Evaluation of *Fragaria* x *ananassa* in an aquaponic system with *Oncorhynchus mykiss* and substrate culture conditions

[1]July P. Aguirre, [1]Ana Torres-Mesa, [2]María M. Perez-Trujillo, [2]Silvia A. Rubio-Castro, [1]Edwin Gómez-Ramírez

[1] Ecotoxicology, Evolution, Environment and Conservation Research Group, Faculty of Basic and Applied Sciences, Applied Biology Program, Universidad Militar Nueva Granada, Kilometer 2 vía Cajicá – Zipaquirá, Colombia; [2] Agrobiology of promising cold climate plant species Research Group, Universidad Militar Nueva Granada, Faculty of Basic and Applied Sciences, Horticultural Management and Production Technology, Kilometer 2 vía Cajicá – Zipaquirá, Colombia. Corresponding author: E. Gómez-Ramírez, edwin.gomez@unimilitar.edu.co

Abstract. Aquaponics is the combination of recirculating aquaculture with hydroponics for the clean production of food. However, studies have focused on leafy greens plants and not on fruit plants, rendering crop diversification in aquaponic systems a challenge. Strawberries (*Fragaria* x *ananassa*) are the most traded red fruit in the world, and Colombia is an important producer in the region. The objective of this study was to evaluate the growth of 'Monterey' strawberry in an aquaponic system and a culture system with substrate in a contained bed. Growth in both systems was determined from non-destructive and destructive sampling during the vegetative and reproductive stages. Rainbow trout (*Oncorhynchus mykiss*) growth parameters and water quality variables were estimated. The number of reproductive structures and yield was higher in the aquaponics plants, indicating precocity in the reproductive stage under this culture system. Significant differences were observed in the dry weight of crowns, being higher in the system of contained beds, which suggests a predominance of vegetative growth of the plants in this system. Water quality conditions remained within the appropriate ranges for the species evaluated. Strawberry growth and yield was considerably better in the aquaponic system compared to the contained bed system. This work shows that this system can be a viable alternative to produce fruiting plants such as strawberries.

Key Words: cleaner production, fruit plants, nutrients, rainbow trout, strawberry.

Introduction. As the human population grows, the demand for food and land to produce it increases, generating environmental sustainability issues related to greenhouse gas emissions, chemical waste production, nutrient loss and soil erosion (Asadullah et al 2020). In addition, agriculture uses more than 70% of the world's total freshwater (Schmautz et al 2015). Therefore, aquaponic systems are presented as a solution for sustainable use of water, nutrients and nutrient recycling (Goddek et al 2019).

Aquaponics is a plant and animal food production technology that combines a recirculating aquaculture system with hydroponics (Ramírez et al 2008). Most studies in these systems focus on leafy greens and herbs such as lettuces and aromatics (Petrea et al 2013; Riaño-Castillo et al 2019; Cardenas Laverde et al 2022). However, there are few studies on plants whose commercial product is fruit or flowers. One cause of this is that fruit production has a higher nutritional requirement, and more knowledge is required in the nutrient dynamics and management of these systems. Therefore, more studies of fruiting plants are required to diversify crops in aquaponics (Somervile et al 2014).

Strawberry (*Fragaria* x *ananassa*) is the most marketed red fruit in the world, for the year 2012, 4.6 million tons were produced, with the United States contributing 33% of the production, Mexico with 9%, Turkey and Spain, both with 7% (Ramírez et al 2008). In 2018, strawberry production in Colombia was estimated at 85010 t with a yield of 39.33 ton ha^{-1} (Agronet 2022). The area planted in strawberry crops has reached 2600 ha, with an estimated average of 348 new hectares per year, for a rapid growth of 90% (Ministerio de Agricultura 2016). Colombian strawberries not only supply local demand, but are exported to 14 countries, where Panama tops the list of consumers (Ministerio de Agricultura 2016).

Rainbow trout (*Oncorhynchus mykiss*) inhabit and grow successfully in waters with temperatures between 14 and 16°C, for this reason, this species has adapted well to the high Andean water bodies of Colombia (Merino-Archila et al 2006). In recent years, there has been a 33% increase in exports to the United States, positioning the country as the second largest exporter of this species (Ministerio de Agricultura 2016).

Due to the successful experiences with the cultivation of rainbow trout in recirculation aquaculture systems (RAS) (Montaña et al 2013) and in aquaponic systems (Vasdravanidis et al 2022) it was decided to work with this species, despite its more demanding water quality requirements. In addition to the great adaptability of strawberries to hydroponic systems (Richardson et al 2022), it was considered appropriate to carry out this research in aquaponic systems. Therefore, the objective of this work was to compare the growth and production of strawberry cultivars "Monterey" in two culture systems, aquaponics and contained bed with substrate. This will contribute to diversifying aquaponics and responding to the gap in knowledge regarding fruiting plants, as well as an alternative for the development of small-scale projects that contribute to food security at the local level.

Material and Method

Study area. The experiment was conducted during a period of nine months (August 2020 to May 2021) in the greenhouses of Ichthyology, horticulture and animal physiology laboratory of the Universidad Militar Nueva Granada Campus Cajicá (Cundinamarca-Colombia). The University is at an altitude of 2559 masl, latitude 4°56'34.7" y longitude 74°00'55.9" and an average temperature of 14 °C (Cárdenas et al., 2022).

