Nutrient recycling through aquaponics and night-lighting

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Abstract

Aim: The effects of night lighting on production of peppermint in an NFT aquaponic system were examined in this study.

Methodology: Hybrid lemon fin barb juveniles were co-cultured with peppermint in an aquaponics system. The peppermint was subjected to 12 hr ambient natural daylight and 0, 6 and 12 hr night lighting respectively for a period of 14 weeks (two batches of 7 weeks each). Nitrogen, phosphorus and potassium uptake of the fish and peppermint were measured. Dissolved oxygen, pH, TDS, conductivity, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen and temperature were monitored during this period. Fish and plant NPK composition were analyzed before and after the experiment.

Results: Night-lighting did not affect the NPK composition and growth of fish. The plants responded positively to increased night-lighting hours. A significant increase in stem length, leaf numbers and production mass (19% higher with 12 hr night-lighting) was observed at harvest. Approximately 18% more nutrients were taken up with night lighting. The total recovery of the hybrid lemon fin barb-peppermint system with a 12 hr natural day lighting and 12 hr night lighting ranged from 27-34% for N, 41-49% for P and 25-31% for K.

Interpretation: The peppermint production and nutrient recovery in the aquaponics system were enhanced with increase in photoperiod.

Key words: Aquaponics, Hybrid lemon fin barb, NFT, Peppermint, Photoperiod

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Introduction

All vegetables require sufficient amount of water, nutrients and sunlight to grow optimally (Noguchi and Amaki, 2016). The push for an increase in the food production to be balanced with the environmental sustainability makes aquaponic and hydroponic systems important parts of 21st century farming alternatives (da Rocha *et al.*, 2017; Makhdom *et al.*, 2017; Savvas, 2003). Furthermore, the vegetables produced through aquaponics are organic, thereby ensuring the welfare of the consumers.

During production in conventional farming systems, nutrients have been reported 'lost' or 'wasted' as much as 45% due to volatilization, runoff and leaching (Badr *et al.*, 2016; Djidonou *et al.*, 2015; Soto *et al.*, 2015; Yan *et al.*, 2008). In conventional pisciculture, 75% of nitrogen and 77% of phosphorus inputs are lost in the water (Folk and Kautsky, 1989). An aquaponic system does not just solve these problems, but also recovers and recycles these nutrients in an environmentally friendly manner (Bernstein, 2011; Liang and Chien, 2013; Rakocy *et al.*, 2006) translating to an increase in productivity per unit area.

However, aquaponically-grown vegetables, just like other plants grown in conventional gardens, need at least 8 to 10 hr of direct sunlight each day to photosynthesize and grow optimally (Malayeri *et al.*, 2011). Photoperiod manipulation has been reported to improve the performance of plants in different studies. For instance, the survival of *in-vitro* stored strawberry plantlets improves significantly when exposed to 12 hr light as opposed to 0 hr light (Reed, 1999). Improved growth and oil production in herbs and oil plants have been reported by Aziz and Craker (2009) and Hälvä *et al.* (1993) with a photoperiod manipulation. Mexican mint plant, which is considerably sensitive to light regimes, has been "photo-manipulated" to induce better performance (Noguchi and Amaki, 2016). Although the importance of photoperiod is well documented for many plants in a conventional farming system, there is paucity of information of light manipulation on herbs in a aquaponic system.

Peppermint (*Mentha piperita*) is a perennial plant that belongs to mint family *Lamiaceae* (Lawrence, 2006). Various herb species including mints are commercially grown for their oils or leaves (Liu and Lawrence, 2007). Essential oils distilled from the genus *Mentha*, for instance, have a long history of use in everyday products from foods to pharmaceuticals (Pandey *et al.*, 2003; Zhao, 1991). Hence, these products have been widely used in folk medicine and cuisines across the world for many years (Lawrence, 2006). The insecticidal potential of these mint oils has also been investigated with promising potentials (Franzios *et al.*, 1997; Pavlidou *et al.*, 2004).

Peppermint is also used for treating headaches and irritable bowel syndrome (Blumenthal, 2003). Nutrient availability,

soil type, moisture and light regimes are factors that have influenced mint production as reported in many studies using conventional farming systems (Alsafar and Al-Hassan, 2009; Malayeri *et al.*, 2011; McElroy *et al.*, 2004; Noguchi and Amaki, 2016; Reed, 2002; Singh and Singh, 1969). In view of the above this study was designed to investigate the effects of night lighting on growth and nutrient balance of peppermint co-cultured with hybrid lemon fin barb in a aquaponic system.

