Theme: Sustainable Agricultural Innovations for One Health and Environmental Resilience

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Physio-biochemical Properties and Growth Performance of Kale [*Brassica oleracea* (L.) var. alboglabra] and Yield of Tilapia (*Oreochromis niloticus*) in a Floating-raft Aquaponics System with Aeration and Organic Foliar Supplements

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ABSTRACT

Background: Aquaponics integrates aquaculture and hydroponics into a resource-efficient production system that utilizes nutrients derived from fish effluents while reducing the need for frequent water replacement. However, nutrient insufficiency and limited dissolved oxygen remain important constraints in floating raft aquaponics.

Methods: The study evaluated the growth performance of Tilapia, as well as the growth and response on physio-biochemical properties of Kale grown in a floating raft aquaponics system. Aerated and without aeration as factor A while organic foliar fertilizers as factor B. Foliar treatments consisted of fermented banana peel extract, fermented malunggay and kangkong leaf extract, a commercial organic foliar fertilizer as positive control and fish effluents alone as the negative control.

Result: Pond aeration did not enhance growth parameters of kale but increased the yield of tilapia. Foliar supplementation significantly improved growth, yield and physio-biochemical attributes, with fermented malunggay leaf extract and commercial organic foliar fertilizer producing the most favorable responses. The results suggest that pond aeration is essential for high fish yield in floating raft aquaponics, whereas foliar supplementation is a key strategy for improving crop performance and quality.

Key words: Aeration, Aquaponics, Fermented foliar supplements, Kale, Tilapia.

INTRODUCTION

Kale (*Brassica oleracea* L.) is a leafy vegetable valued for its high nutritional properties and adaptability to intensive crop production systems. It performs best under favorable environment conditions like balanced nutrient availability but is also sensitive to water stress, which can reduce growth and marketable yield (Drost and Johnson 2010; Cartea *et al.,* 2002). Given its nutritional importance, commercial potential and sensitivity to suboptimal conditions, kale is a promising crop for sustainable cultivation in integrated system such as aquaponics.

Aquaponics is an integrated production system that integrates aquaculture and hydroponics, allowing nutrient-rich wastewater from fish culture to be reused for crops in a recirculating environment (Hollyer *et al.,* 2009; Ogah *et al.,* 2022) and gained increasing attention as a sustainable food production strategy because it reduces water consumption, improvess nutrient recycling while enables the simultaneous production of fish and vegetables in a single unit of land. Similarly, soil-less systems have been reported as promising alternatives for crop production under limited land and water resources, particularly in areas affected by climate change and declining agricultural land availability (Gumisiriza *et al.,* 2020; Barman *et al.,* 2026). In aquaponics, tilapia is the most cultured because of its rapid growth, tolerance to a wide range of environmental conditions, resistance to handling stress and suitability for intensive recirculating systems. Despite these advantages, aquaponic crop production remains constrained by several biological and chemical limitations. Fish effluents alone may not always provide sufficient concentrations of essential plant nutrients, especially micronutrients which are commonly deficient in aquaponics and may limit crop growth and quality (Damon *et al.,* 1998). In addition, oxygen is a critical component because it directly affects fish metabolism, root respiration and the activity of nitrifying bacteria responsible for nutrient transformation.

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Low oxygen availability, which may occur under poor water movement or excessive phytoplankton growth, can impair system balance and reduce both fish and plant productivity (Fitzsimmons, 2006).

To address these limitations, management strategies that improve nutrient availability and oxygen dynamics may enhance crop performance in floating raft aquaponics. Foliar application of formulated foliar fermented plant-based supplements may provide an efficient means of supplying additional nutrients, particularly when root-zone nutrient availability is insufficient. Likewise, the provision of aeration in the pond may improve oxygen levels and support more stable biological processes within the system. Aquaponics has been widely promoted as a sustainable approach to food production. In view of this, physio-biochemical responses of kale grown in a floating raft aquaponics system with aeration and organic foliar supplements was examined, with the aim of identifying practical management strategies for improving crop production.

