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Integrated production of fish (pacu *Piaractus mesopotamicus* and red tilapia *Oreochromis* sp.) with two varieties of garnish (scallion and parsley) in aquaponics system

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Abstract Aquaponics is emerging as an alternative for high-health food production. Being able to identify the technical viability of non-conventional plants and fish species would help to increase the interest and possibilities in aquaponic systems. The goal of the present study was to evaluate the aquaponics production of two garnish species: scallion (S) and parsley (P), using effluents of pacu and red tilapia culture. Two aquaponics devices were used, differing according to the fish species, generating two different effluents. Thus, for plant performance, four treatments were evaluated in a factorial design (plant species and fish effluent as main factors), as followed: Pacu-S, Tilapia-S, Pacu-P, and Tilapia-P, with three replicates each, for 35 days. Fish performance was evaluated using Student's *t* test. Each experimental device included a fish tank, filters, and six experimental units for the plants (floating rafts). Results

Highlights • Comparison between different species of fish and garnish in aquaponics system.
• Pacu *Piaractus mesopotamicus* can be an alternative fish species for aquaponics production.
• Scallion had perform productive better than parsley in aquaponics.
• The major productive parameters of the plants were not affected by fish species cultured.

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indicated that feed conversion ratio (FCR) was higher in tilapia as compared to pacu ($p < 0.05$); however, fish productivity and survival were similar between species. Plant performance parameters were similar with no significant differences regardless of the fish effluent ($p > 0.05$), except for higher number of leaves per plant in scallion cultured using pacu effluent. Plant performance comparing both plant species indicated that scallion performed better as compared to parsley in all parameters. In addition, scallion also performed better related to the plant quality index. The results indicate that pacu presented a viable alternative for the aquaponics production, and regarding to the garnish, scallion performed better results as compared to parsley.

Keywords Alternative species · Diversification · Sustainability · Aquaculture · Effluent

Introduction

The global population has been growing rapidly, with a matching increase in global food demand, especially for high-quality protein, which has been driving the development of several agribusiness sectors such as aquaculture (Edwards 2015). However, large volumes of water are required to produce these animal proteins. Livestock farming uses approximately 12,000 L of water to produce 1 kg of beef meat, and conventional aquaculture uses until 375,000 L to produce 1 kg of fish in a flow through system (Goddek et al. 2015). Consequently, the industrial scale practice of these activities and recent population growth have caused a serious water crisis (Mancosu et al. 2015). In order to avoid further crises related to the use of natural resources, new approaches and technologies are needed in agriculture aiming to achieve greater productivity with minimal environmental impact (Martins et al. 2010; Rijn 2013), when compared to conventional systems.

In this context, aquaponics is emerging as an alternative for food production (Buzby and Lin 2014). The technique involves the integration of aquaculture recirculation systems (intensive cultivation of aquatic organisms) with hydroponics (land plants growing in aqueous solution), only possible by microorganism's presence (Tyson et al. 2011; Rakocy 2012; Zou et al. 2016). This is because, for the ammonia excreted by the fish to become the nutrient for the plants, the system needs autotrophic nitrifying bacteria, which transform ammonia (NH_3) into nitrite (NH_2) and then oxidize to nitrate (NO_3^-), the nitrogen form most required by plants (Zou et al. 2016; Ru et al. 2017). Thus, the residual nutrients from fish farming are transformed in absorbable products by plants, supporting the development of plants and the maintenance of water quality (Endut et al. 2010; Moya et al. 2014).

The "environmental friendly" approach of this cultivation method is due to the low use of water, minimal effluent discharge, nearly full utilization of aquafeeds, and the high productivity of fish and plants compared with conventional productions (Al-Hafedh et al. 2008; Dediu et al. 2012; Mariscal-Lagarda et al. 2012). In addition, the production of chemical and antibiotics-free food (Goddek et al. 2015; Santos 2016) caters to an established consumer market that demanding high-quality fish and vegetables and is willing to pay for the added-value ecological benefits of aquaponic products (Edwards 2015).