Materials and Methods

Experimental set up for the culture of fish and peppermint :

The study was conducted at the Aquaculture Experimental Station, Puchong. The experimental set-up consisted of twelve individual aquaponic units. Each unit consisted of a nutrient film technique (NFT) trough vegetable unit made of 3 UPVC rain gutters (5.95x0.15x0.07m), a 2-tonne fibreglass fish tank and a bio-filter. Each trough row held 25 plants (75 plant pots per culture unit) while a small (135-watt, 4000 l hr⁻¹) aquarium pump was used to recirculate the water in the system. Each tank was filled with 1 tonne de-chlorinated state tap water.

Hybrid lemon fin barb fingerlings (BW:10.33±0.79g, TL: 7.85 ± 0.57cm) were procured from the Jerantut Aquaculture Extension Centre in Perlok Pahang, Malaysia. The fish were randomly stocked at 25 fish tonne⁻¹ and acclimatized to the aquaponic system for 4 weeks before the herbs were introduced.

Two-week-old seedlings of peppermint herb were purchased from a reputable vegetable nursery in Cameron Highlands, Pahang, Malaysia. The plants were randomly assigned to individual aquaponic units in four replicates and placed 8 cm apart, with 12 cm between planting holes of adjacent pipes. The plants were also grown in batch formation of 2 cycles (7 weeks each). Cuttings from same source were used for the second cycle.

Lighting : The peppermint plants were subjected to three treatments: 12 hr natural daylight and 0 hr nightlight (served as control), 12 hr natural daylight and 6 hr nightlight (18 hr lighting), and 12 hr natural daylight and 12 h nightlight (24 hr lighting). For night lighting, red and blue LED plant grow-lights (Philips BR46 & BR28) were used to provide an artificial lighting at an optimum photosynthetic photon flux density range of 650 ± 50 μmol m⁻² s⁻¹. Automatic timers were used to ensure uniformity of light regimes. All treatments were randomly assigned to the culture units in triplicates.

Opaque curtains with white reflective interiors were provided to reflect the light within respective treatments and black exterior to absorb external light preventing it from interfering with the treatments. The curtains were installed on only treatments in which night lighting was applied. The curtains were rolled up during the day (0600 hr) to allow effective exposure of the plants

to natural daylight and rolled down in the evenings (18:00 hr) to optimize night lighting. The lights were switched on at 18:00 hr and switched off at 2400 hr to provide 6 hr and 18:00 hr - 06:00 hr to provide 12 hr night-lighting.

Feeding and sampling : The fish were fed twice daily (09:00 and 16:00 hr) at 6% body weight. Every fortnight, the fish in each tank were sampled and the feed ration adjusted accordingly to the new mean body weight. The fish growth and survival were estimated by the following equations:

$$\text{Specific growth rate, SGR (\%d}^{-1}\text{)} = \frac{\text{Ln Final weight (g)} - \text{Ln Initial weight (g)}}{\text{Duration of trial (d)}} \times 100$$

$$\text{Weight gain, WG (\%)} = \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Initial weight (g)}} \times 100$$

$$\text{Survival (\%)} = \frac{\text{Initial stocking} - \text{Dead fish}}{\text{Initial stocking}} \times 100$$

The protein efficiency ratio (PER) and feed conversion ratio (FCR) were calculated by the following equations:

$$\text{Protein efficiency ratio, PER} = \frac{\text{Fish weight gain (g)}}{\text{Total protein intake (g)}}$$

$$\text{Feed conversion ratio, FCR} = \frac{\text{Total feed consumption (g)}}{\text{Fish weight gain (g)}}$$

Protein gain (g) and lipid gain (g) were calculated by the following equations:

$$\text{Protein gain (g)} = (\text{Weight}_{\text{final}} \times \% \text{ Protein}_{\text{final}}) - (\text{Weight}_{\text{initial}} \times \% \text{ Protein}_{\text{initial}})$$

$$\text{Lipid gain (g)} = (\text{Weight}_{\text{final}} \times \% \text{ Lipid}_{\text{final}}) - (\text{Weight}_{\text{initial}} \times \% \text{ Lipid}_{\text{initial}})$$

$$\text{Daily feed intake, DFI (\%d}^{-1}\text{)} = 100 \times \frac{\text{Total feed intake}}{\text{duration of the feeding period} \times (\text{initial body weight} + \text{final body weight}) / 2}$$

Water quality analysis : The water quality parameters were monitored and recorded once a week to confirm that they are within conducive culture conditions according to Boyd (1997). Temperature, pH, dissolved oxygen, conductivity and total dissolved solids were measured by a multi-probe meter (YSI 556 MPS). Total ammonia-nitrogen ($\text{NH}_3\text{-N}$) and ammonium-nitrogen ($\text{NH}_4\text{-N}$) levels were measured by an ammonia-nitrogen LaMotte test kit. Nitrate nitrogen, phosphate and potassium contents were estimated using an atomic absorption spectrophotometer (Perkin Elmer 2100). The water quality parameters were measured from the fish tank and from the filtered water in order to measure the

Fig. 1 : Light regimes for the herbs in the aquaponic system

effectiveness of the filters (physical and biological). The readings were taken at the early hours of the morning (06:30-08:00 h).

