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Original Article

Effects of Nursery Container Types and Phosphate Fertilization Levels on Early Growth and Quality of Hybrid 'Zumuruda F_1' Tomato Seedlings (*Solanum lycopersicum* L.)

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Abstract

This study was conducted at the Department of Horticulture, Omar Al Mukhtar University, Libya, to evaluate the effects of container type and phosphate fertilization on the growth and quality of 'Zumuruda F_1' tomato seedlings (*Solanum lycopersicum* L.). A randomized complete block split-plot design with three replications was employed, where container type (plastic bags, paper bags, and foam trays) as the main factor and phosphate fertilization levels (P_0, P_1, P_2, and P_3) supplemented with adjusted amounts of urea and Potassium sulfate fertilizers as the sub-factor. Measurements included seedling growth traits and fresh biomass. Seeds were sown on April 13 and the experiment continued for 39 days until May 22. The findings revealed that paper and plastic bags promoted greater vegetative growth and biomass accumulation compared with foam trays, with paper bags yielding the highest fresh weight. Foam trays, irrespective of phosphate level, consistently produced the weakest seedlings. Phosphate fertilization markedly enhanced growth, with P_1 (1000 mg P_2O_5 kg^{-1}) and P_3 (3000 mg P_2O_5 kg^{-1}) recording the tallest plants and greatest leaf numbers, while fresh biomass was maximized under P_3 (12.8 g), demonstrating that elevated phosphorus inputs stimulated growth despite non-linear treatment responses.

Key words: plastic bags; paper bags; tomato transplant; DAP rates; seedling vigor

Introduction

Tomato (*Solanum lycopersicum* L.) is a globally significant vegetable crop, widely recognized for its exceptional nutritional value and high yield potential, making it a key contributor to both food security and agricultural profitability (Ilahy *et al.*, 2018; Tibagonzeka *et al.*, 2018; Higo *et al.*, 2020; Liu *et al.*, 2022). Enhancing local production is crucial to meet consumer demand.

The seedling stage is critical for establishing vigorous plants, directly affecting growth and fruit yield under greenhouse or field conditions (Gavric & Omerbegovic, 2021; Reed *et al.*, 2022; Gallegos-Cedillo *et al.*, 2024). Container type strongly influences seedling growth and quality, as variations in size (volume), shape, drainage, capacity, and aeration affect root development,

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morphology, and transplant success (Landis *et al.*, 2014; Gallegos *et al.*, 2020). Larger container volumes, when combined with adequate aeration, enhance root expansion, improve moisture retention, and support optimal physiological processes, resulting in more vigorous seedlings. Nursery production systems worldwide utilize a range of container types, including biodegradable paper pots, foam trays, and plastic bags, each possessing unique physical and functional properties that can significantly affect seedling vigor and overall nursery performance (Argerich & Poggi, 2003; Haase *et al.*, 2021).

Tomato seedlings are extremely sensitive to phosphorus availability at this stage because they have a small, growing root system and little ability to explore the soil (Martins *et al.*, 2017; Marques *et al.*, 2022; Demirer *et al.*, 2023) .

Phosphorus fertilizer application was found to enhance tomato yields, reaching a peak at 200 kg ha^{-1} before declining significantly ($P < 0.05$). Despite this yield response, it had no substantial impact on the measured physio-chemical traits (Ihsan Abu-Alrub *et al.*, 2019). In addition, increasing phosphorus application has been shown to enhance plant growth parameters, particularly dry weight and chlorophyll concentrations, without producing significant differences compared to the control treatment, as reported by Kaya and Higgs (2001). In the same trend, Martins *et al.*, (2017) indicated in their study that tomato seedlings cultivated on a coconut fiber substrate had a linear increase in leaf area, plant height, and both stem and root fresh biomass with elevated phosphorus levels, achieving optimal development at a phosphorus concentration of 75 mg L^{-1} .

Most existing studies tend to focus on mature plant stages or well-fertilized conditions, with limited studies addressing its effects on seedlings, particularly regarding dosage and its relation to growth stages (De Groot *et al.*, 2004; Araújo *et al.*, 2018), leaving a significant gap in our understanding of how various fertilization levels influence early seedling performance when grown in low-fertility or inert growing media. This lack of information limits the ability to develop optimized fertilization practices for nursery production systems that rely on substrates with poor inherent nutrient content.

