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Effects of nutrient solutions on growth, yield and quality of yardlong bean plant (*Vigna unguiculata* subsp. *sesquipedalis* L.) grown in a hydroponic system

Thi Thuy Le, Phuong Thao Nguyen, Thi Van Pham, Thi Oanh Nguyen*

Department of Plant Physiology and Application, Faculty of Biology, Hanoi National University of Education, Hanoi, Vietnam

**Corresponding author: thuy_lt@hnue.edu.vn*

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Abstract: This study was conducted to evaluate the effects of three nutrient solutions (Hoagland, Knop, and Hydro Umat F) on the growth, yield, and fruit quality of hydroponically cultivated yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis* L.). Results showed that Hydro Umat F extended the plant lifespan (105.4 days) and flowering time (58.65 days), increased the number of branches per plant, and enhanced leaf SPAD values. Plants grown in Hydro Umat F also exhibited the highest yield, as indicated by the number of flowers per plant (46.12), number of pods per plant (20.81), pod length (54.15 cm), pod weight (20.06 g), and total pod weight per plant (417.45 g). The Hoagland solution also promoted plant growth and yield, with a growth duration of 96.74 days, an average of 17.63 pods per plant, a pod length of 47.34 cm, a pod weight of 17.14 g, and a total yield of 302.17 g per plant. In contrast, the Knop solution, containing only six essential nutrients, shortened the plant's growth duration (76.37 days) and significantly reduced the growth and yield of the hydroponic yardlong bean. Regarding pod quality, the pods from plants grown in Hydro Umat F had higher vitamin C content (4.12 mg/g), total protein content (3.21 mg/100 g), and reducing sugar content (13.06 mg/g) compared to those grown in Hoagland and Knop solutions. The findings suggest that Hydro Umat F is a suitable nutrient solution for hydroponic cultivation of yardlong bean, contributing to increased plant yield and fruit quality. These results suggest that Hydro Umat F is a promising nutrient solution for enhancing yield and pod quality in hydroponic yardlong bean cultivation, particularly in the context of the decline in available agricultural land and the rise of urban agriculture in Vietnam.

Keywords: nutrient formulation; urban farming; vegetable physiology

Yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis* L.) is one of the leguminous vegetables which originated in southwestern China (Suma et al. 2021). It is now widely cultivated around Asia, particularly in South and Southeast Asian countries (Mahmud et al. 2023), as well as in regions of Africa and Latin America (Orberá Ratón et al. 2021). Unlike other legume plants, yardlong bean plants have very long pods (30–90 cm) with seed sizes ranging from 8 to 12 mm (Shubha et al. 2022). The pods are highly nutritious, for example, rich in protein (24% of the dry weight of pods), carbohydrates (64%), and contain high levels of essential vitamins (A, B, C, etc.) and minerals such as calcium and phosphorus (Quamruzzaman et al. 2022). Studies on the nutritional value of yardlong bean seeds also have shown that these seeds are a source of insoluble fibre, fats, and various minerals (magnesium, calcium, iron, potas-

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sium, zinc, etc.), as well as secondary compounds beneficial to health, such as saponin, flavonoid, and alkaloids (Antova et al. 2014; Musah et al. 2020). The yardlong bean plant grows in dry and infertile soil conditions (Wang et al. 2013). In Vietnam, yardlong bean plants can be sown in three seasons: spring (March to July), summer (May to September), and autumn (July to November). As one of the most popular legumes in Vietnamese daily meals, the yardlong bean is cultivated in various regions from the North to the Central parts of the country (Nguyen, Tran 2017).