Design of the small-scale aquaponic (AQ) system. This system was composed of a 1000 L tank connected to a 500 L settling tank with a mat mesh on the surface to filter suspended solids. The biofilter was a 200 L tank containing 30 L of 2 cm conduit pipe, functioning as a substrate for the nitrifying bacteria. The sump was a 200 L tank where a 6000 L pump (Resun®) was installed to allow water flow to the plants and the fish tank. Fifteen 'Monterey' strawberry plants were planted in a vertical nutrient film technique (NFT)system (Figure 1), for which four 4" PVC pipes were installed. Coconut fiber was used for support and to keep the roots hydrated. The planting density in this system was 10.08 plants m^{-2}. Aeration was supplied through a blower (Resun®) with a capacity of 370 W, which had four aeration lines in the fish tank and the biofilter. This system was installed under a conventional space-type greenhouse with a transparent polyethylene cover.

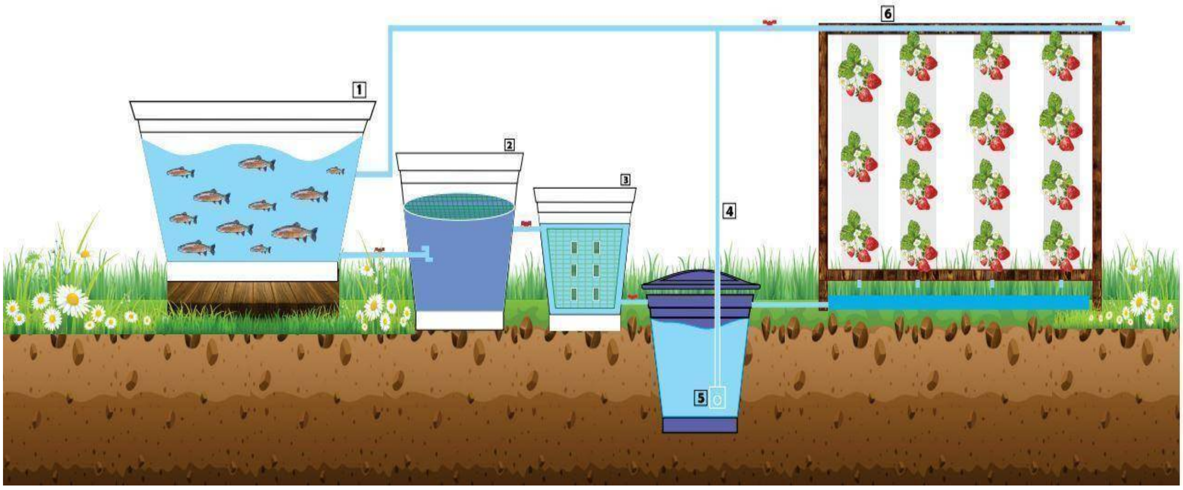

Figure 1. Small-scale aquaponic system. 1 - fish tank; 2 - settling tank; 3 - biofilter; 4 - sump; 5 - submersible pump; 6 - NFT vertical system.

Design of the contained beds (CC). A system composed of three contained beds 30 m long, 1 m wide and 0.4 m deep, supported on the floor and located under a non-climatized space-type greenhouse, with a transparent polyethylene cover, was used in an area that was perimetrically enclosed with white polyshade mesh. Each bed was mulched with black-white plastic mulch. A mixture of black soil and organic matter (60% black soil, 20% compost based on vegetable waste and 20% raw rice husks) was used as substrate. Potassium sulfate (0.45 kg), urea (0.3 kg), compost (11.8 kg) and dolomite lime (3 kg) were added as pre-sowing fertilizers. Irrigation was carried out using drip lines (three per bed, with drippers spaced 10 cm apart, flow rate 16 mL min^{-1} $dripper^{-1}$), which were activated by a programmed irrigation sensor for 40 s every hour, between 6:00 am and 4:00 pm. This same system was used for fertigation with a nutrient solution based on that proposed by Hoagland & Arnon (1950) in Wiser & Blom (2016). The plants were seeded in three rows per bed with planting distances of 35 cm, with a total number of 108 plants and a planting density of 9.23 plants m^{-2}.

Strawberry growth parameters. Bare-root rooted runners of strawberry 'Monterey', with previous cold storage and imported from Chile, were acquired from Proplantas S.A. To estimate growth parameters, two stages of the Association of Applied Biologists (AAB), the British Agrochemicals Association (BAA), the British Crop Protection Council (BCPC) scale for strawberry were considered: fifth expanded leaf (stage 15) and first fruits harvested (stage 85) (Tottman 2008). After planting the stolons in each cultivation system, the inflorescences were removed from their appearance until the plants reached three crowns, at which time the reproductive organs were allowed to grow freely. Plant growth monitoring was carried out in two ways: non-destructive sampling and destructive sampling at the end of each selected stage of development. For the first method, 6 plants per system were labeled and the number of crowns, number of leaves, number of reproductive structures (buds, open flowers, immature fruits and harvested fruits) and leaf area were recorded weekly. The latter consisted of the sum of the individual areas of all the leaflets of each plant. The area of each leaflet was calculated from the measurement of its length and then applying the equation proposed by Grijalba et al (2015), $Y = 0.8316X^{1.0784}$ (R^2 = 0.956), where Y is the leaf area (cm^2) and X is the length of the leaflet (cm).

A destructive sampling was carried out in the vegetative stage (stage 15) and one in the reproductive stage (stage 85), the latter on those labeled plants that finished their first fruiting stage; in each sampling 6 plants were taken per system. The total dry weight of the plant was recorded, considering the dry weight of the different organs such as roots, crowns, leaves and reproductive structures (flowers, immature fruits, harvested fruits). The drying process of the plant material was carried out at 60°C for 48 h.

