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Studies on Growth and Development of Tomato (*Solanum lycopersicum* L.) under Aquaponics System in Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. Author KDSF wrote the protocol, and wrote the first draft of the manuscript. Author SS approved the protocol. Author NCSK put the aquaponic system in place. Authors SS, SBA, DM supervised the fieldwork and performed the statistical analysis. Author CS managed the literature searches. Authors KDSF and BNA conducted the fieldwork and collected data, managed the analyses of the study. All authors read and approved the final manuscript.

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Abstract

Aquaponics is the co-culture of fish and plants in a closed-loop, controlled-environment agricultural system. It offers a sustainable and environmentally friendly production system. Evaluating the growth of tomatoes (*Solanum lycopersicum* L.) in an aquaponics system in Côte d'Ivoire could provide valuable information on

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the adaptability of this crop to this agricultural system. This study was conducted in the context of increasing land pressure and the search for sustainable agricultural practices in Côte d'Ivoire.

It aimed to enhance tomato production by testing the Nutrient Film Technique (NFT) in an aquaponics system. To achieve this, tomato growth in the aquaponics system was compared with cultivation in soil and in a soilless medium of coconut fibre enriched with composted poultry manure. A homogeneous block was established for each growing medium. The experiment was conducted at the École Normale Supérieure (ENS) of Félix HOUPHOUËT-BOIGNY University in Abidjan. The plant material consisted of hybrid tomato seeds of the F1 COBRA 34 variety, and Nile tilapia (*Oreochromis niloticus*) of Brazilian origin were used in the aquaponics system. Three treatments were established, with 12 plants selected per treatment: T1, unamended soil irrigated with tap water (growing bags filled to 2/3 capacity with soil); T2, an aquaponics system with perforated plastic supports secured with gravel; and T3, coconut fibre plus composted poultry manure (2/3 fibre and 1/3 manure in growing bags). Vegetative growth parameters (height, collar diameter, number of leaves, leaf area, and branching) and floral transition were measured for each treatment.

Statistical analysis revealed highly significant differences among treatments in plant height, collar diameter, and leaf area. However, the number of leaves did not differ statistically between plants in the unamended soil treatment (T1) and those in the aquaponics treatment (T2). Tomato plants in the aquaponics system showed the greatest growth, with the highest plant height (43.7 cm), largest collar diameter (6.49 mm), and largest leaf area (193 cm²) compared with those grown in soil and coconut fibre. First flowering occurred 21 days after transplanting in the aquaponics system, earlier than in the soil and coconut-fibre treatments.

These results may be related to the composition of the fish-culture water and suggest that aquaponics could represent a sustainable agronomic alternative for improving vegetable production, particularly in urban areas under climate-change conditions. The study highlights the potential of aquaponics to promote crop growth and shorten the time to flowering, thereby contributing to more efficient and environmentally friendly urban agriculture. However, the relatively small sample size (12 plants per treatment) may limit the generalisability of the results. Future studies with larger sample sizes, longer cultivation periods, and further investigation of the plant-to-fish ratio are recommended to validate these findings and assess economic viability.

Keywords: Aquaponics; vegetative growth; tomato; floral transition; Côte d'Ivoire.

