# Effect of polyculture and monoculture of Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) on water quality, growth performance and productivity of vegetables in an aquaponics system (ASTAF-PRO)

[1]Aya H. Khalil, [2]Ahmed E. A. Badrey, [1]Ahmed S. Harabawy, [1]Ahmed T. A. Ibrahim, [3]Werner Kloas, [2]Alaa G. M. Osman

[1] Department of Zoology, Faculty of Science, New Valley University, Kharga, Egypt; [2] Department of Zoology, Faculty of Science, Al-Azhar University, Assiut, Egypt; [3] Department of Ecophysiology and Aquaculture, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany. Corresponding author: A. E. A. Badrey, ahmedbadrey765.el@azhar.edu.eg

**Abstract**. The current research is part of a collaborative initiative aimed at facilitating the effective transfer of the breakthrough ecotechnology ASTAF-PRO aquaponics from Germany to Egypt, for the purpose of sustainable aquaculture and food production. The present study was conducted to assess the effects of mono and polyculture systems in ASTAF-PRO of monosex Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) on water quality, growth performance, and productivity of vegetables for 90 days. The results indicated that there was a significant increase ($p<0.05$) in the final weight of monosex Nile tilapia and common carp compared to the initial values in polyculture, with a remarkable increase in the average weight over time. Food conversion ratio, condition factor, specific growth rate, and survival rate were better in polyculture. In addition, the ASTAF-PRO unit had two vegetable crops as a secondary product, which increased the productivity of the system. Therefore, polyculture gave the higher plant production. Aquaponics can be considered a strategic alternative to conventional agriculture in Egypt today, and will be a strong alternative to land reclamation and traditional farming methods in the future.
**Key Words**: aquaponics, Egypt, growth, hydroponic production, monosex.

**Introduction**. Aquaculture is one of the major food sectors in the world when it comes to animal protein production. This industry's future growth will also focus on land-based recirculated aquaculture systems (RAS) (Khalil et al 2021). Aquaculture, like all other food production industries, faces problems in terms of long-term sustainability. FAO has recently placed a focus on improving fish output through integrated aquaculture and agriculture farming systems. In this situation, aquaponics methods may be a viable alternative for long-term aquaculture growth (Roy et al 2013). Climate change, rising global population, limited natural resource availability, and the spread of pandemics are all threatening food security (Kummu et al 2012; Khalil et al 2021). Aquaponics systems may be an answer to the aquaculture industry's increasing issues, such as limited water supplies and wastewater discharge into natural water bodies (Nuwansi et al 2016). Aquaponics are complicated systems, and there is insufficient information on the optimal plant nutrient balance in connection to the amount and species of fish, feed, system design, and plant and fish illnesses (Goddek et al 2015; Khalil et al 2021).

In order to create a balance between fish, plant, and bacterial requirements, the RAS element of the aquaponics system must be stabilised with regard to water quality parameters (Yildiz et al 2017). As a result, the plants will grow well. The primary concept is to maximise agricultural productivity while minimising environmental impact (Suhl et al 2016). Aquaponics systems also perform well in terms of water and resource consumption, according to data from various studies (Reyes Lastiri et al 2016; Goddek & Vermeulen 2018). In aquaponics, water flow is essential for the wellbeing of organisms. The dissolved nutrients are removed when the water flows from the fish tanks to the plants in their media beds, pipelines, or canals (FAO 2014). Plants absorb nutrients in aquaponics and assist in cleansing the water of the fish (Nuwansi et al 2016).

To reduce interspecific competition as much as possible, all polyculture techniques necessitate compatibility across co-farmed taxa, assuring animal welfare and, ultimately, the farming system's performance. Some aquaculture methods and technologies are being developed with the goal of increasing production while reducing environmental impacts to assure food safety and sustainability (Bakeer et al 2008). Due to Egypt's limited freshwater resources, the development and expansion of aquaculture output can be achieved by increased fish stocking density, artificial feeding, and, most notably, the widely used polyculture system of several fish species (Abdel-Hakim et al 2012). The principle of polyculture is based on the fact that cultured fish species represent different levels of the food chain and feed in different parts of the water (Milstein et al 2002).

