Australian Journal of Crop Science
AJCS

AJCS 14(11):1794-1799 (2020) ISSN:1835-2707
doi: 10.21475/ajcs.20.14.11.p2674

Effects of aquaponic system on growth and nutrients content and sustainable production of sprouts in urban area

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Abstract

An aquaponic system in urban area was designed and combined fish culture with sprouts production in a closed-loop system that mimics the ecology of the nature. In order to quantify the nutrients content of sprouts grown under different conditions, we conducted a factorial experiment with 3 types of growth conditions, routine cultivation (RC), circulating water supplement cultivation (CWSC) and aquaponic system cultivation (ASC), then produce sprouts (soybean sprouts, mung bean sprouts, pea sprouts and radish sprouts) under these conditions. The results showed that each sprout under ASC condition, height, weight (10 sprouts), vitamin C content, protein content and soluble sugar content were significantly higher than those under RC condition and CWSC condition. Each sprout showed significant difference in height, weight (10 sprouts), vitamin C content and soluble sugar content. The presence of *Carassius auratus auratus* can significantly promote the growth of sprouts in aquaponic system, and increase nutrients content. Therefore, aquaponic system can be promoted vigorously in urban areas.

Keywords: Aquaponic system, Sprouts, Growth, Nutrients content, Urban area.
Abbreviations: RC_routine cultivation, CWSC_circulating water supplement cultivation, ASC_aquaponic system cultivation.

Introduction

Currently, China is the only fishery country in the world, where the total amount of farmed aquatic products exceeds the total amount of natural fish caught. Its aquaculture production has exceeded 50 million tons, accounting for more than 78% of the total aquatic products (Feng, 2019). Aquaculture is also the fastest growing source of animal protein, but in the aquaculture process, the uneaten feed and excretions which contain organic matters such as N and P causing eutrophication (Ding et al., 2015).

The Chinese people have summarized many ingenious methods of circular agriculture in long-term practices, such as Rice-fish Farming (Wan, 2019) and Mulberry-base Fishpond (Wang et al., 2018), which make significant economic and ecological benefits.

Aquaponic is an emerging technology for planting vegetables and culturing fishes in the same system, and combines both aquaculture and hydroponic vegetable cultivation in a closed-loop system that mimics the ecology of nature (Bailey and Ferrarezi, 2017; Ding et al., 2015), which encompasses recirculating aquaculture systems and hydroponics to produce fish and plants, the 2 systems can be connected in series by pipe, or 2 coexist in the same system. This new type of compound farming system, with an ecological design to achieve synergistic symbiosis, so that fish farming does not need frequently water change, and vegetables keep normal growth without fertilization (Ding et al., 2015). Common methods for achieving aquaponic include direct floating method (Gao et al., 2017), nitrification filtration method (Graber and Junge, 2009), separation drip irrigation method (Castro et al., 2006), which have a good water purification effect. Under the constant exploration of scientists, different forms of aquaponic system were invented, such as UVI Commercial Aquaponic System (Bailey and Ferrarezi, 2017), aquaponic system (AS) (Selek et al., 2016), hydroponic system (Ghaly et al., 2005), and so on, promoted the advancement of aquaponic system research.

Aquaponic farmers can produce a great variety of vegetable crops in their systems to meet customer needs and preferences. In the process of using aquaponic system in urban families, light is the biggest limiting factor. It is necessary to supplement LED lights (Kim et al., 2006; Steigerwald et al., 2002; Yorio et al., 2001) to ensure the normal growth of vegetables in the system. Supplemental light will have a positive impact on vegetable growth, which can significantly increase the yield of vegetables, but consumes more electricity at the same time (Park et al., 2012).

Sprouts are formed from seeds during sprouting. The sprouts are outstanding sources of protein, vitamins and minerals and they contain such in the respect of health-maintaining important nutrients like glucosinolates, phenolic and selenium-containing components in the Brassica plants or isonflavons in the soyabean. As the sprouts are consumed at the beginning of the growing phase, their nutrient concentration remains very high (Csapo´-Kiss, 2010). In the sprouts besides the nutrients phytochemicals, vitamins, minerals, enzymes and amino acids are of the most importance as these are the most useful in the respect of the human health (Webb Geoffrey, 2006).