1. Introduction

The tomato (*Solanum lycopersicum* L.) is the second most consumed vegetable, either fresh or processed, worldwide after the potato (Ameyapoh et al., 2021). Tomatoes are rich in nutrients and vitamins and contain carotenoids, flavonoids, and lycopene associated with a healthy diet (Kralik et al., 2023). This staple ingredient in traditional African cuisine (Courchinoux, 2008) reached a global production of 186.821 million tonnes in 2020, cultivated on 5.052 million hectares, with a yield of 37.1 t/ha. In Côte d'Ivoire, national tomato production is estimated at 52,000 tonnes/year (N'Zi et al., 2010). This remains insufficient to meet demand, estimated at more than 100,000 tonnes/year (Soro et al., 2007; Fondio et al., 2013). This shortfall is attributable to several factors, including unsuitable varieties, climatic hazards, diseases and pests, limited agricultural land because of urbanisation, and the intensive use of synthetic chemicals (Yeo et al., 2022). In response to these challenges, innovative production systems, particularly hydroponics and aquaponics, are emerging. In Côte d'Ivoire, soilless cultivation has been introduced to provide urban populations with access to high-quality market-garden produce, reduce constraints associated with land access, create employment for young people and women, and provide an activity for older people (Coulibaly et al., 2021). However, this system depends heavily on a continuous nutrient supply (Hounsa, 2019), most commonly derived from synthetic chemicals that may affect crop quality and consumer health. Aquaponics combines plant cultivation (hydroponics) and fish farming (aquaculture) within a symbiotic ecosystem (Mourantian et al., 2025). Nutrient-rich fish waste is used to fertilise plants, potentially improving yields and resource-use efficiency for both water and inputs (Goddek et al., 2015). Aquaponic cultivation has expanded markedly in recent years, as shown by the increasing number of start-up enterprises that have progressed from backyard or educational installations to fully integrated commercial-scale production (Ibrahim et al., 2023). The novelty of this cultivation platform, combined with the range of fish species and crops that can be produced, has attracted interest from several disciplines (Lobanov et al., 2025; Ansaba & Pradeepkumar, 2025). It offers a sustainable and environmentally friendly agricultural system. Tomato production using this system could support the continuous supply of fresh fruit to urban markets in Côte d'Ivoire. Despite its potential, research on tomato performance under aquaponic systems remains limited, particularly regarding growth, floral transition, and adaptability compared with conventional soil or soilless cultivation. Evaluating tomato growth in an aquaponics system in Côte d'Ivoire could therefore provide valuable information on the crop's adaptability to this production system. This study was initiated to contribute to the continuous production of tomatoes through aquaponics. Specifically, it aimed to evaluate the effect of the aquaponics system on tomato growth and development.

2. Materials and Methods

2.1 Materials

2.1.1 Plant Materials

The plant material consisted of hybrid tomato seeds of the F1 COBRA 34 variety obtained from SEMIVOIRE, an approved seed supplier in Côte d'Ivoire. These seeds were used to produce seedlings.

2.1.2 Animal Materials

The animal material consisted of Nile tilapia (*Oreochromis niloticus*) of Brazilian origin, raised in aquaculture tanks within an aquaponics system.

2.1.3 Growing Media

The growing media consisted of coconut peat, coconut fibre, and sterilised soil. The coconut fibre and peat came from Cocosol, a certified company specialising in coconut substrates in Côte d'Ivoire. The soil was collected from the experimental site and sterilised in an autoclave at 121°C for 30 minutes to prevent contamination. The manure was collected from a poultry farm and composted in the sun for more than one month.

2.2 Methods

2.2.1 Experimental Setup

The experimental site was located at the École Normale Supérieure (ENS) of Félix HOUPHOUËT-BOIGNY University in Cocody, Abidjan (Fig. 1). The Autonomous District of Abidjan is situated in southern Côte d'Ivoire, between latitudes 4°10 and 5°30 North and longitudes 3°50 and 4°10 West (Tuo et al., 2023). The aquaponics method used in this study was the nutrient film technique (NFT). The system consisted of three compartments through which water circulated in a closed circuit. The first was a plant compartment made of perforated PVC pipes and located under a canvas shelter. The second was a sump of 1m^3 equipped with a mechanical filter to retain solid waste and provide a medium for nitrifying bacteria. The third comprised aquaculture tanks (3 tanks of 3.5 m^3), each containing 200 tilapia. Water from the fish tanks flowed by gravity to the sump after filtration. The filtered water was then returned to a reservoir of 1m^3 by an electric motor pump (flow rate: 4,8 m^3/h). Some of this water returned to the fish tanks, while the remainder supplied the growing beds through pipes, allowing the plants to absorb the nutrients it contained.