Stocking two or more complimentary fish species can increase the maximum productivity of a pond by allowing a wide range of available food items and the pond volume to be utilised (Hassan 2011). Polyculture is one system for improving fish production yields by maximising the use of available resources (Mehrim et al 2018). In addition, polyculture can have positive effects on long-term ecological stability and function (Gooley & Gavine 2003; Mehrim et al 2018). The majority of Egypt's aquaculture output is from ponds utilising polyculture farming techniques (GAFRD 2010). Aquaponics fish polyculture and recirculating aquaculture are two possible ways of practicing sustainable agriculture through biological controls. Currently, there is a need and urgency for sustainable aquaculture development.

The population of Egypt, as well as the population of the globe, is increasing, posing a serious threat to food security. Egypt has only lately emerged as an example of a rising country grappling with land and water shortages and a rapidly increasing population (Kishk 1993). Climate change, population and economic expansion, are altering the Nile River's water availability in Egypt today. Egyptian agriculture is facing significant challenges nowadays, mainly due to its high dependence on irrigated crops, which are negatively affected by Egypt’s dry climate, rising population, and increasing water demands. Part of the answer is to use contemporary food production systems like aquaponics to produce more crops per unit of water (raising water productivity). The development of plants in a soilless media in which all of the nutrients provided to the crop are dissolved in water is known as hydroponics.

The choice of tilapia and common carp to be used experimentally in aquaponics systems could be referred to their rapid growth rate and resistance to poor water quality and disease, in addition to their tolerance to a wide range of environmental conditions (Shamsuddin et al 2012; Eissa et al 2015). The present study was conducted to determine some of the challenges and opportunities of polyculture in aquaponics for sustainable food production, water quality, growth performance, and to compare plant growth and productivity in polyculture and monoculture. Another objective was to plant different crops in aquaponics.

**Material and Method**. The current experiment was carried out at the Department of Zoology (aquaponic unit), Faculty of Science, Al-Azhar University (Assiut branch), Assiut, Egypt.

***Experimental design***. 800 apparently healthy live Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) were obtained from a private hatchery from Kafr El-Sheikh, Egypt, with an average body weight of 1.1±0.2 g. Before beginning the experiment in the aquaponics system ASTAF-PRO unit, fish were acclimatized in the laboratory for 21 days. This design followed the method of Kloas et al (2015) and Osman et al (2021), with minor changes. The fish were then divided into three groups: monoculture Nile tilapia (200 fish in rearing tank number 1); monoculture common carp (200 fish in rearing tank number 2); polyculture Nile tilapia and common carp (200 fish in rearing tank number 3). Each tank had a volume of 1 $m^3$. All fish were fed 7% of their body weight twice daily at 9:00 AM and 4:00 PM, six days a week. The diet containing 30% protein used in the experiment was formulated to cover all nutrients required by tilapia and common carp, as recommended by NRC (1993) (Table 1). The fish were reared for three months, between 1 August and 30 October 2020.

Table 1

The composition of the experimental diets

| *Items* | *Percentage* |
|---|---|
| Fish meal (65% protein) | 7 |
| Soy bean meal | 25 |
| Corn gluten | 8 |
| Yellow corn | 10 |
| Wheat bran | 15 |
| Rice bran | 30 |
| Fish oil | 2 |
| Premix | 3 |
| Total | 100 |

***Water quality***. Daily and weekly measurements of water quality parameters before feeding were conducted. Temperature and dissolved oxygen were determined by an oxygen probe (YSI, Pro ODO, Yellow Springs, USA) and pH was measured using a portable pH meter (Hach, Sension 1, Loveland, USA). Total ammonia (TA) was monitored weekly using a colorimeter (Hach, DR/850, Loveland, USA). These parameters were maintained at a suitable limit for Nile tilapia and common carp rearing, by syphoning and removing waste, with periodical water replacement.