Therefore, we innovatively choose sprouts (soybean sprouts, mung bean sprouts, pea sprouts and radish sprouts) which are not subject to seasonal restrictions, just need simple management methods in the aquaponic system, and explore the effect of aquaponic system on sprouts growth and nutrients content, which will contribute to sustainable production of sprouts in urban area.

Results

Effects of aquaponic system on stem diameter of sprouts

Under different growth conditions, the average stem diameter of the 4 sprouts were shown in Table 1. The average stem diameter of mung bean sprouts, pea sprouts and radish sprouts revealed no significant difference under 3 different growth conditions, but the average stem diameter of soybean sprouts under ASC condition was significantly higher than under the former 2 growth conditions.

Compared with the first 2 growth conditions, the average stem diameter of soybean sprouts increased by 12.86% and 13.81%, mung bean sprouts increased by 8.17% and 7.14%, pea sprouts increased by 6.09% and 5.63% under ASC condition. All the sprouts revealed significant difference of stem diameter under ASC condition. Under RC and CWSC conditions, the average stem diameter of soybean sprouts and pea sprouts showed no significant difference.

Effects of aquaponic system on height of sprouts

ANOVA revealed significant variation in height of different sprouts. The height of each sprout under ASC condition was significantly higher than RC and CWSC conditions (Table 2).

Compared with the first 2 growth conditions, the average height of soybean sprouts increased by 22.11% and 25.53%, mung bean sprouts increased by 15.43% and 14.91%, pea sprouts increased by 26.00% and 27.95%, radish sprouts increased by 35.97% and 33.37%, respectively, under ASC condition.

Effects of aquaponic system on weight (10 sprouts) of sprouts

10 of each sprout species were randomly selected and weighted, and the results were shown in Table 3. ANOVA revealed significant variation about the weight in different sprouts, and the weight of each sprout under ASC condition was significantly higher than these under RC condition and CWSC condition. Under RC and CWSC conditions, the weight of mung bean sprouts, pea sprouts and radish sprouts showed no significant difference, but the weight of soybean sprout was significantly heavier under RC condition than these cultivated under CWSC condition.

Compared with the first 2 growth conditions, the weight of soybean sprouts increased by 31.73% and 34.12%, mung bean sprouts by 54.49% and 52.31%, pea sprouts by 12.92% and 13.61%, radish sprouts by 12.26% and 12.13%, respectively, under ASC condition. ANOVA also revealed significant variation of weight among sprout species.

Effects of aquaponic system on vitamin C content of sprouts

Under different growth conditions, the average content of vitamin C in each sprout species is shown in Fig 1. Under 3 growth conditions, pea sprouts achieved the highest average content of vitamin C (52.64mg/100g), followed by radish sprouts (33.27 mg/100 g), bean sprouts (20.08 mg/100 g) and mung bean sprouts (18.91 mg/100 g). ANOVA revealed significant variation in vitamin C content among sprout species. The vitamin C content of each sprout under ASC condition was significantly higher than those under RC condition and CWSC condition, but did not show significant difference under the conditions of RC and CWSC.

Compared with the first 2 growth conditions, the average content of vitamin C in soybean sprouts increased by 24.31% and 23.78%, mung bean sprouts by 17.20% and 18.73%, pea sprouts increased by 7.27% and 7.54%, and radish sprouts increased by 8.18% and 8.48%, respectively, under ASC condition.

Effects of aquaponic system on protein content of sprouts

Under different growth conditions, the average content of protein in different sprout species is shown in Fig 2. Under 3 growth conditions, soybean sprouts achieved the highest content of protein (15.97g/100g), followed by mung bean sprouts (11.05g/ 100 g), radish sprouts (3.64 g/100 g), pea sprouts (3.57 g/100 g). ANOVA revealed significant variation on the protein content of each sprout, except pea sprouts and radish sprouts under RC and CWSC conditions. The protein content of each sprout under ASC condition was significantly higher than those under RC condition and CWSC conditions, but showed no significant difference under the conditions of RC and CWSC.