The experimental trial was conducted from December 2024 to March 2025, during the local off-season. These cultivation systems permit off-season crop production. The experimental design comprised homogeneous blocks in which the tomato plants were grown. Twelve tomato plants were arranged in two rows within two growing trenches for each treatment, giving 36 plants across the three treatments in 3 replications, with a spacing of 30 cm between rows and 30 cm between plants. At the same time, tomato plants of the same age were transplanted into sterilised soil and coconut fibre enriched with poultry manure. These substrates had previously been placed in polyethylene nursery bags. The cultivation systems were considered the treatments. Accordingly, three (3) treatments were established:

- **Treatment T1:** unamended soil irrigated with tap water. The growing bags were filled to 2/3 capacity.
- **Treatment T2:** aquaponics; perforated plastic supports were used to hold the plants in place and were secured with gravel.
- **Treatment T3:** coconut fibre + composted poultry manure. The 12 growing bags were filled 2/3 full with fibre and 1/3 full with poultry manure.

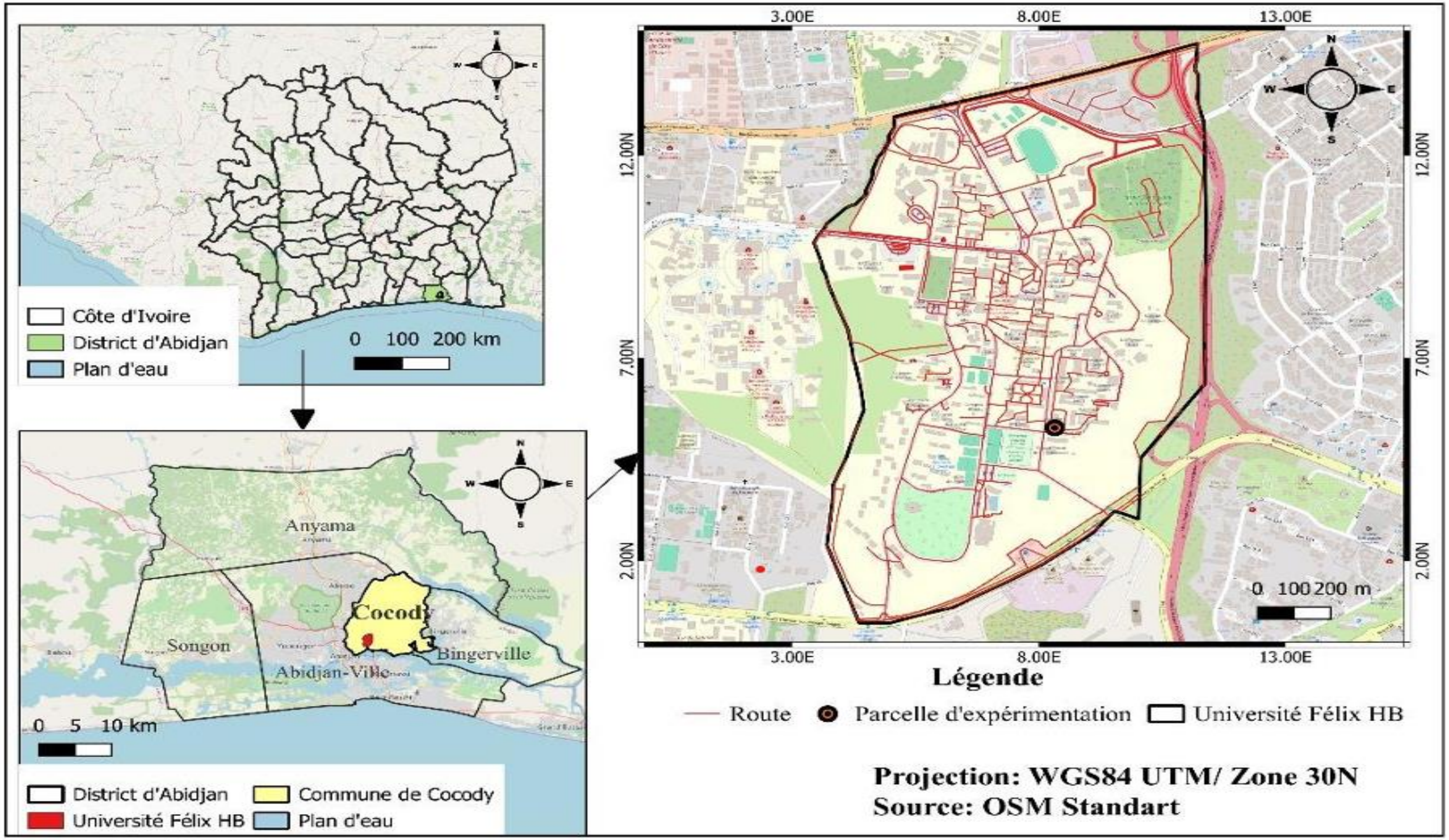

Fig. 1. Geographic location and detailed map of study area

2.2.2 Production of Seedlings

The seedlings used for cultivation were obtained by germinating tomato seeds. Coconut peat enriched with poultry manure was placed in a 50-cell tray at a rate of 3 g per cell. One seed was sown in each cell at a depth of approximately 1 cm and then covered with substrate. After sowing, the nursery was moistened with running water. The seed tray was placed in the shade beneath the aquaponics system. The seeds were watered every two days, and germination occurred 7 days after sowing.

2.2.3 Cultivation of Tomato Plants

Four (4) weeks after germination, vigorous young plants were removed from the seed tray, and the roots were carefully cleaned under running water to remove any remaining substrate. For the aquaponics system, the plants were carefully placed in perforated plastic cups used as supports and then stabilised with gravel. They were installed in the growing channels, consisting of PVC pipes perforated at regular