Agricultural Science; Vol. 7, No. 1; 2025
ISSN 2690-5396 E-ISSN 2690-4799
https://doi.org/10.30560/as.v7n1p1

The Effect of the Combination Polymers – Grape Marc in the Development of Tomato Growing in Soilless

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Received: January 10, 2025 Accepted: January 20, 2025 Online Published: January 29, 2025

Abstract

This study examined the impact of two fertilizers (FI (CRFA) and F2 (Arizona University) and three substrates (S1(100% coconut fiber), S2 (50% coconut fiber, 50% grape marc, and 7g of polymers), and S3 (50% coconut fiber, 50% grape marc, and 13g of polymers)) on tomato growth in a soilless system. Results showed that Fertilizer F2 was the most effective overall. Substrate S3 excelled in node count and flower bud spacing, likely due to improved moisture retention and nutrient availability. Substrate S1 supported optimal stem length and node spacing. Substrate S2 yielded the highest tomato production. These findings suggest that optimizing fertilization and substrate composition can significantly improve tomato yield and quality in soilless systems. This has implications for sustainable agriculture by reducing reliance on soil-based cultivation and potentially increasing crop productivity. Further research in this area could lead to more efficient and environmentally friendly farming practices.

Keywords: fertilizer, soilless system**,** tomato, superabsorbent polymers, grape marc

1. Introduction

The tomato (*Solanum lycopersicum*) is one of the most widespread crops globally, with a production exceeding 180 million tons in 2021. Italy accounted for 53% of the total European production, while China, India, Turkey, and the US were also among the top producers (Eslami *et al., et al.,* 2022). In Lebanon, tomatoes are one of the most cultivated and consumed vegetable crops, with a production of 305,300 tons over an area of 5,000 hectares in 2020 (FAOSTAT, 2020). With a growing global population and rising living standards, traditional agricultural practices face immense pressure due to dwindling freshwater resources (FAO, 2019). This necessitates a shift towards efficient and sustainable farming methods. Hydroponics is emerging as a solution to meet increasing demands (Velazquez-Gonzalez *et al., et al.,* 2022). The search for high-quality, low-cost substrates has led to exploring organic agro-industrial wastes like grape marc compost as alternatives to peat (Abad *et al.,* 2001; Tabet *et al.,* 2022). However, grape marc's high-water content presents challenges compared to coconut substrates Grape marc, a byproduct of winemaking, presents a promising alternative to peat. Its use as a growing medium can reduce waste and promote circularity in the agricultural sector. However, grape marc's high-water content can be a challenge. (IRAL, 2017). Super-absorbents or hydrogels can enhance moisture availability in the root zone by absorbing significant amounts of water and helping plants to grow properly (Malik *et al.,* 2022). This study aims to develop a prototype grow bag technique for hydroponic tomato cultivation with substrate combinations, such as polymers-grape marc, to reduce production costs and increase water holding capacity. By optimizing this approach, we can explore a more sustainable and cost-effective method for tomato cultivation.

2. Material and Methods

2.1 Work Description

The experiment was conducted from April to August 2024 at the Agricultural Research and Training Center (CFRA) of the Faculty of Agronomy at the Lebanese University in Ghazir, Keserwan District (Mount Lebanon) at an altitude of 550 m. It took place in a bi-chapel greenhouse covering 224 m², containing 36 substrate bags for tomato cultivation, with each bag containing three plants. Flower buds first appeared on April 26, 2024, and the first harvest took place on June 23, 2024.

2.2 Experimental Design

The tomato variety used in this experiment was the GH Tomato Delin F1 variety. The 36 bags were divided into groups for each fertilization recipe (F1 and F2) and substrates (S1, S2, and S3). The experimental setup followed split plot design with three repetitions: block 1, block 2, and block 3. Each block included the two fertilization recipes (main factors) and the three substrates (sub-factors). (Figure 1).