Like other plants, the yield of yardlong bean plants is influenced by factors such as cultivar, climate, cultivation conditions, and fertilisation practices. When evaluating the effects of inorganic fertiliser (NPK) and organic fertiliser (poultry manure) on the growth and yield of yardlong bean plants, Siti Naimah et al. (2015) reported that fertilisation formulas resulted in significant differences in leaf number and plant height but had little effect on chlorophyll content; the number of pods per plant ranged from 2 to 16, with the formula using 17.8 g of poultry manure per plant that helped to improve the growth and yield of the yardlong bean plants. High nitrogen (N) content (ranging from 0.91 to 1.81 g N/pot) significantly increased the fresh biomass of the plant; however, the input N content had no clear effect on yield, total N concentration in leaf blades, roots, or the number of nodules on the yardlong bean (Wang et al. 2021). In a study on the nutritional requirements of yardlong bean plants throughout their life cycle, Cunha et al. (2020) concluded that the plant has the highest nutritional demand between 20 and 45 days after germination. When analysing the mineral composition of the plant at the end of the growth cycle, the levels of measured elements decreased in the order K > Ca = N > S = P > Mg (macronutrients) and Fe > B > Zn > Mn > Cu (micronutrients). Protective cultivation (in greenhouses) extended the harvesting period of pods (6–10 days), improved quality, and increased yield from 15.6% to 25.1%, while reducing the incidence rates of leaf spot, rust, and powdery mildew on yardlong bean plants (Zhang et al. 2024). Under the same cultivation conditions, differences in cultivars caused significant variations in plant height (239.1–261.8 cm), first flowering time (31.33–36 days after planting), number of pods per plant (18.34–25.34 pods), pod length (56.17–67.57 cm), and pod weight (24.23–32.40 g) (Mia et al. 2023).

Hydroponics is a widely applied method of safe vegetable production in Vietnam. This method helps conserve water, reduce soil-borne diseases, and increase crop yield, and can be implemented at various scales, from household to commercial farms (Nguyen et al. 2020; Thuy et al. 2024). This study was conducted to assess the effects of three nutrient solutions on the growth, yield, and fruit quality of yardlong bean plants, with the aim of identifying an appropriate nutrient composition for hydroponic cultivation of this plant.

MATERIAL AND METHODS

Plant material and hydroponic nutrient solutions. The yardlong bean seeds used in this study were provided by Phu Nong Seed Company Ltd., Vietnam. The cultivar has green pods and black seeds when ripe.

Tap water was used to prepare three nutrition solutions, including two formulated solutions (Hoagland and Knop) based on the formulas described by Ma et al. (2013), and one commercial solution named Hydro Umat F (produced by Gia Vien Hydroponics Co., Ltd., Vietnam). The nutrient composition of the three solutions is presented in Table 1.

Experimental design. The study used a static hydroponic system, with hydroponic containers measuring 30 × 40 × 45 cm (plastic boxes) and a volume of 15 litres. The yardlong bean seeds were soaked in warm water (45 °C) for 2 h, then sown in compressed coconut coir pellets placed in net pots. After

Table 1. The nutrient contents of three hydroponic solutions

Nutrient solutions	Contents of basic elements in 5 nutrient solution formulations (ppm)											
	N	P	K	Ca	Mg	B	Mn	Zn	Mo	Cu	Fe	S
Hoagland	99.4	30.1	117.2	92.1	24.2	2.5	2.5	0.2	0.2	0.1	5.6	35.4
Hydro Umat F	171.3	33.9	273.8	160.7	50.0	0.5	1.0	0.9	0.6	0.7	3.0	66.5
Knop	117.1	32.5	133.6	138.9	28.8	–	–	–	–	–	1.03	38.1

Missing values mean they do not exist. Fe was supplied as Fe-NaEDTA

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3 days of germination, the seedlings were transferred to the hydroponic containers. Each container was planted with four plants, and each nutrient solution formula included five containers. The experiment was arranged in a randomised block design with three replications (20 plants per replication). When the yardlong bean plants began to climb, bamboo sticks and wire were used as supports. The pH of the nutrient solution was measured using a pH meter (HI98107, Hanna instruments, Romania) and maintained within the range of 6–6.5. The experiment was conducted in two seasons, from May 2022 to August 2022 and from May 2023 to August 2023, in a shaded greenhouse at the Experimental Garden of Hanoi National University of Education, Hanoi, Vietnam. The average temperature during the experimental months ranged from 33 °C to 38 °C.