Rainbow trout (Oncorhynchus mykiss) growth parameters. One hundred fry of rainbow trout were obtained from a certified aquaculture company. The fish were fed Truchina® 43% of crude protein, four times a day. When the fish reached an average length of 10 cm they were fed three times a day. The amount of feed was determined according to the FAO (2014) feeding table.

Ten percent of the total population was used for measurements. Weight was quantified with an ACCULAB® digital scale, total length and standard length were measured with an ichthyometer. For growth parameters, the methodology proposed by Torres-Mesa et al (2023) was followed with some modifications where weight gain (WG), condition factor (K), specific growth rate (SGR) and feed conversion ratio (FCR) were evaluated.

In order to generate an environment that would allow the establishment of nitrifying bacteria at a faster rate, the chemical maturation methodology proposed by Torres-Mesa et al (2023) was adopted. Once the water quality parameters had stabilized, the rainbow trout fry were reared. When NO_3^- levels were in a range above 50 mg L^{-1}, the plants were seeded.

Water quality parameters in aquaponic system and substrate in contained bedding. In AQ, TAN and NO_2^- were measured every two days from the establishment of the system until the parameters were adjusted for the fry. Once the fish were introduced, pH and temperature were measured daily with a HANNA HI99121® pH meter. Dissolved oxygen (DO), dissolved oxygen saturation (%DO), electrical conductivity (EC) and total suspended solids (TSS) were measured weekly with a HANNA instruments HI9829® multiparameter probe. Water samples were taken once a week to measure NAT, NO_2^-, NO_3^-, Fe_2^+, PO_4, Ca_2^+ and once a month K^+ and Mn_2^+ were measured with the Spectroquant Multy® equipment. The water quality parameters were maintained in the appropriate ranges for rainbow trout rearing (Somervile et al 2014).

In the CC, pH and EC of the filtrate were measured weekly with a multiparameter equipment by taking the substrate sample to the laboratory and mixing it with water in a 1:1 volumetric proportion with distilled water. This sample was also used to measure nitrate and calcium content with the LAQUAtwin® portable reader.

Pest and disease control. Initially, the seedlings were disinfected with quaternary ammonium. In the contained bed system, soil pathogens were prevented by applying *Trichoderma harzianum* (PRQTECTOR®) and *Paecilomyces lilacinus* (NEMOCROP®) in doses of 300 g L^{-1} each using the drench injection technique. In the aquaponic system, when there was an incidence of insect pests, the leaves were washed and massaged using agricultural soap, coconut soap or citronella extract. In the contained bed culture system, spraying was carried out to control *Tetranychus* sp. using Vertimec ® (i.a. abamectin) and pitfall traps made with beer bait were used to control slugs and/or snails. In addition, blue and yellow chromatic traps were placed in each of the systems (AQ and CC) to capture whiteflies and thrips adults.

Plant growth and crop yield. The yield and the number of fruits harvested during the first four months of production were determined in the two cultivation systems. Once a week, fruits with more than 75% of their surface area in bright red color were harvested at the harvesting point. The harvested fruits were counted and weighed fresh. The yield and number of fruits per unit area (m^2) and per plant were determined, considering that the AQ occupied an area of 1.29 m^2 with 13 plants distributed vertically, for a density of 10.08 plants m^{-2} and that in the bed culture system with substrate (CC) the monitoring was done in plots of 4.4 m^2 with 41 plants planted on average, for a density of 9.23 plants m^{-2}. In addition, the average weight of each strawberry fruit harvested was calculated.

Statistical analysis. A descriptive analysis was performed using the arithmetic mean and standard deviation to indicate the behavior associated with each variable. For strawberry growth parameters, the assumptions of normality and homogeneity of variance were tested using the Shapiro-Wilk test. The T student test for independent samples at the 5 % significance level ($p < 0.05$ error) was used to compare the effect of the two cropping systems on each response variable at each evaluation date. The analysis was performed with R 3.5.0 software freely distributed on the internet (RStudio Team 2018).

Results and Discussion

Strawberry growth parameters and yields. In general, growth variables were similar between the two systems during the vegetative stage. In the second stage, the number of reproductive structures was significantly higher in the AQ (Table 1). It is important to emphasize that the higher number of reproductive structures found in strawberry seeding in the aquaponic system was also supported by a higher percentage of plants in which sprouting of reproductive structures occurred, 67% compared to 50% obtained in the CC system.

In the destructive sampling, there were no significant differences in the variables of total dry weight, root dry weight, leaf dry weight or reproductive structures (flower buds, inflorescences and fruits). Total crown dry weight (TWD), which included stems and petioles, was significantly higher in the CC system (Table 1).

Table 1

Growth variables of strawberry 'Monterey' by non-destructive and destructive sampling at vegetative and reproductive stage, in the aquaponic (AQ) and contained bed substrate (CC) systems

Stage	*Parameter*	*AQ*	*CC*
Vegetative	NC	1.0±0.00[a]	1.0±0.00[a]
	NL	1.6±0.55[a]	2.0±0.00[a]
	NRE	0.0±0.00[a]	0.0±0.00[a]
	LA (cm^2)	10.59±3.43[a]	12.09±1.62[a]
	TWD (g)	1.92±0.23[a]	1.71±0.29[a]
	RWD (g)	0.96±0.23[a]	0.78±0.15[a]
	CW (g)	0.55±0.14[a]	0.56±0.12[a]
	LWD (g)	0.39±0.25[a]	0.36±0.12[a]
Reproductive	NC	4.5±1.73[a]	6.0±1.00[a]
	NL	38.8±8.06[a]	41.3±6.81[a]
	NRE	26.8±9.29[a]	7.0±9.54[b]
	LA (cm^2)	694.56±76.32[a]	586.39±69.17[a]
	TWD (g)	81.90±47.66[a]	127.16±18.03[a]
	RWD (g)	12.58±6.17[a]	18.67±8.20[a]
	CW (g)	20.37±3.60[a]	32.54±4.74[b]
	LWD (g)	40.73±8.32[a]	52.10±7.23[a]
	RSW (g)	11.72±6.01[a]	11.92±14.01[a]

Note: NC = number of crowns; NL = number of leaves; NRE = number of reproductive structures; LA = leaf area; TWD = total dry weight; RWD = root dry weight; CW = crown dry weight; LWD = leaf dry weight; RSW = reproductive structure weight. Values represent mean±standard deviation. Different letter superscripts on the same row indicate statistical differences according to T-test.

