Survival and Productivity of Culinary Herb Species in a Nutrient Film Technique-type Aquaponic System with Nile Tilapia

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ABSTRACT

Aquaponics is an evolving technology for producing plants and fish (or other aquatic organisms) in an integrated water recirculating system. However, the survival and productivity of terrestrial plants in aquaponic systems have not been evaluated for most plant species. The present study aimed to analyze the survival rate, growth, and biomass production of eight culinary herbs, commonly used in Guatemala, in a Nutrient Film Technique-type (NFT) aquaponic system with Nile tilapia (*Oreochromis niloticus*). The investigated herbs included coriander (*Coriandrum sativum*), parsley (*Petroselinum crispum*), peppermint (*Mentha spicata*), thyme (*Thymus vulgaris*), samat (*Eryngium foetidum*), oregano (*Plectranthus amboinicus*), dill (*Anethum graveolens*), and basil (*Ocimum basilicum*). A total of 50 individuals of each herb species and 150 juvenile Nile tilapias were distributed in 5 aquaponic modules. The survival rate, growth, and biomass production were measured for herbs and tilapias. All the herb species survived against the NFT aquaponic conditions. The findings indicated that the herb survival was species-dependent and ranged 42-98%. There was a significant effect of the herb species both on height and biomass gains. Post hoc comparison showed interspecific differential abilities to grow biomass in NFT aquaponics conditions. Among the investigated herbs, *M. spicata* and *O. basilicum* were the most productive species. Refinement in the selection of initial plants and aquaponic management could improve plant performance.

Keywords: Ecological production, Hydroponics, *Oreochromis*, Recirculating water, Sustainable aquaculture

INTRODUCTION

Aquaponics is an evolving technique to tackle climate change challenges in the agriculture industry (Tyson et al., 2011; König et al., 2018; Palm et al., 2018). In contrast to traditional agricultural resource management, an aquaponic system saves water and reduces waste, costs, and environmental contamination (Lennard and Leonard, 2006; Rizal et al., 2018). The reutilization of water and the use of waste from aquatic organisms to feed the plants in a closed system makes aquaponics a social, ecological, and healthier alternative to meet the sustainable development goals proposed by United Nations (United Nations, 2015; Li et al., 2018; Rizal et al., 2018). Regardless of the fact that aquaponics has been criticized by organic farmers for the industrial origin of the substrate and the absence of soil (Kledal et al., 2019), this form of producing has also been considered the agriculture of the future (Shafeena, 2016).

Although aquaponics has demonstrated to be effective and efficient for small and large scale productions of lettuce, tomatoes, and other salad greens (Somerville et al., 2014; Love et al., 2015), it seems that it is not possible for all plant species to survive and grow in aquatic conditions (Guerra-Centeno et al., 2016). Therefore, it is necessary to identify plant species that can be grown and produced in aquaponic conditions.

Guatemala is a megadiverse country, where many plant species are traditionally used for feeding, spicing, medicinal, and other cultural purposes (Cáceres, 1996; Villar-Anleu, 1998; Knapp and Davidse, 2006). However, there is a dearth of research addressing the productivity of Guatemalan plant species in aquaponic conditions (Guerra-Centeno et al., 2016). Since biomass production is a function of survival and growth, the aim of the current study was to examine these features in eight culinary herb species mainly used in Guatemala (coriander [*Coriandrum sativum* L.], parsley [*Petroselinum crispum* (Mill.) Fuss], peppermint [*Mentha spicata* L.], thyme [*Thymus vulgaris,* L.], samat [*Eryngium foetidum,* L.], oregano [*Plectranthus amboinicus* (Lour.) Spreng], dill [*Anethum graveolens* L.] and basil [*Ocimum basilicum* L.]) using a Nutrient Film Technique-type (NFT) aquaponic system with Nile tilapia (*Oreochromis niloticus* L.).

MATERIALS AND METHODS

Ethical approval

This study was reviewed and approved by the Graduate School Bioethics Committee of the Faculty of Veterinary Medicine and Animal Husbandry of the University of San Carlos of Guatemala, Guatemala City.

Study site

The study was performed inside a greenhouse, in the facilities of the *Instituto de Investigación en Ciencia Animal y Ecosalud* (IICAE) at the Veterinary and Animal Husbandry Faculty, University of San Carlos of Guatemala, located in Guatemala City.