Proximate analysis : The method from the Association of Official Analytical Chemist was followed to analyse the whole body crude lipid, crude protein, moisture, crude fiber and ash content of the hybrid in triplicates .

Nutrient budget : Nutrient recovery and uptake were calculated by the following equations:

$$\text{Nutrient recovery (\%)} = 100 \times \frac{\text{Nutrient uptake in plant or fish}}{\text{Total nutrient in feed given}}$$

Nutrient gain (per pot) was calculated by the following equation:

$$\text{Uptake (mg pot}^{-1}\text{)} = (\text{Final weight} \times \text{Final nutrient content}) - (\text{Initial weight} \times \text{Initial nutrient content})$$

Statistical analyses : Fish and plant growth performance, body and nutrient composition were analysed using One-way ANOVA after prior confirmation of data homogeneity. Water quality data were analysed using 2-way ANOVA. Percentage data for NPK recovery were arcsine transformed. Difference among treatments were identified using Tukey's test.

Results and Discussion

Water quality : Water quality parameters in the fish tanks and plant troughs throughout the experiment are shown in Figs. 2-9. The water temperatures in the fish tanks increased steadily until week 13 when a drop in water temperature was observed (Fig. 2). Meanwhile, water temperature in the vegetable trough was almost similar in all treatments and increased sharply by week 3 and reached almost a stable level from Week 5 to Week 13 before

Fig. 2 : Water temperature in (a.) fish tanks and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

Fig. 3 : Total dissolved solids in (a.) fish tanks and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system.

picking up in Week 14. Meanwhile TDS and nitrate levels (Figs. 3 and 6) increased steadily in the tanks showing no signs of slowing down throughout the duration of the experiment. DO and pH levels were fairly stable while nitrite and ammonia levels (Figs. 7 and 8 respectively) decreased progressively from Week 7 and 5, respectively.

Hybrid lemon fin barb growth performance and body composition: Table 1 shows the growth indices and survival of hybrid lemon fin barb co-cultured with peppermints under different night lighting regimes. No significant differences

($P > 0.05$) in survival, growth, feed intake and efficiency, and yield were observed among the fish groups, although fish growth was slightly lower with peppermint that received 12 hr night lighting. The period of night lighting also did not affect the body proximate composition of fishes (Table 2).

Peppermint performance and composition: The plant performances in different extended night lighting regimes during two culture cycles are summarised in Table 3. The findings of this study showed that peppermint performance was significantly improved ($P \leq 0.05$) as the length of night lighting increased. This

Fig. 4 : Conductivity range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

Fig. 5 : Dissolved oxygen range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

was demonstrated in the leaf area, leaf height, leaf number, chlorophyll content and yield of the peppermint.

The peppermint nutrient compositions before and after being subjected to different lighting regimes are shown in Table 4. Generally, similar trends in plant composition were observed in both plant cycles. Final nitrogen and phosphorus contents significantly increased with the increase of night lighting period. In contrast, final potassium content significantly decreased with the night lighting period.

Nutrient recovery : The total uptake and recovery of NPK were significantly affected by night lighting hours as shown in two

cycles of herb production presented in Tables 5 and 6. Nitrogen and phosphorus were retained more in the peppermints under prolonged hours of exposure to night lighting compared to the control group or those exposed to shorter lighting. Whereas, the potassium gained and consequently recovered at the same rate regardless of light hours. Similarly, there were no significant variations in the gain and recovery of NPK in the fish exposed to different lighting regimes.

Although many fish species can tolerate high levels of ammonia in the environment (Chew *et al.*, 2001; Ip *et al.*, 2004; Moreira-Silva *et al.*, 2010; Tsui, 2004; Tsui *et al.*, 2002), the

Fig. 6 : pH range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

Fig. 7 : Nitrate range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

observed ammonia levels in this study were considered safe for the culture of freshwater fish species (Stickney, 1979). Hence, the aquaponic system in this study had no risk of ammonia toxicity. This explains the high survival of fish in the experiment. There was, however, a noticeable peak on fifth week and subsequent decrease in ammonia content. This was probably an indication of the system trying to gain equilibrium of its nutrient dynamics. Similarly, TDS level in this study were similar to those reported for better performance of fish and plant by Rakocy *et al.* (2006) for an aquaponic system. An excessive level of TDS can harm the fish through phyto-toxicity (Sooknah, 2000), however, this can be easily rectified by increasing water exchange rate or reducing feeding input or stocking density of fish. Generally, the pH levels decreased in the aquaponic system across treatments. This

might be due to accumulation of nitrates in the biofilter (probably by bioaccumulation in the bacteria) as opined by Boyd (1997). The importance of maintaining high DO levels in aquaponic systems cannot be over emphasised. High DO assists in breaking down of organic materials in the water (Rakocy *et al.*, 2006) and improves plant health (Goto *et al.*, 1996). The dissolved oxygen recorded for the aquaponic system in this study was within the recommended range (5-9 mg l⁻¹) for aquaculture purposes largely because aeration was provided to supply additional DO to the system (Boyd, 1997; Graber and Junge, 2009). Hence, most water qualities (except for nitrogenous based water qualities) were not affected by the bio-filtration mechanism of the plant roots as well as different photoperiod applied in various treatments. However, the nitrogenous contents in the system significantly

