Comparative Evaluation of Growth and Yield between Three Nutrient Solutions for Hydroponic Tomato (*Solanum lycopersicum* L.) Cultivation in Côte d'Ivoire

ABSTRACT

Background: The growing demand for tomatoes (*Solanum lycopersicum* L.) in Côte d'Ivoire requires the development of new cultivation techniques and methods across the country. The regular consumption of tomatoes or tomato-based products contributes to the food and nutritional security of the population. However, its low production does not satisfy the Ivorian population.

Objectives: This study was carried out to develop an effective nutrient solution to improve the yield of hydroponic tomatoes in Côte d'Ivoire with the aim of reducing dependence on arable land.

Methodology: Conducted in Bouaké, in the center of the country, this study evaluated three formulations of nutrient solutions on the Mongal F1 tomato variety. Due to the complexity of developing nutrient solutions suitable for all vegetable species, three nutrient solution formulations were prepared by dissolving commercial fertilizers available in local markets. Observations and measurements were made on growth and yield parameters. All data were subjected to an analysis of variance at the 5% level. In case of significant differences, the Tukey test was used for the separation of the means.

Results: The results showed that hydroponics registers to early flowering 28 to 29 days after transplanting, regardless of the nutrient solution used. The height of the plants with solution 1 was lower than that of the plants with solutions 2 and 3, i.e. 58.7 cm compared to 68.2 cm and 67.7 cm. Nutrient Solution 3 produced the highest number of fruits per plant, with 25 fruits, compared to 19 for Solution 2 and 20.5 for Solution 1. This solution proved to be numerically more efficient, with 1128.3 g of marketable fruit per plant, compared to 941.1 g for solution 2 and 1055 g for solution 1. The highest rate of non-marketable fruit was recorded with solution 1, i.e. 4% compared to 3.8% of solution 2 and 2.8% solution 3.

Conclusion: In view of these results, nutrient solution 3 may represent an effective alternative to improve the yield of tomatoes in hydroponics in Côte d'Ivoire. Using this solution will allow growers to adjust nutrient rates and irrigation systems to maximize the yield and quality of marketable fruit.

Keywords: Hydroponic Tomato, Cultivation Techniques, Transplanting, Fertilizers, Nutrient solution

1. INTRODUCTION

The tomato (*Solanum Lycopersicum* L.) is one of the most important vegetable crops in the world. Its consumption contributes to the food and nutritional security of populations (Soma, 2020). Regular consumption of tomatoes or tomato products reduces the risk of cancer and cardiovascular disease (Camara et al., 2022; Liu et al., 2024). In Côte d'Ivoire, tomatoes are a foodstuff that is widely consumed by all social strata. In addition, from an economic point of view, tomato cultivation represents an important source of income for many actors (Coulibaly et al., 2019). The tomato needs for Côte d'Ivoire are estimated at more than 100.000 tonnes (t) per year for an annual national production of about 52.000 t (Senan et al., 2007, N'zi *et al.,* 2010). This production remains low to cover the needs of the Ivorian population (Soro, 2009).

Many factors can be mentioned to explain the low production of tomatoes in Côte d'Ivoire. Indeed, one of the main constraints to tomato production is the insufficiency and/or non-distribution of varieties adapted to the needs of producers and consumers (Rouamba et al., 2013). In addition to this constraint, there is the abusive use of pesticides, the unsuitability of certain types of soil for this crop, the difficulty of preserving tomatoes, and above all the deficit of arable land. In order to remove the constraints of low market gardening production, soilless cultivation seems appropriate. Soilless or hydroponic cultivation allows plants to be grown on an inert substrate, fed by a solution that provides the mineral salts and nutrients necessary for plant growth (Mekki, 2023; Kumar et al., 2023). Thus, by compensating for the lack of arable land suitable for its cultivation and the abusive use of pesticides, hydroponics will contribute to the food and nutritional security of the population. In addition, it could contribute to the preservation of the environment (Parrot et al., 2008) and to the improvement of urban and peri-urban horticulture in Côte d'Ivoire.