Study design

The samples in the current study consisted of eight herb species. Depending on the herb species, seedlings or cuttings were used as propagules (Table 1). The performance of each sample was examined using aquaponic modules (Figure 1). Each module had 8 perforated pipelines and each pipeline had 10 holes. Each pipeline was considered as a block and only housed individuals of a single herb species. Therefore, each aquaponic module held 80 plant individuals (10 per species). This arrangement was replicated in five aquaponic modules. The observation period in aquaponic conditions lasted 90 days, from June to August 2018.

Aquaponic system and modules

The aquaponic modules at the IICAE consisted of a water tank, a pump, a biofilter, and a pipeline circuit. For each module, one plastic 750 L water tank was used. For pumping the water, one submersible 0.5 horsepower pump (BOS Truper®, Mexico) was installed and a hose was coupled to conduct the water flow from the tank to a biofilter (Clear Choice PF-1, Tetra®, Blacksburg, VA, USA). Two 4' PVC pipeline circuits were installed in a zigzag arrangement (Figure 1). Water flow was regulated using a nutrient film technique-type (NFT) design.

Herb management

The herb materials were obtained from commercial suppliers (Superb Superseed S.A and Vivero Botanik, Guatemala City). Prior to the observation period in aquaponic conditions, coriander, parsley, samat, dill, and basil seeds as well as peppermint, thyme, and oregano cuttings were placed into seedbeds with fertilized soil where they remained for up to eight weeks. The herbs were then transplanted to the NFT modules. Only the propagules that had three to five leaflets were selected to be transplanted to the aquaponic conditions.

Tilapia management

While the plant material was in the seedbeds, 300 juvenile Nile tilapia, weighing about 1.5 g each, were obtained from a commercial farm (Cazali Tilapia Farm, Escuintla, Guatemala) and put under quarantine for 30 days in a plastic 1000 L water tank. After that period, 30 tilapia organisms, weighing 2-4 g each, were selected and placed in the water tank of each NFT module (i.e., a total of 150 fish) to start the aquaponic phase. All tilapia organisms were managed following the Food and Agriculture Organization recommendations for small-scale aquaponic food production (Somerville et al., 2014). During the first 30 days of the study, tilapias were fed 45% protein extruded food (Tilapia™, Alcon, Honduras), and from day 31 to day 90, tilapias were fed 32% protein extruded food (Tilapia™, Alcon, Honduras).

Measurements

The height/length and weight of each herb and tilapia organism were measured and recorded at days 0, 45, and 90 of the aquaponic observation period. The height of the plants was measured from the base of the stem to the tip of the apical meristem whilst the length of the tilapia organisms was measured from the tip of the snout, with mouth closed, to the extreme of the tail fin. Heights and lengths were measured in centimeters using a measuring tape and approximated to the nearest tenth. The weight was measured in grams using an electronic balance (iBalance 700™, My Weigh, AZ, USA) and approximated to the nearest tenth. Differences between initial and final measurements were recorded. Growth was considered as both height/length and weight (biomass) gains. The values related to water temperature, pH, electric conductivity, and total dissolved solids were measured every 15 days using a digital tester (HI 991300™, Hanna, RI, USA) and the mean values were calculated.

Statistical analyses

The descriptive statistics included the calculation of the mean and standard deviations for height/length and weight measurements of herbs and tilapia. Since the obtained data did not meet the assumptions of normality, the non-

parametric test of Kruskal-Wallis was used to compare the means values of plant longitudinal growth and biomass production. In this regard, the post hoc test of Mann-Whitney pairwise was run to determine the specific differences. The correlation between survival rate and herb species was analyzed using the Pearson's chi-squared test. Statistical analyses were performed using Past Program®, version 3.20 (Hammer et al., 2001). The significance level for the statistical tests was $p < 0.05$.

Figure 1. Components of a nutrient film technique (NFT) aquaponic module at the IICAE greenhouse, including (1) water container with a submersible pump; (2) hose to conduct the water from the tank to the biofilter; (3) biofilter; (4) PVC pipe circuits for water circulation and plant hosting.