Therefore, this study aimed to evaluate the effects of different nursery container types and phosphorus fertilization levels on the early growth and quality of hybrid 'Zumuruda F_1' tomato seedlings under protected greenhouse conditions. Specifically, the study sought to identify the optimal phosphorus application rates and the most suitable container type for enhancing seedling vigor, promoting root development, and improving overall transplant quality, particularly under low-fertility growing media.

Materials and Methods

This study was conducted under protected greenhouse conditions at the Department of Horticulture, Omar Al Mukhtar University, Al Jabal Al Akhdar, Libya, to evaluate the effects of three nursery container types and four levels of phosphorus fertilization on the growth and quality of tomato seedlings of the commercial hybrid 'Zumuruda F_1' (VT766; EGASEED, Egyptian Agricultural Seeds Co., Cairo, Egypt). Seeds were sown on April 13 and the experiment continued for 39 days until May 22. Experiment comprised 12 treatments representing all possible combinations of the two factors and followed a randomized complete block split-plot design with three replications per treatment. Three types of nursery containers were used as the main factor in the study; Plastic bags (16 x 9 cm), containing 250 grams of culture medium, paper bags (14 x 10 cm), containing 250 grams of culture medium, and foam trays containing 209 cells, each containing approximately 30 grams, were 2.5 x 2.5 cm in size and 7.5 cm in depth. Four levels of phosphate fertilization (0, 1000, 2000, and 3000 mg P_2O_5/kg medium), designated P_0, P_1, P_2, and P_3, respectively supplemented with adjusted amounts of urea and Potassium sulfate fertilizers. Where Di-ammonium phosphate (DAP) fertilizer at a concentration of 48% P_2O_5 was used as a phosphorus source. To maintain constant nitrogen and potassium levels in all treatments, the following were added: 2000 mg N/kg medium using urea fertilizer (46% N), the amount of which was adjusted based on the nitrogen content of the DAP, and 2000 mg K_2O/kg medium using potassium sulfate fertilizer (48% K_2O). Table (1) shows the amounts of fertilizers added per kilogram of the culture medium for each phosphorus treatment .

Table 1. Fertilizer Application Rates Under Different P_2O_5 Treatment Levels.

Treatment	P_2O_5 (mg/kg)	DAP (g/kg culture)	Urea (g/kg culture)	Potassium sulfate (g/kg culture)
P0	0.000	0.00	4.35	4.17
P1	1000	2.08	3.63	4.17
P2	2000	4.16	2.90	4.17
P3	3000	6.25	2.17	4.17

The culture medium consisted of a 1:1:1 volumetric mixture of potting soil, peat moss, and compost. Two seeds were planted in each experimental unit (bag or cell), and thinned at the early seedling stage when plants reached the 2–3 true leaf stage (approximately 7 to 10 days after germination). At this stage, excess seedlings were carefully removed to maintain one plant per unit.

The total number of treatments was 12 (4 levels x 3 types of containers), with 10 cells planted per treatment. Four cells were randomly selected from each treatment for data collection which included vegetative growth traits [Total plant height (cm), stem Length (cm), root Length (cm), number of Leaves, and stem Thickness (cm), and fresh weight (g/plant) (Total plant, leaf, stem, and root fresh weight). Collected data were statistically analyzed.

Irrigation and moisture management

Irrigation was carefully managed throughout the experimental period to maintain adequate and uniform moisture conditions across all treatments. All containers were irrigated manually by tap water using a graduated watering can to ensure precise water application. The amount of water applied was adjusted based on the growth stage of the seedlings and the water-holding capacity of each container type. Soil moisture content was maintained close to field capacity by applying water when approximately 50–60% of the available water had been depleted, as determined by daily visual inspection.

Special attention was given to differences in drainage and water retention among the container types. Containers with lower water-holding capacity received more frequent irrigation with smaller volumes, while those with higher retention were irrigated less frequently to avoid waterlogging. All irrigation events were conducted in the morning to reduce evaporation losses and ensure optimal water availability during the day. This approach ensured consistent moisture conditions across treatments, preventing both drought stress and excessive moisture, which could otherwise confound the effects of container type and phosphate fertilization on seedling growth.