Methods for determining growth parameters. The growth parameters of the yardlong bean plants included: plant height, number of leaves per plant, number of branches per plant, and leaf SPAD (reading), which were determined at flower initiation. The plant height was measured from the substrate surface to the apical tip of the cowpea stem using a tape. The number of leaves and branches of each plant was counted and recorded. The leaf SPAD of the mature leaves (the third leaf from the apex down) was measured using a SPAD 502 (Minolta Camera Co., Osaka, Japan). Ten plants were randomly selected from each experimental formula to calculate the statistics.

The growth duration of the yardlong bean plants, starting from seed sowing, was also evaluated by tracking and recording key time points in the plant's life cycle, including: days to true leaf emergence (the number of days required from sowing to the first true leaf emergence in 50% of plants); days of 50% branching (the number of days required from sowing to 50% of plants showing branching); days of 50% flowering (the number of days required from sowing to the first flowering of 50% of plants); lifespan (the number of days from sowing to the first flowering until 50% of the plants die).

Methods for determining yield parameters. The number of flowers and the number of pods per plant were counted from 10 randomly selected plants of each experimental formula.

The immature green pods were harvested to determine the yield-contributing parameters, including pod length, diameter, and weight. These parameters were measured by using an analytical weight balance. The data for pod weight per plant was determined by weighing all immature pods of the plant. This was conducted on 10 randomly selected plants of each experimental formula to calculate the statistics. The pod weight per box was calculated by multiplying the data of pod weight per plant by 4 (where 4 was the number of plants per box).

The days to the first harvest were calculated from the date of sowing to the time when 50% of the plants had harvestable pods. The flowering duration was counted from the appearance of the first flower to the cessation of flowering.

Methods for determining pod quality parameters. Vitamin C content (mg/g) was analysed using the iodine titration method as described by Thuy et al. (2021). Total protein (mg/100 g) was determined by the micro Kjeldahl method (Mui 2001). The reducing sugar content of the pod was determined using the DNS colourimetric method, as described by Mui (2001). The nitrate content (mg/kg) was determined using the spectrophotometric method with a salicylic acid reagent (Phuong et al. 2020).

Statistical analysis. The data were statistically processed using Microsoft Excel and SPSS version 16.0 software. The data were analysed using one-way ANOVA (Tukey's HSD test) at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Effect of three nutrient solutions on the duration of growth and development of yardlong bean plants. To evaluate the growth process of yardlong bean plants in hydroponic conditions, key time points in the life cycle of the plants were recorded and are presented in Table 2.

The results shown in Table 2 indicate that while there were no statistical differences among the three nutrient solutions in terms of time to first true leaf emergence (around 6 days post-sowing), they exerted significant effects on the following developmental stages of yardlong bean plants. Specifically, plants grown in Hydro Umat F and Hoagland solutions had similar branching times (20.34–20.71 days) and flowering times (32.8–33.12 days). Nonetheless, plants cultivated in Hydro Umat F had the longest growth duration (105.4 days), which was 8.66 days longer than those grown in the Hoagland solution. Meanwhile, yardlong bean plants grown in Knop solution had a later branching time (25.59 days) and the

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Table 2. Effect of nutrient solutions on the growth duration of yardlong bean plants (days)

Nutrient solution	Days to true leaf emergence	Days of 50% branching	Days of 50% flowering	Growth duration (days)
Hoagland	6.25 ± 0.31[a]	20.34 ± 1.13[b]	32.80 ± 2.30[a]	96.74 ± 3.76[b]
Knop	6.41 ± 0.36[a]	25.59 ± 1.87[a]	29.18 ± 1.26[b]	76.37 ± 5.18[c]
Hydro Umat F	6.11 ± 0.28[a]	20.71 ± 1.52[b]	33.12 ± 2.63[a]	105.40 ± 4.11[a]

[a,b,c]different letters in each column indicate the significant differences (α = 0.05) among the four treatments

shortest growth duration (76.37 days), although they flowered approximately 4 days earlier compared to plants grown in the other two solutions.