Fig. 8 : Nitrite range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

Fig. 9 : Ammonia range in rearing tank (a.) and (b.) vegetable troughs in which hybrid lemon fin barb were cultured with peppermint exposed to different light regimes in the aquaponic system

correlated with those recovered in the fish or plant under different photoperiods.

In this study, the survival and growth of hybrid lemon fin barb were not significantly affected by the photoperiod of peppermint. El-Sayed and Kawanna (2004) also observed no difference in the growth performance of Nile tilapia, *Oreochromis niloticus* fingerlings reared under four different photoperiod (light: dark, L:D) cycles (24L:0D, 18L:6D, 12L:12D and 6L:18D). In contrast, Liang and Chien (2013, 2015) found that photoperiod has significant positive effects on the growth performance of tilapia and loach in a raft aquaponic system. In the current study,

the photoperiod was applied directly over the peppermint and not on the fish tank, which might explain the observed differences in the outcome of the current study and those reported in earlier works (Pandey et al., 2003; Naylor et al., 1999; Chew et al., 2001).

The findings of this study showed that plant growth and yield significantly increased as the length of photoperiod was extended with night lighting. Farooqi et al. (1999) had earlier clearly illustrated the fact that three species of *Mentha* (*M. arvensis*, *M. citrata* and *M. cardica*) are long day plants. This means that these plants have substantially higher vegetative proliferation under long-day conditions (24 hr) as compared to

Table 1 : Survival, growth performance and feed conversion ratio of hybrid lemon fin barb grown with peppermint exposed to different period of night lighting

Parameter	Night lighting		
	0 hr	6 hr	12 hr
Survival (%)	95 ± 1.30 ^a	92 ± 1.54 ^a	99 ± 1.75 ^a
Initial individual total length TL (cm)	8.01 ± 0.68 ^a	7.95 ± 0.14 ^a	7.89 ± 0.72 ^a
Final individual total length (cm)	13.53 ± 0.16 ^a	13.88 ± 0.09 ^a	13.72 ± 0.07 ^a
Initial individual body weight BW (g)	10.15 ± 0.86 ^a	10.64 ± 0.69 ^a	10.74 ± 0.11 ^a
Final individual body weight (g)	253.44 ± 0.24 ^a	254.98 ± 0.67 ^a	258.37 ± 0.48 ^a
Weight gain (g)	242.45 ± 15.40 ^a	241.42 ± 13.52 ^a	249.52 ± 12.63 ^a
SGR (% d ⁻¹)	3.27 ± 0.51 ^a	3.23 ± 0.27 ^a	3.24 ± 0.59 ^a
DFI (% BW d ⁻¹)	7.68 ± 1.33 ^a	7.57 ± 1.63 ^a	7.66 ± 1.35 ^a
FCR	4.09 ± 0.14 ^a	4.08 ± 0.27 ^a	4.05 ± 0.78 ^a
PER	0.82 ± 0.38 ^a	0.82 ± 0.52 ^a	0.82 ± 0.05 ^a
Yield* (kg tonne ⁻¹)	6.02 ± 1.04 ^a	5.86 ± 0.89 ^a	6.39 ± 0.52 ^a

Mean ± SE within the same row with different superscripts are significantly different at $P < 0.05$ *14-week yield

Table 2 : Body composition of the hybrid lemon fin barb (% wet weight) grown with peppermint exposed to different length of night lighting

Nutrient (%)	Initial	Night lighting		
		0 hr	6 hr	12 hr
Moisture	74.55 ± 0.67	64.52 ± 2.56 ^a	66.28 ± 2.09 ^a	66.74 ± 1.73 ^a
Crude Protein	12.74 ± 0.41	21.42 ± 1.44 ^a	20.39 ± 1.87 ^a	21.45 ± 1.51 ^a
Crude Fiber	0.11 ± 0.01	0.43 ± 0.10 ^a	0.42 ± 0.21 ^a	0.45 ± 0.11 ^a
Crude Lipid	3.82 ± 0.14	3.34 ± 0.36 ^a	3.41 ± 0.30 ^a	3.29 ± 0.77 ^a
Ash	2.84 ± 0.05	2.36 ± 0.24 ^a	2.34 ± 0.43 ^a	2.31 ± 0.55 ^a
NFE	6.08 ± 0.50	7.39 ± 1.02 ^a	6.85 ± 0.54 ^a	6.03 ± 1.45 ^a

