AQUATIC RESEARCH

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E-ISSN 2618-6365

Aquat Res 6(1), 43-51 (2023) • https://doi.org/10.3153/AR23005 Research Article

Investigation of different lighting (LED, HPS and FLO) in aquaponics systems for joint production of different plants (Lettuce, Parsley and Cress) and koi carp

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Cite this article as:

Memiş D., Tunçelli, G. Tınkır, G. Erk, M.H. (2023). Investigation of different lighting (LED, HPS and FLO) in aquaponics systems for joint production of different plants (Lettuce, Parsley and Cress) and koi carp. *Aquatic Research*, 6(1), 43-51. https://doi.org/10.3153/AR23005

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Submitted: 05.09.2022
Revision requested: 05.09.2022
Last revision received: 25.10.2022
Accepted: 04.12.2022
Published online: 12.12.2022

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Available online at
http://aquatres.scientificwebjournals.com

ABSTRACT

We investigated the effects of growth performance of three plant species parsley (*Petroselinum crispum*), lettuce (*Lactuca sativa*) and cress (*Lepidium sativum*) under the three different lighting sources, Light-Emitting Diode lamp (LED; 200w), High-Pressure Sodium lamp (HPS; 200w) and Fluorescent lamp (FLO; 200w) in an aquaponic system. A total number of 43 koi fish (*Cyprinus carpio* var. *koi*) with 3628 g total biomass (84.4 g per individual) were used. The fish used in the experiment recorded 36% growth and reached an average individual weight of 132.7 g at the end of the experiment. The parsley plant was measured as 8.76 ±7.32 g; 7.45 ±4.13 g; 2.04 ±1.96 g weight after 45 days, the lettuce plant was 54.09 ± 25.60 g; 60.83 ±19.39 g; 17.81 ±6.40 g weight after 54 days, cress plant was 1.03 ±0.58 g; 1.15 ±0.46 g; 1.31 ±0.58 g weight after 42 days, under the HPS, LED, and FLO light sources, respectively. HPS and LED light sources in lettuce and parsley showed better plant development than the FLO, while no significant difference occurred in cress plants under three light conditions. We conclude that using HPS or LED lights in indoor aquaponics has the potential to produce good quality and adequate amounts of plants.

Keywords: Aquaponics, Koi, Light sources, *Petroselinum crispum, Lactuca sativa, Lepidium sativum*

Introduction

Aquaponics combines fish production in a recirculating aquaculture system (RAS) and plant production in a hydroponic unit (Rakocy, 2012; Goddek et al., 2015; Yavuzcan Yildiz, 2017). Considering global climate change, loss of soil productivity and biodiversity, and lack of sources and drinking water, the practice of aquaponics in both commercial and academic fields has dramatically expanded in recent years and has the potential to play an essential role in food production in the future (Goddek et al., 2016; Junge et al., 2017). In addition, aquaponics has the potential to move food production to regions with severe water restrictions. The location of the aquaponics facility close to the town center can reduce the costs associated with the transportation, storage, and processing of vegetable crops (Savidov and Brooks, 2004).

Aquaponic systems are scalable and flexible, featuring systems; therefore, they could be done from small systems to extensive capacity facilities and installed in a broad environment from the basement to the roof, even to the desert. In addition, aquaponics is a suitable food production technique for indoor culture (Yanes et al., 2020). However, artificial lighting must be installed in places where the sun does not reach, such as basements in the city, and to increase efficiency in winter when the sunlight is limited (Hernández and Kubota, 2015). Indoor lighting can be carried out with different lighting types such as fluorescent (FLO), high-pressure sodium (HPS), induction, and light-emitting diode (LED). The source of artificial lighting may dramatically effect on plant anatomy and morphology, food intake, and pathogen development (Massa et al., 2008). Light is a source of energy for photosynthesis and has a signal feature that affects plant growth, flowering timing, and morphogenetic features such as plant height and shape (Xu, 2019). Thus, it is also possible to increase production efficiency by expanding the photoperiod in the seasons when the natural daylight is short and insufficient (Nelson and Bugbee, 2014). Each light source has different electricity consumption, which is another crucial point of view of aquaponics sustainability. Considering that electricity consumption causes the highest cost in aquaponic systems (Forchino et al., 2017), the correct light source selection becomes even more important. In addition, it may be possible to change the light spectrum to suit the welfare of the fish cultured in indoor RAS (Karakatsouli et al., 2010). Light systems impact aquaculture systems' productivity, particularly regarding animal health, growth, and product quality (Tielmann et al., 2017; Bögner et al., 2018). Although research on indoor lighting has been going on for two decades, more information should be learned about the effects of LEDs on a variety of vegetables for larger-scale industrial applications (Olle and Viršilė, 2013). While light-emitting diodes (LEDs) have technical advantages over conventional lighting sources, they have recently been tested only for horticultural applications (Mitchell et al., 2012).

