Quality of lettuce (*Lactuca sativa* L.) grown in aquaponic and hydroponic systems

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Abstract

Aquaponics is the integration of aquaculture and hydroponic systems where, in general terms, the waste produced by aquatic organisms becomes nutrients through bacterial action for plant growth. Water consumption as well as the environmental impact in this type of system are lower compared to more traditional hydroponic and aquaculture counterparts, due to its dual productive nature and closed condition of the system allowing the reuse of water and fish waste. The present study evaluated the yield, nitrate concentration, microbiological and functional quality of lettuce (*Lactuca sativa* L.) grown in two production systems: aquaponics and hydroponics. At the same time, fresh mass gain and feed conversion ratio (FCR) of rainbow trout (*Oncorhynchus mykiss*) were assessed. Lettuces were grown in an aquaponic system using waste water from the fish system, as well as in a hydroponic system with nutrient solution (Hoagland II-modified) both for 21 days. At the end of this period, baby lettuce (8 and 12 cm of length) was harvested. The yield of lettuce grown in aquaponic system was 6.73% higher than that of grown in hydroponic system. Also aquaponically grown lettuce had lower nitrate concentration (1079 mg kg^{-1} FW) than hydroponically grown lettuce (1229 mg kg^{-1} FW). Lettuces grown in both systems showed no significant differences in the microbial and functional qualities. Rainbow trout in the aquaponic system increased 13.6 g over 27.1±0.8 g initial fresh weight, obtaining a FCR of 0.74 after the experiment. These results indicate that the aquaponic system used in the present study is a sustainable alternative for the production of high quality lettuce considering its high yield, lower concentration of nitrates and similar microbiological and functional qualities compared to hydroponic systems, while allowing simultaneous fish farming with a good feed conversion ratio (74 g of food was needed to produce 100 g of rainbow trout).

Keywords: aquaponics, aquaculture, hydroponics, yield, nitrate concentration, microbiological quality, functional quality, lettuce, rainbow trout

INTRODUCTION

Lettuce (*Lactuca sativa* L.) has a greater economic importance among leafy vegetables, due to the possibility of its annual crop, different production systems and the diversity of botanical varieties and cultivars available (Suslow et al., 2003). This vegetable is grown mainly in irrigated soils with high levels of water consumption and safety risks due to pathogenic bacteria that can be present in the water (*Escherichia coli 0157*: *H7, Salmonella* or *Listeria monocytogenes*) (Sirsat and Neal, 2013).

Hydroponic systems are a method of growing plants without the use of soil. Inert solid or liquid media substrates are used to cultivate vegetables. In these systems, all nutrients needed for plant to grow are obtained from synthetic fertilizers (Tonet et al., 2011; FAO, 2014). These systems also allow for high levels of control than cultivating directly in soil with great efficiency in the use of water and fertilizers and less risks of pests and diseases. However, the complete dependence of manufactured fertilizers represents a high cost for

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small farmers (FAO, 2014; Stefanelli et al., 2011). In this sense, integration with other crops, such as the production of fish can be a strategy to increase the economic benefit. In aquaculture, a small proportion of dietary nutrients (25 to 35%) are retained by the fish. Also part of these nutrients is excreted by the fish and accumulated and decomposed in the water systems altering its quality (Endut et al., 2010; FAO, 2014).

A solution to this problem is to use aquaponic systems where aquaculture and hydroponics are integrated. The objective of this system is to produce fish and vegetables in a closed circuit, where the use of synthetic fertilizers is almost zero (Rakocy et al., 2006). In this type of system fish waste is converted into nutrients for plants by the action of nitrifying bacteria (Hollyer et al., 2009).

Nitrate concentration in the lettuce leaves

The excessive supply of nitrate (NO_3) to hydroponic can lead to a rapid growth of the plants and increase the accumulation of NO_3 in leaves. The recommendation indicates that the concentration of NO_3 must be less than 150 mg L^{-1} because more is toxic for fish (FAO, 2014). High concentrations of nitrate in leafy vegetables can be also dangerous to the health of consumers.

Microbiological quality

In the aquaponics system the used waste of fish as nutrients for plants can represent a microbial risk for water and vegetables when they are consumed by people (FAO, 2014).

Functional quality

Consumers demand safety and functional fresh vegetables. These products are considered rich in vitamins, antioxidant compounds, fiber, etc. (Scalzo et al., 2005). These compounds are known for their beneficial effects on consumer health (Hooper and Cassidy, 2006; Pérez-Jiménez and Soura-Calixto, 2007).