2.3 Substrate and Fertilization Recipe

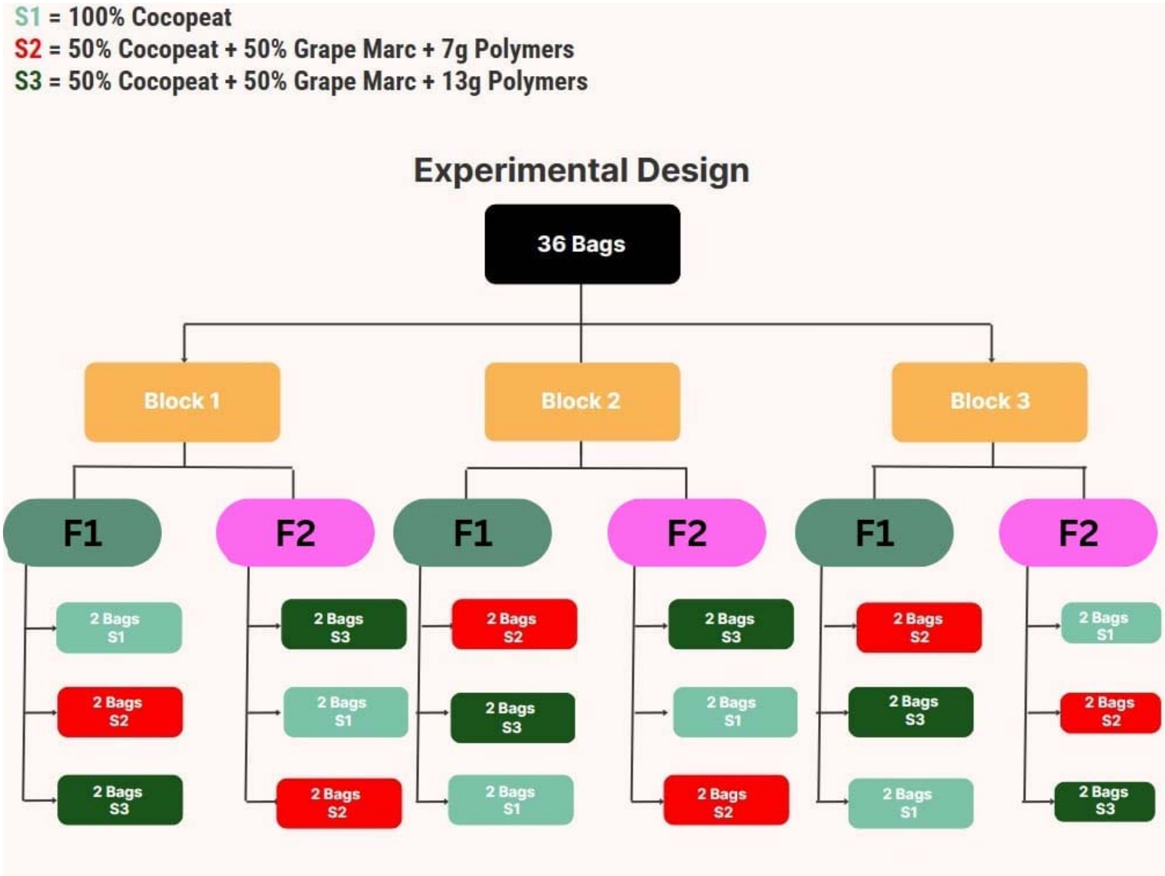

Figure 1. Experimental design

Three different substrate bags (20 liters each) were tested:

- S1: 100% coconut fiber (control).
- S2: 50% coconut fiber and 50% grape marc with 7g of polymers.
- S3: 50% coconut fiber and 50% grape marc with 13g of polymers.

Table 1 provides a clearer overview of the substrate compositions.