This study aimed to investigate LED, HPS, and FLO light sources in aquaponics systems for joint production of different plants (lettuce (*Lactuca sativa*), parsley (*Petroselinum crispum*) and cress (*Lepidium sativum*)) and koi fish (*Cyprinus carpio* var. koi).

Material and Methods

Experimental Design

This research was carried out at Sapanca Inland Fisheries Production Research and Application Unit, Faculty of Aquatic Sciences, Istanbul University. The aquaponics system in which the experiment was conducted consisted of three plant grow beds (220 x 50 x 25 cm) with a volume of 200 L, a circular fish tank with a volume of 750 L, and a sump with a volume of 330 L. Fish reared in a circular fiberglass growing tank which has 750 L water volume. Discharge of nutrient-rich water flows by gravitation from the fish tank into the sump. The mechanical filtration unit removed organic material from the fish tank and let the clean water pass into the biological filter. After the microbial process by which autotrophic bacteria oxidize ammonium to nitrite and then to nitrate, water is pumped to the plant-growing beds by a submersible water circulation pump. Nutrients from the plants and effluent water turn again into the fish tank (Figure 1).

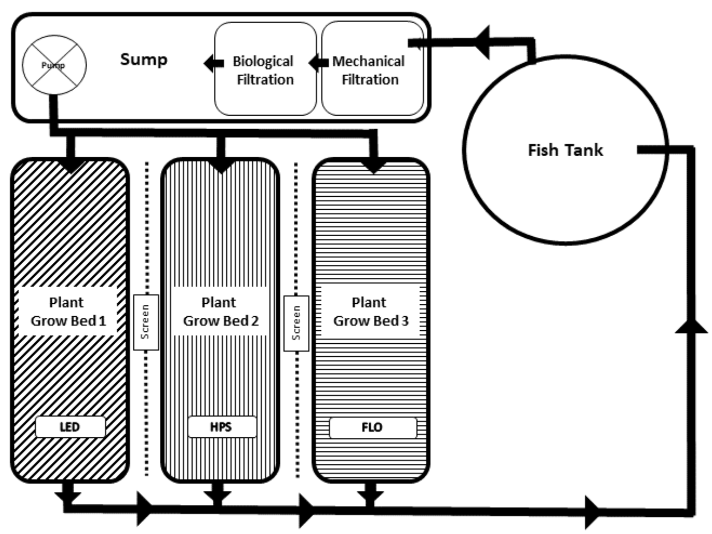

Figure 1. Schematic design of experimental aquaponics system

Light Sources

LED (light emitting diode lamp 200 w, 20000 lumens), HPS high-pressure sodium lamp 200w, 20000 lumens), and Fluorescent (FLO) (200w, 20100 lumens) lamps are used on plant grow beds in the trials. The light sources were adjusted to close standards according to the number of LUX values falling on the leaves and monitored with a digital light meter (MASTECH MS6610, Pittsburgh) (Figure 2).

Figure 2. The plant grow beds under LED (upper left), HPS (bottom middle), and FLO (upper right) lights in the experimental aquaponics system

Fish and Growth Performance

The total biomass of 43 koi fish (*Cyprinus carpio* var. *koi*) used in the experiment was 3628 g (average fish weight 84.37 g). Fish weight and height were measured at two-week intervals. The mean weight of fish was calculated total biomass of fish x number of fish^{-1}. According to Bhaskar et al. (2015), to determine the growth performance of koi fish in the aquaponics system;

Fish Weight Gain (FWG) is calculated as the final weight of fish (g) – the initial weight of fish (g). Fish Growth Rate (FGR) is calculated as $(W_2(g) – W_1(g) \times W_1^{-1}(g)) \times 100$. Specific Growth Rate (SGR) was calculated as $(lnW_2 – lnW_1) \times t^{-1} \times 100$, where W_1 and W_2 were fish weights (g) at the beginning and end of the experiment, and t was the length (d) of the experiment. Feed Conversion Ratio (FCR) was calculated as feed intake (g) x biomass gain^{-1}.

