Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Effect of Plant Spacing and Foliar Application of Growth Stimulant on Growth and Fruit Quality Traits of Summer Squash (*Cucurbita pepo* L.)

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Article Information
Received 22/ 9 /2025
Accepted 5/ 10/2025

ABSTRACT

In the summers of 2022 and 2023, two open-field experiments on summer squash were conducted at South Valley University Farm, Qena Governorate, Egypt. The primary goal was to investigate how summer squash (*Cucurbita pepo* L. cv. Eskandarani) resistance to extreme environmental stress was affected by foliar application of different treatments, such as licorice root (LR) extracts, seaweed (SW), Moringa leaf (ML), and a control (water spray). Overall, the application of 5% ML foliar treatment applied three times throughout the experiment, specifically at 20, 30, and 40 days post-sowing, in conjunction with a plant spacing of 60 cm, resulted in vigorous plant growth. This was evidenced by enhanced vegetative growth parameters as plant height, number of leaves per plant, fresh weight, and dry weight, when compared to other foliar treatments. This was in contrast to other foliar treatments. Furthermore, using ML foliar spray at a planting distance of 60 cm produced the highest values of fruit yield and quality components, such as fruit length, fruit diameter, average fruit weight, and number of fruits per plant. In conclusion, the results showed that, under the environmental conditions of Qena Governorate and similar regions, planting squash at 60 cm intra-row spacing and applying ML 5% topically could be regarded as the best way to achieve vigorous, high yield, and superior fruit quality.

Keywords: Vegetative growth, fruit quality, Summer squash, licorice root, Moringa leaf.

INTRODUCTION

Summer squash (*Cucurbita pepo*, L.) ranks among the most favored vegetable crops for human consumption and is a highly diverse vegetable cultivated during the summer months in Egypt and worldwide (Mahmoud, 2016; Contreras *et al*., 2020). Additionally, one of the most significant income crops is squash, particularly in recently recaptured parts of Egypt. Summer squash fruits are high in fiber (0.8 g), high in moisture content (94.8 g), high in edible portion (94%) and notably low in calories (19 Kcal/100 g) (Tamer *et al*., 2010). The rise in abiotic factors (such as temperature, salinity, drought, etc.) above a threshold level for a long enough duration to permanently harm plant growth and development is known as environmental stress. It depends intricately on exposure rate, duration, and intensity. Frequent exposure to stressors had a negative impact on plant growth, which in turn affected yield and metabolism (Dreesen *et al*., 2012; Rollins *et al*., 2013). The rise in soil temperature due to increased air temperature may be exacerbated when coupled with a drought-induced reduction in soil water content (Sekhon *et al*., 2010). This study hypothesizes that some treatments could be playing a major role in mitigation the advance effect of environmental stress on squash growth and yield. Therefore, improving the agricultural practices of squash production is of great economic interest. This may be achieved by applying simple applicable modern and low-cost strategies such as the use of plant extracts that stimulate the growth and development of this plant and then increase the productivity, which is safe for humans and environments (Savvas *et al*., 2009; Formisano *et al*., 2021; Novello *et al*., 2021).

A relatively recent method of feeding vegetable plants is the foliar application of Moringa leaf, seaweed, and licorice root extracts. These extracts have multiple functions in plant physiology, including regulating ion uptake and enhancing plant resistance to a range of biotic and abiotic stresses (Artyszak, 2018). Additionally, by balancing the levels of endogenous growth hormones, they promote the growth, development, and yield components of numerous vegetable species (Artyszak, 2018). Thus, the purpose of this study was to evaluate how various foliar spray types affected the squash plant's development and fruit characteristics. Thus, the objective of this study was to evaluate the effects of different foliar spray treatments on the growth and fruit quality traits of summer squash

MATERIALS AND METHODS

Experimental site and plant materials

This study was carried out at the Experimental Farm, Faculty of Agriculture, South Valley University, Qena, Egypt, (Latitude 26° 11' 22.2" N and Longitude 32° 44' 25.5" E, and the Altitude 81 m above sea level) during two summer seasons (2023 and 2024) to assess the influence of different types of foliar stimulators *i.e*., moringa leaf extract, seaweed extract and licorice root extract on vegetative traits and yield components characteristics.

Treatments and Experimental Layout:

The experiment was arranged in a split-plot design with three replications. Each replication consisted of 16 plots. Each plot measured 10.5 m^2 and had four rows, each measuring 3.0 m in width and 3.5 m in length. Planting spaces were randomly assigned to the main plots, while the subplots were dedicated to foliar spray treatments with natural plant extracts:

a) Main-plot (plant spacing)
   30 cm, 40 cm, 50 cm and 60 cm
b) Sub-plot (Foliar spray treatments)
   Control (distilled water DW)
   Moringa leaves extract (ML)
   Seaweed grass extract (SW)
   Licorice root extract (LR)

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DOI: 10.21608/jpp.2025.426193.1512

On 2nd half of March 2023, and 2024, squash seeds (El-Askandarani F1 hybrid) were planted at the nursery. Every cultural practice was implemented in accordance with the techniques used for squash being grown in the area that was the subject of the study.