Data analysis:

All data were analyzed using JMP software (Version 11.0 for Windows; SAS Institute Inc., Cary, NC). Levene's test was applied to assess the homogeneity of variances, while the Shapiro-Wilk test ($W > 0.80$) was used to verify the normality of the data distribution. Where necessary, data were transformed using square root or logarithmic transformations to meet the assumptions of normality and homoscedasticity. Treatment means were compared using the Least Squares Means Student's t-test at 5% significance level.

Results and Discussion

Vegetative growth traits

The results showed that container type had a highly significant effect on all measured tomato seedling's vegetative growth. Seedlings grown in paper bags exhibited the greatest total plant height (55.88 cm), stem length (39.75 cm), root length (10.44 cm), and stem thickness (2.11 cm), all of which were significantly higher than those recorded for seedlings grown in plastic bags or foam trays (Table 2). The number of leaves per plant was also highest in paper bags (6.13 leaves), although it did not differ significantly from that in plastic bags (5.75 leaves). Plastic bags produced seedlings with intermediate growth performance, whereas foam trays consistently resulted in the lowest values for all growth parameters, with total plant height, stem length, and root length of 12.75 cm, 7.25 cm, and 5.94 cm, respectively, and a stem thickness of only 0.85 cm.

Phosphate fertilization level (with added amounts of urea and potassium sulfate fertilizers) also significantly influenced seedling growth. The highest total plant height was recorded with P_1 (37.92 cm) and P_3 (37.66 cm), both significantly greater than P_0 (30.83 cm). Similarly, stem length was longest in P_1 (25.83 cm) and P_3 (24.67 cm), while P_2 (20.58 cm) and P_0 (19.83 cm) had shorter stems. Root length reached its maximum at P_3 (9.66 cm), significantly higher than P_2 (6.83 cm), while P_0 (7.66 cm) and P_1 (8.17 cm) showed intermediate values. The number of leaves was significantly higher in P_3 (5.67 leaves) than in P_0 and P_2 (4.33 leaves), while P_1 (4.67 leaves) was not significantly different from P_0 or P_3. Stem thickness was significantly enhanced at P_1 (1.78 cm) and P_3 (1.69 cm) compared to P_0 (1.39 cm), with P_2 (1.62 cm) showing an intermediate response.

Seedlings receiving low and high phosphorus levels (P_1 and P_3) exhibited greater plant height, stem length, root length, leaf number, and stem thickness compared to the unfertilized control (P_0), reflecting the essential role of phosphorus in photosynthesis, root development, and nutrient uptake. However, the response to phosphorus was not strictly linear, as the intermediate level (P_2) did not consistently produce superior growth. This may be attributed to variations in phosphorus availability and uptake efficiency under specific substrate and moisture conditions, as well as potential nutrient imbalances at intermediate concentrations. In contrast, P_1 may have provided adequate phosphorus for early growth, while P_3 ensured a more sustained supply throughout the growth period. The interaction between container type and phosphate fertilization level had a significant effect on all measured vegetative growth traits of tomato seedlings (Table 3). In plastic bags, the tallest plants were obtained at P_3 (41.50 cm), followed by P_2 (38.25 cm) and P_1 (35.50 cm), while the shortest plants occurred at P_0 (28.75 cm). Stem length in plastic bags increased steadily with phosphate application, from 17.00 cm at P_0 to 26.25 cm at P_3. Root length was highest at P_1 (9.25 cm) and P_3 (9.75 cm), compared to only 5.00 cm at P_0. The number of leaves per plant ranged from 4.00 at P_0 to a maximum of 8.00 at P_3, while stem thickness was greatest at P_2 (2.38 cm) and lowest at P_0 (1.45 cm).

For seedlings grown in paper bags, the maximum plant height (63.75 cm) and stem length (50.25 cm) were achieved at P_1, while the lowest values were recorded at P_2 (48.75 cm for height, 32.75 cm for stem length). Root length peaked at P_0 (13.00 cm) and P_3 (12.00 cm), significantly exceeding values at P_2 (7.00 cm). Leaf number was highest at P_3 (7.00) and lowest at P_2 (4.75), whereas stem thickness was greatest at P_1 (2.53 cm) and lowest at P_2 (1.68 cm).