This is the first study that compares an aquaponic system and a contained bed system using strawberries in tropical conditions, which provides an opportunity for further studies on this subject. However, it is necessary to clarify that the scope of this research, according to the methodology used to follow the growth of the plants and its results, applies only until the first harvest of the fruits is completed.

According to results obtained, it is evident that the strawberry developed adequately in the aquaponic system considering that in the dry weight variables there were no significant differences with respect to the contained beds, except for the crown dry weight (CW), in the reproductive stage. These results are similar to those reported by Abbey et al (2019) in which they evaluated the productivity of strawberry cultivars Albion, Portola and Evie 2, in both an aquaponic system and substrate culture. In this research it was found that the dry weight of the fruits in substrate was significantly higher, while the strawberries in aquaponics presented higher fresh weight; no significant differences were found in the number of fruits in both crops, which contrasts with the last two sampling periods for number of reproductive structures (NRE), since in the AQ system it was significantly higher. Both reported in the present work and in the research of Abbey et al (2019), it is evident that it is feasible to establish a strawberry crop in aquaponics for clean production.

No significant differences were found in reproductive structure weight (RSW) but in NRE, being higher in AQ plants. Physiologically this can be explained by the osmotic stress conditions to which the plants may have been exposed in AQ due to higher salinity and higher sodium concentration, a factor to which strawberries have been recognized as susceptible (Casierra-Posada & García 2005; Francisco-Francisco & Benavides-Mendoza 2014). The critical Na concentration reported for solutions is 35 mg L^{-1} (Yara 2011), and on many occasions this threshold was exceeded, reaching concentrations between 100 and 175 mg L^{-1}. This probably led to a saline or osmotic type stress that could promote early flowering, which was reflected in the increase in the number of reproductive structures (Alcantara-Cortes et al 2019), and in the higher percentage of plants that had reached the reproductive stage by the time growth sampling was completed (150 days after transplanting). On the other hand, sodium competes with the uptake of potassium, ammonium, calcium and magnesium becoming a growth inhibitor (Rottenberg 2019). This could contribute to explain the significant differences found in biomass accumulation in the vegetative structures of strawberry plants, specifically in the crown dry weight (CW) at the reproductive stage, since plants grown in the contained beds were visibly more vigorous. In this regard, a greater development of crowns in strawberry plants, both in biomass accumulation and in the increase of their quantity per plant, is directly related to a higher fruit production (Hancock et al 2008).

Root weight is an important indicator of plant growth and performance, since the formation of tissues translates into an adequate absorption of water and nutrients for the benefit of the aerial part (Lopez-Perez et al 2005). According to the above, the root of the CC system was expected to develop adequately because it contained a greater amount of nutrients and presented a greater vegetative growth. However, the root dry weight (RWD) was not differentially significant among the systems. This could possibly be influenced by the coconut fiber used in the AQ, because this substrate provides a highwater retention that favors the good development of the root and retains some nutrients present in the solutions (Medina-Bolívar et al 2016).

The greater growth of vegetative structures in strawberry plants in the CC conditions would represent an advantage in the long term for the productive future of the plant, because the number of crowns is directly related to the greater emission of inflorescences and consequently of flowers and fruits, which favors crop yield (Grijalba et al 2015). In addition, a greater amount of photoassimilates could be produced per plant, which would eventually be translocated to the different structures for plant growth. Finally, they would reach the primary suppliers such as the fruits, which would be reflected in the greater weight and size of the strawberries. In this regard, Rangel et al (2021) found that the net photosynthesis rate of the plants grown in the CC system was 20% higher than that of the AQ plants. Table 2 shows the results of the agronomic yield of 'Monterey' strawberry in both systems, expressed in number and fresh weight of fruit harvested per unit area, as well as per plant.

Table 2

Agronomic performance of strawberry in aquaponic (AQ) and substrate contained bed (CC) systems, evaluated per unit area and per plant, and average fruit weight, during the first 4 months of harvest

	Yield per unit area (m^2)		*Yield per plant*		
System	No. fruits	Fresh weight (g)	No. fruits	Fresh weight (g)	Weight per fruit (g)
AQ	130	1884.48	12.92	183.03	14.58
CC	61.64	1239.77	6.67	132.26	21.88

In AQ, strawberries obtained higher fruit productivity, both in number and fresh weight per unit area, being 110.9% and 52% higher, respectively (Table 2). The same results were observed in the yield per plant, being higher in AQ, with 93.7% by number of fruits and 38.4% fresh weight compared to CC (Table 2). In relation to weight per fruit, determined as the quotient between the fresh weight of the total fruit harvested, it was found that it was higher in the CC system (Table 2). The greater number of fruits harvested in the AQ system corresponds to the greater number of reproductive structures (NRE) that were counted in the reproductive stage, which was 282.8% higher than in the CC system (Table 1). These higher yields could be since the productive cycle of strawberries in tropical conditions varies between one and two years, and due to the photoperiod and temperature conditions that allow the flowering of short-day or day-neutral varieties to be permanent throughout the year (Cabeza & Faura 2010). For this reason, it is suggested to extend the time of study in future research with this plant and with the climatic conditions of the tropics.