MATERIALS AND METHODS

Study site and research period

The experiment was conducted at Visayas State University, Baybay City, Leyte, Philippines, in 2018. All experimental activities, data collection and related research procedures were carried out within the facilities of the University during the research period.

Aquaponics system components and set-up

A pond measuring 2 m × 25 m with a depth of 0.5 m was used. It was filled with 7000 gallons of tap water and aerated using an air pump with an air flow capacity of 4200 L/Hr from 8 am to 5 pm. A rectangular styrofoam was utilized as floating raft bed and was holed to fit the pots at equal distance. The pots were crafted from soft drink plastic bottles that holds plant samples. Tilapia (*Oreochromis niloticus*) fingerlings with a weight of 5-10 g and 14-17 mm long were reared in the pond for 2 months to allow growth and significant accumulation of fish wastes to be used as nutrient source for the plants. Stocking density was 1000 fry in 25 m^3. Commercial fish feeds available in local agricultural store was used. The initial feeding rate was 10-6%/day of the body weights of the fingerlings, 5-3% feeding rate was applied when the fish attain a body weight of 70 to 120 g and 2% of the body weight when the fish will attain more than 265 g.

Plant materials

Kale seeds were sown in seedling tray following the standard practices of management in terms of medium used, fertilization, care and maintenance. The seedlings were pricked and transplanted into pots 14 days after seed sowing. Pots were filled with sterilized planting medium (1:1:1) ratio of river sand, vermicasts and carbonized rice hull. The seedlings were hardened and later transplanted into the crafted pots filled with similar planting medium and was placed on the modified floating raft beds to avoid submersion of the whole plant but keeps and stabilize the plants on the water surfaces prior to treatment application.

Experimental design and treatments

Two factorial experiment was conducted in a randomized complete block design (RCBD) replicated 3 times. The different formulated fermented plant juice as foliar fertilizer and commercial foliar fertilizer were set as factor “B” while the ponds with and without aeration as factor “A”.

The banana peel, malunggay and kangkong leaves were chopped and fermented separately for 1 month. The ferment was diluted with water at a ratio of 1L ferment to 65L tap water. The different formulated foliar fertilizers from fermented plant juice were applied 2 times per week to prevent acid accumulation on the pond and was recalibrated as the plant grows.

Data collection

The observation of growth parameters of both kale and tilapia was recorded from five selected representative plants and fish from each replication wherein measurements were recorded as per standard method. Total Soluble Solids (TSS) was measured using the hand refractometer. Titratable Acidity (TA) through titration of aliquot with 0.1N NaOH. The FRSA of kale was analyzed using an ultraviolet-visible (UV-vis) spectrophotometer set at wavelengths of 517 nm. Chlorophyll was determined using the same instrument set at wavelengths 645 nm and 662 nm.

Data analysis

The data was subjected to an analysis of variance (ANOVA). Treatment means having significant differences were subjected to least significant difference (LSD), Statistical analysis was carried out using Statistical Tool for Agricultural Research (STAR) version 2:0:1 2014 Biometrics and Breeding Informatics, PBGB Division International Rice Research Institute, Los Baños Laguna.

RESULTS AND DISCUSSION

Growth performance and survival percentage of Tilapia

Fish raised in pond with aeration was heavier, longer and had wider body width and had higher per cent survival rate compared to fish in non-aerated pond (Table 1). The enhanced quality of tilapia was a result of good oxygen supply in aerated pond. Ample oxygen levels in the water ensure growth; promotes the health, appetite and tolerance from the effects of temperature-induced stress. Mallya (2007) reported that oxygen saturation level had a positive effect on the growth and feed conversion ratio. Moreover, significant increase in growth and slightly higher survival of fish was also observed in aerated ponds, a conformity on the effect of aeration on fish survival in aquaculture ponds by Qayyum *et al.* (2005).