To master this technique, research has been carried out in order to better adapt the technology to local conditions and to solve many outstanding questions about the success of this technology (Fondio et al., 2013). Among these issues is the development of effective nutrient solutions to improve the production of hydroponic tomatoes in Côte d'Ivoire. The present work, which is part of this context, aims to evaluate the effectiveness of three nutrient solution formulations to optimize the growth and production of tomatoes in hydroponics in Côte d'Ivoire. The results of this study will provide valuable recommendations to tomato growers, allowing them to choose the most suitable fertilizer formulations for their local conditions.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the Bouaké region between May and September. This region is located in a climatic transition zone where the distribution of the year into two dry seasons and two rainy seasons is not regularly depending on the year. Annual rainfall varies from 1,100 to 1,300 mm/year and the period from April to September is the wettest. The average humidity of the air varies from 50% in January (the Harmattan period) to 87% in July, August and September (the rainy season). Maximum temperatures range on average from 27.5°C in August to 34.4°C in February, and minimum temperatures range from 20.4°C in January to 22°C in March. The duration of insolation varies on average between 99 hours in August and 243 hours in January. The months of July, August and September are the least sunny with 110, 99 and 122 hours marked by constantly overcast and rainy days.

2.2. Growing medium

Coco coir is an excellent substrate for hydroponics due to its advantageous physical and chemical properties. In this study, Medium Nursery coco coir, with a grain size of 0-20 mm, was used to provide an optimal growing environment for the plants. It was used as a substrate in growing trays at a rate of 4 bags of 50 kg per tray. Table 1 presents its characteristics.

Table 1. Features of the Coco Coir Medium Nursery

Characters	Coco Coir Medium Nursery
Particle size	0-20 mm
Description	Blend of fine, chips and short fiber Very good structural strength due to its high lignin content Very good ventilation ensured by the presence of short fibers and chips (cubic fraction)
Usage	Potting substrate for cup and container production
Medium chemical analysis (1/1.5 volume aqueous extraction)	pH (water): 6.7 Conductivity (mS/cm): 0.10-0.15 N-NO_3: 0.8 mg/l N-NH_4^+: 0.2mg/l P:1mg/l K:20mg/l
Average Physical Analysis	Dry bulk density:70g/l Dry/Raw Matter: 50% Organic/dry matter: 97% Porosity: 95% Water at pF1: 31% Water at pF2: 12% Air at pF1: 64% Water availability (DE) :200 ml/l substrate

2.3. Nutrient Solution Formulation

The commercial tomato variety Mongal F1 was chosen for this study because of its high demand in the local market in Côte d'Ivoire. Due to the complexity of developing nutrient solutions suitable for all vegetable species, three nutrient solution formulations were prepared by dissolving commercial fertilizers available in local markets. Formulations 1 and 2 were developed from fertilizers purchased only in Abidjan, while formulation 3 combines fertilizer from Abidjan and another from the Bouaké market. The formulations are presented in Table 2.

Table 2. Nutrient Solution Formulation

Solutions	Fertilizer	Quantities of dissolved fertilisers (g) per 1000 l of water	Elements major (microMol)	Electrical conductivity of the solution (dS/m)
Solution 1	Callifert 10-8-10 NPK 00-23-19 Super Latex 18-08-18 Nitrate de calcium NPKS Mix 12-22-22	150 500 500 400 500	N : 16.77 P_2O_5 : 1.95 K_2O : 3.29 Mg : 1 Ca : 3.39	CE=2.042
Solution 2	Callifert 10-8-10 NPK 00-23-19 Super Latex 18-08-18 Nitrate de calcium NPKS Mix 12-22-22	100 700 500 550 250	N : 15.36 P_2O_5 : 1.86 K_2O : 3.06 Mg : 1.24 Ca : 3.99	CE=2.055
Solution 3	Callifert 10-8-10 NPK 00-23-19 Super Latex 18-08-18 Nitrate de calcium NPKS Mix 12-24-18	100 500 300 600 700	N : 17.2 P_2O_5 : 2.22 K_2O : 3.03 Mg : 1.36 Ca : 3.65	CE=2.154

2.4. Experimental Set-up

The study was conducted in tanks arranged in a split-plot arrangement, with 4 replicates (Fig. 1). Nutrient solution was the main factor, while variety served as a secondary factor. The tanks, 12 in number, were 1.5 m long, 1 m wide and 25 cm deep.