Preharvest experiment					
	Main (Spaces)	Sub-plot (Foliar spray)			
R1	30 cm	Control (DW)	Moringa leaves	Seaweed grass	Licorice root
	40 cm	Control (DW)	Moringa leaves	Seaweed grass	Licorice root
	50 cm	Control (DW)	Moringa leaves	Seaweed grass	Licorice root
	60 cm	Control (DW)	Moringa leaves	Seaweed grass	Licorice root
	Main (Spaces)	Sub-plot (Foliar spray)			
R2	30 cm	Licorice root	Seaweed grass	Control (DW)	Moringa leaves
	40 cm	Licorice root	Seaweed grass	Control (DW)	Moringa leaves
	50 cm	Licorice root	Seaweed grass	Control (DW)	Moringa leaves
	60 cm	Licorice root	Seaweed grass	Control (DW)	Moringa leaves
	Main (Spaces)	Sub-plot (Foliar spray)			
R3	30 cm	Moringa leaves	Control (DW)	Licorice root	Seaweed grass
	40 cm	Moringa leaves	Control (DW)	Licorice root	Seaweed grass
	50 cm	Moringa leaves	Control (DW)	Licorice root	Seaweed grass
	60 cm	Moringa leaves	Control (DW)	Licorice root	Seaweed grass

Preparation of plant extracts

The seaweed grass, licorice root, and moringa leaves (obtained from Agriculture Research Center, Giza) were rinsed with tap water three times. To keep the samples air-dried, they were then placed in the laboratory for three to four days at room temperature (± 25°C) after drying with a cloth. The samples were ground into a fine powder using a mechanical grinder. Five grams of powder from each sample were soaked for twenty-four hours in one liter of distilled water. Three times during the experiment, 20, 30, and 40 days after planting, the solution was filtered, and the filtrate—100% of the stock solution, which may be further diluted—was applied as a foliar spray (FS) for plant treatments (5% solutions).

Data recorded

Vegetative growth traits:

Growth parameters: A random selection of five plants will be collected from each plot 70 days post-sowing during both seasons of the study to assess the vegetative characteristics of summer squash plants, including stem length (cm), fresh and dry weight of the plant (g), and the number of leaves per plant.

Fruit traits: number of fruits per plant, fruit length (FL), diameter (FD), fruit shape index (FSI) and fruit weight (FW).

Statistical analysis

To find the differences between treatments, analysis of variance (ANOVA) was used (Split plot). As shown by Gomez and Gomez (1984), means were compared using L.S.D. at a 0.05 probability level.

RESULTS AND DISCUSSION

Effect of plant spacing:

According to the data in the Table 1, plant spacing had a substantial impact on growth characteristics on average for both growing seasons. According to the findings, plant growth characteristics rose when plant spacing was raised from 30 to 60 cm. However, Lower plant density produced maximum stem length (12.91 and 13.26 cm) and number of leaves/plant (13.77 and 14.05). Also yield parameters of fruit length (8.18 and 8.18 cm), fruit diameter (2.09 and 2.1 cm), fruit shape index (3.97 and 4.33) and average fruit weight (102.6 and 101.96 g) was maximum produced in wider plant spacing. The intense competition between plants for water and nutrients with the next plants in the row may be the cause of the decline in plant growth brought on by a reduction in plant spacing (Kultur et al., 2001). Also, the increased number of leaves under lower plant densities (wider spacing) could be attributed to more sunlight interception for photosynthesis, which may have resulted in production of more assimilate for partitioning towards the development of more leaves (Mehmet, 2008). In the same tendency, and according to Al-Abdul-salam and Abdul-Salam (1995), Dimitrov and Kanzirska (1997); Saad (2002); Ban et al. (2006); Fayed (2010) and Islam et al. (2011), squash plant development characteristics rose as plant spacing increased.

Table 1. Effect of planting space on some growth traits and fruit quality of squash plants in two summer seasons (S1 & S2)

Plant spaces	NL		SL (cm)		PFW (g)		PDW (g)	
	S1	S2	S1	S2	S1	S2	S1	S2
	Growth traits							
30 cm	13.69	13.40	11.88	11.52	237.10	237.04	36.01	36.47
40 cm	14.07	14.12	12.18	12.08	263.77	263.49	37.09	36.70
50 cm	13.86	13.89	12.83	12.90	272.56	272.65	39.86	39.91
60 cm	13.77	14.05	12.91	13.26	285.65	286.19	41.63	41.93
LSD	NS	NS	0.50	0.99	1.29	1.95	1.34	1.01
	Fruit quality							
	FD		FL		FSI		FW	
30 cm	2.67	2.39	8.33	7.92	3.15	2.87	70.59	70.73
40 cm	2.64	2.45	8.18	7.80	3.12	2.95	74.81	74.45
50 cm	2.29	2.12	8.54	8.16	3.78	3.77	83.94	83.70
60 cm	2.09	2.10	8.18	8.18	3.97	4.33	102.64	101.96
LSD	0.14	NS	NS	NS	0.26	0.97	1.44	1.39