In a study comparing five yardlong bean varieties (labelled V1 to V5) grown in Bangladesh, Ahmed et al. (2024) recorded their flowering times, which ranged from 34 to 38 days. Meanwhile, the first flowering time of four other yardlong bean varieties (labelled FLK-203 to FLK-206) grown in Bangladesh occurred earlier, averaging between 27.67 and 32.67 days after planting (Mahmud et al. 2023). However, in another study by Mia et al. (2023) with the same four varieties, when the growing conditions (soil type, planting season) were altered, flowering times ranged from 31.3 to 36 days after sowing. However, the flowering order of the varieties remained the same as in the earlier study by Mahmud et al. (2023). This indicates that growing conditions have a significant impact on the flowering ability of yardlong bean plants. The variety of yardlong beans in this study, when grown hydroponically, had their first flowering time (30–34 days after planting), which is within the average range reported by the studies mentioned above.

Compared to the Hoagland and Hydro Umat F solutions (Table 2), although there was no significant difference in the content of elements in the solutions, the composition of the Knop solution only included six basic elements (N, P, K, Ca, Mg, and Fe), lacking most of the essential micronutrients. This could be the reason why the yardlong bean plants had a shorter life cycle and earlier flowering compared to the other two nutrient solutions.

Effect of three nutrient solutions on some growth parameters of yardlong bean plants at flowering time. In this study, to assess the effect of nutrient solutions on the growth of yardlong bean plants, parameters including the number of branches/plant, number of leaves/plant, plant height, and leaf SPAD index were determined at the stage when the plants begin flowering. The results are presented in Table 3.

Yardlong bean is an herbaceous plant with unlimited growth potential. The research results (Table 3) show that the use of Hoagland solution significantly promoted the height growth of the yardlong bean plant (216.63 cm at the flowering stage), which was 12.55 cm and 24.76 cm higher than plants grown in Hydro Umat F and Knop solutions, respectively. However, when comparing the number of leaves per plant and the number of branches per plant, it was observed that plants grown in Hydro Umat F had a similar number of leaves but a higher number of branches per plant compared to those grown in the Hoagland solution. This suggests that focusing nutrition on the branching process may have affected the height growth rate of plants grown in this solution. In contrast, plants grown in Knop solution exhibited poor growth in both height and number of leaves and branches. Thus, it can be concluded that the composition and concentration of elements in the nutrient solution had a significant impact on the growth ability of the plants. Other studies also show that the height of yardlong bean plants is highly dependent on growing conditions. For example, with the same four yardlong bean varieties

Table 3. Effect of nutrient solutions on the number of branches, number of leaves, plant height, and SPAD index of yardlong bean plants

Nutrient solutions	Number of branches/plant	Number of leaves/plant	Plant height (cm)	Leaf SPAD reading
Hoagland	2.73 ± 0.27[b]	16.32 ± 1.18[a]	216.63 ± 5.19[a]	34.81 ± 1.31[b]
Knop	1.60 ± 0.09[c]	13.64 ± 1.47[b]	191.87 ± 6.81[c]	25.09 ± 2.09[c]
Hydro Umat F	3.47 ± 0.15[a]	16.25 ± 1.06[a]	203.75 ± 4.18[a]	38.01 ± 1.15[a]

[a,b,c]different letters in each column indicate the significant differences (α = 0.05) among the four treatments

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(FLK-203, FLK-204, FLH-205, and FLK-206), Mahmud et al. (2023) measured plant heights ranging from 157.67 to 190 cm, while Mia et al. (2023) reported plant heights ranging from 239.1 to 261.8 cm.

Table 3 indicates that the highest SPAD index was measured in plants grown in Hydro Umat F solution, followed by plants grown in Hoagland solution, with the lowest SPAD index in plants grown in Knop solution. When studying the effect of N content on the growth of yardlong bean plants, Wang et al. (2021) found that plants fertilised with N had significantly higher SPAD index compared to the control group with no fertilisation during flowering. Other studies have shown that leaf greenness reflects the nitrate level in plants, and the SPAD meter can reliably estimate the N level in plants, as well as their yield, such as cucumbers and rice (Swain et al. 2010; Padilla et al. 2017). In comparison with these results, our study shows that there is not a very strong correlation between the N content in the nutrient solutions and the SPAD index. Specifically, the SPAD index measured in the leaves of plants grown in Hydro Umat F was the highest (38.01), and this solution also had the highest N content among the three solutions used in the study. However, the N content in Hoagland and Knop solutions did not differ significantly. The N content in Knop was 17.7 ppm higher, but the SPAD index in plants grown in Knop solution was significantly lower (9.72 units) than in the Hoagland solution. This may be related to the differences in the iron content in these two nutrient solutions (Table 1).

