup>	10.80 <sup>b</sup>	11.20 <sup>b</sup>
NWG (g)	17.93 <sup>a</sup>	7.20 <sup>b</sup>	7.47 <sup>b</sup>	7.87 <sup>b</sup>
Fish biomass (kg m <sup>-3</sup> ) (Av. Yield)	0.396 <sup>d</sup>	1.727 <sup>c</sup>	2.538 <sup>b</sup>	3.729 <sup>a</sup>
SGR (%)	2.08 <sup>a</sup>	1.28 <sup>b</sup>	1.31 <sup>b</sup>	1.35 <sup>b</sup>
Condition factor (K)	1.46 <sup>a</sup>	1.22 <sup>b</sup>	1.16 <sup>bc</sup>	0.98 <sup>c</sup>
FCR	2.85 <sup>c</sup>	4.10 <sup>a</sup>	4.24 <sup>a</sup>	3.87 <sup>b</sup>
Survival (%)	93.33 <sup>a</sup>	82.00 <sup>b</sup>	78.33 <sup>c</sup>	83.25 <sup>b</sup>

\* SD = Stocking Density, C = 2 m<sup>-3</sup>, SD1= 20 m<sup>-3</sup>, SD2 = 30 m<sup>-3</sup>, SD3= 40 m<sup>-3</sup>

Values with same superscript (a, b,.....d) in row do not differ significantly (p≤0.05)

TLG-Total Length Gain; NWG- Net Weight Gain; SGR- Specific Growth Rate; FCR- Feed Conversion Ratio

**Table 5.** Comparative growth and pigment content of lettuce in SM and HM

Growth parameters	SM	HM	CD <sup>1</sup> (=0.05)
IPH (cm)	7.51	7.32	NS <sup>2</sup>
PH at 30 DAT (cm)	13.22	19.45	3.80
PH at 60 DAT (cm)	16.8	20.37	1.96
PH at 90 DAT (cm)	17.4	24.17 (1.39)	2.39
PHI (%)	2.32	3.30 (1.42)	-
IRL (cm)	3.36	3.46	NS
FRL (cm)	10.39	32.77 (3.15)	3.38
RLI (%)	20.13	25.85 (1.28)	-
Yield (Qt acre <sup>-1</sup> ) <sup>a</sup>	27.90	32.20 (1.15)	NS
Yield (cup <sup>-1</sup> or plant <sup>-1</sup> )	485.27	632.78 (1.30)	79.53
Chlorophyll a (mg g <sup>-1</sup> )	4.64	5.34	0.39
Chlorophyll b (mg g <sup>-1</sup> )	2.97	3.62	0.30
Total chlorophyll (mg g <sup>-1</sup> )	2.60	3.14	0.11
Carotenoids (mg g <sup>-1</sup> )	3.53	3.89	0.29

Values in parentheses indicate change over control

<sup>a</sup>three cuttings of lettuce during 3 month experimental period in all SM and HM  
IPH/FPH – Initial/Final Plant Height, PHI – Plant Height Increase, IRL/FRL – Initial/Final Root Length, RLI – Root Length Increase, DAT –Days After Transplanting

HM as compared to SM (1.15, 1.22, 1.21 and 1.10 times higher, respectively) (Table 5). Rambe (2013) mentioned that leaf width is conducive to photosynthesis due to the presence of chlorophyll, because of which plants can independently prepare their own food for their growth. Therefore, more the number of leaves, more space for photosynthesis and better

**Table 6.** Quality of lettuce in different treatments after completion of experiment (%)

Parameter (%)	Lettuce		P value
	SM	HM	
Protein	1.39±0.23	1.41±0.17	0.94
Fat	0.30±0.02	0.26±0.00	1.12
Carbohydrate	1.35±0.41	1.08±0.04	0.54
Ash	1.63±0.03	1.51±0.20	0.59
Moisture	93.33±0.29	94.00±0.12	0.10
Fiber	1.98±0.03	1.72±0.03	0.00

p-value 0.05 or less indicate significant difference

plant growth. Higher pigment content in HM is indicative of extra leaf width and more number of leaves. Coronel et al (2008), also observed that total chlorophyll content was 1.09 times greater in the lettuce grown hydroponically as compared to traditionally grown lettuce. Sabwa et al. (2022) too reported higher total chlorophyll content (0.019-0.56 µg l<sup>-1</sup>) in aquaponics grown lettuce.

**Nutrient composition of lettuce:** After completion of experiment, quality (%) of lettuce in terms of proteins, fat, carbohydrates, ash, fiber and moisture, was estimated for each treatment and control. The differences for nutrient composition among treatments and control were insignificant except fiber (Table 6).

## CONCLUSION

The overall results indicated the potential of aquaponic technology with higher fish productivity (over 9 times) and lettuce biomass (15%) with improved pigment content. The synergistic combination of Koi carp and lettuce in aquaponics system with encouraging results is attributed to improved

water quality maintained in the aquaculture tanks of aquaponic system for fish through water recirculation and availability of copious amount/uptake of nutrients by the lettuce in the hydroponic unit, as compared to traditional soil bed system.

### ACKNOWLEDGEMENTS

The financial support provided by Centre for Development of Advanced Computing (C-DAC), Mohali of Ministry of Electronics and Information Technology (MeitY) for establishing automated aquaponic unit at College of Fisheries, GADVASU, Ludhiana is highly acknowledged.

### AUTHOR CONTRIBUTION

Khushvir Singh – Conducted the experiment, analyzed the data and manuscript writing, Vaneet Inder Kaur – Conceived the idea and critical evaluation of data and editing of manuscript, Meera D. Ansal – Designing of experiment and evaluation of results, Dilpreet Talwar – Helped in maintenance of vegetable crops in hydroponic unit, Abhishek Srivastava - Helped in maintenance of fish in aquaponics unit, Kulbir Singh – Helped in overall maintenance of hydroponic unit.

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