Table 1. Physico-chemical analysis of substrates according to IRAL

Physico-chemical parameters	Unit	Grape Marc	Coconut fiber rate
Water content	%	32.17	11.32
Dry matter	%	67.83	88.68
Ash content	%	16.69	5.55
pH water (1:10)	1:10	7.45	5.19
Electrical conductivity (EC)	mS.cm-1	5.15	0.61
Organic matter (combustion)	%MS	83.31	94.45
Carbon (combustion)	%MS	46.28	52.47
Kjeldahl nitrogen	%MS	0.46	1

The components of the fertilization recipes F1 (CRFA) and F2 (Arizona University) are outlined in Table 2.

Table 2. Components of fertilization recipes F1 and F2 during the two phases of the production cycle in ppm

Components of fertilization recipes	Phase I 0-6 weeks		Phase II 6 – 12+ weeks	
	F1	F2	F1	F2
Nitrogen (N)	237.50	224.00	376.18	189.00
Phosphorus (P)	140.70	47.00	125.00	47.00
Potassium (K)	216.60	281.00	434.00	351.00
Calcium (Ca)	57.00	212.00	171.00	190.00
Magnesium (Mg)	39.72	65.00	75.85	60.00
Iron (Fe)	12.53	2.00	13.95	2.00
Manganese (Mn)	4.97	0.55	4.46	0.55
Zinc (Zn)	1.02	0.33	5.84	0.33
Boron (B)	2.44	0.28	2.20	0.28
Copper (Cu)	0.13	0.05	0.85	0.05
Molybdenum (Mo)	0.11	0.05	0.10	0.05

Source: Sunco, Ltd., and University of Arizona, Controlled Environment Agriculture Center, http://tinyurl.com/ljlj785/

The grape marc, obtained from a local winery, underwent a 6-week solarization process. This involved initial sun-drying for 2 days followed by covering with nylon sheets to enhance the solarization effect. Consequently, Fertigation was applied via an irrigation station with a dosatron.

2.4 Measured Parameters

Data collection included stem length, number and distance of nodes, number and distance between flower buds, and yield. Measurements were taken manually using a measuring tape, and fruits were weighed using a precision scale.

2.5 Ec and pH Measurements

Electrical conductivity (EC) and pH were measured daily using a Multi-Function Water Tester. The EC was maintained between 1.69 and 2.49 ms/cm, and the target pH was between 6.5 and 6.99 (Adams, 2002).

2.6 Statistical Analysis

Statistical analyses were processed using GLM (General Linear Model) via Sigma stat software. As a split-plot design experiment was employed, Repeated Measures ANOVA was used to compare the main factors F1 and F2 along with sub-factors (S1, S2, S3) and their interactions at a significance level of 5% for all studied parameters (stem length, number of nodes, distance between nodes, number of flower buds, distance between flower buds, and yield). Duncan's Test was applied to indicate significantly different treatments**.**

3. Results and Discussion

3.1 Effects of Fertilization and Substrate

In Table 3, results showed that fertilization recipe F2 yielded superior outcomes in flower bud number and yield compared to F1. Substrate S3 exhibited enhanced moisture retention, promoting node count and flower bud spacing, while S2 achieved the highest yield due to its balance of water retention and nutrient availability.

Table 3. Effects of Fertilization and Substrate on Different Parameters

Treatment	F1	F2	S1	S2	S3
Stem length (cm)	233.78 ± 29.40	217.33 ± 25.27	232.67 ± 24.65	227.67 ± 29.30	216.33 ± 26.50
Number of nodes	24.22 ± 1.65 *	23.00 ± 2.05	21.67 ± 0.94	23.50 ± 1.12	25.67 ± 1.11*
Nodes distance (cm)	9.69 ± 1.33	9.57 ± 1.55	10.75 ± 1.04*	9.69 ± 1.08	8.46 ± 1.19
Number of flower buds	41.77 ± 1.99	44.33 ± 3.46	43.5 ± 4.23	43 ± 2.38	42.66 ± 2.21
Flower buds distance (cm)	21.39 ± 0.94	21.72 ± 0.55	21.24 ± 0.60	21.32 ± 0.47	22.1 ± 0.90
Yield (kg)	141.58	173.75*	101.49	111.53	102.31

(*) indicates a P-value < 0.05 (statistically significant).