Effect of three nutrient solutions on yield contributing parameters. Plants grown in Knop solution exhibited a short growth and development period, with early flowering (Table 2), and also produced the earliest harvest, 43.18 days after planting. This was followed by plants grown in Hoagland solution (46.63 days) and plants grown in Hydro Umat F solution (48.7 days) (Table 4).

Yardlong bean is a plant with unlimited growth, and the growth in height and number of branches leads to prolonged flowering throughout its life cycle. In this study, the use of Hydro Umat F and Hoagland solutions significantly extended the flowering period of the yardlong bean plants, with flowering durations of 55.13–58.65 days, nearly twice as long as the flowering time of plants grown in Knop solution. This result again demonstrates that the composition and concentration of the nutrient solution have a significant impact on the flowering process in yardlong bean plants.

The prolonged and continuous flowering period resulted in a significant increase in the number of flowers and pods per plant. Specifically, plants grown in Hydro Umat F solution had 46.12 flowers and 20.81 pods per plant. These results were higher than those obtained from plants grown in Hoagland and Knop solutions. With 25.7 flowers per plant, plants grown in Knop solution had the lowest number of pods (10.28 pods per plant), which is 58.2% of the pods produced by plants grown in Hoagland solution and 49.3% of those grown in Hydro Umat F solution.

Along with the number of pods per plant, pod size and weight are important parameters determining the yield of yardlong bean plants. The results show that there was no significant difference in pod diameter among the experimental treatments; however, a substantial difference in pod length was observed, resulting in varying pod weights (Table 5).

Wang et al. (2021) indicated that, under soil cultivation conditions, the amount of N supplied to the plants did not significantly affect the yield of yardlong beans. Under hydroponic conditions, our study's results also showed that the high N content in the Hydro Umat F solution, along with the complete range of other essential nutrients, significantly increased the yield of hydroponically grown yardlong beans. This was reflected in parameters such as pod length (54.15 cm), fresh pod weight (20.06 g), and pod weight per plant (417.45 g). The results (Table 5) show that the yield per hydroponic box using the Hydro Umat F solution was nearly 2.7 times and

Table 4. Flowering time, number of flowers, and pods of yardlong bean as influenced by nutrient solutions

Nutrient solutions	Days to first harvest (days)	Flowering duration (days)	Number of flowers/plant	Number of pods/plant
Hoagland	46.63 ± 3.42^{ab}	55.13 ± 4.08^{b}	40.87 ± 2.17^{b}	17.63 ± 1.36^{b}
Knop	43.18 ± 3.09^{b}	30.07 ± 3.71^{c}	25.70 ± 3.11^{c}	10.28 ± 1.65^{c}
Hydro Umat F	48.70 ± 2.15^{a}	58.65 ± 3.75^{a}	46.12 ± 2.03^{a}	20.81 ± 1.47^{a}

[a,b,c]different letters in each column indicate the significant differences (α = 0.05) among the four treatments

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Table 5. Some parameters related to the yield of yardlong bean under the influence of nutrient solutions

Nutrient solutions	Pod length (cm)	Pod diameter (cm)	Pod weight (g)	Pod weight/plant (g)	Pod weight/box (g)
Hoagland	47.34 ± 2.37[b]	0.86 ± 0.08[b]	17.14 ± 1.10[b]	302.17 ± 5.61[b]	1208.68 ± 31.76[c]
Knop	41.18 ± 3.12[c]	0.91 ± 0.05[a]	15.19 ± 1.54[c]	156.15 ± 9.11[c]	624.60 ± 28.45[b]
Hydro Umat F	54.15 ± 2.78[a]	0.88 ± 0.06[ab]	20.06 ± 1.29[a]	417.45 ± 10.26[a]	1669.80 ± 38.94[a]

[a,b,c]different letters in each column indicate the significant differences (α = 0.05) among the four treatments

1.4 times higher compared to using the Knop and Hoagland solutions, respectively. Unlike the Knop solution, the Hoagland solution supplements six micronutrients (Table 1), which significantly increases the yield of yardlong beans. Specifically, the pod length and weight of plants grown in the Hoagland solution were higher compared to those grown in the Knop solution. Along with the difference in the number of pods per plant (Table 4), these results indicate that the yield of plants grown in the Hoagland solution was nearly twice that of those grown in the Knop solution.