In foam trays, growth was consistently limited across all phosphate levels. Plant height remained low, ranging from 11.75 cm at P_3 to 14.50 cm at P_1. Stem length was also minimal, with the highest value of only 8.25 cm at P_1. Root length was generally short (5.00–7.25 cm), and leaf number did not exceed 3.00 except for

P_0 (2.50 leaves). Stem thickness in foam trays was markedly lower than in other containers, with the highest value (1.00 cm) recorded at P_1 and the lowest (0.70 cm) at P_0. Overall, the best vegetative growth performance was observed in paper bags with P_1 for plant height and stem thickness, and in paper bags with P_0 or P_3 for root length. Foam trays, regardless of phosphate level, consistently produced the weakest seedlings .

The significant interaction between container type and phosphate level is mainly due to differences in root-zone conditions that affect nutrient availability and uptake efficiency. In plastic bags, the steady increase in growth with higher phosphate levels indicates that phosphorus was a limiting factor, likely due to relatively poor aeration and restricted root activity; thus, higher P levels improved plant growth. In paper bags, the best performance at P_1 suggests that low phosphorus supply was sufficient under improved aeration and better root development conditions. The reduction in growth at P_2 may be attributed to nutrient imbalance or reduced phosphorus use efficiency at higher concentrations. While adequate phosphorus at P_3 also supports root growth through improved metabolic activity.

In contrast, foam trays consistently produced weak seedlings due to physical limitations such as restricted root volume and poor root-zone conditions, which limited growth regardless of phosphate level.

Overall, plant response to phosphorus depended on container properties, with paper bags providing the most favorable conditions for efficient nutrient utilization .The present study demonstrates that both container type and phosphate fertilization significantly influence the vegetative growth and quality of hybrid 'Zumuruda F_1' tomato seedlings, confirming and extending findings from previous research carried out by other workers. Container type had a pronounced effect on all measured growth parameters, with paper bags consistently producing the tallest plants, longest stems and roots, and thickest stems, followed by plastic bags, while foam trays resulted in the lowest growth performance. These results align with prior studies reported by Argerich & Poggi, 2003; Landis et al., 2014; and Gallegos *et al.*, 2020, which were emphasizing the critical role of container characteristics, such as size, drainage, aeration, and volume, on root development, morphology, and overall seedling vigor. Specifically, the superior growth observed in paper bags is likely attributed to better aeration and root space, which facilitate nutrient uptake and physiological activity, consistent with observations that larger or well-aerated containers enhance seedling vigor which was also confirmed by Haase et al., 2021 in their study. Phosphate fertilization also markedly affected seedling growth. Seedlings receiving moderate to high phosphorus levels (P_1 and P_3) exhibited greater plant height, stem length, root length, leaf number, and stem thickness compared to the unfertilized control (P_0), reflecting the essential role of phosphorus in photosynthesis, root development, and nutrient uptake (Martins *et al.*, 2017). Notably, the increase in growth with phosphorus application up to certain levels corroborates findings by Kaya and Higgs (2001) and Ihsan Abu-Alrub *et al.*, (2019), who reported that phosphorus enhances dry biomass and chlorophyll content, though excessive application may not further improve certain traits. Similarly, Martins *et al.,* (2017) observed linear increases in vegetative growth with rising phosphorus levels, achieving optimal development at defined concentrations, reinforcing the importance of precise phosphorus management for nursery seedlings.

The interaction between container type and phosphorus level further highlights the combined influence of physical and nutritional factors. In paper bags, seedlings reached maximal height and stem length at P_1, while root length and leaf number peaked at higher phosphorus levels (P_3), suggesting that container capacity may modulate the optimal phosphorus requirement for different growth traits. Plastic bag seedlings benefited from higher phosphorus levels (P_3), whereas foam tray seedlings showed limited response across all treatments, indicating that suboptimal root environment can constrain nutrient efficiency. These results emphasize that both adequate root space and proper fertilization are necessary to achieve vigorous seedlings, particularly in low-fertility or inert media, a gap noted in previous studies that often focused on mature plants or well-fertilized conditions (De Groot *et al.*, 2004; Araújo *et al.*, 2018). Collectively, this study confirms that optimizing both container type and phosphorus nutrition is critical for producing vigorous tomato seedlings with strong root systems and enhanced transplant quality. These findings provide practical guidance for nursery management under greenhouse conditions, particularly for substrates with limited nutrient availability, and contribute to closing the knowledge gap regarding early-stage phosphorus requirements and container effects on seedling performance.