***Evaluation of growth performance***. Monthly growth measurements of Nile tilapia and common carp were done by randomly sampling and bulk-weighing at least 25% of both Nile tilapia and common carp. Growth performance was measured using the following parameters: initial weight (IW, g), initial length, final body weight (FW, g), total weight gain (TWG, g), specific growth rate (SGR, % $day^{-1}$), feed conversion ratio (FCR), survival rate (SR, %), and condition factor (K).

SGR = 100 [(FW)-(IW)]/number of experimental days

FCR = feed fed (g) (dry weight)/WG (g)

SR% = (number of fish at the end/number of fish at the start)*100 (Ricker 1975)

K = fish weight (g) x 100 $L^3$ (cm)

***Plant growth***. 2 crops were grown during the experiments in polyculture and monoculture, choosing species well adapted to hydroponic production. The species used were eggplants (*Solanum melongena*) and chili peppers (*Capsicum annuum*). The seedlings were obtained from El-Salam nurseries, Assiut, Egypt. Eggplant seedlings were grown in pots containing perlite as a medium, with a density of one stem per cup, placed according to polyculture or/and monoculture, and with a distance between glasses of 15 cm. An equal number of seedlings was used in polyculture and monoculture (30 seedlings in polyculture and 30 in monoculture for each plant).

***Statistical analysis***. Data were presented as mean ±SD. The results were subjected to one-way analysis of variance (ANOVA) to test the effect of treatment inclusion on fish performance. Data were analyzed using the SPSS v. 16 software. Differences between means were compared using Duncan's multiple range tests at $p<0.05$ level.

## Results and Discussion

***Water quality parameters***. The values of the measured water quality variables (water temperature, pH, dissolved oxygen, and total ammonia) are presented in Table 2. The water temperature during the experimental period was within the range of 18.8 and 27.2°C. The pH values were between 7.1 and 8.2, and the dissolved oxygen values ranged from 5.1 to 5.9 mg $L^{-1}$. Ammonia values between 0.04 and 0.4 mg $L^{-1}$ were encountered (Table 2).

Table 2

Water quality parameters of experimental tanks

| *Parameters* | *Monoculture Nile tilapia* | | *Monoculture Common carp* | | *Polyculture Nile tilapia + common carp* | |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | Min | Max |
| Temperature (ºC) | 18.5 | 26.9 | 18.5 | 26.7 | 18.5 | 27.2 |
| pH | 7.2 | 7.6 | 7.1 | 7.4 | 7.3 | 8.2 |
| Dissolved oxygen (mg $L^{-1}$) | 5.4 | 5.9 | 5.1 | 5.8 | 4.6 | 5.2 |
| Ammonia (mg $L^{-1}$) | 0.05 | 0.4 | 0.04 | 0.21 | 0.1 | 0.3 |

***Growth performances of fish***. The growth performance parameters of monosex Nile tilapia and common carp in monoculture and polyculture in terms of initial body weight, final body weight, total weight gain, specific growth rate, feed conversion ratio, survival rate and condition factor are presented in Table 3. The average initial weight of fish was 1.1±0.2 g. The growth rate varied in between the 2 systems. In monoculture, both species showed the lowest mean final body weight, as well as the lowest total mean increase in body weight compared to polyculture (38.5, 30.5-41.2, 36.1 and 37.4, 40-29.3, 34.8 (g $fish^{-1}$) for Nile tilapia and common carp, respectively). The highest specific growth rate (SGR) value occurred in monoculture, for carp, and the lowest in the polyculture of tilapia. Generally, the carp polyculture and monoculture showed increasing SGR throughout the experiment. In polyculture, FCR decreased for both species. The FCR values of the carp monoculture were higher than those of tilapia monoculture. In polyculture, the survival rate was significantly higher for Nile tilapia than in monoculture ($p<0.05$). Tilapia reared in monoculture exhibited the lowest survival rate (82.2%), followed by carp in polyculture and monoculture, with 90 and 91%, respectively (Table 3).