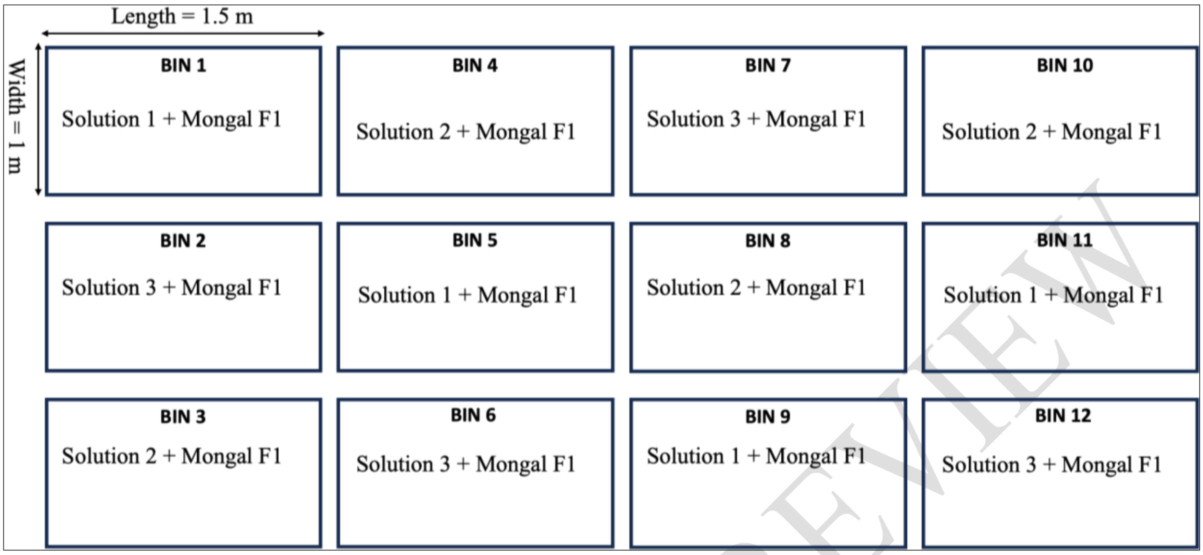

Fig. 1. Schematic diagram of the experimental set-up for the evaluation of nutrient solutions

2.5. Sowing and transplanting

During the month of May, the tomato seeds were sown in polyethylene cells containing a substrate made of 2/3 vegetable compost and 1/3 coconut fibre. Once the seeds were sown, the cells were watered daily with a nutrient solution prepared with 100 liters of water, 10 g of Callifert, 80 g of NPK 00-23-19, 40 g of NPKS Mix, 20 g of Superlatex, and 100 g of Calcium Nitrate. After sowing in the nursery, the cells were installed under a shade house for the first three days. When the seeds germinated on the fourth day, the cells were sunbathed each day and replaced under the shade each evening to shelter them from rain and adverse weather conditions. After 18 days in the nursery, the tomato plants were transplanted into trays filled with coconut fibre, at a rate of 12 plants per tray, divided into 3 rows of 4 plants. Each plant was spaced 30 cm apart on and between the rows. For each nutrient solution formulation, four trays were used, for a total of 12 trays. Watering was carried out by drip irrigation at a rate of 2 litres per hour, with a total supply of 150 litres of each solution.

2.6. Measured parameters

The measurements focused on the height of the plants at 30 days after transplanting, the date of first flowering of each plant, as well as the total number and weight of the fruits harvested, distinguishing non-marketable fruits from marketable fruits per container.

2.7. Data analysis

All data were subjected to an analysis of variance at the 5% level. In case of significant differences, the Tukey test was used for the separation of the means. The analyses were carried out with the R software, version 4.2.

3. RESULTS

3.1. Effect of nutrient solutions on flowering

Table 3 presents the results of the effect of nutrient solutions on flowering of the Mongal F1 tomato variety. The results indicated that there was no significant difference between nutrient solutions in the time to first bloom of 50% of plants (*P* = 0.16). Regardless of the nutrient solution, the plants flowered between 28 and 29 days after transplanting. Conversely, a significant difference (*P* = 0.008) was noted between the nutrient solutions regarding plant height at the flowering stage. Plants treated with Solution 1 were 58.7 cm taller, lower than plants treated with Solutions 2 and 3, which were 68.2 cm and 67.7 cm, respectively.