Mean ± SE within the same row with different superscripts are significantly different at $P < 0.05$

shorter day conditions (12 hr) which lead to slower growth. Similarly, in a study conducted by Jeong *et al.* (1996), the leaf area of round-leaved mint is larger at a photoperiod regime of 16 hr compared to the shorter regime (8 hr). Pollet *et al.* (2009) and Kitaya *et al.* (1998) also observed an increase in fresh and dry mass of *Hedera helix* and lettuce with extended photoperiods under similar experimental conditions.

The plants under 24 hr lighting showed faster growth compared to other plants. Ikeda *et al.* (1988) had earlier reported that a longer light period (24 hr) leads to faster growth of lettuce and turnip by about 10 folds within a week as compared to those with a shorter light period (12 hr). Similarly, Miguel *et al.* (2002) also reported higher fresh mass yields of several medicinal plants exposed to longer day length (24 hr). Liang and Chien (2013) had emphasised that a continuous photoperiod of 24 hr in an aquaponic system has a positive effect on water spinach growth with 8-12% gain in 2-4 weeks. The underlining principle for improved performance of some plants under a longer photoperiod regime has been earlier explained by the ease of use of larger amount of carbohydrate for metabolism and growth in the plant (Zhang *et al.*, 2018). Mao *et al.* (2013) had also stated that an increased photoperiod regime can stimulate

photosensitive pigments in plants to induce gene expression for growth, quality and nutrient uptake. This might be evident the fact that higher chlorophyll content was observed in peppermint exposed for prolonged photoperiod (24 hr) in this current study in contrast to those under shorter photoperiod regimes. Similarly, Liang and Chien (2015) had opined that the faster growth of plants exposed to longer photoperiod in an aquaponic system due to higher amount of photons received by the plants for photosynthesis. However, not all plants are significantly affected with changes in light regimes. Hence, due to differences in the biology and photoperiodic preferences of different plants, growth characteristics can differ under different light regimes for different plant species or strain. McElroy *et al.* (2004) demonstrated that the root weight of Florida betony exposed to short-day and long-day photoperiods are similar after 10-week culture period. Meanwhile, Gubbels (1954) had postulated observed that additional illumination to the normal, day-length depresses yield and fruit size of tomatoes but hastens fruit ripening by more than three weeks.

In both crop cycles, longer photoperiods markedly increased growth characteristics of peppermint such as leaf area, stem length and chlorophyll content while reducing the levels of

Table 3 : Peppermint characteristics exposed to 12 hr daylight, followed by different lengths of night lighting