Growth parameters of kale

Kale grown in aerated pond were significantly shorter and fewer leaves compared to those grown in unaerated pond but had comparable leaf size with plants grown in non-aerated pond (Table 3). The improved performance of kale in non-aerated pond can be partly attributed to the slightly lower NH4 content (Table 2) that can be correlated to the phytochemical properties in response to nitrogen form. A study by Fallovo (2011) in Brassica species revealed high concentration of NO_3 increases the flavonoid, carotenoid and chlorophyll, thus resulted to enhanced photosynthesis. Furthermore, Kopsell *et al.* (2007) reported that increasing NO_3 concentrations in a mixed supply of NO_3/NH_4 enhanced the carotenoid and chlorophyll concentrations in kale grown in winter/spring under low PAR levels these signifies that kale favors NO_3-N compared to NH_4-N.

Plant height was improved by fermented malunggay leaves and commercial organic fertilizer supplements than fish effluents alone. Numerous leaves were obtained by commercial organic foliar supplements followed by fermented malunggay and kangkong leaves supplementation while fermented banana peel and fish effluents alone had the least number of leaves. Widest leaf expansion was observed in plants supplemented with fermented malunggay leaves followed fermented kangkong leaves and commercial organic fertilizer and those supplemented with fish effluents alone had the smallest leaves. The notable effects of supplements can be attributed to their higher nutrient contents than that of fish effluents alone (Table 2) The nutrients present in formulated supplements both the macro and micronutrients are essential for plant growth as discussed by Uchida, (2000) that nitrogen combined with carbohydrates and sulfur to create amino acids the building blocks of proteins which are used in plant growth and development while phosphorus plays a vital role in energy storage and transfer and potassium as an enzyme activator that promotes metabolism and translocation of photosynthates.

Aerated and non-aerated pond were dissimilar in effects on root elongation (Table 3). In aerated pond, plants grown in fish effluents alone had comparable length of roots to those supplemented with commercial organic fertilizer. Those supplemented with fermented banana peel had longer roots than those supplemented with malunggay and kangkong leaves. The different effects of nutrient supplementation on the response of root elongation can be attributed to their different pH which varies in acidity level from 5.7-6.0 in average (Table 2). Zu *et al.* (2014) reported that low pH directly inhibit root development while Alam *et al.* (1999) reported that excess H+ affects plant growth by damaging the root tissue which affects root elongation.

Kale grown in pond without aeration were significantly heavier than those grown in aerated pond (Table 3). Heavier plants from unaerated pond were attributed to its tall height with more and bigger leaves. Nevertheless, the application of fermented malunggay leaves resulted to production of heaviest plants followed by application of commercial organic fertilizer. The prominent effects of fermented malunggay leaves and commercial organic fertilizer could be linked to their higher nutrient contents which enhanced the growth and development of kale leading to production of bigger and hence heavier plants.

Physio-biochemical properties of kale

Antioxidant capacity of kale was not significantly affected by the type of pond (Table 4). In aerated pond, the application of fermented malunggay leaves resulted to the highest FRSA content but in unaerated pond it was drastically low. Kale applied with fermented banana peel showed the highest FRSA content in non-aerated pond followed by fish effluents alone while those supplemented with commercial organic fertilizer had the lowest FRSA in non-aerated pond. The increased concentration of antioxidant capacity resulting from supplementation of fermented banana peel as well as malunggay leaves could be linked to elevated potassium content (Table 2). Undesirable effects of high potassium were reported by Ding and Xu (2011), wherein an increased potassium on leafy vegetables associated with decreased magnesium concentration causes stress

Table 1: Growth performance of Tilapia raised in aerated and non-aerated ponds.

Pond type	Fish fresh weight (g)	Fish length (cm)	Fish width (cm)	Per cent survival (%)
Aerated (A)	205	17.3	9.4	91.4
Non-Aerated (NA)	180	15.6	7.7	90.2

Table 2: Elemental analysis and pH of formulated foliar supplements.