Table 3

Growth parameters of Nile tilapia (*Orechromis niloticus*) and common carp (*Cyprinus carpio*) stocked under monoculture and polyculture systems

| *Parameters* | *Monoculture Nile tilapia* | *Polyculture Nile tilapia* | *Monoculture Common carp* | *Polyculture Common carp* |
|---|---|---|---|---|
| Initial body weight (g per fish) | 1.1±0.09 | 1.2±0.07 | 1.2±0.02 | 1.3±0.08 |
| Final body weight (g per fish) | $38.5±1.7^{c}$ | $41.2±1.2^{ab}$ | $30.5±0.8^{a}$ | $36.1±1.2^{b}$ |
| Total weight gain (g per fish) | $37.4±1.6^{c}$ | $40.0±1.1^{b}$ | $29.3±0.8^{a}$ | $34.8±1.2^{b}$ |
| Feed conversion ratio | $1.6±0.1^{ab}$ | $1.1±0.3^{a}$ | $2.0±0.1^{c}$ | $1.3±0.2^{b}$ |
| Specific growth rate (% per day) | $2.3±0.2^{a}$ | $2.2±0.3^{a}$ | $2.6±0.03^{ab}$ | $2.5±0.03^{b}$ |
| Survival rate (%) | $88.2±2.3^{a}$ | $94.2±1.0^{ab}$ | $91.0±1.0^{b}$ | $90.0±1.0^{a}$ |
| Condition factor | $1.2±0.1^{a}$ | $1.2±0.1^{a}$ | $1.4±1.4^{b}$ | $1.4±1.4^{b}$ |

Note: means in the same row with different superscripts are significantly different ($p<0.05$).

***Chili peppers***. Plants grow faster and healthier in polyculture than in monoculture, and they are more productive in polyculture, as shown in Figures 1 and 2. Production of chili peppers in polyculture and monoculture was 4 and 3.5 kg, respectively.

Figure 1. Chili peppers (*Capsicum annuum*) in the polyculture.

Figure 2. Chili peppers (*Capsicum annuum*) in monoculture.

***Eggplants***. Eggplants were planted in an equal number of seedlings. The polyculture eggplants grew better and faster than those in monoculture. In polyculture, they grew well, as shown in Figures 3 and 4. The productions of eggplants in polyculture and monoculture were 5 and 4.5 kg, respectively.

Figure 3. Eggplants (*Solanum melongena*) in polyculture.

Figure 4. Eggplants (*Solanum melongena*) in monoculture.

According to Trang et al (2017), Setiadi et al (2018), and Estim et al (2019), aquaponics can enhance water quality and increase fish survival when compared to conventional fish farming. Water quality factors such as temperature, pH, oxygen, nitrate, nitrite, and ammonia generally affect fish growth performance and health (Islam et al 2018). The water quality parameters of the culture medium were within acceptable ranges for fish (Boyd 1990; Omitoyin 2007). The recorded temperature in the experiment was between 18.5-27.2ºC, with ni differences between treatments. Although the water temperature fluctuated day by day, it was in the optimal range for tilapia growth. Sallenave (2016) explained that temperature is important not only for the fish itself in an aquaponics system, but also for the plant growth and the optimum performance of the biofilter (nitrifying bacteria). Water temperatures that ranged from 18.5 to 32.9°C and 15-30°C, respectively, are suitable for fish culture (Boyd 1990; Omitoyin 2007; Sallenave 2016; Islam et al 2018; and Osman et al 2021).

The pH is the most interactive parameter with other water quality parameters (Essa & Sayed 2015). The pH can affect fish health when it rises or falls above the allowable limit, but in this study, the pH of the aquaponics was within the allowable limit, according to Boyd (1998) and Osman et al (2021), who reported that the optimum pH for fresh water fish is usually between pH 7.5 and 8.5.