intervals, which allowed optimal immersion of the roots in the circulating nutrient solution. For the soil and coconut-fibre treatments, the plants were transplanted into bags prepared for this purpose. Irrigation was applied immediately after transplanting. Two weeks after transplanting, 500 g of composted poultry manure was added to the plants in treatment 3. Weeding was carried out as required, and a phytosanitary treatment was applied as a preventive measure.

2.2.4 Crop Evaluation

Two weeks after planting, the various parameters were measured using recognised standard techniques. Data were collected weekly from 12 tomato plants selected at random from each cultivation system.

Several growth parameters were measured in this experiment.

- Plant height was measured from the collar to the tip of the terminal bud using a tape measure (cm).
- The numbers of leaves and branches were counted manually from the base of the plants.
- Collar diameter was measured using a precision calliper (mm).
- Leaf area was determined using the following expression:

$$LA = L \times W \times 0.75 \ (cm^2)$$

Where : L = leaf length (cm), w = leaf width (cm), 0.75 = correction factor

The numbers of flower clusters and flowers were determined by manual counting.

2.2.5 Statistical Data Analysis

The collected data were coded using Excel 2016. After normality was assessed using the Shapiro test, the data were subjected to the Kruskal–Wallis test using RStudio software version 2023.12.1. When a significant difference was found for a characteristic, Dunn’s test was performed at a significance level of 5% to separate the means. The graphs and figures were produced using Excel software.

3. Results and Discussion

3.1 Growth of Tomato Plants in Different Cropping Systems

3.1.1 Effect of Cropping Systems on Tomato Plant Height

The change in tomato plant height across the different cultivation systems is shown in Fig. 2. Statistical analysis revealed a highly significant difference among treatments ($P < 0.001$). Continuous growth was observed in all treatments. The greatest height (43.7 cm) was recorded in the aquaponics system, whereas the lowest height (23.8 cm) was recorded in the coconut-fibre treatment enriched with poultry manure.