Table 1. Descriptive statistics of experimental arrays of eight investigated herbs species in five aquaponics modules

Herb species	Number of individuals per pipeline, per module	Total number of individuals	Type of propagule
Coriander (*Coriandrum sativum*)	10	50	Seedling
Parsley (*Petroselinum crispum*)	10	50	Seedling
Peppermint (*Mentha spicata*)	10	50	Cutting
Thyme (*Thymus vulgaris*)	10	50	Cutting
Samat (*Eryngium foetidum*)	10	50	Seedling
Oregano (*Plectranthus amboinicus*)	10	50	Cutting
Dill (*Anethum graveolens*)	10	50	Seedling
Basil (*Ocimum basilicum*)	10	50	Seedling
Total	80	400	---

The findings of the current study indicated that all herb species survived to the NFT aquaponic conditions. Survival rates were within the range of 0.42-0.98 (Table 2) and were associated with herb species ($p < 0.01$). There was a significant effect of the herb species both on height ($p < 0.01$) and biomass ($p < 0.01$) gains. The obtained results of post hoc comparison were indicative of interspecific differential abilities to grow biomass in NFT aquaponics conditions (Table 3). Peppermint and basil were the most productive species. Regarding biomass production, the growth rate of plants varies according to their species (Figures 2 and 3). For most plant species, growth was marked by a slow initial phase, followed by an accelerated phase (Figure 4).

Survival and productive parameters of Tilapia
Tilapias survived and showed a growing response in the water tanks of the NFT aquaponic modules (Table 4).

Water parameters
The mean values related to water temperature, pH, electric conductivity, and total dissolved solids were 24.9 ± 1.2 °C, 7.8 ± 0.5, 458.1 ± 309.7 µS, 232.7 ± 157.4 ppm, respectively.
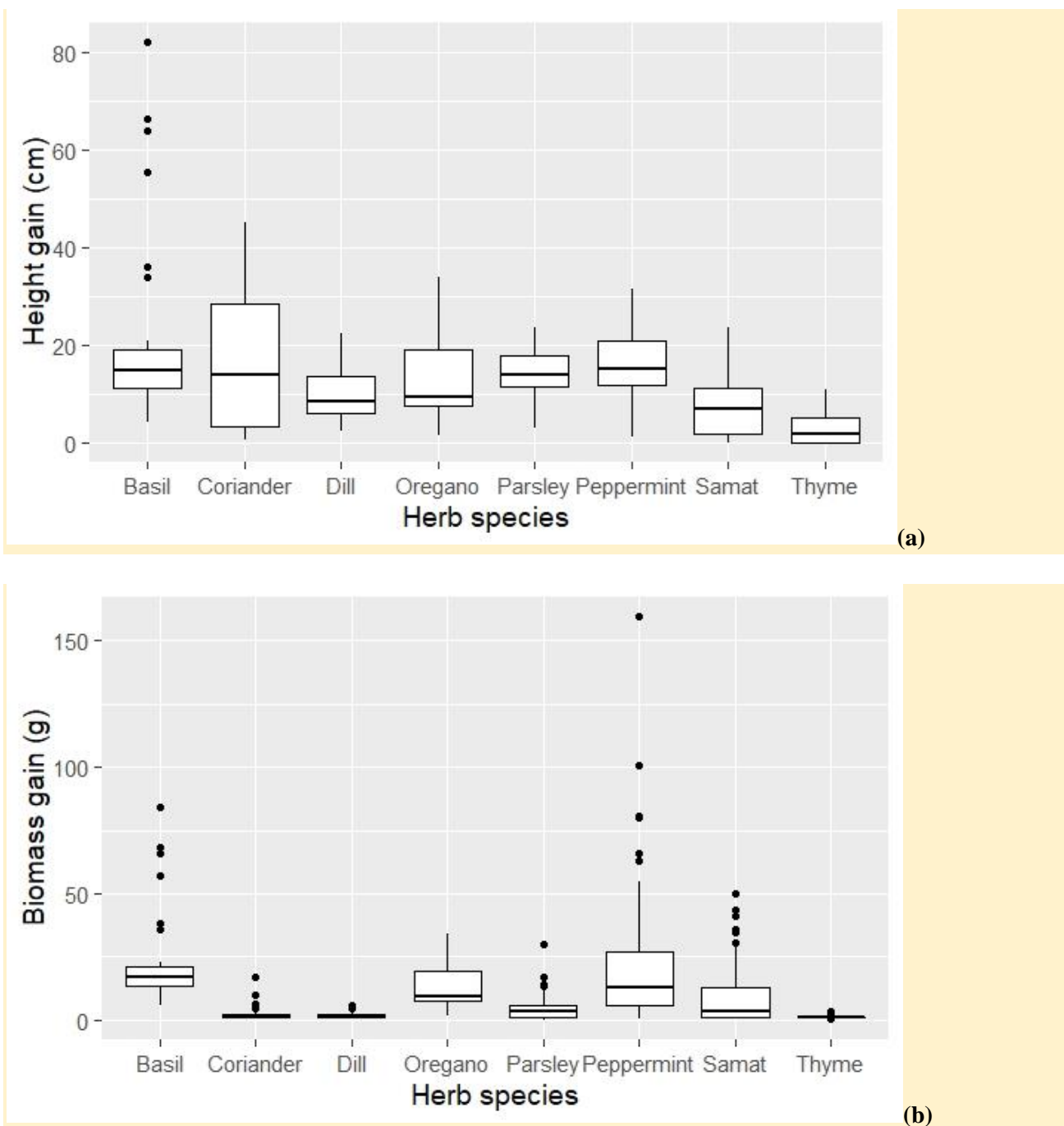