Fresh Weight (g/ plant) :

Container type had a pronounced effect on the fresh weight components of tomato seedlings (Figure 1). Paper bags consistently produced the highest values for all measured parameters, with plant fresh weight (≈17g/ plant), root fresh weight (≈8.5 g/ plant), leaf fresh weight (≈7.5 g/ plant), and total fresh weight of vegetative growth (≈16 g/ plant) exceeding those obtained in both plastic bags and foam trays. Stem fresh weight in paper bags was also greater than in other containers, although the difference from plastic bags was less pronounced. Plastic bags resulted in intermediate values, with plant fresh weight around 10 g / plant, root fresh weight ≈4 g/ plant, leaf fresh weight ≈5 g / plant, and total fresh vegetative weight ≈9.5 g / plant. In contrast, foam trays consistently produced the lowest fresh weight values across all parameters, with plant fresh weight remaining below 1.5 g / plant and other components correspondingly minimal.

Table 2. Effect of types of nursery containers and the levels of phosphate fertilizer on the vegetative growth of tomato seedlings.

Treatment	Total Plant Height (cm)[z]	Stem Length (cm)	Root Length (cm)	Number of Leaves/ Plant	Stem Thickness (cm)
Types of containers					
Plastic bags	36.00 b[y]	21.19 b	07.88 b	5.75 a	1.91 b
Paper bags	55.88 a	39.75 a	10.44 a	6.13 a	2.11 a
Foam trays	12.75 c	07.25 c	05.94 c	2.38 b	0.85 c
Levels of phosphate					
(mg P_2O_5/kg medium)					
P_0 (0)	30.83 b	19.83 b	7.66 ab	4.33 b	1.39 b
P_1 (1000)	37.92 a	25.83 a	8.17 ab	4.67 ab	1.78 a
P_2 (2000)	33.08 ab	20.58 ab	6.83 b	4.33 b	1.62 ab
P_3 (3000)	37.66 a	24.67 a	9.66 a	5.67 a	1.69 a

[z]Plant height from the soil line to the top of plant.

[y]Means followed by the same letter are not significantly different at $P<0.05$.

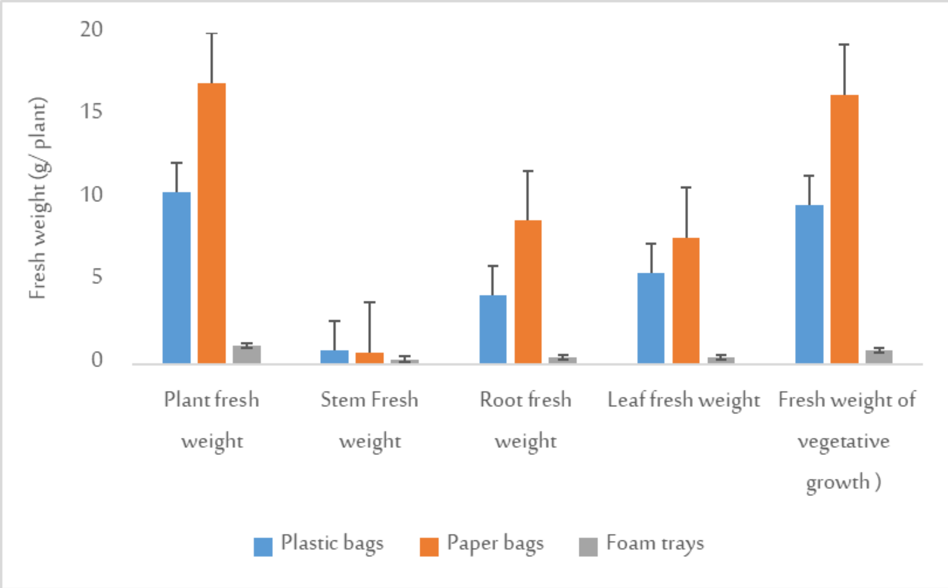

Figure 1. Effect of seedling container type on the fresh weight of different parts of tomato seedlings.