Parameter	Night lighting period					
	Cycle 1			Cycle 2		
	0 hr	6 hr	12 hr	0 hr	6 hr	12 hr
Initial leaf area (cm ² leaf ⁻¹)	3.26 ± 0.08 ^a	3.21 ± 0.28 ^a	3.37 ± 0.03 ^a	2.22 ± 0.10 ^a	2.41 ± 0.03 ^a	2.37 ± 0.11 ^a
Final leaf area (cm ² leaf ⁻¹)	8.51 ± 0.15 ^c	9.18 ± 0.16 ^b	9.68 ± 0.12 ^a	9.62 ± 0.29 ^c	11.43 ± 1.36 ^b	12.32 ± 0.32 ^a
Leaf area gained (cm ² leaf ⁻¹)	5.65 ± 0.12 ^b	5.97 ± 0.14 ^{ab}	6.31 ± 0.15 ^a	7.05 ± 0.35 ^c	9.02 ± 1.21 ^b	10.11 ± 1.20 ^a
Leaf area gained (%)	198.31 ± 6.83	186.30 ± 6.32	187.29 ± 5.78	295.46 ± 4.56	356.57 ± 5.14	409.82 ± 5.78
Specific growth rate in leaf area (% day ⁻¹)	0.12 ± 0.001 ^b	0.12 ± 0.001 ^{ab}	0.13 ± 0.002 ^a	0.14 ± 0.002 ^b	0.14 ± 0.001 ^b	0.16 ± 0.003 ^a
Initial height (cm pot ⁻¹)	14.34 ± 0.46 ^a	14.09 ± 0.81 ^a	14.36 ± 0.17 ^a	11.21 ± 1.09 ^a	12.23 ± 1.63 ^a	11.66 ± 0.56 ^a
Final height (cm pot ⁻¹)	36.27 ± 0.59 ^c	38.23 ± 0.81 ^b	46.63 ± 0.06 ^a	35.45 ± 0.93 ^c	37.32 ± 0.51 ^b	43.87 ± 0.64 ^a
Height gained (cm pot ⁻¹)	21.92 ± 0.94 ^c	24.14 ± 0.04 ^b	29.27 ± 0.11 ^a	22.94 ± 0.94 ^c	24.99 ± 1.45 ^b	33.55 ± 1.71 ^a
Height gained (%)	153.80 ± 11.00	173.10 ± 10.40	168.63 ± 2.33	197.52 ± 7.46 ^b	201.34 ± 6.24 ^b	284.52 ± 3.50 ^a
Specific growth rate in height	0.45 ± 0.008 ^c	0.49 ± 0.001 ^b	0.60 ± 0.001 ^a	0.46 ± 0.010 ^c	0.50 ± 0.001 ^b	0.68 ± 0.001 ^a
Initial leaf number (leaves pot ⁻¹)	23.27 ± 0.96 ^a	21.29 ± 0.49 ^a	24.04 ± 0.09 ^a	19.55 ± 1.27 ^a	18.17 ± 1.29 ^a	19.78 ± 0.93 ^a
Final leaf number (leaf pot ⁻¹)	40.53 ± 1.70 ^c	46.55 ± 0.68 ^b	55.30 ± 0.61 ^a	39.38 ± 1.53 ^c	44.93 ± 0.89 ^b	51.74 ± 1.01 ^a
Leaf number gained (leaf pot ⁻¹)	22.26 ± 1.17 ^c	26.26 ± 0.56 ^b	30.26 ± 0.56 ^a	19.83 ± 1.09 ^c	26.76 ± 1.62 ^b	31.96 ± 2.27 ^a
Leaf number gained (%)	122.56 ± 7.75	129.68 ± 4.65	120.85 ± 2.04	102.28 ± 3.46 ^c	145.82 ± 3.43 ^b	159.89 ± 2.62 ^a
Specific leaf number gained (% day ⁻¹)	0.45 ± 0.012 ^c	0.54 ± 0.006 ^b	0.62 ± 0.006 ^a	0.40 ± 0.011 ^c	0.54 ± 0.001 ^b	0.66 ± 0.004 ^a
Initial chlorophyll (mg cm ⁻²)	15.05 ± 0.49	16.64 ± 0.80	17.29 ± 1.88	14.62 ± 1.51	15.26 ± 1.22	13.44 ± 1.24
Final chlorophyll (mg cm ⁻²)	22.75 ± 0.32 ^c	27.31 ± 0.24 ^b	35.67 ± 0.66 ^a	23.01 ± 0.59 ^c	26.21 ± 1.44 ^b	33.53 ± 0.71 ^a
Chlorophyll gained (mg cm ⁻²)	7.70 ± 0.42 ^c	10.67 ± 0.90 ^b	18.38 ± 1.22 ^a	8.36 ± 0.77 ^c	10.77 ± 0.91 ^b	19.89 ± 1.18 ^a
Chlorophyll gained (%)	51.53 ± 4.14 ^b	65.36 ± 8.66 ^b	113.80 ± 23.20 ^a	57.43 ± 3.65 ^b	71.75 ± 6.53 ^b	145.87 ± 20.94 ^a
Specific chlorophyll gained (% day ⁻¹)	0.16 ± 0.004 ^c	0.22 ± 0.009 ^b	0.38 ± 0.012 ^a	0.18 ± 0.001 ^c	0.22 ± 0.006 ^b	0.40 ± 0.012 ^a
Initial fresh weight (g unit culture ⁻¹)	314.21 ± 9.19 ^a	309.79 ± 6.55 ^a	310.03 ± 8.54 ^a	309.21 ± 10.71 ^a	307.51 ± 7.92 ^a	309.53 ± 7.93 ^a
Final fresh weight (g unit culture ⁻¹)	1542.55 ± 30.63 ^c	1690.94 ± 35.17 ^b	1870.79 ± 40.11 ^a	1583.78 ± 27.53 ^c	1738.65 ± 31.21 ^b	1910.46 ± 36.26 ^a
Yield (g m ⁻²)	573.44 ± 10.33 ^c	628.60 ± 8.56 ^b	695.46 ± 10.07 ^a	591.12 ± 9.74 ^c	650.37 ± 7.84 ^b	717.04 ± 11.43 ^a

Mean ± SE within the same row and growth cycle with different superscripts are significantly different at $P < 0.05$

nitrogenous compounds in the culture water, particularly, nitrite and ammonia concentrations. These water quality parameters have been established as part of nutrient cycles for plants by researchers (Aslan and Kapdan, 2006; Garcia *et al.*, 2000; Li *et al.*, 2010; Ruiz-Marin *et al.*, 2010). Hence, it can be hypothesised that the observed better plant growth in this study might indicated the efficiency in the uptake and use of available nutrients, specifically nitrogen in the aquaponic as the light hours were prolonged. In consonance with the current findings, Delgadillo-