Compared with sprouts under RC and CWSC conditions, the average content of protein in soybean sprouts increased by 13.70% and 11.64%, mung bean sprouts by 20.47% and 17.49%, pea sprouts increased by 12.72% and 16.77%, and radish sprouts increased by 3.34% and 2.77%, respectively, under ASC condition.

Effects of aquaponic system on soluble sugar content of sprouts

Under different growth conditions, the content of soluble sugar in each sprout is shown in Fig 3. Radish sprouts achieved the highest average content of soluble sugar (10.48g/100g), followed by soybean sprouts (6.94g/100g), mung bean sprouts (5.68g/100g) and pea sprouts (1.77g/100g). ANOVA revealed significant variation on the content of soluble sugar in different sprouts. The soluble sugar content of each sprout under ASC condition was significantly higher than these under RC condition and CWSC conditions, but did not show significant difference under the conditions of RC and CWSC.

Compared with sprouts under RC and CWSC conditions, the average content of soluble sugar was increased significantly under ASC condition. Among them, soybean sprouts increased by 29.07% and 25.08%, mung bean sprouts increased by 18.90% and 15.41%, pea sprouts increased by 63.12% and 44.65%, and radish sprouts increased by 13.29% and 9.76%, respectively.

Table 1. Effects of different growth conditions on stem diameter of sprouts. Tukey's test was used and the difference in uppercase letters indicate that the differences in stem diameter among sprouts are significant (p<0.05), the difference in lowercase letters indicate that stem diameter of sprout differ significantly (p<0.05) under different growth conditions.

Sprout species	Stem diameter(mm)		
	RC	CWSC	ASC
Soybean sprouts	2.41±0.10Ab	2.39±0.07Ab	2.72±0.10Aa
Mung bean sprouts	2.08±0.07Ba	2.1±0.12Ba	2.25±0.10Ca
Pea sprouts	2.3±0.08Aa	2.31±0.13Aa	2.44±0.11Ba
Radish sprouts	1.39±0.09Ca	1.38±0.06Ca	1.39±0.03Da

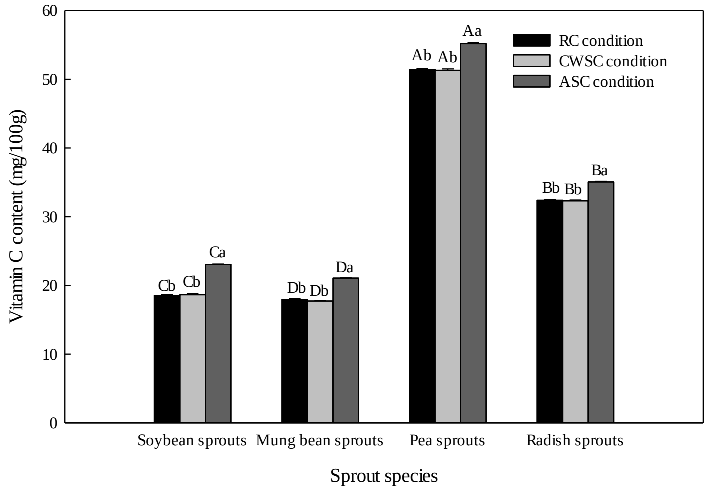

Fig 1. The mean values and standard deviations for vitamin C content of sprouts under different growth conditions. Bars are the standard deviation of means in sprouts under different growth conditions. Tukey's test was used and the difference in uppercase letters indicate that the differences in vitamin C content among sprouts are significant (p<0.05), and the difference in lowercase letters indicate that the vitamin C content of sprout differ significantly (p<0.05) under different growth conditions.