Among the plants, options ranging from leafy vegetables, flowers, fruits, and garnishes are available (Love et al. 2015; Bailey and Ferrarezi 2017). In recent years, leafy vegetables (i.e., herbs and lettuces) are responsible for most aquaponics production around the world (Love et al. 2015; Knaus and Palm 2017), but the use of garnishes is becoming more popular because they have interesting characteristics such as fast growth, good adaptability, and applications for cooking and flavoring (Moya et al. 2014). Tilapia (*Oreochromis* sp) is the most used species in aquaponics (Tyson et al. 2011; Dediu et al. 2012; Love et al. 2015) due to good growth performance, adaptation to different environments, and can be reared across a range of water conditions (Moya et al. 2014; Goddek et al. 2015).

Other fish species are identified as potential candidates, such as catfish (Endut et al. 2010; Palm et al. 2014), rainbow trout (Forchino et al. 2017), European sea bass, (Nozzi et al. 2016) and carp (Haque et al. 2015; Shete et al. 2016), or shrimp species such as Pacific white shrimp (Pinheiro et al. 2017) and giant river prawn (Sace and Fitzsimmons 2013). Another species that could be cultivated in aquaponics is pacu (*Piaractus mesopotamicus*). This fish is relatively non-sensitive to water variations and is commercially produced in Latin America (Fernandes et al. 2000; FAO 2016), however no reports of aquaponic production with pacu were found.

For the integration between fish and plants to be successful in aquaponics, it is necessary to choose the species carefully (Knaus and Palm 2017). Water parameters that are beneficial for fish growth must be similar to those required by plants (Diem et al. 2017). Moreover, feeding management and physiology of aquatic organisms are common factors that affect nutrient availability to plants (Knaus and Palm 2017). Scarce research has been carried out to know the influence of different fish species on plant production. Palm et al. (2014) evaluated the performance of some vegetables influenced by rearing of African catfish (*Clarias gariepinus*) and tilapia, during 53 days in an aquaponic system. The authors reported tilapia culture effluent was better for lettuce, basil, and cucumber production, in contrast to African catfish results. This tendency was observed by Knaus and Palm (2017); the production of plants (basil and parsley) improved with effluent from tilapia compared with African catfish.

Knowing the technical feasibility of cultivating unconventional fish species for plant production enables producers to diversify even more the aquaponics production and can also be an important factor to reduce the risks related to market price fluctuations (Diver 2006). Moreover, the increased number of potential fishes and plant cultivars allows investors to choose species that will produce according to the local characteristics. Respectively, the market and geographic and climatic conditions of each region are important to achieve a commercially viable production (Goddek et al. 2015). With this in mind, the present study aimed to evaluate the integrated production of two different types of garnishes: parsley (*Petroselinum crispum*) and scallion (*Allium* sp.) using effluent from pacu *Piaractus mesopotamicus* and tilapia *Oreochromis* sp. culture under aquaponics condition.

Materials and methods

The study was conducted at the Aquaculture Laboratory (LAQ), from the Santa Catarina State University (UDESC), in Laguna, Santa Catarina, Brazil. The experiment was set up in a greenhouse (18 m^2, 3 m height), covered with 1.5-mm plastic liner and 50% luminosity reduction sun shade net.

Experimental design

During 35 days, two different varieties of garnish were tested: parsley (*Petroselinum crispum*) (P) and scallion (*Allium* sp.) (S), using two fish effluents (from pacu and tilapia culture), totaling four treatments (P-Pacu, P-Tilapia, S-Pacu, and S-Tilapia), with three replicates per treatment. The experimental apparatus was composed of two independent recirculation systems: one containing pacu (*P. mesopotamicus)* and the other with red tilapia (*Oreochromis* sp.*)*. Each system had six rectangular plastic tanks (0.5 m^2, 30 cm height) used as experimental units for plant culture (hydroponic system) and one main 500 L circular plastic tank used for fish culture (called "macrocosm") (Fig. 1). The floating aquaponics (Lennard and Leonard 2006) utilized one styrofoam block (50 mm, 18 kg m^{-3} density) covering all the plant tank surface in each experimental unit.

Both systems (pacu and tilapia) were equipped, in sequence, with a mechanical sedimentation filter (100 L volume conical tank, 62 cm height), a biological filter (60 L volume rectangular tank, 35 cm height and 0.23 m^2 bottom area, with 0.1 m^3 of PET caps as substrate for nitrifying bacteria, aerated with a 26-cm long Aerotube® micro-perforated diffuser), a bag filter (~ 500 μm mesh, 40 × 15 cm), and a 100 L sump plastic tank. In both systems, sedimentation and bag filters were constantly used to avoid deposition of particulate matter in the plant roots (Rakocy 2012). Water from the fish tank (macrocosm) passed through both filters by gravity until the sump, where a submersible pump (800 watts, 3500 L h^{-1}) pumped the water to the experimental units (~ 8 L min^{-1} water flow) and returned by gravity to the macrocosm. The biological filters were acclimated for 30 days for the establishment of nitrifying bacteria. Throughout the experiment, no water was exchanged; only dechlorinated freshwater was added to compensate for evapotranspiration losses.