Plant and Growth Performance

In each plant experiment, a total of 84 plant seedlings were used, a total of 28 each under the three different lights on the plant beds. Since three different plants (parsleys, lettuces, and cress) were used, a total of 252 plants were cultivated during all experiments. Measurement of the plant height (cm), root length (cm), and total plant weight (g) of the parsley, lettuce and cress plants were made at the beginning and end of the experiment in each group using scales with a precision of ±0.01 (Radwag, Poland), and the total number of leaves (pieces) were counted (Figure 3).

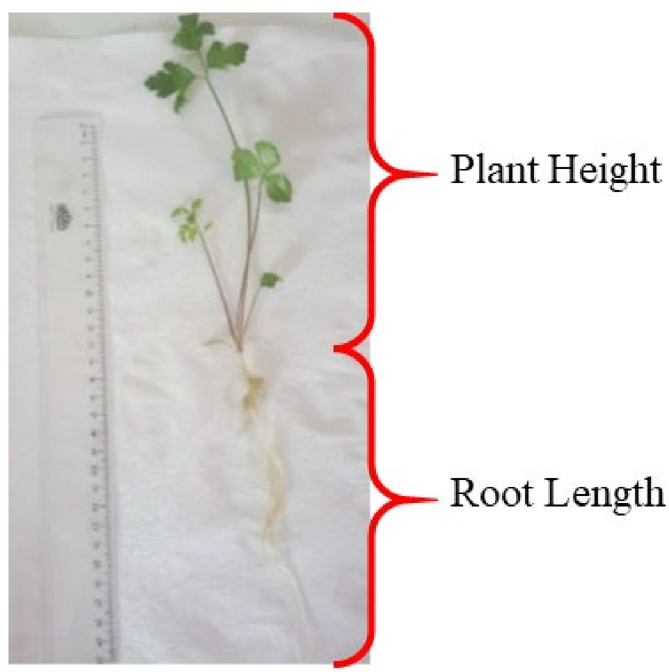

Figure 3. Measurements of plant height and root length

When all the measurements were done, seedlings were transplanted onto the rockwool cubes (cube size: 4.0 cm long x 4.0 cm wide x 4.0 cm high) onto plant growth beds of the aquaponics system, which sets subjected to the different lighting treatments. In the initial plant measurement data, the difference of variation between individuals was kept to a minimum in terms of not creating an effect between groups. The initial values for the plants are summarized in Table 1.

Table 1. Initial plant growth parameter values for plants (parsley, lettuce, and cress)

Parameters	Parsley	Lettuce	Cress
Individual biomass (g)	0.81±0.01	1.50±0.21	0.19±0.05
Plant Height (cm)	5.33±1.67	10.22±0.98	8.24±0.99
Leaf number	1.00±0.01	3.00±0.01	5.14±0.42
Root Length (cm)	3.94±0.63	6.08±0.79	3.63±0.82

In this study, harvest periods were reported as 45 days for parsleys, 44 days for lettuces, and 42 days for cress.

Water Quality Parameters in Aquaponics System

Dissolved oxygen (DO), temperature (°C), electrical conductivity (EC), and pH were checked before fish were fed with extruded pellet feed in the morning daily. Temperature and pH were measured using a 3110 pH meter with SenTix® 41 Epoxy Electrode (WTW, Germany), DO was measured with an oxygen meter (OxyGuard Handy Polaris probe, Birkerød, Denmark), and EC using a digital pen-type portable TDS meter (Az Instrument, Taiwan).

Total ammonia-nitrogen (TAN), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), and iron were measured according to APHA (2005) once a week using by spectrophotometer (Shimadzu, Kyoto, Japan).

Statistical Analysis

The obtained data were analyzed by using statistical software (IBM SPSS v.21, USA) in which one-way ANOVA and the post hoc Tukey's test were performed at a significance level of ($P<0.05$) at 95% confidence limits to know the significant difference between the treatments means for different parameters.

Results and Discussion

The water quality of the aquaponics system was monitored as the mean of daily temperature (°C), dissolved oxygen (mg/L), pH, and electrical conductivity (µS/cm) parameters were presented in Table 2 during each plant growing period.

Table 2. Temperature (°C), dissolved oxygen (mg/L), pH and electrical conductivity (µS/cm) parameter values of system water which measured daily during each plant growing period.