Dissolved oxygen is also a critical environmental factor linked to the proper physiological functions of fish, being a limiting factor for fish lifespan (Zhao et al 2018). In this study, it was observed that the polyculture treatment had a lower DO level compared to the other groups. This observation is congruent with the findings of Osman et al (2021), who observed that dissolved oxygen levels in the ASTAF-PRO ranged from 4.4 to 5.7 mg $L^{-1}$ and in the POND system from 4.5 to 6.6 mg $L^{-1}$. The mean values of the DO obtained in this study were within the recommended range, between 4 and 6 mg $L^{-1}$ (Eding et al 2009).

In fish production systems, ammonia is the most common nitrogenous excretory product of fish. In aquaponics, the toxic ammonia is converted first to nitrite and then to nitrate through biofiltration (Nelson 2008). The ammonia level in this study was less than the recommended value of 1 mg $L^{-1}$ (van Rijn & Rivera 1990; Osman et al 2021). This means that aquaponic systems are extremely effective at decreasing waste, particularly total ammonia, while also offering one of the greatest water quality management systems available (Savidov & Brooks 2004). This finding is consistent with previous studies that found a reduction in total ammonia in aquaponic systems (Endut et al 2009; Eissa et al 2015; Osman et al 2021).

The growth pace varies with species, and sometimes even within species, being influenced by a variety of factors such as seasonality, availability of food and oxygen, stocking density, aquaculture system, age and others (Viadero 2005). In the present study, the obtained data showed that the growth performance of fish was affected in polyculture. The average final body weight of monosex Nile tilapia and common carp increased over time, recording good growth for fish in polyculture. The obtained results are in accordance with the findings of Mehrim et al (2018), who recorded the same result for *O. niloticus* reared in a polyculture system with *M. cephalus* at a stocking rate of 75% to 25%. Improving growth performance may be related to mixed fish species, which can show symbiotic effects and provide nutrients for other organisms (Mehrim et al 2018). Tahoun et al (2013) indicated that tilapia–mullet polyculture led to improving water quality and increasing growth performance, which enhanced the efficiency of natural food resources and system sustainability. As a result, species cultivated together in one pond as part of a polyculture approach tolerate each other's presence, and one species helps the other species develop and feed more efficiently (Papoutsoglou et al 1992; Mehrim et al 2018). FCR and SGR are important indicators of fish feed quality. A lower FCR indicates better feed utilisation (Mugo-Bundi et al 2013; Opiyo et al 2014). In the present study, the FCR values were lower and better in polyculture compared to monoculture. Our results are in line with those of Rakocy et al (2016), where FCR ranged from 1.7 to 1.8.

The survival rate of tilapia in this study is better than that reported by Mulqan et al (2017) and Andriani et al (2019) in aquaponics using water spinach. However, the overall survival rate of tilapia in this study was high, above 80% (SNI 2009). The condition factor K is an index that reflects interactions between biotic and abiotic factors in the physiological condition of fish (Ali et al 2015). The results of the present study indicated that the fish in all the groups had a high condition factor (Table 3).

Plant growth is affected by the amount of nutrients absorbed. Ammonia from feed and fish metabolism is broken down into nitrogen used by plants. Plant growth is in line with the reduction of ammonia levels in the water (Endut et al 2009). Plant selection in aquaponics is related to fish density and nutrient concentrationa. In an aquaponic recirculation system, a hydroponic section serves as a biofilter (Endut et al 2009).

**Conclusions**. The integration of the hydroponic vegetable production unit into the aquaponics fish culture system was a success in this study. It was proved that an aquaponics system is an environmentally friendly, soilless, fish and vegetable production system. The study demonstrated that there was a significant difference in the growth performance of *O. niloticus* and common carp in polyculture and monoculture. Tilapia and common carp with chilli peppers and eggplants showed the best growth performance and productivity in the polyculture system. The combination of tilapia and common carp with vegetables is suitable and has the potential to be applied in an aquaponics system.

**Conflict of Interest**. The authors declare that there is no conflict of interest.

## References

Abdel-Hakim W. M., Moustafa Y. M. M., Gheeth R. H. M., 2012 Foliar application of some chemical treatments and planting date affecting snap bean (*Phaseolus vulgaris* L.) plants grown in Egypt. Journal of Horticultural Science & Ornamental Plants 4(3):307-317.