Mirquez *et al.* (2016) reported higher removal rates of NH_4^+ and PO_4^{3-} in batch cultures of mixed microalgae and bacteria exposed to longer photoperiods. The removal of PO_4^{3-} and K^+ from the fish waste and culture system was evident in the nutrient recovery results. Although, Gopal (1987) and Whiteman and Room (1991) had opined that temperature may have a direct influence on nutrient absorption capacity, the similarities in the water and system temperatures under different photoperiod regimes in this study dismissed the temperature effect on the results. The

Table 4 : Peppermint composition after being subjected to different night lighting regimes in a aquaponic system

Parameter	Night lighting		
	0 hr	6 hr	12 hr
Cycle 1			
Initial N (mg g ⁻¹)	25.19 ± 0.01	26.99 ± 0.04	25.15 ± 0.02
Final N (mg g ⁻¹)	41.96 ± 0.07 ^c	48.75 ± 0.21 ^b	56.44 ± 0.01 ^a
Initial P (mg g ⁻¹)	0.415 ± 0.11	0.403 ± 0.25	0.402 ± 0.17
Final P (mg g ⁻¹)	0.714 ± 0.21 ^c	0.875 ± 0.14 ^b	1.103 ± 0.33 ^a
Initial K (mg g ⁻¹)	1.135 ± 0.27	1.125 ± 0.38	1.115 ± 0.54
Final K (mg g ⁻¹)	2.94 ± 0.13 ^a	2.89 ± 0.34 ^a	2.38 ± 0.47 ^b
Cycle 2			
Initial N (mg g ⁻¹)	27.01 ± 0.10	25.04 ± 0.02	26.31 ± 0.24
Final N (mg g ⁻¹)	37.70 ± 0.11 ^c	49.22 ± 0.14 ^b	57.05 ± 1.13 ^a
Initial P (mg g ⁻¹)	0.441 ± 0.25	0.415 ± 0.29	0.462 ± 0.32
Final P (mg g ⁻¹)	0.684 ± 0.47 ^c	0.882 ± 0.33 ^b	1.125 ± 0.23 ^a
Initial K (mg g ⁻¹)	1.13 ± 0.54	1.15 ± 0.16	1.12 ± 0.46
Final K (mg g ⁻¹)	2.86 ± 0.42 ^a	2.74 ± 0.48 ^a	2.41 ± 0.66 ^b

Mean ± SE within the same row and plant cycle with different superscripts are significantly different at $P < 0.05$

Table 5 : Nutrient uptake of peppermint and hybrid lemon fin barb after being subjected to different night lighting regimes in a aquaponic system

Nutrient uptake(g culture unit ⁻¹)		Night lighting		
		0 hr	6 hr	12 hr
Fish				
N		205.80 ± 6.32 ^a	190.23 ± 5.13 ^a	219.03 ± 6.89 ^a
P		43.21 ± 4.28 ^a	40.74 ± 3.17 ^a	48.47 ± 6.46 ^a
K		43.78 ± 5.36 ^a	47.09 ± 5.26 ^a	49.87 ± 4.76 ^a
Herb			Cycle 1	
N		56.75 ± 8.22 ^c	74.62 ± 4.14 ^b	97.72 ± 6.08 ^a
P		0.97 ± 0.02 ^c	1.35 ± 0.03 ^b	1.94 ± 0.32 ^a
K		4.18 ± 0.31 ^a	4.54 ± 0.53 ^a	5.51 ± 0.71 ^a
			Cycle 2	
N		51.59 ± 3.03 ^c	77.41 ± 1.62 ^b	100.40 ± 6.22 ^a
P		0.95 ± 0.04 ^c	1.41 ± 0.03 ^b	2.01 ± 0.18 ^a
K		4.18 ± 0.12 ^a	4.41 ± 0.52 ^a	4.23 ± 0.39 ^a
Total Herb (2 cycles)				
N		107.35 ± 16.26 ^c	151.03 ± 10.50 ^b	197.12 ± 2.44 ^a
P		1.92 ± 0.15 ^b	2.76 ± 0.17 ^b	3.95 ± 0.63 ^a
K		8.36 ± 1.11 ^a	8.95 ± 1.07 ^a	8.36 ± 1.21 ^b
System Total				
N		313.23 ± 12.08 ^c	341.93 ± 8.34 ^b	416.12 ± 6.57 ^a
P		45.12 ± 1.53 ^b	43.49 ± 1.74 ^b	52.42 ± 2.94 ^a
K		52.14 ± 1.11 ^a	56.04 ± 3.75 ^a	58.23 ± 3.58 ^a

artificial illumination devices used in this study did not generate much heat as the temperature of tubes seldom reached 20°C, as claimed by the manufacturer.