Fermented	Available N (ppm)		Total (%)					Total (ppm)		Average pH
Supplements	NH_4-N	NO_3-N	P	K	Na	Ca	Mg	Zn	Fe	
Banana peel	37.38	6.90	97.85	288.92	5.08	33.69	21.23	41.5	58.0	6
Malunggay leaves	58.15	10.46	129.85	284.00	6.77	89.54	26.46	11.5	203.5	5.7
Kangkong leaves	56.15	11.38	118.15	332.31	12.15	95.85	27.85	19.5	295.0	5.7

Nutrient analysis by Central Analytical Services Laboratory of Phil Rootcrops, Visayas State University, Baybay City, Leyte.

Table 3: Growth parameters of kale as affected by types of fishponds and formulated foliar supplements.

Pond type	Plant height (cm)	Number of leaves	Leaf area (cm^2)	Fresh weight (g)		Root length (cm)	
Aerated (A)	8.68b	6.83b	95.80				
Non-aerated (NA)	9.65a	7.68a	99.49				
				A	NA	A	NA
Treatments							
T0-Control (Fish Effluents)	7.02d	5.94d	65.84d	21.8e	26.28d	15.63a	16.07a
T1-Fermented malunggay leaves + T0	10.62a	7.84b	124.67a	62.67a	67.83a	9.63c	9.87c
T2-Fermented banana peel + T0	8.22c	6.61c	86.58c	33.33d	38.33c	10.73b	10. 97b
T3-Fermented kangkong leaves + T0	9.33b	7.71b	97.14b	46.52c	51.4b	9.57c	9.77c
T4-Commercial organic fertilizer + T0	10.65a	8.16a	106.50b	55.60b	69.08a	15.77a	16.00a
CV (%)	4.71	2.52	8.14	2.7		2.13	

Mean separation within columns by Least Significant Difference (LSD) between types of fishpond and different formulated foliar supplements as treatments at 5% level of significance.

Table 4: Antioxidant capacity, chlorophyll *a* and *b* and total soluble solids of Kale as affected by types of fishponds and formulated foliar supplements.

Pond type	Free radical scavenging activity (FRSA) %		Chlorophyll (ppm)				Total soluble solids (°Brix)	
			a		*b*			
Aerated (A)	34.56b		4.11		6.1		1.21 a	
Non-aerated (NA)	39.95a		4.31		7.3		0.71 b	
	A	NA	A	NA	A	NA	A	NA
Treatments								
T0-Control (Fish Effluents)	33.06c	44.79b	3.83c	3.45c	3.16e	6.38e	1.23	0.73
T1-Fermented malunggay leaves + T0	42.24ab	30.20d	4.66b	4.70b	4.73 c	7.37b	1.23	0.73
T2-Fermented banana peel + T0	38.25b	56.97a	0.74d	1.25d	3.37d	6.54d	1.20	0.70
T3-Fermented kangkong leaves + T0	24.58d	28.10d	4.59b	6.25a	8.26b	9.73a	1.20	0.70
T4-Commercial organic fertilizer + T0	34.66c	39.71c	6.74a	5.91a	10.79a	6.96c	1.20	0.70
CV (%)	4.81	5.34	0.35	10.64				

Mean separation within columns by least significant difference (LSD) between types of fishponds and different formulated foliar supplements as treatments at 5% level of significance.

(Inthichack *et al.,* 2012). Effects of stress on plants antioxidant properties were studied in which Caverzan *et al.* (2016) reported that increase antioxidant defense mechanisms under stresses was observed. Inversely, Hasanuzzaman *et al.* (2018) reported that potassium has a regulatory function in several biochemical-physiological processes and was found to provide abiotic stress tolerance which enhances antioxidant defense in plants under various environmental adversities. In addition, fermented banana peel had the highest zinc content and in the study of Sida-Arreola *et al.* (2017) revealed that zinc increased activity of the enzyme superoxide dismutase and increase antioxidant capacity. Chlorophyll *a* content was improved in non-aerated pond and shows that the use of commercial organic fertilizer stimulates favorable chlorophyll *a* content wherein fermented banana peel had the lowest content. The elevated chlorophyll on aerated plants could be attributed to the improved growth (Table 4) in which attained numerous leaves and consequently increases photosynthetic activity. Fallovo *et al.* (2009) discussed that NO_3 and NH_4 uptake also influences the uptake of other anions and cations which involved in maintaining electroneutrality within the plant as can be seen in Table 2 that non-aerated pond had lesser NH_4 compared to aerated pond. Decrease magnesium, potassium and calcium concentrations in leaf tissues due to increase NH_4 supply was also reported by Guo *et al.* (2007) in which magnesium played an important role in photosynthesis as it is present in chlorophyll and involved in thylakoid stacking. Chlorophyll *b* content response similar between pond types. In aerated pond, the commercial organic fertilizer significantly increases chlorophyll *b* contents while in unaerated pond with fermented kangkong leaves supplementation favorably promoted chlorophyll *b* contents followed by fermented malunggay leaves and fish effluents alone had lowest influence on chlorophyll *b*.