Groups	Temperature (°C)	Oxygen (mg/L)	pH	EC (µS/cm)
Parsley	21.23±0.98	6.99±0.34	7.08±0.41	503.43±49.58
Lettuce	17.82±1.40	6.31±0.56	7.22±0.13	536.11±30.79
Cress	16.58±1.57	5.43±0.54	7.26±0.09	442.88±32.14

Mean water temperature has been measured lower than other species during the trial of the cress plant due to the ambient temperature in winter. In addition, when the electrical conductivity values were examined, it was seen that it was lower than lettuce and parsley during the growth of the cress plant. However, during the study, each plant's growing conditions were kept suitable for aquaponic systems for each species according to Somerville et al. (2014). At the end of the experiments, the mean measurements such as phosphate, total phosphorus, nitrite, nitrate, and iron, are shown in Table 3.

It has been determined that lettuce was more successful in using nitrate in water than parsley and cress plants. Looking at the values in Table 3, it is understood that as time progress, the nitrate in the water in the lettuce plant decreases continuously, while it remains relatively constant in the cress, and it increases in the parsley. According to Liu et al. (2016), the lettuce plant absorbed more nitrate under LED light than fluorescent light and HPS light. This study showed why lettuce plant creates larger biomass in LED light, and the results confirm our work.

Harvest results of plants, such as individual biomass (g), plant height (cm), leaf number, and root length (cm) parameters, were summarized in Table 4.

Table 3. Water quality parameter values such as Phosphate (PO_4), total phosphorus (TP), nitrite (NO_2), nitrate (NO_3), and iron (Fe) during the Parsley, Lettuce, and Cress production periods.

Parameters (mg/L)	Species	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	(Mean ±SD)
PO_4	Parsley	0.63	1.26	2.05	2.74	3.19	3.61	3.62	2.44±1.08
	Lettuce	0.81	5.78	5.2	5.25	5.78	4.7	4.71	4.60±1.60
	Cress	4.71	1.86	2.86	2.91	3.45	2.45	2.13	2.91±0.88
TP	Parsley	0.96	1.89	2.4	3.08	3.88	4.51	4.15	2.98±1.20
	Lettuce	1.23	6.08	6.03	5.96	5.91	5.44	5.27	5.13±1.62
	Cress	5.27	2.39	3.58	3.66	4.19	2.79	2.3	3.45±0.99
NO_2	Parsley	0.07	0.03	0.14	0.08	0.12	0.14	0.02	0.09±0.05
	Lettuce	0.04	0.73	0.42	0.34	0.27	0.39	0.09	0.33±0.21
	Cress	0.09	0.15	0.09	0.07	0.12	0.44	0.13	0.16±0.12
NO_3	Parsley	9.05	8.42	13.24	19.16	21.92	28	29.84	18.52±8.01
	Lettuce	29.08	26.07	23.75	15.31	13.54	9.98	2.38	17.16±8.88
	Cress	2.38	0.35	0.3	1.24	0.37	1.11	1.04	0.97±0.68
Fe	Parsley	0.02	0.03	0.05	0.04	0.04	0.05	0.04	0.04±0.01
	Lettuce	0.03	0.09	0.07	0.09	0.1	0.1	0.16	0.09±0.04
	Cress	0.16	0.24	0.4	0.34	0.25	0.22	0.15	0.25±0.08

Table 4. Effect of lighting with HPS, LED, and FLO lamps on the individual biomass (g), plant height (cm), leaf number, and root length (cm) of parsley, lettuce, and cress end of the experiments.

Plant variable	Species	HPS	LED	FLO
Individual biomass (g)	Parsley	8.76±7.32 ^{a}	7.45±4.13 ^{a}	2.04±1.96 ^{b}
	Lettuce	54.09±25.60 ^{a}	60.83±19.39 ^{a}	17.81±6.40 ^{b}
	Cress	1.03±0.58 ^{a}	1.15±0.46 ^{a}	1.31±0.58 ^{a}
Plant Height (cm)	Parsley	22.04±5.32 ^{a}	15.14±3.71 ^{b}	12.45±3.57 ^{b}
	Lettuce	55.25±14.85 ^{a}	54.96±15.22 ^{a}	29.79±12.40 ^{b}
	Cress	10.37±2.62 ^{a}	9.35±1.73 ^{a}	12.70±2.66 ^{b}
Leaf number	Parsley	7.54±1.07 ^{a}	7.96±1.40 ^{a}	5.61±0.99 ^{b}
	Lettuce	28.25±4.03 ^{a}	24.54±3.31 ^{b}	20.18±1.59 ^{c}
	Cress	12.96±2.81 ^{a}	12.61±1.77 ^{a}	15.04±2.06 ^{b}
Root length (cm)	Parsley	22.54±12.67 ^{a}	18.00±7.29 ^{a}	9.25±5.17 ^{b}
	Lettuce	37.30±12.57 ^{a}	43.54±11.58 ^{a}	18.59±11.80 ^{b}
	Cress	6.22±1.23 ^{a}	7.06±1.83 ^{b}	6.20±0.61 ^{a}

Data were subjected to one-way ANOVA ($n = 29$). Means within a line followed by different letters are significantly different at $p < 0.05$ according to the posthoc Tukey test.