(a)

(b)

Figure 2. Variation in biomass production for survivors of eight herb species in NFT aquaponic conditions, by day 90 of observation: *a* = height gain; *b* = biomass gain.

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Figure 3. Variation in growth of peppermint individuals from the same block, by day 90 of observation period.
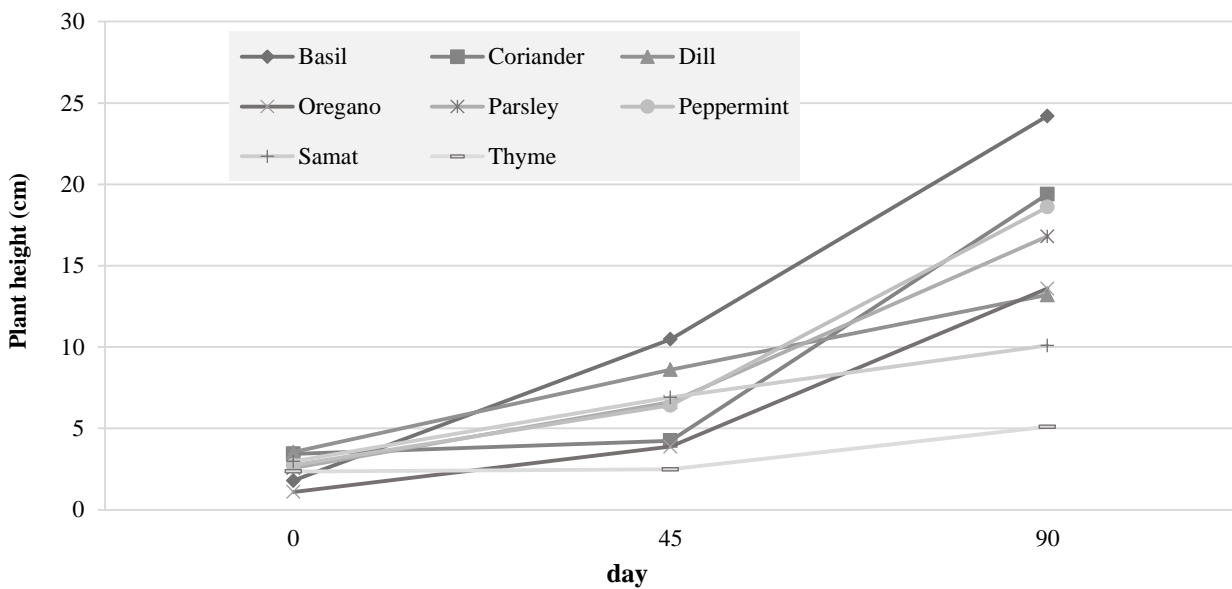

Figure 4. Mean height for eight species of culinary herbs in an NFT aquaponic system from transplantation (day 0) to the end of the observation period (day 90).