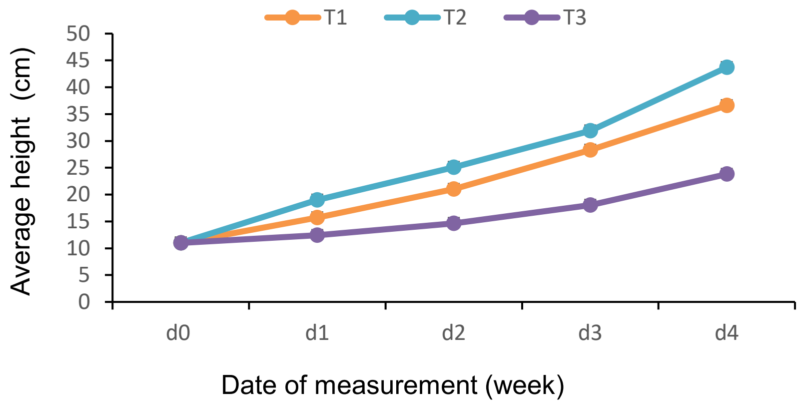

Fig. 2. Growth of tomato plants during different crops at the transplanting stage
T1= simple soil; T2= aquaponics; T3= coconut fiber + poultry manure; d0=start of cultivation; d1= first week of measurement; d2= second measurement date; d3= third week of measurement; d4= fourth week of measurement

The higher growth rates observed in plants grown using the aquaponics system may be explained by the nutrient-rich water from the fish tanks, indicating a beneficial effect of aquaponics on tomato growth. This result is consistent with Rakocy et al. (2006), who attributed improved growth to the continuous availability of nutrients from the nitrification of fish waste, particularly nitrogen in the form of nitrate. Suhl et al. (2016) demonstrated that this consistency in mineral nutrition stimulates growth metabolism, particularly during the juvenile stage. Mikobi et al. (2020) also observed accelerated vegetable growth in aquaponics, indicating that this technology is suitable for tropical conditions.

3.1.2 Influence of the Growing System on the Diameter of Tomato Plants

Fig. 3 shows the change in tomato plant collar diameter across the different cultivation systems. A highly significant difference ($P < 0.001$) was observed among the systems from the first to the fifth week after transplanting. The largest collar diameters were recorded for plants grown in the aquaponics system (T2) and unamended soil (T1), at 6.49 mm and 6.23 mm, respectively. The smallest diameter, 5.17 mm, was recorded for plants grown in coconut fibre enriched with poultry manure (T3). However, Dunn's test indicated no significant difference between the unamended soil (T1) and aquaponics (T2) treatments, which had statistically similar collar diameters.

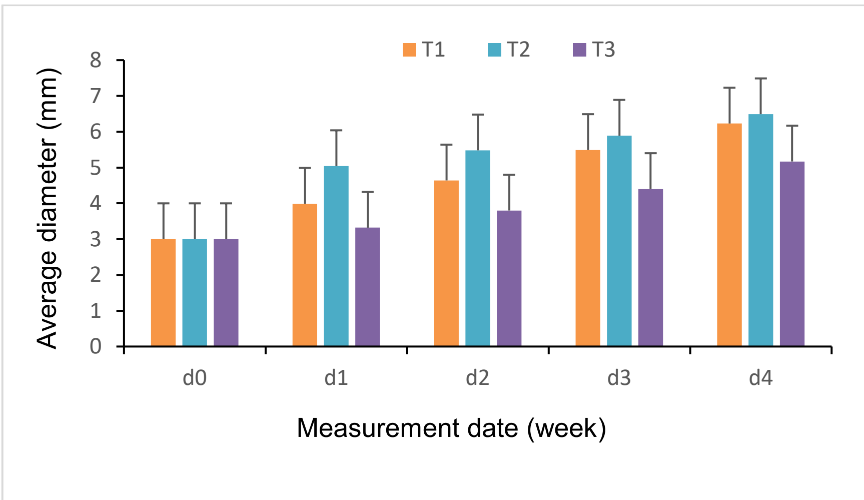

Fig. 3. Average diameters of growing tomato plants according to cultivation systems
T1= simple soil; T2= aquaponics; T3= coconut fiber + poultry manure; d0=start of cultivation; d1= first week of measurement; d2= second measurement date; d3= third week of measurement; d4= fourth week of measurement

For collar diameter, plants in the aquaponics (T2) and soil (T1) systems had statistically similar values, both significantly higher than those of plants grown in coconut fibre enriched with poultry manure (T3). Plant diameter generally reflects stem robustness and the capacity to support a developed plant architecture. According to Goddek et al. (2015), balanced calcium and potassium nutrition in aquaponics promotes the thickening of vascular tissues and strengthens the stems.