Table 2. Effects of different growth conditions on height of sprouts. Tukey's test was used and the difference in uppercase letters indicate that the differences in stem diameter among sprouts are significant (p<0.05), the difference in lowercase letters indicate that stem diameter of sprout differ significantly (p<0.05) under different growth conditions.

Sprout species	Height (mm)		
	RC	CWSC	ASC
Soybean sprouts	165.5±4.29Ab	161±1.10Ab	202.1±0.3Aa
Mung bean sprouts	88.8±1.35Cb	89.2±1.13Cb	102.5±1.05Ca
Pea sprouts	72.3±0.72Db	71.2±0.36Dc	91.1±0.36Da
Radish sprouts	102.3±0.85Bc	104.3±0.36Bb	139.1±0.92Ba

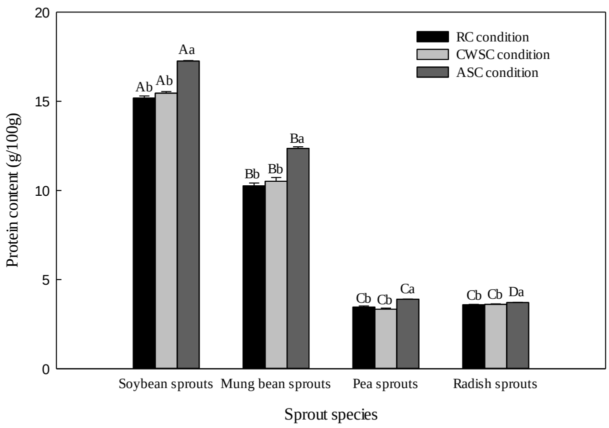

Fig 2. The mean values and standard deviations for protein content of sprouts under different growth conditions. Bars are the standard deviation of means in sprouts under different growth conditions. Tukey's test was used and the difference in uppercase letters indicate that the differences in protein content among sprouts are significant (p<0.05), and the lowercase letters indicate that the protein content of sprout differ significantly (p<0.05) under different growth conditions.

Table 3. Effects of different growth conditions on weight of sprouts. Tukey's test was used and the difference in uppercase letters indicate that the differences in stem diameter among sprouts are significant (p<0.05), the difference in lowercase letters indicate that stem diameter of sprout differ significantly (p<0.05) under different growth conditions.

Sprout species	10 sprouts weight (g)		
	RC	CWSC	ASC
Soybean sprouts	11.54±0.12Ab	11.34±0.03Ac	15.21±0.04Aa
Mung bean sprouts	3.9±0.02Cb	3.95±0.04Cb	6.02±0.04Ca
Pea sprouts	10.34±0.03Bb	10.28±0.02Bb	11.68±0.05Ba
Radish sprouts	1.68±0.04Db	1.68±0.03Db	1.89±0.02Da

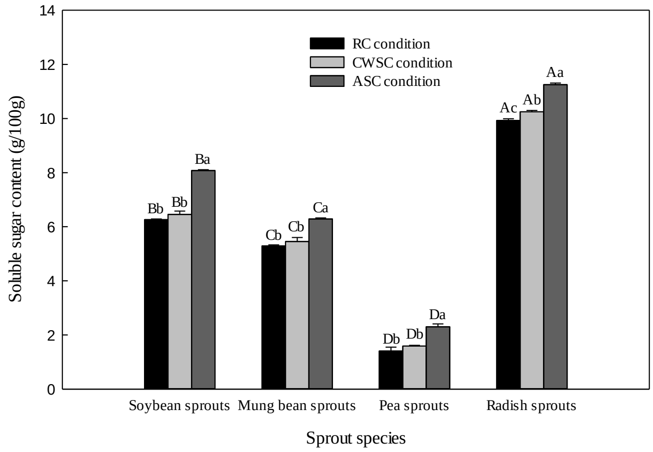

Fig 3. The mean values and standard deviations for soluble sugar of sprouts under different growth conditions. Bars are the standard deviation of means in sprouts under different growth conditions. Tukey's test was used and the difference in uppercase letters indicate that the differences in soluble sugar among sprouts are significant (p<0.05), and the lowercase letters indicate that the soluble sugar of sprout differ significantly (p<0.05) under different growth conditions.