Table 3. Flowering time for half of plants and height of plants at flowering according to nutrient solutions

Solutions	50% flowering after transplanting	Height of plants at flowering stage (cm)
Solution 1	29 a	58.7 b
Solution 2	28.7 a	68.2 a
Solution 3	28.2 a	67.7 a
Average	28.7	64.6
P (%)	0.16	0.008

Column numbers assigned to the same letter do not differ significantly at the 5% threshold (Tukey test).

3.2. Effect of nutrient solutions on the number of tomatoes per bin

The results observed show that there is no significant difference (*P* = 0.20) between nutrient solutions for the total number of tomatoes, the number of marketable tomatoes and the percentage of non-marketable tomatoes per bin (**Table 4**). However, numerically, solution 3 recorded the highest number of tomatoes with 311, compared to 256 and 237 for solutions 1 and 2 respectively. On average, the number of non-marketable tomatoes was 9, representing 3.5%. Regarding the total number of marketable tomatoes, a significant difference (*P* = 0.05) between nutrient solutions was observed. Solution 3 produced 302 marketable tomatoes, while Solutions 1 and 2 generated 246 and 228 respectively. Solution 2 had the lowest number of marketable tomatoes with 228 fruits.

Table 4. Number of fruits per bin according to nutrient solutions

Solutions	Total number of fruits per bin	Total number of marketable fruits per bin	Number of non-marketable fruits per bin	Rate of unmarketable fruit per bin (%)
Solution 1	256 a	246	10 a	4.06 a
Solution 2	237 a	228 b	9 a	3.95 a
Solution 3	311 a	303 a	8 a	2.64 a
Average	268	259	9	3.55
P (%)	0.20	0.05	0.82	0.82

Column numbers assigned to the same letter do not differ significantly at the 5% threshold (Tukey test).

3.3. Effect of nutrient solutions on the number of tomatoes per plant

As shown in **Table 5**, the analysis of variance did not reveal a significant difference (*P* = 0.20) between nutrient solutions in terms of the number of tomatoes per plant and the number of non-marketable tomatoes per plant. On average, 22 tomatoes were recorded per plant. In terms of numbers, Solution 2 produced the lowest number of tomatoes per plant in 19.7, while Solution 3 had the highest number with 26 fruits per plant. For the number of marketable fruits, a significant difference (*P* = 0.04) between nutrient solutions was noted. Solution 3 yielded 25 fruits per plant, compared to 19 for solution 2 and 20.5 for solution 1. Regarding the number of non-marketable fruits per plant, the results showed no significant difference (*P* = 0.80), the average being 0.7 fruits per plant.

Table 5. Number of fruits per plant according to nutrient solutions

Solutions	Total number of fruits per plant	Total number of marketable fruits per plant	Number of non-marketable fruits per plant
Solution 1	21 a	20,50	0.81 a
Solution 2	19.70 a	19 b	0.72 a
Solution 3	26 a	25 a	0.70 a
Average	22.23	21.50	0.74
P (%)	0.20	0.04	0.80

Column numbers assigned to the same letter do not differ significantly at the 5% threshold (Tukey test).

3.4. Effect of nutrient solutions on tomato weight per bin

The results, shown in **Table 6**, show that the analysis of variance did not reveal a significant difference (*P* = 0.60) between nutrient solutions for total fruit weight, marketable and non-marketable fruit weight, and mean fruit weight. However, solution 3 produced 13,789 g of fruit, compared to 11,620 g for solution 2 and 12,961 g for solution 1. In terms of marketable fruit weight, solution 3 recorded 13,540 g, compared to 11,293 g and 12,661 g for solutions 2 and 1 respectively. Solution 1 recorded a weight of non-marketable fruit of 273.3 g, compared to 250.5 g and 249.2 g for solutions 2 and 3. For the average fruit weight, solution 3 recorded the lowest weight with 44.5 g compared to 49.87 and 48.78 g for solutions 1 and 2.