MATERIALS AND METHODS

Location of the experiments

This study was conducted in the greenhouse and laboratories of the Centro de Estudios Postcosecha (CEPOC) of the Faculty of Agricultural Science of University of Chile located at 33°40’ South latitude and 70°40’ West longitude.

Experimental design

The design was completely randomized with 2 treatments and 3 replicates per treatment for a total of 6 experimental units. Treatments corresponded to aquaponic and hydroponic systems, both with lettuce crop under floating root system conditions.

Crop management

1. Aquaponic system.

The rainbow trout (*Oncorhynchus mykiss*) juveniles were cultured in a rectangular tank with 120 L of dechlorinated tap water. Forty fish were used in each tank. The fish were fed two times day^{-1} with commercial pellets (48% of protein) at 1.44% of their body mass. A submersible pump (Sicce IDRA, Italy) located in the bottom of the tank pumped 10 L min^{-1} to the biofilter section. The biofilter was connected to the hydroponic section where lettuces were cultivated by floating root (Figure 1) and these two sections were at the same height separated by 0.7 m. Later, the water was conducted by gravity through the pipe again to tank closing the circuit (Figure 1) (Rakocy et al., 2006).

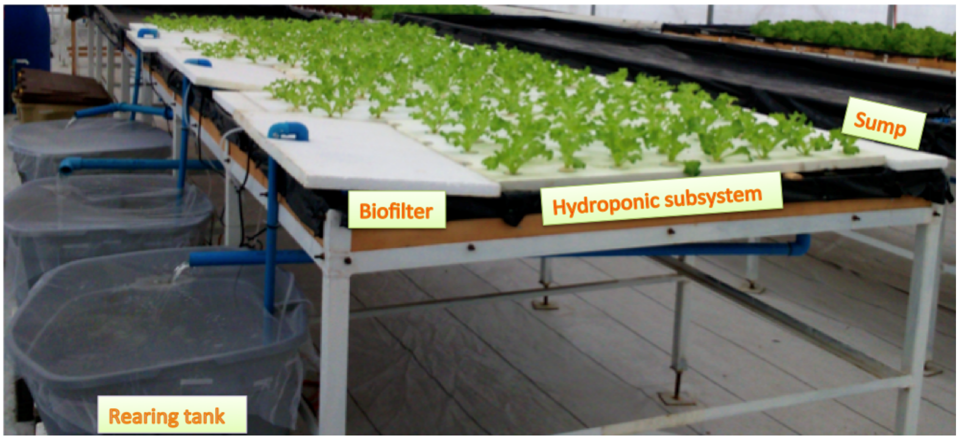

Figure 1. Aquaponics system components.

2. Hydroponic system.

Tables dimensions were 1.5×0.6 m and expanded polystyrene sheets of medium density (20 kg m^{-3}) and 2.54 cm of thickness were used. Plants were placed on every hole of 5 cm of diameter. Thirty plants were cultivated m^{-2} following a zig-zag design.

Measurements

The plants from each system were harvested when the leaves reached 8 to 12 cm of length (after 21 days from transplant). Harvested leaves were placed in 60 bags (50 g bag^{-1}). Ten bags were used per repetition. Randomized samples were taken for microbial analysis (Selma et al., 2012); concentration of nitrate by nitrate ion-selective electrode method proposed by Sadzawka et al. (2007); total phenols measured by colorimetric method of Singleton and Rossi (1965); antioxidant capacity measured by DPPH proposed by Brand-Williams et al. (1995) and FRAP described by Benzie and Strain (1996). Also feed conversion ratio (FCR) was obtained for fish at the end of the experiment following the method described by Merino (2015).

Statistical analysis

The results were analyzed by analysis of variance (ANOVA). The statistical program Infostat (version 2015, National University of Cordoba, Argentina) was used. When there were significant differences ($P \leq 0.05$), the multiple comparison test of Tukey at a level of significance of 5% was applied.

RESULTS AND DISCUSSION

Yield and nitrate concentration

Significant differences in yield of fresh mass and nitrate concentration in lettuce were found between both systems. Higher yield crop with lower concentration of nitrate in lettuce was determined in aquaponic compared to hydroponic systems (Figure 2).

The yield of lettuce grown in the aquaponic system was similar to that of reported by Pantanella et al. (2012). These authors obtained 2.71 kg m^{-2} after 21 days from transplant using 'Roman' lettuce (20 plants m^{-2}) grown on floating root and Nile tilapia (*Oreochromis niloticus* L.) in high density with 8 kg fish m^{-3}.