Table 2. Survival rate and biomass production of eight herb species in an NFT aquaponic system after 90 days of observation

Herb species	Final number (survival rate)	Height gain median (range) [cm]	Biomass gain median (range) [g]	Total biomass per species at day 90 (g)
Coriander	19 (0.38)	16.0 (4.0-47.0)	1.7 (0.5-16.7)	69.2
Parsley	49 (0.98)	17.0 (5.0-25.0)	3.3 (0.0-29.9)	242.8
Peppermint	49 (0.98)	17.0 (4.0-34.0)	12.7 (0.5-159.5)	1168.9
Thyme	38 (0.76)	4.5 (1.0-13.0)	0.9 (0.5-3.5)	48.7
Samat	44 (0.88)	9.0 (1.0-25.0)	3.1 (0.2-49.8)	418.4
Oregano	21 (0.42)	10.0 (2.0-35.0)	9.2 (1.4-33.8)	265.4
Dill	29 (0.58)	12.0 (2.0-25.0)	1.1 (0.5-5.9)	54.9
Basil	27 (0.54)	17.0 (6.0-84.0)	16.7 (5.9-83.9)	1006.5

The initial number of individuals was 50 for all species. NFT: nutrient film technique

Table 3. Mann Whitney Pairwise post hoc comparisons for biomass gain values of eight herb species

Items	Coriander	Parsley	Peppermint	Thyme	Samat	Oregano	Dill	Basil
Coriander	-	.011	< .001	.084	.037	< .001	.728	< .001
Parsley	.011	-	< .001	< .001	.991	< .001	.001	< .001
Peppermint	< .001	< .001	-	< .001	< .001	.356	< .001	.129
Thyme	.084	< .001	< .001	-	.002	< .001	.027	< .001
Samat	.037	.991	< .001	.002	-	.005	.045	< .001
Oregano	< .001	< .001	.356	< .001	.005	-	< .001	.007
Dill	.728	.001	< .001	.027	.045	< .001	-	< .001
Basil	< .001	< .001	.129	< .001	< .001	.007	< .001	-

Table 4. Survival and production parameters of Nile tilapia in an NFT aquaponic system at day 90.

Parameters	Mean (SD)
Mean final number per module	27.0 (1.9)
Mean survival rate per module (%)	90.0 (6.2)
Mean final individual length (cm)	17.3 (2.2)
Mean final individual weight (g)	106.2 (37.9)
Mean biomass per tank (g)	2866.2 (660.9)

NFT: nutrient film technique; SD: standard deviation

DISCUSSION

All the evaluated species showed some potential to survive and grow in NFT aquaponics conditions. However, the observed variation in survival rate and biomass production suggested the existence of some factors affecting both individual and species-related abilities for production in aquaponic conditions. The outcomes of the current study underlined the more recent studies on the differential abilities of plant species in terms of biomass adaptation and production in NFT aquaponics (Hu et al., 2015; Guerra-Centeno et al., 2016; Valdez-Sandoval et al., 2017), according to which a large number of factors could contribute to such differences. To name a few, the findings of the present study suggested propagule size (in the early aquaponic stage), hydraulic charge (water flow), and root-covering algae as the most important growth-limiting factors. Life in aquatic conditions might be the most important constrain to earth-evolved plant species. It is known that flooding hinders growth and development for most vascular plants (Jackson and Colmer, 2005). The major constrain in flooding conditions is an inadequate supply of oxygen to the submerged roots. Oxygen diffusion in water is about 10,000 times slower than in air (Colmer, 2003). Some flood-resistant plant species can survive and even grow in flooding conditions due to various evolutive adaptations, including metabolic, hormonal, and morphological responses (e.g., adventitious roots and aerenchyma, Blom and Voesenek, 1996; Visser et al., 2000, Visser et al., 2003). As a result, it can be concluded that although it is impossible for all the plant species to survive in floodplains, some plant species could survive in aquaponic conditions if oxygen is available to plant roots via circulating water (Maucieri et al., 2018).

Regardless of water recirculation and oxygen carriage in aquaponic NFT systems, a hemp wick is required in case of small transplanted propagules to pass water from the nutrient film flow to the plant substrate by capillarity. This issue usually causes water stagnation in the substrate inside the net pots that can, to some extent, decreased oxygen availability for the plant. In the present study, there were instances of water stagnation, death or poor foliage, and root development in some coriander, parsley, thyme, oregano, and dill individuals which neither survived nor showed growth.