Rainbow trout growth parameters. In the present study, rainbow trout fry were reared during 6 months of experimentation (154 days). The final biomass of rainbow trout was 14.58 kg, the variable weight gain per individual was 124.59 g and the total weight gain was 14.25 kg. The condition factor (K) was 1.45. SGR 2.38 and FCR 0.79 (Table 3).

Table 3

Productive parameters of *O. mykiss*

Parameter	*O. mykiss*	*Birolo et al (2020)*
NF	100	78
IW (g individual^{-1})	3.27±0.67	93.07
FW (g individual^{-1})	127.86±23.69	217.17
IB (g)	326.50	7.260
FB (kg)	14.584	16.940
WGI (g individual^{-1})	124.59	124.10
WGT (kg)	14.25	9680
K	1.45	1.35
SGR (% day^{-1})	2.38	
FCR	0.79	

Notes: NF = number of fish; IW = initial weight per individual; FW = final weight per individual; IB = initial system biomass; FB = final system biomass; WGI = weight gain per individual; WGT = system weight gain; K = condition factor; SGR = specific growth rate; FCR = feed conversion ratio. Values represent mean±standard deviation.

Birolo et al (2020) evaluated the growth of rainbow trout in a small-scale aquaponic system (500 L tanks) with *Lactuca sativa* for 117 days with 78 fish. According to the growth parameters of the present study with the results obtained by Birolo et al (2020), it is evident that there are better results in many of the variables evaluated, despite beginning with smaller fish (fry). For SGR 2.38±.06% d^{-1}, and FCR of 0.79±0.16, the AQ in this study exhibits better growth variables. Additionally, the FCR was better obtained by Velichkova et al (2019) of 2.42, in aquaponic systems with *L. sativa*. However, the FCR obtained in this work was higher than of Alcarraz et al (2016) of 0.74 in a small-scale AQ system with lettuce. This could be due to several factors: the higher level of crude protein (48%) in the diet, the smaller size of the fish and consequently higher growth rates and/or a lower stocking density.

The K value is estimated to evaluate the nutritional status and therefore the welfare of fish and other aquatic organisms (Leyton Flor 2015). If the condition factor K presents values lower than 1, it indicates that water quality problems might have occurred. On the contrary, a value greater than 1 indicates adequate conditions for fish growth (Acosta et al 2008). Likewise, this study showed higher values for the condition factor K 1.45, with respect to the 1.35 obtained by Birolo et al (2020). This is indicative that the fish grew in a favorable environment with good water quality conditions (Table 4), and that they had transformed the food properly (Colque García 2020).

Also, in the study conducted by Sánchez et al (2014) an aquaculture recirculation system (RAS) was evaluated where 12 tanks of 250 L were used with 324 rainbow trout fry; 27 fry with an IW of 32.45±2.20 g from floating cages were planted in each tank. The productive variables showed an FW of 111.81±8.79 g at 75 days of experimentation, which compared to our research is equivalent to the measurements from month 4 to month 6 (91 days), therefore the FW results are similar (Table 3).

Water quality parameters in aquaponic system and substrate in contained bedding. Table 4 shows the average values of nutrients measured in each of the evaluated systems and the water quality parameters in the aquaponic systems. The values of NAT, PO_4^{3-}, Fe_2^+, K^+ are results of soil analysis. Sodium (Na) values were measured at 90 days after the transplant due to the symptoms presented in the plants of the aquaponic system).

In the aquaponic system the pH and water temperature remained within the recommended limits for rainbow trout (Timmons & Ebeling 2010). However, at some periods, the pH value was higher than 6.5, exceeding the limit appropriate for the absorption of nutrients by the strawberry (moderately acidic 5.7-6.5) (Cabeza & Faura 2010). Although some authors report that strawberries can tolerate pH values between 6 and 7, without considerably affecting their growth (Coronel Ochoa 2014). On the other hand, the contained bed systems were permanently at a low pH, which allowed adequate nutrient absorption.

Table 4

Dynamics of nutrients and other physicochemical parameters in the nutrient solution of the aquaponic system (AQ) and in the substrate filtrate of the contained beds (CC) (1:1 v/v method)

Parameter	*AQ*	*CC*
pH	6.35±0.59	4.86±0.40
EC (mS cm^{-1})	0.54±0.24	0.79±0.18
NO_3^- 5 (mg L^{-1})	101.05±42.25	191.57±54.47
NO_2^-	0.046±0.06 mg L^{-1}	-
TAN	0.56±0.59 mg L^{-1}	26.0 mg kg^{-1}
PO_4^{3-}	15.13±7.56 mg L^{-1}	67.9 mg kg^{-1}
Fe^{2+}	0.28±0.15 mg L^{-1}	170.6 mg kg^{-1}
Ca^{2+} (mg L^{-1})	56.54±34.58	135.36±34.41
K^+	16.43±9.61 mg L^{-1}	603 mg kg^{-1}
Na (mg L^{-1})	175	35
DO (mg L^{-1})	6.30±0.87	-
DO (%)	91±11.17	-
Twater (ºC)	19.12±1.00	-
TDS (mg L^{-1})	219±133.48	-

Notes: EC = electrical conductivity; TAN = total ammoniacal nitrogen; NO_2^- = nitrite; NO_3^- = nitrate; PO_4^{3-}= phosphate; Fe_2^+= iron; Ca_2^+= calcium; K^+ = potassium; Na = sodium. Parameters corresponding to water quality in the aquaponic system: DO = dissolved oxygen, %DO = dissolved oxygen saturation; Twater = water temperature; TDS = total dissolved solids. Values represent mean±standard deviation.