3.1.1 Stem Length

The analysis shows that fertilization treatments F1 (233.78 cm) outperformed F2 (217.33 cm); however, this difference is not statistically significant (P > 0.05). Similarly, the three substrates did not significantly impact stem length (P > 0.05); with S1 (control) showing the highest mean at 232.67 cm followed by S2 at 227.67 cm and S3 at 216.33 cm. According to Ayankojo (2020), increased nitrogen application correlates with improved growth rates, although excessive nitrogen does not always lead to higher yields or greater water use efficiency. Additionally, phosphorus is crucial for optimizing plant development; Sobrinho *et al.,* (2024) demonstrated that higher phosphorus doses significantly enhance tomato growth when irrigation is properly managed. Kathi *et al.,* (2021) affirmed that while polymers can help mitigate water stress, they do not necessarily enhance stem growth compared to balanced irrigation or fertilization alone.

3.1.2 Number of Nodes

Fertilization resulted in a higher mean number of nodes for F1 averaging 24.22 compared to F2's average 23.00; with P < 0.05 indicating that fertilization recipes significantly influence node development. Almeida *et al.,* (2020) demonstrate that fertilizers positively affect tomato growth and yield in soilless systems, promoting greater node counts. While Singh *et al.,* (2021) highlight that organic amendments like grape marc enhance growth parameters such as node development. Among substrates, S3 had the highest average node count at 25.67 cm, followed by S2 at 23.50 cm, while S1 had an average count at 21.67 cm, showing a highly significant effect (P < 0.05). This suggests that substrate choice impacts node development due to factors like nutrient retention and water-holding capacity. Studies indicate that superabsorbent polymers (SAPs) can significantly improve plant growth metrics when used at optimal doses (Yang *et al.,* 2020). The findings highlight the importance of proper polymer dosage for enhancing plant development, with S3's effective use of recommended polymer levels correlating with increased node production (Yang *et al.,* 2022; Başak *et al.,* 2020).

3.1.3 Node Distance

Analysis shows that fertilization treatments F1 enriched with higher nitrogen and phosphorus levels result in a mean distance between nodes of 9.69 cm while F2 yields 9.57 cm; however, P = 0.83 > 0.05 indicating no statistically significant difference, suggesting both treatments provide similar conditions for node spacing**.**This suggests both treatments provide similar conditions for node spacing. Research by Iqbal *et al.,* (2022) supports the importance of nitrogen in promoting plant growth and spacing, while optimal plant spacing can reduce resource competition (Whitehead & Singh, 2000). Among the substrates, S1 exhibits the highest mean distance between nodes at 10.75 cm, followed by S2 at 9.69 cm and S3 at 8.46 cm. The P-value of 0.03 < 0.05 indicates that the differences are statistically significant, highlighting the crucial role of substrate composition in influencing plant growth patterns. Iqbal *et al.,* (2022) and Altrão *et al.,* (2022) suggest that substrates with optimal moisture retention enhance root development and node spacing. The lack of polymer application in S1 may allow for unrestricted root growth, resulting in greater node spacing compared to S2 and S3, where polymer applications may affect root expansion (Chapman *et al.,* 2012). Overall, results favor S1 for distance between nodes.

3.1.4 Number of Flower Buds

The number of flower buds in tomato plants shows that treatment F2 yielded an average of 44.33 flower buds compared to F1's 41.77, although the $P > 0.05$, indicating no significant difference. The increased flower count in F2 may be attributed to its higher calcium content, which enhances pollen germination and tube growth and is essential for fertilization (Yara International, 2023). Additionally, F2's nutrient balance, with lower nitrogen and phosphorus but higher potassium levels, likely contributes to improved plant health and flowering potential (Zhang *et al.,* 2022). When comparing the substrates, flower bud production is quite similar across all types: S1 averages 43.5 buds, S2 produces 43 buds, and S3 shows 42.66 buds, indicating no significant differences among them (Singh *et al.,* 2021).