There was no significant difference between groups for parsley and cress on individual biomass (g) values. However, in the lettuce plant, the individual biomass (g) of the fluorescent light group (17.81 ±6.40 g) was three times lower compared to HPS (54.09 ±25.60 g) and LED (60.83 ±19.39 g) light.

The plant height of lettuce and cress plants was statistically the same between HPS (55.25 ±14.85 cm, 10.37 ±2.62cm respectively) and LED (54.96 ±15.22 cm, 9.35 ±1.73 cm respectively) but low in fluorescent light (29.79 ±12.40 cm, 12.70 ±2.66 cm respectively) have been found. The highest results in the height of the parsley plant were observed in HPS (22.04 ±5.32 cm) light, and the difference between LED (15.14 ±3.71 cm) and FLO (12.45 ±3.57 cm) lights were found to be insignificant.

In the number of leaves of parsley and cress plants, between HPS (7.54 ±1.07 and 12.96 ±2.81, respectively) and LED (7.96 ±1.40 and 12.61 ±1.77, respectively) lights, there was no significant difference. The number of leaves in plants under the FLO light (5.61 ±0.99 and 15.04 ±2.06, respectively) was significantly different and lower than in other light sources. In the lettuce plant, we found that the HPS group had the highest leaf number (28.25 ±4.03), followed by LED (24.54 ±3.31) and the lowest FLO (20.18 ±1.59).

The harvest period, after the seedlings are planted in the system, varied widely among the species. Martineau (2012) harvested the lettuce plants in 28 days, Roosta (2014) reached the harvest time in 45 days in his study with parsley, and Buzby et al. (2016) harvested the cress plant in 36 days. These harvest times are obtained as similar in other scientific studies.

Although there was no significant difference between the groups in the cress plant, the performance of HPS and LED lights in parsley and lettuce plants was found to be higher than the FLO light source. As reported by Martineau (2012), HPS, LED, and regular light applications achieved 114.3 ±54.2 g, 94.3 ±46.5 g, and 102.5 ±28.7 g fresh lettuce mass values, respectively. Lettuce plants not exposed to any additional artificial light created 82.3 ±38.2 g of fresh biomass in the same study. Both LED and HPS light applications were significantly similar in the production of fresh and dry biomass for lettuce; the HPS light is reported to be slightly larger in fresh biomass compared to LED light, but the difference is not significant. This study confirms the results of our study.

There is a strong relationship between biomass gain and feed intake of the fish in aquaponics. The mean initial biomass of fish was 3628 g at the start of the experiment, and it reached 5442 g at the end of the study with the feed intake of fish. At the end of the experiment, it was determined that among the 3 groups, the fish in the lettuce group showed the highest growth rate of 17.86% (Tables 5 and 6).

Table 5. Total Initial Fish Weight, Individual Initial Fish Weight, Total Final Fish Weight, and Individual Final Fish Weight values in the experimental groups.

Groups	Total Initial Fish Weight (g)	Individual Initial Fish Weight (g)	Total Final Fish Weight (g)	Individual Final Fİsh Weight (g)
Parsley	3628	84.4	4193	99.8
Lettuce	4193	99.8	4942	117.7
Cress	4942	117.7	5442	132.7

Table 6. Fish weight gain (g), Fish growth rate (%), Specific growth rate (%), and Feed conversion ratio values for each plant growth period.

Periods	FWG (g)	FGR (%)	SGR (%)	FCR (%)
Parsley	565	15.57	0.33	2.38
Lettuce	749	17.86	0.35	3.74
Cress	500	10.12	0.23	3.13

FWG: Fish Weight Gain calculated as the final weight of fish (g) – the initial weight of fish (g)
FGR: Fish Growth Rate calculated as (W_2 (g) – W_1 (g) x W_1^{-1} (g)) x 100
SGR: Specific Growth Rate calculated as ($ln W_2 – ln W_1$) x t^{-1} x 100, where W_1 and W_2 were fish weights (g) at the beginning and end of the experiment, and t was the length (d) of the experiment.
FCR: Feed conversion ratio was calculated as feed intake (g) x biomass gain^{-1}

The water quality parameters of the system were determined to be of good quality for the plant growing conditions. In this study, in which three different plant and light trials were used, it was observed that the koi fish were healthy during the experiment in the aquaponics system.