3.1.3 Effect of the Growing System on the Number of Tomato Leaves

The number of leaves produced by tomato plants was recorded in each cultivation system (Fig. 4). Dunn's multiple-comparison test showed that the number of leaves did not differ statistically between plants in the unamended soil treatment (T1) and those in the aquaponics treatment (T2) throughout the trial. However, plants grown in coconut fibre enriched with poultry manure produced the fewest leaves.

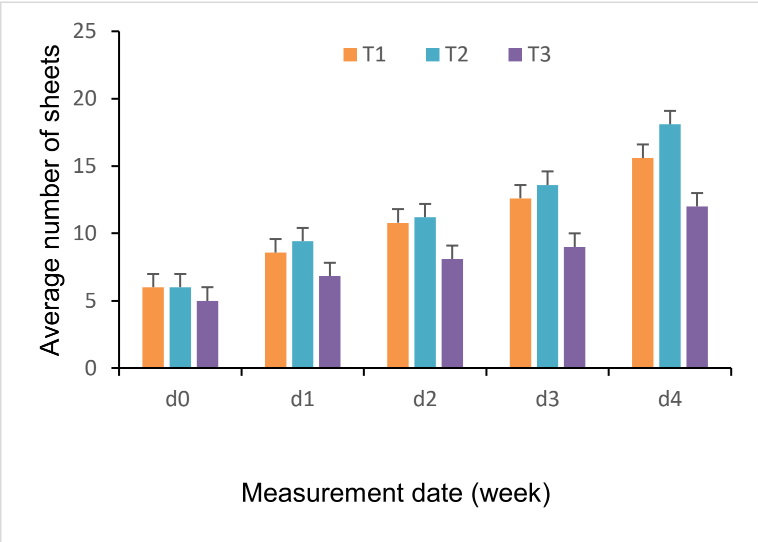

Fig. 4. Average number of leaves on tomato plants growing according to the cultivation system

T1 = simple soil; T2= aquaponics; T3= coconut fiber + poultry manure; d0=start of cultivation; d1= first week of measurement; d2= second measurement date; d3= third week of measurement; d4= fourth week of measurement

The increase in leaf number reflects the vigorous growth of plants in the aquaponics system. Because leaf number is an indirect indicator of photosynthetic capacity, the conditions in the aquaponics system appeared to support greater expression of vegetative potential. A stable nutrient supply is associated with dense leaf development (Schmautz et al., 2016). Ikoyo-Eweto and Orija (2022) also reported greater leaf density in tomatoes grown in aquaponics than in hydroponics.

3.1.4 Leaf Area of Tomato Plants in Different Crops

The leaf areas of tomato plants grown under the different cultivation systems are shown in Fig. 5. Statistical analysis revealed a highly significant difference among the systems ($P < 0.001$). In the fourth week of cultivation, the largest leaf area was recorded in the aquaponics treatment (T2), with an average of 193 cm^2, followed by the unamended soil treatment (T1), with an average of 167 cm^2. By contrast, plants grown in coconut fibre enriched with poultry manure (T3) had the smallest leaf area (89 cm^2).

The average leaf area was significantly greater in the aquaponics treatment, reflecting more efficient use of available resources by the plants. This performance may be explained by optimal regulation of the root environment, particularly the pH and oxygenation of the nutrient solution, which are essential to the vegetative development of tomato plants (Somerville et al., 2014). In addition, Nadia et al. (2023) noted that probiotics and beneficial microorganisms in aquaponics systems could improve nutrient uptake and accelerate leaf-tissue growth.