These results indicate that larger-capacity containers (paper and plastic bags) supported greater biomass accumulation in tomato seedlings compared to small-cell foam trays, with paper bags being the most favorable for maximizing fresh weight.

Phosphate fertilization had a significant impact on the fresh weight components of tomato seedlings (Figure 2). The highest total plant fresh weight was observed at the P_3 level (3000 mg P_2O_5/kg), reaching approximately 13.7 g per plant, which was significantly greater than all other treatments. Stem fresh weight showed a similar trend, with P_3 again producing the highest weight, followed by P_1 (1000 mg P_2O_5/kg), P_2 (2000 mg P_2O_5/kg), and P_0 (control) showing the lowest values.

Root fresh weight increased progressively with phosphate levels, with P_3 resulting in the greatest root mass (~5.8 g), significantly higher than other treatments. Leaf fresh weight also followed this pattern, with the highest values recorded at P_3 (~7 g), and the lowest at P_0 (~3 g).

Overall fresh weight of vegetative growth was highest under P_3 fertilization (~12.8 g), significantly exceeding P_1, P_2, and P_0 treatments. These results demonstrate that increasing phosphate fertilizer levels enhanced the fresh biomass accumulation in tomato seedlings, with P_3 providing the most substantial growth response. Paper bags, especially with the P3 fertilizer level, consistently produced the best results (Table 4). The highest plant fresh weight (21.33 g), leaf fresh weight (10.33 g), and fresh weight of vegetative growth (20.32 g) were all observed in seedlings grown in paper bags with P3. The highest root fresh weight (10.18 g) occurred with the P1 phosphate level in paper bags, which was statistically similar to the P3 level (10.00 g) in the same container type.

Foam trays were the least effective container type, demonstrating significantly lower fresh weight across all phosphate levels. The lowest values for all measured characteristics (plant fresh weight, stem fresh weight, root fresh weight, leaf fresh weight, and fresh weight of vegetative growth) were consistently found in seedlings grown in foam trays. For example, the highest plant fresh weight in foam trays was only 1.25 g, which is dramatically lower than the 21.33 g seen in the optimal paper bag/P3 combination.

Plastic bags showed a moderate response, with fresh weight characteristics generally increasing with higher phosphate levels. While not as effective as paper bags, the P3 treatment in plastic bags yielded a plant fresh weight of 18.70 g, a significant improvement over the P0 level (3.56 g) in the same container type. The highest stem fresh weight (1.52 g) was also recorded in plastic bags at the P3 level.

This indicates a clear interaction between container size and nutrient availability: larger containers (paper and plastic bags) allow for greater biomass accumulation, and this effect is maximized when sufficient phosphate is supplied.

The current study highlights the critical influence of both container type and phosphate fertilization on the fresh weight accumulation of hybrid 'Zumuruda F_1' tomato seedlings, providing insights that extend previous findings on early seedling development. The observed superiority of paper bags in promoting plant, stem, root, and leaf fresh weight aligns with earlier reports emphasizing that container size, aeration, and root volume strongly affect root growth, nutrient uptake, and overall seedling vigor (Argerich & Poggi, 2003; Landis *et al.*, 2014; Gallegos *et al.*, 2020). Larger containers, such as paper and plastic bags, allow unrestricted root expansion, which enhances water and nutrient absorption, ultimately translating into higher biomass accumulation, whereas foam trays with restricted root space limit fresh weight development. These results are consistent with global nursery practices, where container characteristics are a key determinant of seedling quality (Haase *et al.*, 2021).

Phosphate fertilization significantly enhanced all fresh weight components, with the P_3 treatment (3000 mg P_2O_5/kg) producing the greatest biomass. This confirms the essential role of phosphorus in promoting photosynthesis, root elongation, and leaf development, as documented in tomato seedlings (Martins *et al.*, 2017; Demirer *et al.*, 2023). Similar trends were reported by Ihsan Abu-Alrub *et al.* (2019) and Kaya and Higgs (2001), who found that phosphorus application increased vegetative growth and dry biomass, though excessive or unoptimized rates sometimes plateau in effect. The progressive increase in root and leaf fresh weight with higher phosphorus levels observed in this study reinforces the importance of precise phosphorus management for early seedling vigor, particularly when grown in low-fertility or inert media.