Plants

Seedlings of parsley (mean initial weight 1.15 ± 0.36 g and mean initial height 1.08 ± 0.22 cm) and scallion (1.16 ± 0.29 g and 15.55 ± 1.71 cm) were distributed in the styrofoam trays at a density of 15 plants m^{-2}, seven seedlings from each variety per experimental unit (microcosm).

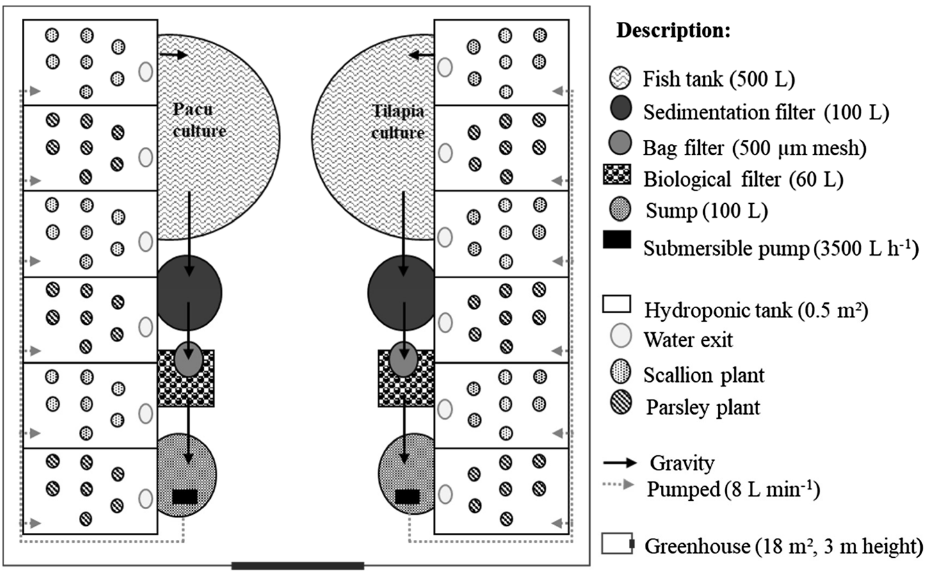

Fig. 1 Schematic overview of experimental setup, with two independent recirculation systems for the aquaponic production of garnishes (parsley and scallion) using effluent from pacu and red tilapia culture

Plant roots were constantly aerated with one airstone (20 mm diameter, 30 mm height), placed in the center of experimental units, connected to an air blower (2 hp). Final plant parameters measured were the following: height of leaves (cm), yield (kg m^{-2}), number of leaves per plant, and specific growth rate (SGR = [(ln final leaves wet weight − ln initial leaves wet weight) $time^{-1}$] 100) (% day^{-1}).

Additionally, a plant quality index (PQI) was evaluated by grades based upon visual aspects of the leaves. Visual parameters included abnormalities in the leaf surface such as yellowish color and/or imperfections (wrinkles and burns). The grades were from A to D as followed: (A) excellent, up to 5% of the leaf surface with imperfections; (B) good, up to 33% imperfections; (C) average, up to 66% imperfections; (D) poor, 100% of leaves surface with imperfections. To avoid deviations, only one trained evaluator determined the plant grades.

Fish

The fish, pacu (*P. mesopotamicus)* and tilapia (*Oreochromis sp)* ("Florida Red" strain) were obtained from a local commercial hatchery (Piscicultura Panamá, Paulo Lopes-SC, Brazil). Juvenile pacu (initial weight of 31.5 ± 12.3 g) and tilapia (31.5 ± 10.8 g) were stocked in each system, totaling initial biomass of 1.6 kg per system. Due to unavailable macrocosm repetition, fish were individual tagged with colored beads allowing fish statistical analysis.