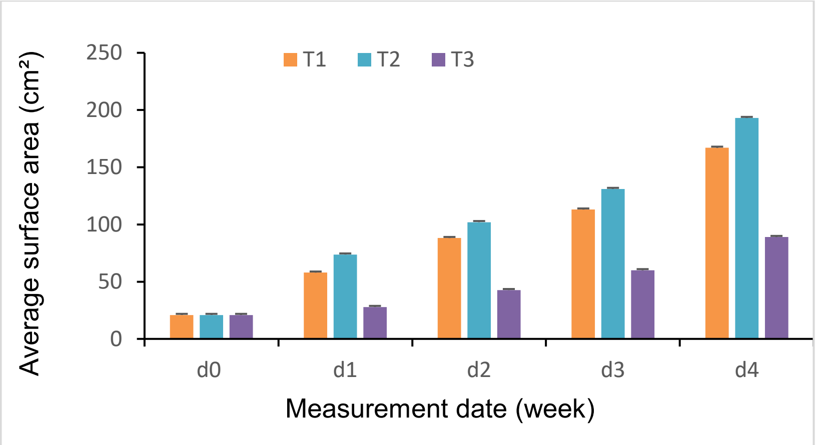

Fig. 5. Average leaf area of tomato plants in cultivation

T1= simple soil; T2= aquaponics; T3= coconut fiber + poultry manure; d0= start of cultivation; d1= first week of measurement; d2= second measurement date; d3= third week of measurement; d4= fourth week of measurement

3.1.5 Effect of the Growing System on the Number of Branches on Tomato Plants

No significant difference among the cultivation systems (P = 0.05) was observed in the number of tomato branches up to the fourth week of cultivation. However, branch number increased gradually in all three systems and reached its maximum in the final week of measurement (the fifth week after transplanting). At this stage, plants in unamended soil (T1) had the highest mean number of branches (3.5), followed by those in aquaponics (T2; 2.67) and coconut fibre enriched with poultry manure (T3; 1.67).

No significant differences in branch number were observed among treatments, although soil cultivation showed a slight tendency to favour the early formation of secondary branches. Tomato branching may require a longer observation period before treatment effects become apparent. Love et al. (2015) recommended long-term trials to better assess the structural effects of aquaponics on the branching of cultivated plants.

3.2 Impacts of the Growing System on Tomato Flowering

3.2.1 Time to Flower Emergence by Growing System

The time to emergence of the first flowers on tomato plants was recorded for each cultivation system. The shortest time to flowering was observed in the aquaponics system (T2), at 21 days after transplanting. By contrast, plants grown in coconut fibre enriched with manure (T3) flowered slightly later, at 26 days.

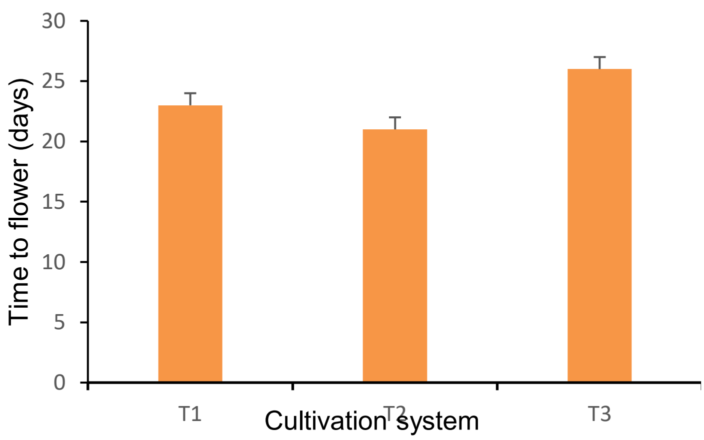

Fig. 6. Date of appearance of the first tomato flowers for the different crops

T1 = simple soil; T2= aquaponics; T3= coconut fiber + poultry manure

3.2.2 Number of Flower Clusters Produced in Different Growing Systems

Tomato plants flowered in all cultivation systems tested. The number of flower clusters increased gradually over time in all three systems. Statistical analysis using the Kruskal–Wallis test followed by Dunn's multiple-comparison test revealed a highly significant difference ($P < 0.001$). The highest average value was recorded in the aquaponics system (T2), at 3.08 flower clusters in the fifth week after transplanting, compared with the other systems (T1 and T3).