3.1.5 Distance between Flower Buds

The analysis of the distance between flower buds indicates that treatment F2 has a mean distance of 21.72 cm, slightly higher than F1's21.39 cm, however, with a $P > 0.05$, indicating no statistically significant difference. Among substrates, S3 shows the highest mean distance at 22.1 cm, while S1 and S2 have means of 21.24 cm and 21.32 cm, respectively, with a P-value > 0.05, also suggesting no significant differences. These findings imply that both fertilization recipes and substrate choices do not strongly influence flower bud spacing (Khan *et al.,* 2021). This consistency could indicate that other environmental factors, such as light availability or water management, may play more crucial roles in influencing flower bud spacing than the fertilization recipes or substrates themselves (Zhang *et al.,* 2022).

3.1.6 Plant Yield

At the end of the experiment, treatment F1 yielded a total harvest weight of 141.58 kg, while treatment F2 produced a significantly higher weight of 173.75 kg, with a $P < 0.05$ promoting plant growth. Studies have shown that specific nutrient applications can substantially increase plant biomass and overall yield (Li *et al.,* 2023), with balanced fertilization being crucial for maximizing tomato yields (Wageningen University, 2018; Tabet *et al.,* 2020). Among substrates, control substrate S1 produced the lowest total weight at 101.49 kg while substrate S3 resulted in a total weight of 102.31 kg. However, substrate S2 yielded the highest total weight at 111.53 kg with P-value greater than 0.05, indicating no significant difference. Research indicates that incorporating superabsorbent polymers can increase the water-holding capacity of the soil, allowing plants to access moisture during critical growth stages, particularly under drought conditions (Fernando *et al.,* 2013). However, the additional polymers in S3 did not lead to a significant improvement in performance over S2; a study demonstrated that using an optimal concentration of SAPs resulted in a notable increase in tomato yield, root growth, and overall plant health, highlighting the polymers' role in mitigating water stress (Günes *et al.,* 2007). Overall, results favor treatments F2 and S2.

3.2 Interactions between different Fertilization recipes and Substrates on All Parameters

The results of interactions between different fertilization recipes and substrates on all parameters are showed in table 4.

Table 4. Interaction between different fertilization recipes and substrates on all parameters

Treatment	F1S1	F1S2	F1S3	F2S1	F2S2	F2S3
Stem length	231.00 ± 31.48	243.67 ± 40.92	226.67 ± 23.63	234.33 ± 22.81	211.67 ± 11.50	206.00 ± 35.04
Number of nodes	22.33 ± 0.58	24.33 ± 0.58	26.00 ± 1.00	21.00 ± 1.00	22.67 ± 1.15	25.33 ± 1.53
Nodes distance (cm)	10.35 ± 1.51	10.00 ± 1.53	8.73 ± 1.06	11.14 ± 0.69	9.37 ± 0.93	8.19 ± 1.70
Number of flower buds	41.33 ± 2.49	42.33 ± 2.05	41.67 ± 0.94	45.67 ± 4.5	43.67 ± 2.49	43.67 ± 2.62
Flower bud distance (cm)	20.93 ± 0.65	21.23 ± 0.35	22.01 ± 1.21	21.55 ± 0.31	21.43 ± 0.54	22.19 ± 0.40
Yield (kg)	44.7	50.08	46.8	56.79	61.45	55.51