Aeration was provided by a 30-cm diameter circle made of AeroTube® connected to the air blower (2 hp) and placed at the bottom of the tank. Fish were fed a commercial diet (32% crude protein, Nutricol, São Ludgero-SC, Brazil) three times a day (0900 h, 1400 h, and 1800 h) totaling 5% of fish biomass, which represented ~ 2 g feed day^{-1} $plant^{-1}$, adapting the method of Rakocy (2012). At the end, fish parameters evaluated were mean final weight (g), feed conversion ratio (total feed intake × $biomass^{-1}$), specific growth rate (SGR), productivity (kg m^{-3}), and survival rate (%).

Water quality

The water quality parameters of temperature and dissolved oxygen DO (YSI Mod. 55, YSI Incorporated, Yellow Springs-OH, USA) were monitored daily in the experimental units and in the macrocosms. The pH (EcoSense pH10A Pen Tester, YSI Incorporated, Yellow Springs-OH, USA) and concentrations of total ammonia nitrogen (TAN), nitrate (NO_3-N), nitrite (NO_2-N), and orthophosphate (PO_4) in the macrocosms were monitored twice a week using photo-colorimetric protocols (Alfakit AT 101, Alfakit, Florianópolis, SC, Brazil). Alkalinity was also measured twice a week, using titration method (Alfakit 2460 and 2058, Alfakit, Florianópolis, SC, Brazil).

Statistical analysis

For plant performance, data homogeneity and homoscedasticity were determined (Zar 1984), followed by analysis of variance (two-way ANOVA; using "plant species" and "fish effluent" as main factors). The Tukey test was applied to detect significant differences between treatments (Sokal and Rohlf 1995). For fish performance and water quality parameters, Student's *t* test ($p < 0.05$) was applied, also respecting normality and homogeneity assumptions (Sokal and Rohlf 1995).

Table 1 Water quality parameters measured in the fish tanks (macrocosm) during the experimental period (35 days). *SD* standard deviation, *Min* minimum values, *max* maximum values

Parameters	Pacu macrocosm				Tilapia macrocosm				Value of *p**
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	
Dissolved oxygen (mg L^{-1})	6.95	0.57	5.92	8.06	6.95	0.61	6.02	8.15	0.91
Temperature (°C)	27.10	2.54	21.40	29.70	27.14	2.41	20.70	29.80	0.74
pH	7.56	0.37	6.92	7.85	7.47	0.61	6.45	7.92	0.81
Ammonia nitrogen (mg L^{-1})	0.70	0.38	0.29	1.32	0.43	0.29	0.13	0.85	0.12
Nitrite (mg L^{-1})	0.06	0.04	0.01	0.11	0.04	0.03	0.02	0.08	0.76
Nitrate (mg L^{-1})	1.07	0.33	0.47	1.46	0.99	0.59	0.22	1.85	0.44
Orthophosphate (mg L^{-1})	9.42	3.73	5.45	14.80	8.89	3.04	4.10	12.55	0.28
Alkalinity (mg L^{-1} de $CaCO_3$)	54.00	14.19	36.00	80.00	51.14	10.70	40.00	64.00	0.77

*From Student's *t* test

Results

Water quality

Table 1 presents the descriptive statistics and Student's *t* test results of water quality parameters measured in the macrocosms (fish tanks), while Figs. 2 and 3 presents nitrogenous compounds, alkalinity, and orthophosphate fluctuations over time. All the parameters measured were similar ($p > 0.05$) between treatments. DO, temperature, and pH means were 6.95 and 6.95 mg L^{-1}, 27.10 and 27.14 °C, and 7.56 and 7.47 for pacu and tilapia macrocosm, respectively; while ammonia nitrogen, nitrite, nitrate, orthophosphate, and alkalinity were 0.70 and 0.43, 0.06 and 0.04, 1.07 and 0.99, 9.42 and 8.89, and 54.00 and 51.14 mg L^{-1}, respectively. In the experimental units (plant tanks), temperature mean values (±SD) from P-Pacu, P-Tilapia, S-Pacu, and S-Tilapia were 25.56 ± 2.20, 25.70 ± 2.01, 25.59 ± 2.28, and 25.81 ± 2.03 °C; respectively. DO mean values were 7.49 ± 0.48, 7.33 ± 0.48, 7.44 ± 0.49, and 7.32 ± 0.42 mg L^{-1}, respectively.