Table 6. Fruit weight per bin according to nutrient solutions

Solutions	Total weight of fruit per bin (g)	Total weight of marketable fruit per bin (g)	Weight of non-marketable fruit per bin (g)	Average fruit weight (g)
Solution 1	12 961 a	12 661 a	273.3 a	49.87 a
Solution 2	11 620 a	11 293 a	250.5 a	48.78 a
Solution 3	13 789 a	13 540 a	249.2 a	44.50 a
Average	12 790	12 498	257.66	47.72
P (%)	0.60	0.60	0.95	0.68

Column numbers assigned to the same letter do not differ significantly at the 5% threshold (Tukey test).

3.5. Effect of nutrient solutions on tomato weight per plant

Table 7 shows that no significant differences (*P* = 0.70) were observed between nutrient solutions for fruit weight per plant, marketable and non-marketable fruit weight per plant. Nevertheless, solution 3 obtained 1,149.1 g of fruit per plant, compared to 1,080.1 g for solution 1 and 968.3 g for solution 2. In terms of marketable fruit, solution 3 recorded 1,128.3 g per plant, compared to 1,055 g and 941.1 g for solutions 1 and 2. The average weight of the non-marketable fruits was 21.5 g per plant.

Table 7. Total fruit weight per plant according to nutrient solutions

Solutions	Fruit weight per plant (g)	Marketable fruit weight per plant (g)	Weight of non-marketable fruit per plant (g)
Solution 1	1 080.10 a	1055 a	22.80 a
Solution 2	968.30 a	941.10 a	20.90 a
Solution 3	1 149.10 a	1 128.30 a	20.70 a
Average	1 065.80	1041.50	21.50
P (%)	0.70	0.70	0.95

Column numbers assigned to the same letter do not differ significantly at the 5% threshold (Tukey test).

4. DISCUSSION

4.1. Effect of nutrient solutions on flowering and plant height

This study was carried out to develop an effective nutrient solution for hydroponic tomato cultivation in Côte d'Ivoire. Hydroponics is a method of soilless cultivation, where plants are grown on an inert substrate and fed with a nutrient solution rich in mineral salts necessary for their growth (Kumar et al., 2023). The results of the study showed no significant differences between nutrient solutions with respect to the flowering date of 50% of the plants. Regardless of the nutrient solution, the plants flowered between 28 and 29 days after transplanting. The absence of a significant difference in flowering time may indicate a good balance of solutions in terms of mineral element concentrations, which is corroborated by their similar electrical conductivities (between 2.042 and 2.154 dS/m). Each solution therefore adequately provided the necessary elements to support development through flowering. The time to first flowering recorded in this study appears to be earlier than in conventional soil cultivation, where it can vary from 40 to 60 days after transplanting, depending on the variety. These results confirm the work of Fondio et al. (2013), who noted that hydroponic tomato cultivation seems to induce an early flowering time (30 days after transplanting) compared to soil cultivation (40 days after transplanting). According to Chettri et al. (2024) an excessive concentration of nitrogen in the solution can cause a delay in the flowering of plants, to the benefit of their vegetative growth. The flowering times obtained in this study are earlier than those of Gianquinto et al. (2007), who observed first-bloom times for hydroponic tomatoes ranging from 29.1 to 33.7 days after transplanting in Brazil.

The results of this study also revealed a significant difference between nutrient solutions in terms of plant height at the flowering stage. The height of the plants with solution 1 was the smallest, at 58.7 cm, compared to 68.2 cm and 67.7 cm for solutions 2 and 3, respectively. The height of plants at the flowering stage appears to be strongly influenced by the concentration of mineral elements in nutrient solutions. Solutions 2 and 3, being more concentrated, provide more essential nutrients that promote higher vegetative growth. Key nutrients such as nitrogen, phosphorus and potassium play a crucial role in plant growth (Medakhal and Fathiza, 2020; Chettri et al., 2024). A higher concentration of these elements in solutions 2 and 3 could explain the faster and higher vegetative growth of the plants. Weill et al. (2014) reported that an increase in nitrogen content stimulates the growth of tomato plants. However, too high a concentration of mineral elements in the nutrient solution can lead to excessive consumption of macro-elements (calcium, magnesium, sulfur and phosphorus) and cause antagonism between divalent ions (Ca-Mg) and potassium (Rietra et al., 2015). This antagonism can reduce the uptake of Ca^{2+} ions, leading to calcium deficiencies and causing blossom end rots in tomatoes

(Snoussi, 2015). It is therefore necessary to have adequate equipment to control the concentration of nutrient solutions in mineral elements in order to avoid these excesses and antagonisms.