The optimum electrical conductivity varies among plant species and phenological stage, but in hydroponics it is recommended around 1.5-1.8 mS cm^{-1} (Nelson 2008) and for strawberry in hydroponics is 0.8-1.2 mS cm^{-1} (Yara 2010). However, both types of crops AQ and CC showed lower electrical conductivity values. In aquaponic systems it is usual to find low values of electrical conductivity and in spite of that the plants produce high yields (Torres-Mesa et al 2023). The reason for the low conductivity values in aquaponic systems is attributed to two main factors: first, nutrients in aquaponics are constantly generated and second, due to the organic nature of the nutrients, low concentrations of salts are obtained (Ramírez Sánchez et al 2011).

In the CC system, there were no Fe_2^+ deficiencies since from the establishment of the crop it was above the adequate range according to the soil analysis and with the fertilization program, no deficiency or toxicity symptoms were observed. The K^+ level in the soil analysis was found to be low, but no deficiency symptoms of this nutrient were observed. AQ systems are usually deficient in iron and potassium, mainly due to the low pH levels that these nutrients require to remain available, in addition to the fact that the fish feed has low amounts of these elements (Caló 2011). It is recommended to add Fe_2^+ in chelate form every three weeks for green leaf plants in aquaponic (Rakocy 2012). However, in this study, weekly addition was not sufficient and had to be increased to twice a week from the beginning of the reproductive stage. Considering the range supported by rainbow trout (< 1.0 mg L^{-1}) (Somervile et al 2014) and the results reported in this study, it is advisable to add DTPA-Fe two or more times a week and possibly with a higher concentration. Additionally, it can be complemented with foliar fertilization. Regarding K levels, they can be compensated with the addition of potassium hydroxide, which is an amendment used to raise pH (Caló 2011).

In the CC system, the fertigation plan was complemented with calcium nitrate added foliarly at the beginning of flowering, due to the observation of some visual symptoms detected in the young leaves. According to the results obtained in the measurements, Ca_2^+ levels in the AQ system were below the critical level for solutions (< 80 mg L^{-1}), while in the CC they were within the adequate levels (Yara 2010). However, when calcium nitrate was added as an amendment to the aquaponic system, Ca_2^+ levels increased considerably. Therefore, an addition of calcium nitrate and calcium hydroxide may be a good alternative for plants that demand high concentrations of this element.

Conclusions. The growth of *Fragaria* x *ananassa* 'Monterey' was good in the two crops evaluated, demonstrating that strawberry can be appropriately produced in aquaponics and that it can obtain results equivalent to crops in soil. Furthermore, the aquaponic systems exhibited a higher number of flowers and fruits harvested, which results in a greater yield in the first four months of production. The growth parameters of *Oncorhynchus mykiss* were similar to those reported in aquaponic and RAS systems, obtaining good results in TCE and FCA. Likewise, the results were better than those reported for traditional rainbow trout farming. Water quality conditions remained within the appropriate ranges for the species evaluated, which was reflected in the good growth of both species in the aquaponic systems.

Acknowledgements. This work was supported by the Vicerrectória de investigaciones of Universidad Militar Nueva Granada, Cajicá, Colombia by project CIAS 3135 - 2020.

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

References

Abbey M., Anderson N., Yue C., Short G., Schermann M., Phelps N., Venturelli P., Vickers Z., 2019 An analysis of strawberry (*Fragaria* × *ananassa*) productivity in northern latitudinal aquaponic growing conditions. Journal of the American Pomological Society 73(1):22-37.

Acosta F., Tenjo N., Fischer G., Miranda D., 2008 Propagación de uchuva (*Physalis peruviana* L.) mediante diferentes tipos de esquejes y sustratos. Revista Facultad Nacional de Agronomía Medellín 61:4347-4357. [in Spanish]

Agronet, 2022 Estadísticcas Agrícolas. Área, producción y rendimientos por cultivo. Available at: https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=1. Accessed: February, 2022. [in Spanish]

Alcantara-Cortes J. S., Acero Godoy J., Alcántara Cortés J. D., Sánchez Mora R. M., 2019 Principales reguladores hormonales y sus interacciones en el crecimiento vegetal. Nova 17(32):109-129. [in Spanish]

Alcarraz E., Flores M., Tapia M. L., Bustamante A., Wacyk J., Escalona V., 2016 Quality of lettuce (*Lactuca sativa* L.) grown in aquaponic and hydroponic systems. Acta Horticulturae 1194:31-38.

Asadullah M., Khan S., Khan H., Aslam R., Shaukat I., 2020 Sustainability and development of aquaponics system: a review. Earth Sciences Pakistan 4(2):78-80.

Birolo M., Bordignon F., Trocino A., Fasolato L., Pascual A., Godoy S., Nicoletto C., Maucieri C., Xiccato G., 2020 Effects of stocking density on the growth and flesh quality of rainbow trout (*Oncorhynchus mykiss*) reared in a low-tech aquaponic system. Aquaculture 529:735653.

Cabeza R., Faura R., 2010 Fresa (*fragaria* x *ananassa* Duch.): producción y manejo poscosecha. Camara de Comercio de Bogotá, 133 pp. [in Spanish]

Caló P., 2011 Introducción a la acuaponía. Ministerio de Agricultura, Ganaderia y Pesca, Direccion de Acuicultura, CENADAC, 15 pp. Available at: http://chilorg.chil.me/download-doc/86262. Accessed: March, 2022.