Ali A. E., Mekhamar M. I., Gadel-Rab G. A., Osman A. G. M., 2015 Evaluation of growth performance of Nile tilapia *Oreochromis niloticus niloticus* fed *Piophila casei* maggot meal (magmeal) diets. American Journal of Life Sciences 3(6-1):24-29.

Andriani Y., Anna Z., Iskandar S. Z., Wiyatna M. F., 2019 The effectiveness of commercial probiotics appropriation on feed on Nile tilapia (*Oreochromis niloticus*)'s

growth and feed conversion ratio. Asian Journal of Microbiology Biotechnology and Environmental Sciences 21(1):1-4.
Bakeer M. N., Mostafa M. A. A., Samra I. M. A., 2008 Effect of *Mugil cephalus* size and density at initial stocking on growth performance and fish marketable size at harvest. Journal of the Arabian Aquaculture Society 3(1):16-32.
Boyd C. E., 1990 Water quality in ponds for aquaculture. 2nd Edition. Auburn University, Alabama, 482 p.
Boyd C. E., 1998 Pond aquaculture water quality management. Springer Science & Business Media, 700 p.
Eding E., Verdegem M., Martins C., Schlaman G., Heinsbroek L., Laarhoven B., Ende S., Verreth J., Aarsten F., Bierbooms V., 2009 Tilapia farming using recirculating aquaculture systems (RAS) – case study in the Netherlands. Handbook for Sustainable Aquaculture, Project no. COLL-CT-2006-030384.
Eissa I. A. M., El-Lamie M. M., Hassan M. A., El-Sharksy A. M., 2015 Impact of aquaponic system on water quality and health status of Nile tilapia *Oreochromis niloticus*. Suez Canal Veterinary Medical Journal 20(2):191-205.
Endut A., Jusoh A., Ali N., Wan Nik W. N. S., Hassan A., 2009 Effect of flow rate on water quality parameters and plant growth of water spinach (*Ipomoea aquatica*) in an aquaponic recirculating system. Desalination and Water Treatment 5(1-3):19-28.
Essa M., Sayed T., 2015 Transferability of calibrated microsimulation model parameters for safety assessment using simulated conflicts. Accident Analysis & Prevention 84:41-53.
Estim A., Saufie S., Mustafa S., 2019 Water quality remediation using aquaponics sub-systems as biological and mechanical filters in aquaculture. Journal of Water Process Engineering 30:100566.
Goddek S., Delaide B., Mankasingh U., Ragnarsdottir K. V., Jijakli H., Thorarinsdottir R., 2015 Challenges of sustainable and commercial aquaponics. Sustainability 7(4):4199-4224.
Goddek S., Vermeulen T., 2018 Comparison of *Lactuca sativa* growth performance in conventional and RAS-based hydroponic systems. Aquaculture International 26:1377-1386.
Gooley G., Gavine F., 2003 Integrated agri-aquaculture systems. A resource handbook for Australian industry development. RIRDC Project no MFR-2A, 189 p.
Hassan A. A. R., 2011 Zooplankton as natural live food for three different fish species under concrete ponds with mono- and polyculture conditions. Egyptian Journal for Aquaculture 1(1):27-41.
Islam M. M., Sunny A. R., Hossain M. M., Friess D. A., 2018 Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. Singapore Journal of Tropical Geography 39(2):244-265.
Khalil S., Panda P., Ghadamgahi F., Rosberg A., Vetukuri R. R., 2021 Comparison of two commercial recirculated aquacultural systems and their microbial potential in plant disease suppression. BMC Microbiology 21:205.
Kishk M. A., 1993 Combating desertification, is it always possible? The case of small Egyptian farmers. GeoJournal 31(1):77-84.
Kloas W., Groß R., Baganz D., Graupner J., Monsees H., Schmidt U., Staaks G., Suhl J., Tschirner M., Wittstock B., Wuertz S., Zikova A., Rennert B., 2015 A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. Aquaculture Environment Interactions 7(2):179-192.
Kummu M., de Moel H., Porkka M., Siebert S., Varis O., Ward P. J., 2012 Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Science of The Total Environment 438:477-489.
Mehrim A. I., Refaey M. M., Khalil F., Shaban Z. E., 2018 Impact of mono- and polyculture systems on growth performance, feed utilization, and economic efficiency of *Oreochromis niloticus*, *Mugil cephalus*, and *Mugil capito*. Journal of Animal and Poultry Production 9(9):393-400.
Milstein A., Wahab M. A., Rahman M. M., 2002 Environmental effects of common carp *Cyprinus carpio* (L.) and mrigal *Cirrhinus mrigala* (Hamilton) as bottom feeders in