Plants performance

Table 2 presents the plant performance in pacu and tilapia devices. All the plant parameters were higher in scallion as compared to parsley ($p < 0.05$), regardless of fish effluent type. On the other hand, when comparing the fish effluent, just the number of scallion leaves per plant was higher in pacu device (27.5 ± 2.13) as compared to tilapia (21.33 ± 1.44). Plant mortality rates were higher for parsley (in both devices) as compared to scallion with no mortalities. In addition, plant quality index (Fig. 4) also indicated better results for scallion. Only scallion received grade A's, with higher percentage in pacu device (S-Pacu). For parsley, no grade A's were observed, and this species was the only one to receive grade D, with higher percentage in P-Tilapia (Fig. 4).

Fish performance

Fish performance results are presented in Table 3. Survival and productivity were similar between species, with mean values of 99% and 7.1 kg m^{-3}. Feed conversion ratio was

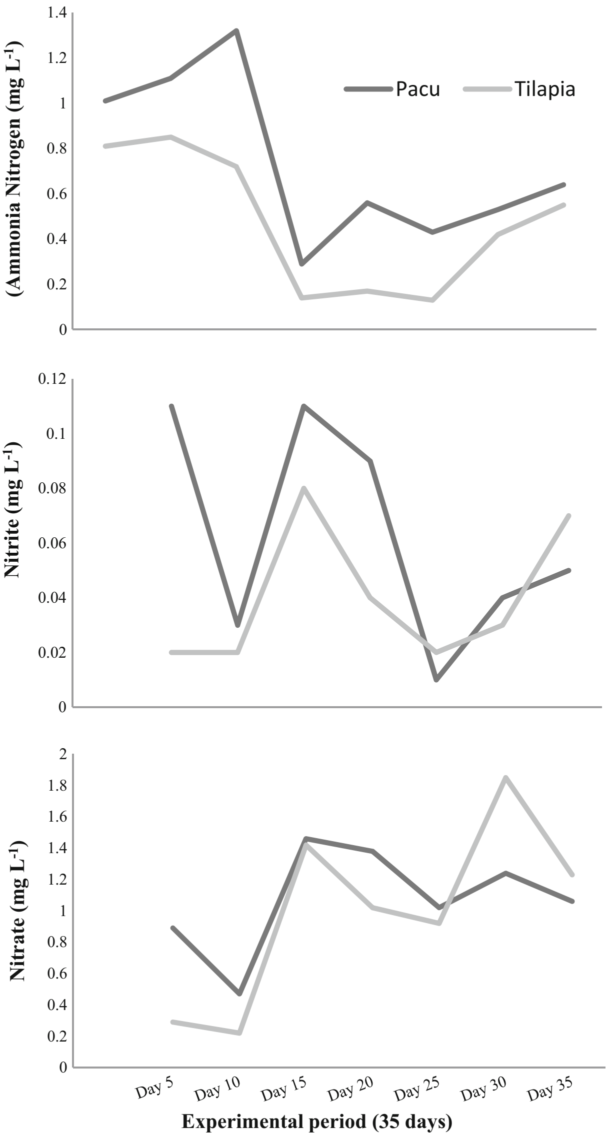

Fig. 2 Variation of nitrogenous compounds (ammonia nitrogen, nitrite, and nitrate, expressed in mg L^{-1}) in the macrocosm of pacus and red tilapias

significantly higher in tilapia (2.00) as compared to pacu with 1.59. Final weight and SGR were similar between treatments ($p > 0.05$).

Discussion

Except for orthophosphate values, all the water quality parameters were similar to those reported in previous studies of red tilapia culture (Al-Hafedh et al. 2008; Wang et al. 2016)