Bigger propagules with well-developed roots, such as those of beans and peppers, can easily reach the water flow and survive the water stasis inside the plant substrate (Valdez-Sandoval et al., 2017). Leaves and stems development could favor survival in early aquaponic stages as atmospheric oxygen can be captured via stomas and lenticels through convection (Pardos, 2004). Other aquaponic systems, such as a raft or floating bed, could favor the survival and growth of little propagules, as the tiny roots (i.e., typical of early propagules) directly contact the recirculating water. However, it should be mentioned that a larger amount of water may lead to a lower density of nutrients and less absorption by the propagules (Lennard and Leonard, 2006).

Another issue of consideration in the current study was related to the association between algae and suspended solids accumulation in the roots and delayed plant growth. The algae or solids film that forms on the root system could

block the diffusion of oxygen and other nutrients from the water film to the roots (Roosta and Afsharipoor, 2012; Hu et al., 2015). However, this possible growth-inhibition factor must be examined more thoroughly in experimental conditions.

A third factor that could decrease survival and growth is the speed of the water flow. It is known that high hydraulic loads cut the contact time between roots and water, and consequently hinder the absorption of nutrients (Wongkiew et al., 2017). Additionally, the mechanical action of the water flow that permanently impacts the root system of the plant can affect the formation of adventitious roots, an important factor for radicular aerenchyma formation (Blom and Voesenek, 1996). The low growth of many thyme individuals (i.e., the size remained almost the same as transplantation size) in the present study could be due to the effect of such mechanical action. However, the obtained results of such low growth may vary according to the plant species and, therefore, this issue should be empirically investigated for all plant species.

Concerning the growing behavior of plants, the generalized slow growth rate observed in the first days is consistent with our earlier observations (Guerra-Centeno et al., 2016; Valdez-Sandoval et al., 2017). This slow growth rate was probably caused by a low nitrogenated waste production when the fish were still small. Once the fish get larger in size, the amount of available nitrogenous waste allows the accelerated growth of the plants, depending on their species (Hu et al., 2015). Additionally, many of the herb individuals exhibited a retarded radicular development during some weeks after transplantation to the NFT modules. Based on the findings of the current study, it can be concluded that the stagnant phase that eventually retarded growth and biomass production could be overcome using more mature propagules with well-developed roots. Direct contact of well-developed roots with the recirculating water not only favors oxygen absorption but also nitrogen uptake (Hu et al., 2015).

Another interesting finding of this study was the divergent ability of individual plants to survive, adapt, and grow in NFT aquaponic conditions. This can suggest that the genetic traits of the fittest individuals can be fixed through selection management leading to the technical and financial feasibility for small or large production. In the current study, peppermint and basil were the only herb species that showed small and large-scale production potential in the NFT system. However, the rest of the species should not be undervalued by these results.

With regard to tilapia, the observed survival rates and growth responses were higher or consistent with earlier studies in similar conditions (Mbahinzireki et al., 2001; Coyle et al., 2004; Bahnasawy, 2009). This confirms the feasibility of tilapia to produce in recirculating systems supporting their sustainability and economical profitability (Blidariu and Grozea, 2011).

In the present study, the plant performance values were, in general, below those reported for aquaponic (Espinosa-Moya et al., 2018) or soil conditions (Telci et al., 2004; Salim et al., 2014); therefore, there is a need to do further studies in order to derive conclusions and decisive decisions in selecting the investigated herb species for production purposes in conditions similar to the IICAE NFT systems.

CONCLUSION

Peppermint (*Mentha spicata*) and basil (*Ocimum basilicum*) were the most productive species in NFT aquaponics conditions. Among the investigated species, the obtained results of these plants showed potential for commercial or domestic production. Based on the findings of the current study, it is, however, believed that the survival and production capabilities of the other herb species in NFT aquaponics conditions could be improved by refinement or modifications in the management techniques, including initial individual plant selection, water flow management, suspended solids management, and algae control.

DECLARATIONS

Competing interests
The authors declared no conflict of interest.

Authors' contribution
Carlos Valdez-Sandoval designed the plan of the study and managed the funds. Dennis Guerra-Centeno conceived the idea and drafted the manuscript. Manuel Lepe-López analyzed and interpreted the data. Mercedes Díaz-Rodríguez collected the data and reviewed the manuscript. Lariza Pineda-Alvizures processed the data and reviewed the manuscript.

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