major Indian carp polycultures. Aquaculture Research 33(14):1103-1117.
Mugo-Bundi J., Oyoo-Okoth E., Ngugi C. C., Manguya-Lusega D., Rasowo J., Chepkirui-Boit V., Opiyo M., Njiru J., 2013 Utilization of *Caridina nilotica* (Roux) meal as a protein ingredient in feeds for Nile tilapia (*Oreochromis niloticus*). Aquaculture Research 46(2):346-357.
Mulqan M., El Rahimi A. S., Dewiyanti I., 2017 [The growth and survival rates of tilapia juvenile (*Oreochromis niloticus*) in aquaponics systems with different plants species]. Jurnal Ilmiah Mahasiswa Kelautan dan Perikanan Unsyiah 2(1):183-193. [In Indonesian].
Nelson R. L., 2008 Aquaponic food production: Growing fish and vegetables for food and profit. Nelson and Pade, 217 p.
Nuwansi K. K. T., Verma A. K., Prakash C., Tiwari V. K., Chandrakant M. H., Shete A. P., Prabhath G. P. W. A., 2016 Effect of water flow rate on polyculture of koi carp (*Cyprinus carpio* var. koi) and goldfish (*Carassius auratus*) with water spinach (*Ipomoea aquatica*) in recirculating aquaponic system. Aquaculture International 24(1):385-393.
Omitoyin B. O., 2007 Introduction to fish farming in Nigeria. University of Ibadan Press. 90 p.
Opiyo M. A., Githukia C. M., Munguti J. M., Charo-Karisa H., 2014 Growth performance, carcass composition and profitability of Nile tilapia (*Oreochromis niloticus* L.) fed commercial and on-farm made fish feed in earthen ponds. International Journal of Fisheries and Aquatic Studies 1(5):12-17.
Osman A. G. M., Farrag M. M. S., Badrey A. E. A., Khedr Z. M. A., Kloas W., 2021 Water quality and health status of monosex Nile tilapia, *Oreochromis niloticus* cultured in aquaponics system (ASTAF-PRO). Egyptian Journal of Aquatic Biology & Fisheries 25(2):785-802.
Papoutsoglou S. E., Petropoulos G., Barbieri R., 1992 Polyculture rearing of *Cyprinus carpio* (L.) and *Oreochromis aureus* (St.) using a closed circulated system. Aquaculture 103(3-4):311-320.
Rakocy J., Masser M. P., Losordo T., 2016 Recirculating aquaculture tank production systems: Aquaponics - integrating fish and plant culture. Oklahoma Cooperative Extension Service SRAC-454, 16 p.
Reyes Lastiri D., Slinkert T., Cappon H. J., Baganz D., Staaks G., Keesman K. J., 2016 Model of an aquaponic system for minimised water, energy and nitrogen requirements. Water Science and Technology 74(1):30-37.
Ricker W. E., 1975 Computation and interpretation of biological statistics of fish populations. Bulletin - Fisheries Research Board of Canada 191:1-382.
Roy M., Salam M. A., Hossain M. B., Shamsuddin M., 2013 Feasibility study of aquaponics in polyculture pond. World Applied Sciences Journal 23(5):588-592.
Sallenave R., 2016 Important water quality parameters in aquaponics systems. Circular 680, New Mexico State University, Las Cruces, 8 p.
Savidov N., Brooks A. B., 2004 Evaluation and development of aquaponics production and product market capabilities in Alberta. Ids Initiatives Fund Final Report, Project #679056201, 190 p.
Setiadi E., Widyastuti Y. R., Pribadi T. H., 2018 Water quality, survival, and growth of red tilapia, *Oreochromis niloticus* cultured in aquaponics system. E3S Web of Conference 47:02006.
Shamsuddin M., Hossain M. B., Rahman M. M., Asadujjaman M., Ali M. Y., 2012 Performance of monosex fry production of two Nile tilapia strains: GIFT and NEW GIPU. World Journal of Fish and Marine Sciences 4(1):68-72.
Suhl J., Dannehl D., Kloas W., Baganz D., Jobs S., Scheibe G., Schmidt U., 2016 Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. Agricultural Water Management 178:335-344.
Tahoun A. A., Suloma A., Hammouda Y., Abo-State H., El-Haroun E., 2013 The effect of stocking different ratios of Nile tilapia *Oreochromis niloticus,* striped mullet *Mugil cephalus*, and thinlip grey mullet *Liza ramada* in polyculture ponds on biomass yield, feed efficiency, and production economics. North American Journal of