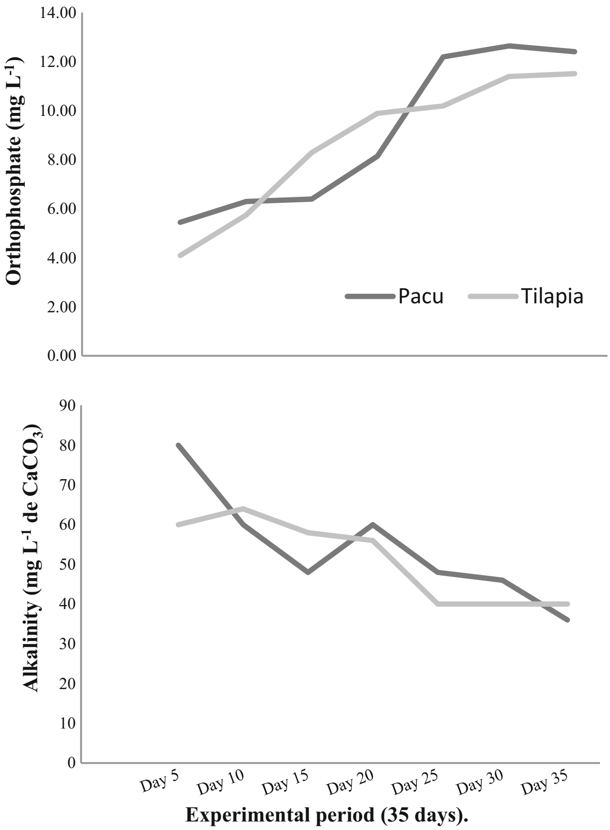

Fig. 3 Variation of orthophosphate (mg L^{-1}) and alkalinity (mg L^{-1} of $CaCO_3$) in the macrocosm of pacus and red tilapias

and pacu (Polese et al. 2010; Fiod et al. 2010). Although with higher values compared to other published work, orthophosphate tended to stabilize at the end of the trial (Fig. 3), probably due to the plant absorption (Bakhsh and Chopin 2012; Rakocy 2012; Roy 2017). Moreover, temperature, DO, pH, nitrogen compounds, and alkalinity mean values corroborated with usual values observed in aquaponics systems (Sikawa and Yakupitiyage 2010; Roosta 2014).

Literature is scarce regarding parsley and scallion performance in aquaponics. Regarding other garnish species, Roosta (2014) cultivated mint, radish, parsley, and cilantro in an aquaponics system integrated with common carp. The authors tested the influence of supplemental potassium application on the leaf area and its effects on plant growth. Without the K application, parsley reached an average height of 19 cm and yield of 757 g m^{-2}. In our study, the mean values were close (~ 17.8 cm), although the yields were lower (~ 87 g m^{-2}). These results could be attributed to many general factors: nutrient availability (Ru et al. 2017), production design, types and physiological stages of plants (Goddek et al. 2015), and environmental or water quality variations (Delaide et al. 2017). In addition, some specific factors possibly contributed to the non-maximal growth of the parsley in our experiment, compared with the following Roosta (2014): (i) differences in g feed day^{-1} $plant^{-1}$ with 4.5 g as compared to 2.0 g feed day^{-1} $plant^{-1}$ in the present study, (ii) days of culture (45 versus 35 days in our study), and (iii) number of plants per square meter with 13 plants m^2.

Table 2 Mean (± standard error) of productive performance of parsley and scallion in aquaponics system, influenced by production of pacu and red tilapia during the experimental period (35 days)

	Height of leaves (cm)	Leaves wet weight (g)	Yield (g m^{-2})	SGR (% day^{-1})	Number of leaves $plant^{-1}$	Plant discard (%)
Treatments						
Pacu-scallion	29.26 ± 1.13	10.8 ± 1.18	144.10 ± 34.5	7.77 ± 0.37	27.50 ± 2.13	0
Pacu-parsley	17.93 ± 1.05	7.39 ± 1.1	88.69 ± 32.4	7.13 ± 0.49	NA	14
Tilapia--scallion	31.59 ± 0.50	9.37 ± 0.75	139.20 ± 6.95	7.58 ± 0.23	21.33 ± 1.44	0
Tilapia--parsley	17.65 ± 1.02	6.94 ± 0.77	85.57 ± 12.9	6.76 ± 0.35	NA	5
Mean						
Pacu	23.59 ± 1.09	9.10 ± 1.14	116.40 ± 33.5	7.45 ± 0.43	27.50 ± 2.13 a	7.0
Tilapia	24.62 ± 0.76	8.16 ± 0.76	112.40 ± 9.93	7.17 ± 0.29	21.33 ± 1.44 b	2.5
Scallion	30.42 ± 0.82 A	10.10 ± 0.97 A	141.70 ± 20.7 A	7.68 ± 0.30 A	24.41 ± 1.79	0
Parsley	17.79 ± 1.04 B	7.17 ± 0.94 B	87.13 ± 22.7 B	6.95 ± 0.42 B	NA	9.5
Values of *p**						
Plant	< 0.01	< 0.01	0.04	0.04	0.02**	–
Efluent fish	0.11	0.15	0.74	0.43	–	–
P × E	0.06	0.96	0.86	0.81	–	–