Importantly, the interaction between container type and phosphate fertilization demonstrated a synergistic effect on seedling biomass. Paper bags combined with P_3 consistently resulted in the highest fresh weight for plant, leaf, and vegetative growth, whereas the root fresh weight peaked at P_1 in the same container, showing that optimal phosphorus requirements may differ among growth components. Plastic bags showed intermediate responses, with P_3 substantially improving biomass compared to unfertilized controls, while foam trays remained consistently limited across all fertilization levels. This interaction emphasizes that both physical space and nutrient availability jointly regulate early growth, and one factor cannot fully compensate for limitations in the other. Such findings address gaps noted by De Groot *et al.*, (2004) and Araújo *et al.*, (2018), where seedling-stage responses to phosphorus under low-fertility conditions were underexplored.

Overall, the results indicate that maximizing seedling fresh weight and vigor requires an integrated approach: selecting containers that support unrestricted root growth and providing sufficient phosphorus to stimulate photosynthetic capacity and nutrient uptake. These findings provide practical guidance for nursery management and transplant preparation, highlighting that the combination of paper bags and high phosphorus levels produces robust seedlings suitable for greenhouse and field production, thereby supporting both local productivity and the economic efficiency of tomato cultivation.

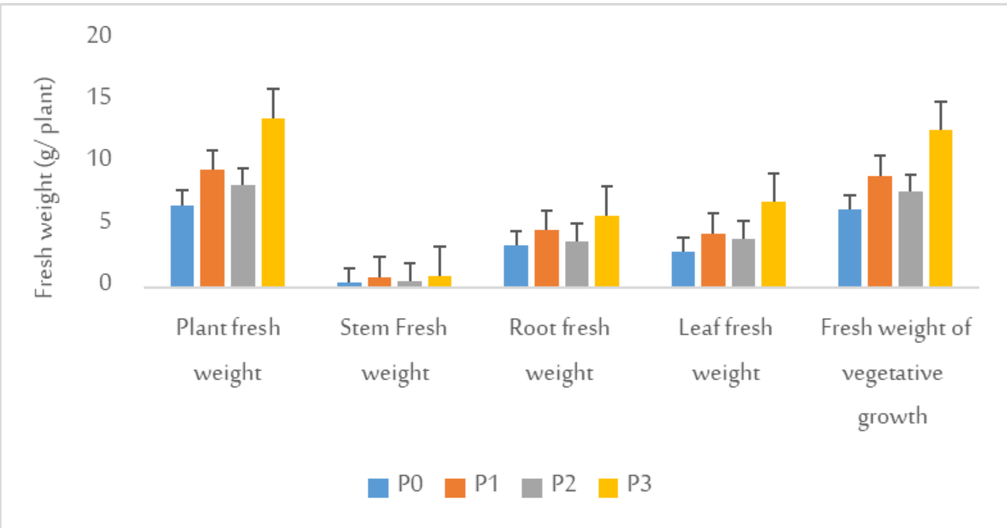

Figure 2. Effect of phosphate fertilizer amounts on the fresh weight of different parts of tomato seedlings.

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Table 4. Effect of interaction between phosphate fertilizer levels and types of containers on fresh weight characteristics (g/ plant) of tomato seedlings.

Types of containers	Treatment: Levels of phosphate (mg P_2O_5/ kg medium)	Plant fresh weight	Stem Fresh weight	Root fresh weight	Leaf fresh weight	Fresh weight of vegetative growth
Plastic bags	P_0 (0)	3.56 fg^z	0.30 ef	1.80 e	1.55 d	3.35 e
	P_1 (1000)	8.55 e	0.72 c	3.22 de	4.60 c	7.82 d
	P_2 (2000)	10.82 de	0.62 de	4.45 d	5.75 bc	10.20 cd
	P_3 (3000)	18.70 b	1.52 a	7.17 c	10.00 a	17.17 b
Paper bags	P_0 (0)	15.50 c	0.70 c	8.05 b	6.75 bc	14.80 c
	P_1 (1000)	18.73 b	0.52 e	10.18 a	8.03 b	18.20 b
	P_2 (2000)	12.77 d	0.66 de	6.52 cd	5.56 bc	12.17 cd
	P_3 (3000)	21.33 a	1.00 b	10.00 ab	10.33 a	20.32 a
Foam Trays	P_0 (0)	0.85 g	0.15 g	0.32 h	0.83 fg	0.70 fg
	P_1 (1000)	1.25 g	0.20 f	0.52 f	0.53 e	1.05 f
	P_2 (2000)	1.18 g	0.38 ef	0.37 g	0.43 fg	0.80 fg
	P_3 (3000)	1.00 g	0.37 ef	0.32 h	0.30 fg	0.62 fg