Cardenas Laverde D., Torres Mesa A. C., Gómez Ramírez E., 2022 Identificación de aceites esenciales y parámetros productivos de *Mentha spicata* cultivada en sistemas acuapónicos y camas contenidas. Revista de Investigación Agraria y Ambiental 13(2):149-163. [in Spanish]

Casierra-Posada F., García N., 2005 Crecimiento y distribución de materia seca en cultivares de fresa (*Fragaria* sp.) bajo estrés salino. Agronomía Colombiana 23(1):83-89. [in Spanish]

Colque García R., 2020 Determinación del factor de conversión alimentaria y crecimiento de trucha arco iris (*Oncorhynchus mykiss*) bajo diferentes densidades y niveles de alimentación en estanques artificiales en Llaullini, La Paz. Apthapi 6(1):1820-1838. [in Spanish]

Coronel Ochoa M. E., 2014 Comparación de rendimientos de cultivos de fresa (*Fragaria* × *ananassa*) bajo los sistemas de hidroponía y acuaponía. Trabajo de fin de titulacion de Ingeniero Agropecuario, Universidad Tecnica Particular de Loja, 109 pp. [in Spanish]

FAO, 2014 Manual práctico para el cultivo de la trucha arcoíris. Organización de las Naciones Unidas para la Alimentación y la agricultura (FAO), Guatemala, 39 pp. [in Spanish]

Francisco-Francisco N., Benavides-Mendoza A., 2014 Impacto de la salinidad y la temperatura diurna sobre la fluorescencia de la clorofila en fresa. Revista Mexicana de Ciencias Agrícolas 5(1):157-162. [in Spanish]

Goddek S., Joyce A., Kotzen B., Burnell G., 2019 Aquaponics food production systems - combined aquaculture and hydroponic production technologies for the future. Springer Cham, 619 pp.

Grijalba C. M., Pérez-Trujillo M. M., Ruiz D., Ferrucho A. M., 2015 Strawberry yields with high-tunnel and open-field cultivations and the relationship with vegetative and reproductive plant characteristics. Agronomía Colombiana 33(2):147-154.

Hancock J., Sjulin T. M., Lobos G., 2008 Strawberries. In: Temperate fruit crop breeding: germplasm to genomics. Springer Dordrecht, pp. 393-437.

Leyton Flor S., 2015 Estimación del factor de condición de Fulton (K) y la relación longitud-peso en tres especies ícticas presentes en un sector sometido a factores de estrés ambiental en la cuenca alta del río Cauca. Revista de La Asociación Colombiana de Ciencias Biológicas 1(27):21-31. [in Spanish]

Lopez-Perez L., Cárdenas Navarro R., Lobit P., Martinez-Castro O., Escalante-Linares O., 2005 Selección de un sustrato para el crecimiento de fresa en hidroponía. Revista Fitotecnia Mexicana 28:171-174. [in Spanish]

Medina-Bolívar J., Pinzón-Sandoval E., Cely G., 2016 Efecto de sustratos orgánicos en plantas de fresa (*Fragaria* sp.) cv 'Albion' bajo condiciones de campo. Ciencia y Agricultura 13(2):19-28. [in Spanish]

Merino-Archila M., Salazar-Ariza G. Gómez-León D., 2006 Guía práctica de piscicultura en Colombia. República de Colombia, Ministerio de Agricultura y Desarrollo Rural, Instituto de Desarrollo Rural, Bogotá, 80 pp. [in Spanish]

Ministerio de Agricultura, 2016 Colombia se afianza como el segundo exportador de trucha y tilapia a Estados Unidos. Available at: https://www.minagricultura.gov.co/noticias/Paginas/colombia-se-afianza-como-exportador-de-trucha-y-tilapia.aspx#:~:text=%22Con el empuje que le,%22%2C dijo el Ministro Iragorri. Accessed: November, 2022. [in Spanish]

Montaña C., Hurtado H., Gómez E., 2013 Rainbow trout (*Oncorhynchus mykiss*) fry initiation in closed water recirculation systems. Revista Colombiana de Ciencias Pecuarias 26(3):211-218.

Nelson R. L., 2008 Aquaponic food product - raising fish and plants for food and profit. Nelson and Pade, Inc., 218 pp.

Petrea S. M., Cristea V., Dediu L., Contoman M., Lupoae P., Mocanu M., Coada M., 2013 Vegetable production in an integrated aquaponic system with rainbow trout and spinach. Bulletin UASVM Animal Science and Biotechnologies 70(1):45-54.