Lennard and Leonard (2006) harvested 4.47±0.12 kg m^{-2} of 'Oak' leaf lettuce (40 plants m^{-2}) in root floating technique using waste of 5 kg of Murray cod m^{-3}. Similarly, Licamele (2009) obtained yields of 4.7 kg m^{-2} in 'Rex' lettuce (32 plants m^{-2}) after 35 days with Nile tilapia (*Oreochromis niloticus* L.) with a density of 5 kg fish m^{-3}. The highest yield described in these studies could be due to Nile tilapia and Murray cod being maintained at 20 to 25°C, the optimal range for these fish and also for nitrifying bacteria and lettuce growth (FAO, 2014). Other studies also report that the yield of leafy vegetables in aquaponics is similar or even superior than hydroponic system (Graber and Junge, 2009; Savidov, 2005).

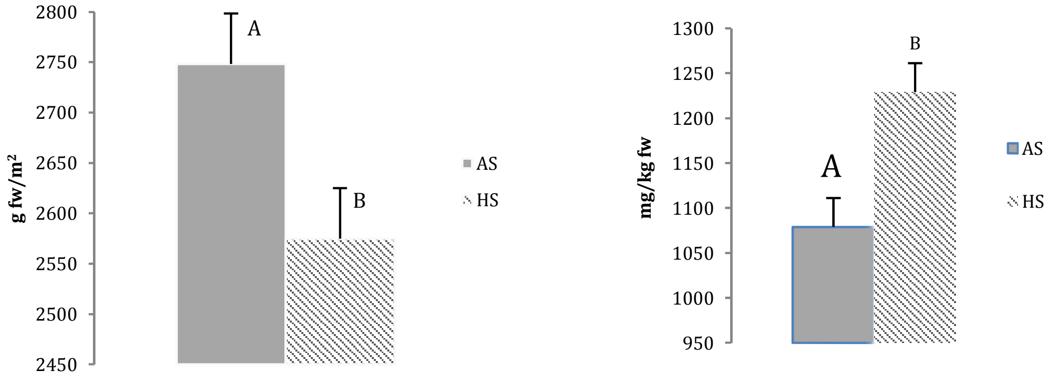

Figure 2. Yield (g fw m^{-2}, left) and nitrate concentration (mg kg^{-1} fw, right) of lettuce grown in aquaponics (AS) and hydroponics (HS) systems. The bars represent the average (*n*=3) ±SD (P≤0.05).

The nitrate concentration in lettuce cultivated in our aquaponics system was greater than the results obtained by Blidariu et al. (2013). These authors found 810 mg kg^{-1} fw in Spanish lettuce cultivated with residues of pikeperch (*Sander lucioperca*). The nitrate concentration (1087.2±458.1 mg kg^{-1} fw) in our hydroponic lettuce was higher than the data reported by Lastra et al. (2009) for the cultivars 'Grand Rapids', 'Breeze', 'Divine' and 'Prima'. The higher nitrates concentration found in hydroponic lettuce in the present study could be explained due to the greater availability of nitrate in the nutrient solution at the beginning of the experiment (150 mg L^{-1}). While for the lettuce in the aquaponic system the average concentration of nitrate was 14.9 mg L^{-1}. The high doses of nitrate would be the reason of the accumulated nitrates in leaf tissues (Lastra et al., 2009; Stefanelli et al., 2011) in the hydroponic system. The harvest time is a key factor in the accumulation of nitrate due to nitrate reductase (NR) having been reported to be more active in PAR radiation (Raigon et al., 2006). In this study, lettuces were harvested at 12 h in both systems. According to Contreras (2014) lower accumulation of nitrates in chard leaves (*Beta vulgaris* L. var. *cicla*) were found when the harvest was at 12 or 21 h compared to 8 h in the morning. Moreover, nitrates are accumulated in leaves being higher in the oldest leaves compared to the youngest (Anjana et al., 2006). The nitrate contents were always below to the maximum limit stablished by European Commission (2011) in both systems. The maximum is 4000 mg nitrate kg^{-1} fw for lettuce harvested from a greenhouse in winter time.

Microbiological counts

In both systems no significant differences were observed in microbial counts at harvest (Figure 3). The mesophilic aerobic bacteria counts (MAB) in leaves were similar to those reported by Sirsat and Neal (2013) with 3.2 log CFU g^{-1} for 'Romaine' lettuce cultivated in aquaponics under a greenhouse. Scuderi et al. (2011) reported counts of 6.0 log CFU g^{-1} for lettuce grown in a hydroponic floating root system. Enterobacteriaceae count was less than 2.3 log CFU g^{-1} reported by Scuderi et al. (2011) in a similar study.