The FCR value ranged from 1.95 to 6.49 and the SGR value ranged from 0.29 to 0.84 in a study by Hussain et al. (2014) with juvenile koi fish, which they raised from 4.22 g initial weight to 6.81 g final weight at a water temperature of 24.03°C (Hussain et al., 2014). In a study by Hussain et al. (2015) using juvenile koi fish that they reared from 5.97 grams initial weight to 8.60 g final weight at a water temperature of 25°C, the FCR value varied from 2.28 to 2.34, and the SGR value was varied from 0.80 to 0.83 (Hussain et al., 2015). In a study conducted by Nuwanski et al. (2016) with juvenile koi fish, which they brought from 2.45 grams initial weight to 3.36 grams final weight, at 25.56°C water temperature, the FCR value was 5.6, and the SGR value was 0.7 (Nuwanski et al., 2016). Nuwanski et al., (2017) used koi fish that had an initial fish weight of 0.30 and final fish weight of 2.24, and they found SGR 3.32 ±0.03, FCR 1.32 ±0.03. In an aquaponic study, which was carried out at 22.5-27.4°C water temperature and 2% feeding rate, in 60 days when juvenile koi weighing 4.04 g were brought up to 6.99 g, FCR values of 4.13-5.29 and SGR values of 0.73-0.94 has been reported (Nuwanski et al., 2019). According to Nuwansi et al. (2020), which is also an aquaponic study, while koi fish were increased from 6.94 to 12.66 g at high temperatures (27.8-28.3°C), FCR values of 3.31-3.41 and SGR values of 1-1.04 were obtained. In this study, the water temperature was kept at about 17-21°C in the system, which is a relatively low water temperature compared to mentioned studies. In addition, the initial fish weights used in our study were relatively higher than in the mentioned studies. These could explain FCR, and SGR differentiation from the mentioned koi fish reared in aquaponics studies.

Although indoor lighting is performed with different types of illumination sources such as fluorescent (FLO), high-pressure sodium (HPS), induction, and light-emitting diode (LED), it is essential to know which source is the most suitable for the particular plant. It is known that artificial lighting can have dramatic effects on the source, plant anatomy and morphology, food intake, and pathogen development (Massa et al., 2008). In addition, light is both an energy source for photosynthesis and a signal property that affects plant growth, flowering timing, and morphogenetic characteristics such as plant height and shape (Xu, 2019).

Each light source needs its climate set points for the optimum growth performance of the plant (Dueck et al., 2011). It has been reported that different light sources can alter the metabolite status in plant bodies (Fukuda, 2019). LED lights are known to have some advantages such as adjustability of the light spectrum, small size, long-lasting, low heat effects to the ambient for plants (Lin et al., 2013; Oliver et al., 2018). At the same time, it has been shown in studies that LED lights can achieve the same efficiency by consuming 75% less energy compared to light sources such as Metal Halide (Singh et al., 2015).

Conclusion

In conclusion, the experiment realized in the aquaponics system showed that using HPS or LED lights has the potential to produce adequate amounts of parsley and lettuce. It has been found that HPS and LED light sources provide a similar increase in plant biomass in all species, but fluorescent light is insufficient against these two light sources. Despite the high initial cost, LEDs stand out as the right choice for installation for their narrow bandwidths and easy adjustment, allowing their arbitrary combinations to suit any plant at any stage. Therefore, LEDs can be considered the most promising source for plant lighting. In the future, it seems possible that other artificial lighting sources will be gradually replaced by LEDs by providing technological developments and price reductions. Further experimentation for different plants under various growing conditions is recommended to obtain the necessary data on improving the artificial lighting performance of the aquaponics system.

Compliance with Ethical Standards

Conflict of interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Ethics committee approval: All experiments in this study were carried out in accordance with the "Regulation on the Welfare and Protection of Aquatic Vertebrates Used for Scientific Purpose" from the Republic of Turkey Ministry of Agriculture and Forestry (30751).

Funding disclosure: This work was supported by the Scientific Research Projects Coordination Unit of Istanbul University. Project number 27335.

Acknowledgments: We thank Istanbul University, Faculty of Aquatic Sciences, Limnology Laboratory's staff who helped us with the water parameters measurement.

Disclosure: -

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