Capital letters indicate differences between the varieties of plants and lowercase letters between the fish species

NA data not available

**From Student's *t* test

In the same study, Roosta (2014) observed the positive effect of K application in yields of the parsley, 757 to 1247 g m^{-2}, respectively. This increase in production could be explained by the lack or incorrect balance of nutrients in the fish feeds, i.e., Ca, K, and Mg, essential nutrients for plant growth (Seawright et al. 1998; Rakocy et al. 2006; Ru et al. 2017). In hydroponic production, the nutrients are usually added respecting the specific requirements of each plant species, aiming to maximize the productive results (Chekli et al. 2017). When comparing the parsley production of the present study with the hydroponic data of Chondraki et al. (2012), it is also possible to determine why this species did not reach the best yield. These authors tested if the production of hydroponic parsley (with balanced solution of nutrients in water) is influenced by sodium chloride and calcium foliar spray. They reached an average leaf wet weight (~ 17 g) and height (~ 23 cm) greater than the present study (~ 7.0 g and 17.8 cm, respectively).

On the other hand, in relation to scallion produced in a hydroponic system, Kane et al. (2006) evaluated different solutions of nutrients and pH ranges in the growth of three types of onion (*Allium cepa* L. ("Deep Purple" and "Purplette") and *A. fistulosum* L. ("Kinka")). For all treatments tested, after 30 days of cultivation, the wet weight (~ 5.5 g) was lower than that found in the present study (~ 10 g), with significant differences between the treatment cultivated at pH 5.8 (5.3 g) and 6.5 (6.21 g). Evidencing that possibly the experimental conditions were more suitable for the scallion than for the parsley culture. In this sense, differences in performance of the two garnishes evaluated in our study may be related to the

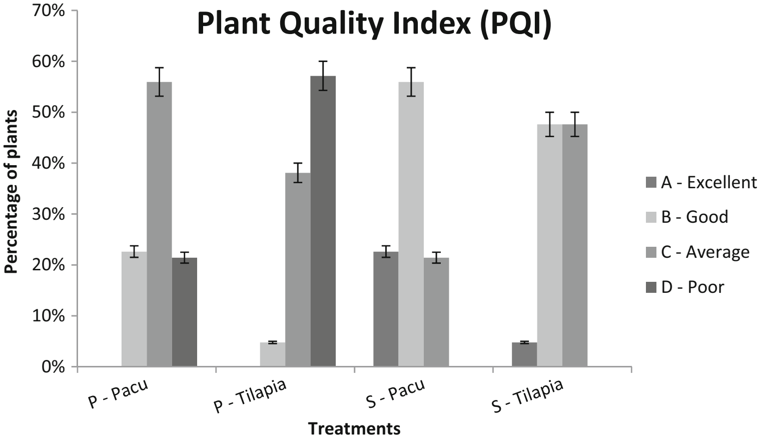

Fig. 4 Mean (± standard error) percentage of plants that received grade: A excellent, up to 5% of the leaf surface with imperfections, B good, up to 33% imperfections, C average, up to 66% imperfections, and D poor, 100% of leaf surface with imperfections, per treatment

deficiency of a particular nutrient, the wrong balance between them and/or intrinsic characteristics of such species, e.g., regarding to the environment conditions.

Plant quality index also indicated that scallion developed better than parsley in aquaponics system. Nevertheless, most of plants from both species presented imperfections in the leaf surfaces, especially leaf yellowing. This anomaly may be related, among other factors, to the deficiency of nutrients, i.e., nitrogen (Rakocy 2012; Petrazzini et al. 2014). It is important to note that nitrate concentrations did not show a decreasing trend, which may indicate deficiency in nutrient absorption. In addition, the absence of some nutrients that are poorly available in fish feeds (Medina et al. 2016) could also cause the plant's imperfections.

The importance of supplementation and correct balance of nutrients can be seen in the results of Delaide et al. (2016). These authors tested the lettuce production in a hydroponic system, conventional aquaponic (without supplementation), and aquaponic with supplementation, and obtained a 39% increase in the vegetable production in the supplemented aquaponic compared to the other two treatments. The production data of the present study show that it is possible to cultivate scallion and parsley in aquaponics, however mineral supplementation evaluations, such as the experimental design by Delaide et al. (2016), are strongly encouraged.