In a study on the impact of nutritional conditions and host plants on nodule formation, Sinsiri and Homchan (2002) reported that hydroponically grown yardlong beans with an input N level of 70 ppm did not form *Rhizobium* nodules. In this study, we also did not observe nodule formation in the roots of yardlong bean plants under hydroponic conditions using any of the three nutrient solutions. The lack of N fixation ability means that the growth and yield of the yardlong bean plants depend entirely on the nutrient content and composition of the hydroponic solution. Under organic farming conditions, Orberá Ratón et al. (2021) reported that the plant height of yardlong beans ranged from 28.24 to 29.92 cm, and in the experimental formula with inorganic NPK fertilisation, the pod length reached only 31.26 cm, with average yields ranging from 0.4 to 0.65 kg/m². When comparing the yield of four yardlong bean varieties, Mahmud et al. (2023) found that under the same soil cultivation and fertilisation conditions, pod length (ranging from 50.33 to 65.33 cm), pod weight (from 18.53 to 34.53 g), and pod weight per plant (ranging from 99.67 to 177.85 g) all varied. Therefore, the findings of this study suggest that hydroponic cultivation has the potential to improve the yield of yardlong beans under the tested conditions.

Effect of three nutrient solutions on quality contributing parameters. The content of vitamin C, reducing sugars, total protein, and nitrate content in the pods of yardlong beans grown in the three nutrient solutions is shown in Table 6.

The results of the nutrient content analysis (Table 6) indicate that the Hydro Umat F nutrient solution had the most positive impact on the quality of yardlong bean pods. Specifically, the vitamin C content in the pods of beans grown in Hydro Umat F was the highest (4.12 mg/g), followed by Hoagland solution (3.62 mg/g), and the lowest in Knop solution (2.36 mg/g). A similar trend was observed for reducing sugar content, which ranged from 7.80 to 13.06 mg/g, and nitrate content, which ranged from 605.95 to 667.42 mg/kg. Notably, the highest total protein content was found in the beans grown in Hydro Umat F solution (3.21 mg/100 g), although there was no significant difference in protein content between the pods grown in Knop and Hoagland solutions.

The composition and nutrient content of plants are believed to depend largely on environmental conditions and the characteristics of the variety (Ntatsi et al. 2018; Choi et al. 2024). Previous studies on yard-

Table 6. The effect of nutrient solutions on the vitamin C content, reducing sugar content, total protein content, and nitrate content in yardlong bean pods

Nutrient solutions	Vitamin C content (mg/g)	Reducing sugar content (mg/g)	Total protein (mg/100 g)	Nitrate concentration (mg/kg)
Hoagland	3.62 ± 0.11[b]	11.84 ± 0.30[b]	2.93 ± 0.10[b]	618.47 ± 6.30[c]
Knop	2.36 ± 0.13[c]	7.80 ± 0.24[c]	2.90 ± 0.11[b]	630.35 ± 7.42[b]
Hydro Umat F	4.12 ± 0.15[a]	13.06 ± 0.18[a]	3.21 ± 0.12[a]	667.42 ± 8.21[a]

[a,b,c]different letters in each column indicate the significant differences (α = 0.05) among the four treatments