During the different phases of production, the interaction between the different fertilization recipes and the different substrates did not show any significant difference in all parameters. Regarding the stem length, the variables did not exhibit strong collaboration or antagonism sufficient, however there are variations in the average lengths among combinations showing that F1S2 yields the highest value at 243.67 cm which aligns with findings from studies indicating that optimal substrate and fertilization combinations are crucial for maximizing tomato growth (Gonzalez *et al.,* 2023; Zhou *et al.,* 2022; Singh *et al.,* 2021). Concerning the number of nodes, the most favorable results were in favor of F1S3 with the highest count of 26, having F1 rich in nitrogen phosphorus combined appropriate substrate such as S3 recommended dose polymersof 13g can improve crop yields and promote vigorous vegetative growth (Vera-Garcia *et al.,* 2023; Ewulo *et al.,* 2015). On the other hand, F2S1 demonstrates superior growth compared to all other combinations, nodes distance 11.14 cm and number of flower buds of 45.67. Research has shown that while node spacing is critical for optimizing light interception and air circulation, the lack of significant differences among these treatments indicates that other environmental factors, such as light availability and water management, may also play crucial roles in determining plant architecture (López-Pereira et al., 2022). Some studies suggest that consistent nutrient management and substrate selection can enhance overall plant health without necessarily affecting node spacing significantly (Gonzalez *et al.,* 2023). Furthermore, the elevated calcium content and optimized nutrient ratios in F2 enhances the pollen germination, flower production and fruit set in tomato plants (Yara International, 2023; Li et al., 2023). The lack of significant difference among the distance between flower buds suggests that both fertilization strategies and substrate variations do not have a strong impact on the spacing of flower buds in tomato plants (Du et al., 2021). Despite this, the best results were in favor of F2S3 (22.19 cm). In addition, the highest total weight was observed in treatment F2S2 (61.45 kg). This aligns with findings that have shown that substrate composition significantly affects plant growth parameters, emphasizing the importance of selecting appropriate growing media to enhance yield potential (Chowdhury et al., 2024). Finally, the study's findings may be limited by environmental factors (climate, seasonality, pests), crop-specific responses, and region-specific factors (soil, water quality, management practices). Key implications include the significant impact of polymer concentration on plant health. Optimal polymer dosage is crucial for enhancing plant development, while excessive use can be detrimental. Substrate composition, including organic amendments like grape marc, also influences plant growth. Proper fertilization, particularly with nitrogen and phosphorus, is essential for yield optimization, but excessive nitrogen application might not always lead to higher yields or water use efficiency.

4. Conclusion

According to our study, it is evident that fertilization recipes and substrates employed in our experiment, significantly influence various growth and productivity parameters of tomato plants in soilless culture. The results show that Fertilization recipe F2, rich in potassium and calcium, consistently outperformed F1 in terms of improving node and flower buds spacing, increasing the number of flower buds and yield. However, recipe F1 with its higher nitrogen and phosphorus content, demonstrated greater efficacy in promoting stem length and node development. While substrate S1 (100% cocopeat) excelled in promoting stem length, node development and number of flower buds due to its superior water retention and aeration properties. Substrate S3 (50% coconut fiber and 50% grape marc with 13g of polymers) showed the best results for node count and flower bud spacing, benefiting from enhanced moisture retention and nutrient availability. In terms of plant yield, substrate S2 (50% coconut fiber and 50% grape marc with 7g of polymers) performed the best, striking an ideal balance between water retention and root support while addressing the minimal water retention capacity of grape marc. Notably, the interactions between fertilization recipes and substrates did not significantly influence any of the measured parameters, suggesting that these factors operate independently. The study highlights the independent roles of fertilization recipes and substrates in optimizing tomato growth and yield in soilless systems. Fertilization recipe F2 and substrates S2 and S3 played pivotal roles in improving tomato productivity, aligning with the study's goal of optimizing soilless cultivation techniques. Grape marc, an agro-industrial by-product, and polymers offer several advantages in improving water use efficiency, reduced costs, enhanced sustainability, improved plant health and reducing costs in commercial hydroponic systems. Further research and development are needed to optimize the use of these materials and maximize their benefits

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