Table 4. Description of growth conditions

Abbreviated growth condition name	Full growth condition name	Management Description
RC	Routine cultivation	① Seeds selection; ② Seeds disinfection; ③ Germination under shading and moisturizing conditions; ④ After germination, put them into the seedling tray, cultivate the sprouts under shading and moisturizing conditions.
CWSC	Circulating water supplement cultivation	① Seeds selection; ② Seeds disinfection; ③ Germination under shading and moisturizing conditions; ④ After germination, put them into the seedling tray, cultivate the sprouts under shading and circulating water supplement conditions by the aquaponic system (without fish).
ASC	Aquaponic system cultivation	① Seeds selection; ② Seeds disinfection; ③ Germination under shading and moisturizing conditions; ④ After germination, put them into the seedling tray, cultivate the sprouts under shading and circulating water supplement conditions by the aquaponic system (4 squids, total weight 755g).

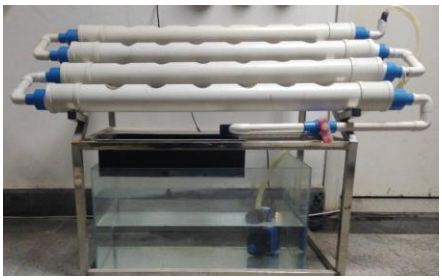

Fig 4. Aquaponic system. An iron frame (74.6cm*49.5cm*74.9cm) was welded, which hydroponic PVC pipes was set on it (vegetables can be cultured on the PVC pipes, but this experiment do not involve this content), then placed an aquarium in the lower part (60cm*30cm*33cm). Placed a customized seedling tray (40cm*20.9cm*10cm) on the middle of the iron frame, directly above the aquarium. A pump (7W) was used to pump the water in the aquarium to the hydroponic PVC pipes through a soft pipe, the water flowed to the seedling tray, after filtering then back to the aquarium, established the closed-loop system.

Fig 5. Seedling tray and seeding diagram. The cultivation of sprouts was carried out by using a customized seedling tray, and 4 drain holes with a diameter of 5 mm were placed side by side at the end of 3 cm from the bottom. The ceramsite was placed at the bottom of the seedling tray with 3 cm of thickness, then a white towel was placed on the ceramsite (30cm × 50cm). The seedling trays were divided into 5 areas by plastic spacers with mesh holes (4 kinds of sprouts are randomly placed in 4 areas; the last area near the inlet is buffer zone, no seeding). After sowing, the sprouts in each growth conditions were covered with an opaque black cloth and harvested 10 days later.

At the same time, under CWSC condition, the content of soluble sugar among four kinds of sprouts increased compared with those under RC condition. It even reached significant level in the radish sprout. Among them, soybean sprouts increased by 3.14%, mung bean sprouts by 3.02%, pea sprouts by 12.53%, and radish sprouts by 3.29%.

Discussion

Aquaponic system saves energy and ensure sustainable sprouts production

Aquaponics technology is a kind of resource saving, environment friendly, recyclable mode of production combined with the characteristics of aquaculture and hydroponic cultivation of vegetables, which meets the law of low carbon agriculture and sustainable development (Ding et al., 2015). In the process of using aquaponic system in urban area, it is necessary to supplement LED lights (Kim et al., 2006; Steigerwald et al., 2002; Yorio et al., 2001). In our experiment, we cultivated sprouts in aquaponic system, which can grow without light. So, it is energy saving and environmentally friendly and ensure sustainable sprouts production.