While nitrogen and phosphorus accumulation enhanced

in peppermint under prolonged light regime, accumulation of potassium was less. This observation might be linked to possible nutrient sparing effects. Gubbels (1954) reported high accumulation of nitrogen in tomato leaves and fruits but a decrease in phosphorus and an increase of potassium in its

Table 6 : Nutrient recovery (%) of peppermint and hybrid lemon fin barb after being subjected to different night lighting regimes in a aquaponic system

% Recovery		Night lighting		
		0 hr	6 hr	12 hr
Fish				
N		18.22± 2.11 ^a	17.55± 2.09 ^a	18.25± 1.74 ^a
P		42.65±2.25 ^a	39.00± 1.26 ^a	46.14± 1.43 ^a
K		21.61± 1.68 ^a	22.57± 1.39 ^a	27.09± 1.26 ^a
Herb			Cycle 1	
N		5.02± 0.23 ^c	6.81± 1.06 ^b	8.15± 0.44 ^a
P		0.96±0.02 ^b	1.29± 0.05 ^b	1.85± 0.02 ^a
K		2.06± 0.74 ^a	2.15± 0.09 ^a	2.23±0.11 ^a
			Cycle 2	
N		4.54± 0.29 ^c	7.16± 0.12 ^b	8.40± 0.88 ^a
P		0.94±0.05 ^b	1.35± 0.26 ^b	1.91± 0.33 ^a
K		2.06± 0.21 ^a	2.11± 0.34 ^a	2.31± 0.19 ^a
System Total				
N		27.97±2.05 ^c	31.81±2.14 ^b	34.80±1.93 ^a
P		44.54±2.44 ^b	41.65±2.83 ^b	49.90±3.57 ^a
K		25.73±2.56 ^b	26.86±2.49 ^b	31.65±1.69 ^a

Means ± SE within the same row with different superscripts are significantly different at $P < 0.05$

leaves. In another setup, an increase phosphorus uptake caused a decrease in potassium content in the leaves of tomatoes. The difference in the nature of plants, harvesting time and NPK level available for uptake in different system (used in these studies) can be linked to difference in performance characteristics highlighted. Similar observations were noted Petrucio and Esteves (2000) in *Eichhornia crassipes* and *Salvinia auriculata*.

The trend of NPK recoveries in hybrid lemon fin barb in this study was similar regardless of different photoperiod regimes for peppermint. The NPK recoveries ranged between 17.55-18.25, 39.00-46.14 and 21.61-27.09%, respectively. Folke and Kautsky (1989) had earlier reported 25% nitrogen and 23% phosphorus recovery in cultured caged salmon from the feed input. The differences could be linked to the fish species, feed composition and/or culture systems used.

Nutrient recovery was significantly higher when lighting was received all day long (0 hr darkness) compared to short and long period of darkness (6 and 12 hr lighting). Although, there is paucity of information about the effect of photoperiod on nutrient recoveries of plant in aquaponic systems, Khater *et al.* (2015) found that factors such as increase in the system's flow rate can substantially increase nutrient recovery in tomato plants raised in a aquaponic system. However, since same aquaponic conditions were applied for all treatments and the nutrients available for uptake by the plant were similarly supplied from the same sources (fish waste and uneaten feed), it can be concluded that prolonged photoperiod enhanced nutrient recovery by peppermint (Naylor *et*

al., 1999; Rakocy, 2006; Saba and Steinberg, 2012; Wilkie, 1997) and improved plant growth.

NPK recovery by peppermint in two culture cycles were near by same. A similar trend for total recovery of nutrients was observed in peppermint-hybrid lemon fin barb system, especially with nitrogen. Guzel *et al.* (2018) reported 1.68% K and 0.04% P recovery in *Cucumis sativus* and *Cyprinus carpio* co-cultured in a aquaponic system compared to 2.49% K and 0.038% P for *Cucumis sativus* grown in a hydroponic system. Duckweed harvested from wetlands has been reported to recover 7-47g of phosphorus m⁻², while 8% phosphorus and 10% nitrogen was recovered in its aquaculture (Zhao *et al.*, 2014; Guterstam, 2002). The NPK recovered by peppermint in this research seemed to be slightly higher than those reported in previous studies (4-8% N recovery, 0.90-1.91% P recovery and 2% K recovery). The estimated unutilised nutrients in wastewater in this study was 65-73% N, 50-59% P, 69-75% K, which suggests that these "wasted" nutrients can be used to increase the yield in the aquaponic system. This increase can be doubled or tripled by adding more growing troughs.

The findings of the present study demonstrated that night lighting and a longer photoperiod increased the growth performance of the peppermint but not the fish. While maximizing the available sunlight during the day, the night lighting enhanced the herb production and total nutrient recovery of the peppermint-hybrid lemon fin barb aquaponic system. The efficiency of peppermint as additional biofilters in removing nitrogenous waste in aquaponics should be further explored.

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