^{z}Means followed by the same letter are not significantly different at P<0.05.

Conclusion

Collectively, the results highlight that container type and phosphorus fertilization are key determinants of tomato seedling growth and quality. Paper bag containers exhibited superior performance compared with plastic bags and foam trays, which can be attributed to their greater volume and improved growth environment, leading to enhanced seedling vigor, higher fresh biomass accumulation, and more robust vegetative development. The highest phosphate fertilizer level (P_3: 3000 mg P_2O_5/kg) was the most effective in promoting biomass accumulation, but its benefits were most pronounced in the larger paper and plastic containers. The significant interaction between container type and phosphate level highlights that the effectiveness of nutrient application is dependent on the physical growing environment. Ultimately, the combination of paper bags and P_3 fertilization represents the most effective strategy for producing robust, high-quality tomato seedlings, while the use of small-cell foam trays is shown to be a major limiting factor to growth. These findings offer valuable insights for the development of optimized nursery management practices, contributing to improved transplant establishment and increased overall crop productivity.

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تأثير أنواع أوعية المشاتل ومستويات التسميد الفوسفاتي على خصائص النمو الخضري لشتلات الطماطم الهجينة "Zumuruda F1" (*Solanum lycopersicum* L.)

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المستخلص

تم إجراء هذه الدراسة بهدف تقييم التأثيرات المختلفة لكلٍّ من أوعية المشاتل ومستويات التسميد الفوسفاتي على نمو وجودة شتلات الطماطم "زمردة (*Solanum lycopersicum* L.) "F_1، حيث أُنجز البحث في قسم البستنة بجامعة عمر المختار، الجبل الأخضر – ليبيا، واعتمد تصميم القطاعات العشوائية الكاملة المنشقة، ومثّل نوع الوعاء العامل الرئيس؛ (أكياس بلاستيكية، أكياس ورقية، وصواني إسفنجية)، بينما مثّلت مستويات الفوسفات: (P_0، P_1، P_2، P_3): (0، 1000، 2000، و3000 ملجم P_2O_5/ كج من الوسط الزراعي) العامل الثانوي. وقد تم تقييم مجموعة من الخصائص المرتبطة بالنمو الخضري ومكونات الوزن الطازج استجابة للعوامل المدروسة؛ حيث استمرت التجربة لمدة 39 يوماً. أظهرت النتائج تفوق الأكياس الورقية والبلاستيكية في دعم النمو الخضري وتراكم الكتلة الحيوية مقارنة بالصواني الإسفنجية صغيرة الخلايا؛ إذ سجلت الأكياس الورقية أعلى القيم في الوزن الطازج. في المقابل، أظهرت الصواني الإسفنجية أضعف الشتلات بغض النظر عن مستويات الفوسفات المضافة. كما أسهم التسميد الفوسفاتي في تحسين النمو بوضوح؛ حيث سجلت المعاملتان P_1 (1000 مجم P_2O_5 كجم$^{-1}$) وP_3 (3000 مجم P_2O_5 كجم$^{-1}$) أعلى قيم لطول النبات وعدد الأوراق، في حين بلغ الوزن الحيوي الطازج أقصى قيمة له تحت P_3 (12.8 جم)، مما يؤكد أن المستويات المرتفعة من الفوسفور تعزز النمو الخضري رغم الاستجابات غير الخطية بين المعاملات.

الكلمات الدالة: أكياس بلاستيكية، أكياس ورقية، شتلات الطماطم، معدلات DAP، قوة الشتلات.

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