Soluble solids accumulation on Kale was significantly affected by aeration. Plants grown in aerated pond had higher soluble solids than without aeration while the different supplements had no significant differences (Table 4). Carotenoid content was not influenced by the type of ponds (Table 5). In aerated pond, the application of foliar supplements reduces the carotenoid content while plants without supplementation had the highest carotenoid content. This could be linked to a decrease chlorophyll content wherein Härtel and Grimm (1998) reported that there is a co-regulation exists between chlorophyll and carotenoid synthesis which governed by a selective accumulation of carotenoid components by which suppression of chlorophyll synthesis leads to elevated carotenoid. Conversely, kale grown in non-aerated pond supplemented with commercial organic fertilizer substantially improved carotenoid content while fermented banana peel had the lowest. Vitamin C and titratable acidity of kale were not significantly different between pond types

Table 5: Vitamin C, titratable acidity and total carotenoids of Kale as affected by types of fishponds and formulated foliar supplements.

Pond type	Vitamin C (mg/100ml)		Titratable Acidity (%)		Total carotenoids (ppm)	
	A	NA	A	NA	A	NA
Aerated (A)						
Non-aerated (NA)						
Treatments						
T0-Control (Fish Effluents)	19.63	19.63c	0.264	0.30c	10.42a	9.09b
T1-Fermented malunggay leaves + T0	20.55	25.57b	0.231	0.40b	9.57b	8.85c
T2-Fermented banana peel + T0	19.63	15.98d	0.297	0.20d	0.45d	7.77d
T3-Fermented kangkong leaves + T0	19.63	26.03b	0.231	0.40b	8.32c	8.80c
T4-Commercial organic fertilizer + T0	19.18	32.42a	0.297	1.22a	8.35c	11.12a
CV (%)	8.92	3.22	18.11	5.10	2.62	0.88

Mean separation within columns by least significant difference (LSD) in types of fishponds and different formulated foliar fertilizer as treatments at 5% level of significance.

but significant different among supplements (Table 5). The use of commercial organic fertilizer had remarkable effect on vitamin C and titratable acidity while fermented banana peel had the slightest effect. Organic foliar fertilizer, fermented malunggay and kangkong leaves contains considerable amount of nutrients compared to fermented banana peel (Table 2), this imposes direct or indirect effects on the production of plant metabolites for example nitrogen a necessary component of several vitamins (Uchida, 2000) thus, plants supplied with nutrients would result to higher levels of vitamins.

CONCLUSION

This study confirms that the productivity of floating-raft aquaponics depends on management interventions that address the differing physiological requirements of fish and plants. Aeration was essential for improving Tilapia growth and survival, but it did not confer comparable benefits to Kale growth, indicating that oxygen enhancement alone was insufficient to overcome crop nutritional limitations in the system. By contrast, organic foliar supplementation, especially fermented malunggay leaf extract and commercial organic fertilizer, significantly enhanced kale growth, biomass and selected physio-biochemical attributes, demonstrating the importance of complementary nutrient inputs beyond fish effluents alone. Collectively, these findings highlight that integrating aeration for aquaculture performance with targeted foliar supplementation for crop nutrition represents a practical strategy for strengthening the biological efficiency and production potential of floating-raft aquaponics under tropical growing conditions.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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