Aquaculture 75(4):548-555.
Trang N. T. D., Konnerup D., Brix H., 2017 Effects of recirculation rates on water quality and *Oreochromis niloticus* growth in aquaponic systems. Aquacultural Engineering 78(B):95-104.
Van Rijn J., Rivera G., 1990 Aerobic and anaerobic biofiltration in an aquaculture unit — nitrite accumulation as a result of nitrification and denitrification. Aquacultural Engineering 9(4):217-234.
Viadero R. C., 2005 Factors affecting fish growth and production. In: Water encyclopedia. John Wiley & Sons, pp. 129-133.
Yildiz H. Y., Robaina L., Pirhonen J., Mente E., Dominguez D., Parisi G., 2017 Fish welfare in aquaponic systems: Its relation to water quality with an emphasis on feed and faeces - A review. Water 9(1):13.
Zhao Z., Dong S., Xu Q., 2018 Respiratory response of grass carp *Ctenopharyngodon idellus* to dissolved oxygen changes at three acclimation temperatures. Fish Physiology and Biochemistry 44(1):63-71.
*** FAO, 2014 Small-scale aquaponic food production. Integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper 589, 288 p.
*** GAFRD (General Authority for Fish Resources Development), 2010 The 2009 statistical yearbook. Ministry of Agriculture and Land Reclamation, Cairo, Egypt.
*** NRC, 1993 Nutrient requirements of fish and shrimp. National Academy Press, Washington D. C., 392 p.
*** SNI, 2009 [Indonesian National Standard: Bacteria identification method on conventional fish part 3: *Streptococcus iniae* and *Streptococcus agalactiae*]. Badan Standardisasi Nasional 7545(3):16. [In Indonesian].

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Authors:
Aya Hassan Khalil, Department of Zoology, Faculty of Science, New Valley University, 72511 Kharga, Egypt, e-mail: ayakhalil15296@gmail.com
Ahmed El sayed Ali Badrey, Department of Zoology, Faculty of Science, Al-Azhar University, Al-Azhar St., 71524 Assiut, Egypt, e-mail: gmal_ahmed77@yahoo.com
Ahmed Sayed Harabawy, Department of Zoology, Faculty of Science, New Valley University, 72511 Kharga, Egypt, e-mail: Harabawy2005@yahoo.com
Ahmed Thabet Abdel Ibrahim, Department of Zoology, Faculty of Science, New Valley University, 72511 Kharga, Egypt, e-mail: ahmedt1983@nvu.edu.eg
Werner Kloas, Department of Ecophysiology and Aquaculture, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany, e-mail: werner.kloas@igb-berlin.de
Alaa Gadelkarem Mahmoud Osman, Department of Zoology, Faculty of Science, Al-Azhar University, Al-Azhar St., 71524 Assiut, Egypt, e-mail: agosman@azhar.edu.eg

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