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long beans have shown significant variation in nutrient content, with a wide range of values. For example, Choi et al. (2024) reported that the vitamin C content in 14 yardlong bean varieties in South Korea ranged from 0.7 to 2.62 mg/g, while crude protein content ranged from 24.31% to 29.10%. Similarly, Quamruzzaman et al. (2022) recorded the vitamin C content in five yardlong bean varieties in Bangladesh, ranging from 18.20 to 20.22 mg/100 g, and total protein content ranging from 2.80 to 3.3 g/100 g. In a previous study by Khatun et al. (2022) on 4 out of 5 of these varieties, protein content was found to range from 2.8 to 3.3 g/100 g, and total sugar content ranged from 1.49 to 2.34 g/100 g. Compared to this data, our study shows that the use of Hydro Umat F significantly increased the vitamin C and protein content, and reduced the sugar content in the yardlong bean pods. Therefore, not only environmental conditions and variety, but also nutritional factors have a significant effect on the nutrient content of yardlong bean pods.

In addition to nutritional value, nitrate content is an important indicator for evaluating the quality and safety of hydroponically grown produce. Nitrate itself is not highly toxic, but when converted to nitrite in the human digestive system, its toxicity can increase by up to 10 times (Ranasinghe et al. 2018; Ebrahimi et al. 2020), and it is considered a potential cause of certain cancers and thyroid disorders in humans (Bahadoran et al. 2016; Quijano et al. 2017). In this study, the highest nitrate content in the pods of yardlong beans was found in plants grown in the Hydro Umat F solution (667.42 mg/kg), which was 37.07 mg/kg and 48.95 mg/kg higher than the results obtained from plants grown in Knop and Hoagland solutions, respectively. This shows that the variation in nitrate content in yardlong bean pods is related to the N content in the hydroponic solution. With the highest N content among the three nutrient solutions tested, Hydro Umat F led to an increase in nitrate accumulation in the yardlong bean pods compared to the other two solutions. Many studies have shown that nitrate accumulation in vegetables is influenced by several factors, including the biological characteristics of the species, light conditions, and particularly the source of nitrate (fertilisers), which are considered significant factors (Colla et al. 2018; Uddin et al. 2021; Dezhangah et al. 2022). The use of high-N fertilisers to improve yield is one of the main causes of nitrate accumulation in fruits and vegetables (Ebrahimi et al. 2020).

The nitrate content in hydroponically grown yardlong bean, ranging from 618.47 to 667.42 mg/kg, was substantially lower than that found in certain leafy vegetables like lettuce (1 830 mg/kg), cabbage (1 980 mg/kg), and radish (6 260 mg/kg). Nevertheless, it was considerably higher compared to other legumes such as red bean (157 mg/g), white bean (185 mg/kg), and split pea (375 mg/kg), as well as the results reported by Zahra et al. (2016) for yardlong bean (106 mg/kg). In another study published by Hosseini et al. (2023), the nitrate content in the pods of other leguminous plants was also quite high, for example, in green peas (880 mg/kg) and beans (103.94 mg/kg). The differences in these results indicate that, in addition to N input sources, the form of hydroponic cultivation (with soluble, easily absorbed N) may contribute to the higher accumulation of nitrate in the yardlong bean pods in this study. Additionally, the discrepancies in the results may be due to differences in cultivation conditions, analytical methods, and variety characteristics. Although the nitrate content in the yardlong bean pods in this study is higher than in other reports, with the recommended acceptable daily intake of nitrate being around 3.7 mg/kg body weight (Keller et al. 2017), an adult can safely consume about 350 g of hydroponically grown yardlong beans per day without impacting health.

CONCLUSION

The research results show that the Hydro Umat F nutrient solution has demonstrated superior effectiveness in promoting growth and increasing the yield of yardlong bean plants compared to those grown in Hoagland and Knop solutions. Specifically, the plants grown in Hydro Umat F solution not only had the longest life cycle (105.4 days) but also yielded the highest productivity, as reflected by parameters such as the number of pods per plant (20.81 pods), pod length (54.15 cm), and pod weight per plant (417.45 g). Additionally, the quality of the pods was significantly improved, with higher vitamin C content (4.12 mg/g), total protein (3.21 mg/100 g), and reduced sugar content (13.06 mg/g) compared to plants grown in Hoagland and Knop solutions. In conclusion, while the study findings suggest that the Hydro Umat F solution performs more effectively in hydroponic cultivation, further research is necessary to confirm this result with greater certainty.

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