Aquaponic system produces more nutritious sprouts

In the last decades of the 20^{th} century, the attention of experts dealing with the healthy nutrition turned more and more towards the determination of the biological value of the nutritional sprouts (Penas et al., 2008). In this period, the consumption of the germinated seeds became common also in Western Europe as the sprouts meet the requirements of the modern nutrition (Csapo´-Kiss, 2010). Some health-protecting phytochemicals can be found in the sprout in a much higher concentration than in the developed plant (Fernández-Orozco et al., 2006). The potential protective effect of the consumable sprouts and their active components against cancer was studied in several *in vivo* and *in vitro* model experiments, which showed a positive correlation between the prevention from cancer of several organs and the consumption of the vegetable or its active components (Moreno et al., 2006; Munday and Munday, 2002). It is continuously necessary to develop such new kind of foods in an amount that makes the market supplying systems possible (Webb Geoffrey, 2006). In our study, the weight of soybean sprouts, pea sprouts and radish sprouts were heavier under RC condition than these cultivated under CWSC condition (Table 3). The result is consistent with the traditional method of cultivating sprouts (Yue and Ye, 2015). Under ASC condition, height (Table 2), weight (Table 3), vitamin C content (Fig 1), protein content (Fig 2) and soluble sugar content (Fig 3) in all 4 sprouts were significantly higher than those under RC condition and CWSC condition. Both yield and nutrients content of sprouts were improved under ASC condition, and these sprouts have considerable added value due to their abilities in absorbing metabolites of fish and purifying the water where *Carassius auratus auratus*.

Materials and methods

Plant materials

Aquaponic system (assembled in Sichuan Tea College, Yibin University, Sichuan Province, the fishes purchased from local market), soybean, mung bean, pea and radish seeds (purchased from Beijing Academy of Agriculture and Forestry) to produce soybean sprouts, mung bean sprouts, pea sprouts and radish sprouts.
$Na_2S_2O_3$ standard solution, 0.5% starch solution, 2mol.dm-3HAc solution, iodine solution, Coomassie blue staining solution, standard protein solution (0.5mg/ml bovine serum albumin), anthrone, standard glucose solution (0.1mg/ml).
Mortar, conical flask, analytical balance, test tube, measuring cylinder, glass rod, pipette, acid burette, cuvette, visible spectrophotometer.

Growth conditions

The structure of aquaponic system is shown in Figure 4. We filled the plastic bucket with tap water for 2 days (used as aquaculture water), and the fish (4 *Carassius auratus auratus*, total weight 755g) were fed every 3 days. We irrigated sprouts with fish farming water to achieve a sustainable production of sprouts in urban area.

In this study, the following 3 growth conditions were used to culture the sprouts, as shown in Table 4.

The experiment was conducted in Yibin (28°47′55.26″N, 104°36′43.13″E, 377 masl), Sichuan Provence, China during Apr 11, 2019- May 15, 2019, and the sprouts were cultured on the balcony to get rid of the rain and other influence factors. The customized seedling tray and seeding method are shown in Figure 5.

Data scoring and analysis

A factorial experiment was designed and we produced 4 sprouts under 3 growth conditions, each with 3 complications. The stem diameter (mm) was measured by vernier caliper, the height (mm) was measured by a ruler, the weight (10 sprouts) was determined by analytical balance, the vitamin C content was determined by the way of Iodometric determination (Bekele and Geleta, 2015), and the protein content was determined by the way of Coomassie Blue Staining Method (Krauspe and Scheer, 1986), the soluble sugar content was determined by the way of anthrone colorimetric method (Buysse and Mercks, 1993).

Descriptive analysis and analysis of variance (ANOVA) were conducted for the tested traits using Excel 2016 and SPSS Statistics 20.0, and SigmaPlot 12.5 was used for mapping based on the analysis results.

Conclusion

During this experiment, the water in the aquaponic system was clean and did not need changing. It just needed some water top up because of water loss due to daily evaporation and transpiration of sprouts. The sprouts cultivated under ASC condition absorbed metabolites of fish and purified the water, and also significantly increased their nutrients content and yield, which deserves further research and promotion.

Acknowledgments

This work was supported by the Cultivation Project of Yibin University (02180184, 02180181), National College Students' Innovation and Entrepreneurship Training Program (0818000201), Key Lab of Aromatic Plant Resources Exploitation and Utilization in Sichuan Higher Education (02180256).

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