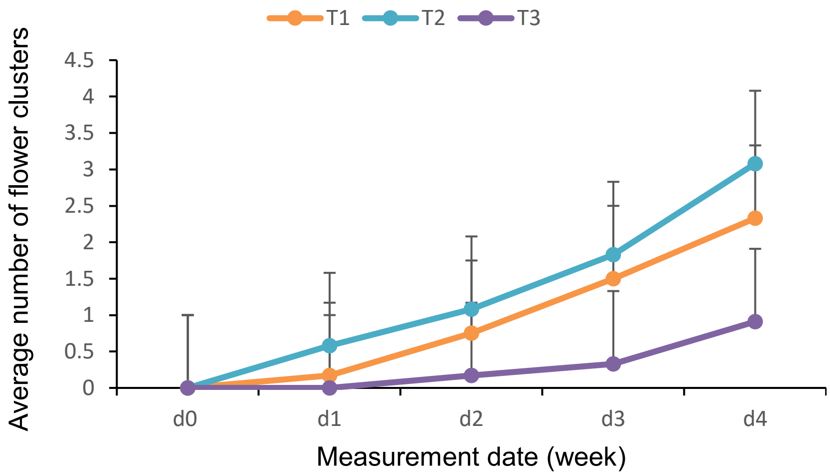

Fig. 7. Evolution of the number of tomato flower clusters during different crops
T1 = simple soil; T2= aquaponics; T3= coconut fiber + poultry manure; d0=start of cultivation; d1= first week of measurement; d2= second measurement date; d3= third week of measurement; d4= fourth week of measurement

Tomato flowering occurred earlier in the aquaponics system. This early flowering may have resulted from the constant and balanced availability of nutrients, particularly phosphorus, in the fish-tank water. These results are consistent with Yang and Kim (2020), who also observed earlier flowering of tomatoes in aquaponics than in hydroponics. Similarly, Mikobi et al. (2020) reported early flowering in several vegetables grown in aquaponics, highlighting the potential of this system for short-cycle crops, particularly in urban environments. These findings indicate that floral precocity and the number of flower clusters depend on mineral nutrient availability. However, Love et al. (2015) cautioned that a very short experimental period may be insufficient to assess the long-term effects of aquaponics, particularly on fruit production. Furthermore, the substrate-based system comprising coconut fibre and poultry manure (T3) produced the least satisfactory results. Plant growth was slower, probably because of the time required for mineral release and the limited availability of nutrients. This result is supported by Coulibaly et al. (2021), who reported this constraint in organic substrates. Edadah et al. (2016) also noted that these substrates require time to make their nutrients available to plants.

4. Conclusion

This study compared tomato growth and flowering in an aquaponics system with cultivation in unamended soil and coconut fibre enriched with composted poultry manure. Under the experimental conditions, aquaponically grown plants attained the greatest height, collar diameter, and leaf area, while their leaf number was statistically similar to that of plants grown in unamended soil. The aquaponics treatment also produced the earliest flowering, with the first flowers observed 21 days after transplanting. These results indicate that the nutrient film technique aquaponics system supported vegetative development and shortened the time to floral transition relative to the other cultivation systems evaluated. Aquaponics may therefore provide a useful option for tomato production in areas affected by land pressure and the need for more resource-efficient urban agriculture in Côte d'Ivoire. Nevertheless, the findings should be interpreted within the limits of the experimental scale and duration. Further research using larger samples, longer cultivation periods, and different plant-to-fish ratios is needed to confirm the observed responses, determine effects on fruit yield and quality, and assess the economic feasibility of the system.

5. Limitations

The study used only 12 plants per treatment and covered a relatively short cultivation period. These conditions may limit the generalisability of the observed growth and flowering responses. Fruit yield, fruit quality, long-term system stability, and economic performance were not evaluated. In addition, the plant-to-fish ratio was not experimentally optimised. Larger and longer trials across different seasons and locations are therefore required to confirm the findings and determine the agronomic and economic performance of the aquaponics system.

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Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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