Table 3 Mean (± standard error) of productive performance of pacu and red tilapia in aquaponics system, during the experimental period (35 days)

Zootechnical parameters	Macrocosm		Values of p*
	Pacu	Tilapia	
Initial weight (g)	31.50 ± 1.71 ^{A}	31.56 ± 1.50 ^{A}	0.89
Final weight (g)	68.68 ± 2.18 ^{A}	70.13 ± 3.98 ^{A}	0.92
FCR	1.59 ± 0.08 ^{B}	2.00 ± 0.28 ^{A}	0.02
SGR (% day^{-1})	2.35 ± 0.10 ^{A}	2.23 ± 0.08 ^{A}	0.49
Productivity (kg m^{-3})	7.14	7.15	
Survival (%)	100	98	

Capital letters indicate differences between the fish species

We did not find any literature studies related to pacu raised in aquaponics system. The mean survival values observed in our study were similar to those reported in RAS for pacu (Furuya et al. 2008; Fiod et al. 2010) and for tilapia in aquaponics systems (Al-Hafedh et al. 2008; Bakhsh and Chopin 2012; Wang et al. 2016). Regarding feed conversion ratio (FCR), the higher value observed in tilapia could be related to the worse adaptation to low water temperatures (~ 20 °C) as compared to pacu in the beginning of the trial. The pacu, an endemic species from the Pantanal region and Uruguay basin (Urbinati and Gonçalves 2005), is more adapted to low temperatures, which could be the reason for the better FCR. Even so, our tilapia FCR was similar to those reported by Rakocy et al. (2004) and Kamal (2006) with tilapias raised in aquaponics system (~ 1.85).

In addition, Kamal (2006) testing different densities of pepper (10, 15, and 20 plants m^{-2}) in aquaponics with tilapia (initial weight of 10.5 g and initial biomass of 1.05 kg m^{-3}) during 180 days obtained an average yield of 17.95 kg m^{-3} in the density of 15 plants m^{-2} (same density to our study). This value cited above is higher than ~ 7.1 kg m^{-3} reached in our study. On the other hand, SGR of 1.6 (Kamal 2006) and 0.7 and 0.6 day^{-1} observed by Palm et al. (2014) for tilapia and African catfish, respectively, were lower than 2.35 and 2.23% day^{-1} for pacu and tilapias in the present study. This was possibly due to differences in initial weight and initial biomass, modifying the growth rates between studies.

Regarding pacu growth performance, Signor et al. (2010) and Polese et al. (2010) evaluated different diets for pacu in cages and RAS, respectively and reached mean FCR's of 3.0 and 1.5 and SGR of 0.7 and 1.1% day^{-1}, respectively. The mean values of FCR obtained by Polese et al. (2010) corroborates with our study, but those found by Signor et al. (2010) and both SGR values were lower than the 2.35% day^{-1} reached in our study. These results could indicate a good adaptation of pacu to the aquaponics system. In contrast, Fiod et al. (2010) evaluated different feeding frequency in pacu juveniles (initial weight of ~ 24 g) also in RAS, obtained superior performance. The authors reached FCR and SGR of 0.7 and 3.15% day^{-1}, respectively. These differences may be associated to factors such as water quality, nutrition, health, and genetics (Watanabe et al. 2012). Certainly, more studies should be conducted to improve the yield of pacu in aquaponics and make it commercially applicable.

The plant performance results presented in our study showed that both garnish species, scallion and parsley, have potential to be cultivated in aquaponics system, regardless of fish effluent type, only if nutrient deficiency/balance is understood and resolved. In addition, both tilapia and pacu had similar growth performance, showing that pacu can be grown in aquaponics, which allows farmers and investors to select the best species according to their market and location. Such technology may be an alternative to different production systems, including urban aquaculture (Goddek et al. 2015). On the other hand, aiming to optimize the production and make it commercially viable, the authors emphasize the importance of more research related to the correct balancing of nutrients to improve the visual aspects, followed by financial analysis aimed at the use of these garnish plants in larger production scale.

Conclusion

The results indicated that pacu is an alternative fish species for aquaponics production and productive performance of garnish plants was similar to those obtained with tilapia. Regarding the garnish species, scallion obtained the better production performance and visual aspects compared to parsley, showing better productive potential.

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