Rakocy J., 2012 Aquaponics-integrating fish and plant culture. In: Aquaculture production systems. Tidwell J. H. (ed). John Wiley & Sons, Inc., pp. 344-386.
Ramírez D., Sabogal D., Jiménez P., Hurtado Giraldo H., 2008 La acuaponía: una alternativa orientada al desarrollo sostenible. Facultad de Ciecias Básicas 4(1):32-52. [in Spanish]
Ramírez Sánchez L. M., Pérez Trujillo M. M., Jiménez P., Hurtado Giraldo H., Gómez Ramírez E., 2011 Evaluación preliminar de sistemas acuapónicos e hidropónicos en cama flotante para el cultivo de orégano (*Origanum vulgare*: Lamiaceae). Revista Facultad de Ciencias Básicas 7(2):242-259. [in Spanish]
Rangel W., Córdoba C. A., Pérez-Trujillo M. M., Aguirre Galindo J., Torres-Mesa A., Rubio-Castro S. A., Gómez-Ramírez E., 2021 Relaciones hídricas en plantas de fresa "Monterey" en dos sistemas de cultivo: acuapónico con trucha arcoíris y cama contenida con sustrato. Simposio Internacional Virtual de Cultivo En Sustrato e Hidroponía, 30 de marzo, 6 y 8 abril 2021, La Plata, pp. 48. [in Spanish]
Riaño-Castillo E. R., Caicedo-Gegén L., Torres-Mesa A., Hurtado-Giraldo H., Gómez-Ramírez E., 2019 Cambios en los niveles de nutrientes en solución hidropónica de espinaca baby (*Spinacia oleracea* L.), para su futura aplicación en acuapónia. Orinoquia 23(1):73-84. [in Spanish]
Richardson M. L., Arlotta C. G., Lewers K. S., 2022 Yield and nutrients of six cultivars of strawberries grown in five urban cropping systems. Scientia Horticulturae 294: 110775.
Rottenberg O., 2019 Manejo de la salinidad en la solución del sustrato. Salinidad y fertirrigación. Metroflor-agro. Available at: https://www.metroflorcolombia.com/manejo-de-la-salinidad-en-la-solucion-del-sustrato-salinidad-y-fertirrigacion/. Accessed: June, 2022. [in Spanish]
RStudio Team, 2018 RStudio: integrated development for R. Rstudio. R Foundation for Statistical Computing, PBC, Boston, MA. Available at: https://www.r-project.org/. Accessed: June, 2023.
Sánchez O. I., Sanguino O. W., Gómez C. A., García C. R., 2014 Evaluation of a rainbow trout (*Oncorhynchus mikyss*) culture water recirculating system. Revista MVZ Córdoba 19(3):4226-4241.
Schmautz Z., Graber A., Mathis A., Griessler Bulc T., Junge R., 2015 Tomato production in aquaponic system: mass balance and nutrient recycling (abstract). Conference: Aquaculture Europe 2015, Rotterdam, The Netherlands, 2 pp.
Somervile C., Cohen M., Pantanella E., Stankus A., Lovatelli A., 2014 Small scale aquaponic food production: integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper No. 589. FAO, Rome, 262 pp.
Timmons M., Ebeling J., 2010 Recirculating aquaculture. 2nd edition. Cayuga Aqua Ventures, 948 pp.
Torres-Mesa A., Cifuentes-Torres L., Hurtado-Giraldo H., Gómez-Ramírez E., 2023 Evaluation of plant-fish ratio in an aquaponic system with different stocking densities of *Cyprinus carpio* and *Carassius auratus*. AACL Bioflux 16(1):606-615.
Tottman D., 2008 The decimal code for the growth stages of cereals, with illustrations. Annals of Applied Biology 110(2):441-454.
Vasdravanidis C., Alvanou M., Lattos A., Papadopoulos D., Chatzigeorgiou I., Ravani M., Liantas G., Georgoulis I., Feidantsis K., Ntinas G., Giantsis I., 2022 Aquaponics as a promising strategy to mitigate impacts of climate change on rainbow trout culture. Animals 12(19):2523.
Velichkova K., Sirakov I., Stoyanova S., Staykov Y., 2019 Cultivation of lettuce (*Lactuca sativa* L.) and rainbow trout (*Oncorhynchus mykiss* W.) in the aquaponic recirculation system. Journal of Central European Agriculture 20(3):967-973.
Wiser L., Blom T., 2016 The effect of nitrogen and phosphorus ratios and electrical conductivity on plant growth. American Journal of Plant Sciences 7(12):1590-1599.
Yara, 2011 Strawberry plantmaster TM. Knowledge grows. Available at: https://www.yara.co.uk/crop-nutrition/strawberries/soil-and-water-management/. Accessed: May, 2022.

Received: 28 July 2023. Accepted: 18 September 2023. Published online: 13 October 2023.
Authors:
July Paola Aguirre, Ecotoxicology, Evolution, Environment and Conservation Research Group, Universidad Militar Nueva Granada, Km 2 Via Cajicá- Zipaquira, 110111, Cajicá, Colombia, e-mail: est.july.aguirre@unimilitar.edu.co
Ana Torres-Mesa, Ecotoxicology, Evolution, Environment and Conservation Research Group, Universidad Militar Nueva Granada, Km 2 Via Cajicá- Zipaquira, 110111, Cajicá, Colombia, e-mail: ana.torres@unimilitar.edu.co
María Mercedes Perez-Trujillo, Agrobiology of promising cold climate plant species Research Group, Universidad Militar Nueva Granada, Km 2 Via Cajicá- Zipaquira, 110111, Cajicá, Colombia, e-mail: maria.perez@unimilitar.edu.co
Silvia Alejandra Rubio-Castro, Agrobiology of promising cold climate plant species Research Group, Universidad Militar Nueva Granada, Km 2 Via Cajicá- Zipaquira, 110111, Cajicá, Colombia, e-mail: silvia.alejandra@unimilitar.edu.co
Edwin Goméz-Ramirez, Ecotoxicology, Evolution, Environment and Conservation Research Group, Universidad Militar Nueva Granada, Km 2 Via Cajicá- Zipaquira, 110111, Cajicá, Colombia, e-mail: edwin.gomez@unimilitar.edu

How to cite this article:
Aguirre J. P., Torres-Mesa A., Perez-Trujillo M. M., Rubio-Castro S. A., Gómez-Ramírez E., 2023 Evaluation of *Fragaria* x *ananassa* in an aquaponic system with *Oncorhynchus mykiss* and substrate culture conditions. AACL Bioflux 16(5):2589-2600.