The psychrophilic bacteria count was lower than the value reported by Orellana (2011), who found 4.9 log CFU g^{-1} in rocket leaves grown in hydroponic system. According to Selma et al. (2012), psychrophilic bacteria can quickly decrease the quality of refrigerated products like vegetables. Low microbial counts in leaves were found in all harvest times according to the Chilean legislation, probably due to drinking water was used in the experiments (Hollyer et al., 2009; MINSAL, 2014). Also lettuces were not in contact neither with water nor nutrient solution in aquaponics or hydroponic systems, respectively (Erickson, 2012).

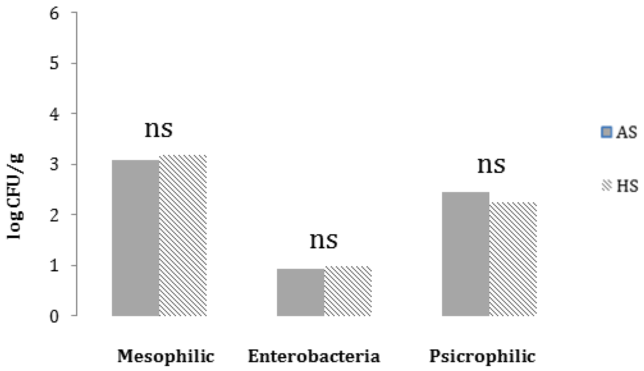

Figure 3. Mesophilic, entorobacteria and psicrophilic bacteria (log CFU g^{-1}) in lettuce grown in aquaponics (AS) and hydroponics (HS) systems. The bars represent the average (*n*=3) ±SD (P≤0.05).

Functional compounds

Similar total phenolics and antioxidant capacity content measured by DPPH and FRAP were found for both systems cultivated leaves (Table 1). Total phenol contents registered in this experiment were higher compared to those reported by Llorach et al. (2008). These authors found 18.2, 63.5 and 125.5 mg GAE 100 g^{-1} fw for 'Iceberg', 'Romaine' and 'Continental' lettuces, respectively. However, the total phenol content was similar to those found in Spanish lettuce (164 mg GAE 100 g^{-1} fw) and lower than 'Red Oak leaf' (322 mg GAE 100 g^{-1} fw) and 'Lollo Rosso' (571 mg GAE 100 g^{-1} fw) (Llorach et al., 2008).

Table 1. Total phenols and antioxidant capacity of lettuce leaves grown in aquaponics and hydroponics systems. Average (*n*=3) ±SD.

System	mg GAE 100 g^{-1} fw	mg TE 100 g^{-1} fw	
		DPPH	FRAP
Aquaponics	156.6±29.4	181.5±43.9	255.5±16.5
Hydroponics	150.3±70.3 ns	132.7±21.3 ns	309.8±42.1 ns

The results are compared in vertical between systems. ns: not significant (P≤0.05).

Antioxidant capacity determined by DPPH and FRAP methods was lower than the values reported by Llorach et al. (2008). According to these authors 'Continental' lettuce had 244.1 mg TE 100 g^{-1} fw (by DPPH) and 323.4 mg TE 100 g^{-1} fw (by FRAP). The total phenolics and antioxidant capacity show considerable variations depend on cultivars, cultural practices, type of processing and storage conditions (Nicolle et al., 2004). In general, red lettuce had higher content of functional compounds than green lettuces (Rivera, 2014).

Feed conversion ratio (FCR)

In terms of FCR, values obtained were within the range described by Merino (2015) (Table 2). These authors stated that FCR<1 is considered appropriate for rainbow trout with a weight less than 100 g. In others studies, Lennard and Leonard (2006) and Palm et al. (2014) obtained in aquaponics systems FCR between 0.85 to 0.93 for Murray cod (*Maccullochella peelii*) and Nile tilapia (*Oreochromis niloticus*), respectively. FCR depends of the quality and amount of food and water quality used during culture (Palm et al., 2014). The food used in this experiment contained 48% protein and water quality parameters were considered (data not shown) recommended for rainbow trout (Woynarovich et al., 2011).

Table 2. Feed conversion ratio (FCR) for rainbow trout cultivated in aquaponic system with lettuce. Average (n=3) ±SD.

	Weeks of culture				Consumed food	FCR
	0	1	2	3		
Accumulated biomass (g)	1085±33	1294±53	1453±52	1614±78	393±40	0.74

CONCLUSIONS

- The aquaponic lettuce obtained a higher yield and a lower concentration of nitrates compared to hydroponic;
- Lettuces produced in both systems had similar microbial and functional qualities;
- Rainbow trout produced in aquaponic system showed a high feed conversion ratio.

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