4.2. Effect of nutrient solutions on tomato fruit production

The results showed no significant differences between nutrient solutions regarding the total number of fruits, fruit weight, and the rate of unmarketable fruits. Although the differences were not significant, solution 3 produced the highest number of fruits numerically (311 or 1,149.10 g/plant) compared to solutions 1 (256 or 1,080.10 g/plant) and 2 (237 or 968.30 g/plant). The average number of non-marketable fruits was 9, which corresponds to a rate of 3.5%. This figure reflects a certain level of loss in production, but it remains relatively low, which is encouraging for the overall quality of production. However, it remains crucial to monitor this rate in order to reduce losses as much as possible. The absence of significant differences between nutrient solutions for fruit weight, total number of fruits and rate of non-marketable fruit could result from the relative differences in mineral element concentrations in the solutions. However, the fact that solution 3 produced the highest number of fruits numerically can be explained by its relatively high mineral element content (Sawadogo et al., 2021), making it a more favorable solution for fruit production. This is because minerals play a crucial role in plant development, especially for essential nutrients such as nitrogen, phosphorus and potassium, which are necessary for growth and fruiting. A higher concentration of these elements can improve the uptake and use of nutrients by plants, leading to increased fruit production (Garane et al., 2019; Abul-Soud et al., 2021).

In terms of the total number of marketable fruits, a significant difference was observed between nutrient solutions. Solution 3 obtained the highest number of marketable fruits, with 302 fruits (or 1,128.30 g/plant), compared to 246 fruits (1,055 g/plant) and 228 fruits (or 941.10 g/plant) for solutions 1 and 2. The significant difference between the solutions can be attributed to the relationship between the total number of fruits and the number of non-marketable fruits, the variability of this parameter being related to these two components. Solution 3, due to its balanced composition and relatively high mineral content, may have provided tomato plants with essential nutrients more effectively. This was able to optimize photosynthesis, growth, and fruiting, leading to a higher number of marketable fruits. Gianquinto et al. (2007) produced fruit yields in Brazil ranging from 289 to 946 g/plant depending on hydroponic solutions and systems. Their results are lower than ours, which are between 968 and 1,149 g/plant. These findings highlight the importance of precise nutrient balancing in nutrient solutions to maximize the yield of high-quality fruit. In addition, although the focus is on quantitative and qualitative yields, an economic analysis of different nutrient solutions would be useful to assess their commercial viability. In addition, the study focuses on a single tomato variety. Testing several varieties with the same nutrient solutions would make it possible to check if the results are applicable to other cultivars. Future research will build on these points to improve and refine the study's findings.

5. CONCLUSION

This work was carried out to evaluate the effectiveness of three nutrient solution formulations to optimize the growth and production of tomato in hydroponics in Côte d'Ivoire. The results showed that hydroponics registers to early flowering 28 to 29 days after transplanting, regardless of the nutrient solution used. The height of the plants with solution 1 was lower than that of the plants with solutions 2 and 3, i.e. 58.7 cm compared to 68.2 cm and 67.7 cm. Nutrient Solution 3 produced the highest number of fruits per plant, with 25 fruits, compared to 19 for Solution 2 and 20.5 for Solution 1. This solution proved to be numerically more effective, with 1128.3 g of marketable fruit/plant, compared to 941.1 and 1055 g/plant for solutions 2 and 1. The highest rate of non-marketable fruit was recorded with solution 1, i.e. 4% compared to 3.8% and 2.8% for solutions 2 and 3. In view of this work, nutrient solution 3 is recommended to maximize the yield and quality of tomatoes in hydroponics in Côte d'Ivoire.

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 the writing or editing of this manuscript.

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