NL: number of leaves, SL: stem length, PFW: plant fresh weight and PDW: plant dry weight as well as FD: Fruit diameter, FL: Fruit length, FSI: Fruit shape index, FW: Fruit weight

Effect of foliar spraying:

When comparing the effects of different foliar treatment, it was discovered that, in contrast to the check treatment (control), all growth parameters rose when all foliar were sprayed during the two growing seasons. With the exception of fruit shape index (FSI), where seaweed (SW) predominated in the first season (3.47) and licorice root (LR) in both seasons (3.47 & 3.59), the data in Table (2) unequivocally demonstrate that the highest significant results of all aspects of plant growth and fruit traits were recorded by spraying the plant with ML extract first, followed by SW extract. In contrast, the check treatment (control) achieved the lowest levels of vegetative indicators in both seasons.

Table 2. Effect of moringa leaves (ML), seaweed (SW) and licorice root extracts as foliar spray on some growth and fruit parameters of squash plants during the two studied seasons (S)

Treatment	Number of leaves (NL)		Stem length (SL, cm)		Plant fresh weight (PFW, g)		Plant dry weight (PDW, g)	
	S1	S2	S1	S2	S1	S2	S1	S2
DW	12.63	12.52	11.56	11.45	154.72	154.84	23.98	24.41
ML	15.07	15.13	13.10	13.12	355.19	355.18	53.44	53.53
SW	14.30	14.36	12.92	12.91	278.33	278.29	40.91	40.78
LR	13.38	13.46	12.23	12.30	270.84	271.06	36.26	36.29
LSD	0.711	0.738	0.395	0.626	1.04	0.859	1.035	0.762
	Fruit diameter (FD, cm)		Fruit length (FL, cm)		Fruit shape index (FSI)		Fruit weight (FW, g)	
DW	2.06	1.90	7.47	7.13	3.71	3.50	70.64	70.99
ML	2.73	2.57	9.14	9.00	3.38	3.43	98.36	97.40
SW	2.62	2.55	8.93	8.52	3.47	3.41	88.46	88.09
LR	2.27	2.03	7.68	7.39	3.47	3.59	74.53	74.37
LSD	0.19	0.37	0.35	0.33	NS	NS	0.91	0.68

The natural supplies of several growth-promoting chemicals (macro and micronutrients, IAA) may be the reason for the growth-enhancing potential of ML or SW extract (Nagodawithana, 1991). These findings are consistent with those of Shehata et al. (2012), El-Sawy (2007), El Ghamriny et al. (1999), and Swelam (2012).

Interaction's impact

Plant development and fruit characteristics at the end of growing seasons were significantly impacted by the interaction between foliar spray and plant spacing (Fig. 1).

According to the data shown in Figure 1, plants spaced 60 cm apart and treated with moringa leaf extract and seaweed extract had the highest growth parameters.

The interacted spacing 60 cm × moringa foliar spray treatment applications exhibited the highest significant effects on most vegetative growth traits with increment percentage by 30.29% (NL), 35.73% (SL), 193.49% (PFW) and 147.22% (PDW) comparing with the general control (spaced at 30 cm without Foliar spray). On the other hand, the lowest values recorded by plants sprayed with water (control).

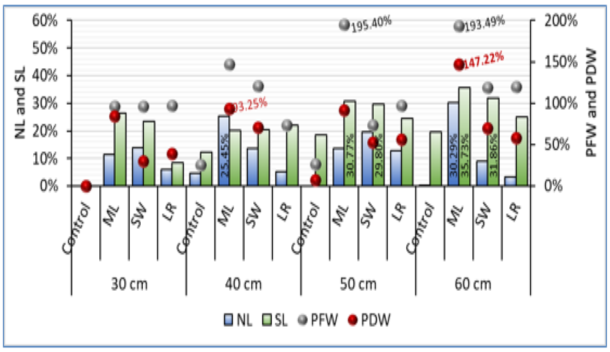

Fig.1.Effect of plant spacing and foliar application on vegetative growth characters of summer squash

Data in Table 3 show the dual interaction effect of plant spacing × bio-stimulator foliar spray (Sp.×Bio.) on fruit traits, i.e., fruit diameter, length, and shape index, as well as the average fruit weight in the two studied seasons.

Table 3. Dual interaction effect of plant spacing (Main-plot) and bio-stimulators (sub-plot) application on fruit qualities of squash plants in 1st season

Treatments		Fruit diameter (FD, cm)	Fruit length (FL, cm)	Fruit shape index(FSI)	Fruit weight (FW, g)
First season					
30 cm	Control	2.16	7.43	3.44	63.290
	ML	2.83	8.69	3.08	92.460
	SW	2.93	9.80	3.38	75.230
	LR	2.73	7.40	2.72	51.390
40 cm	Control	2.52	7.57	3.02	62.850
	ML	2.93	8.97	3.06	89.770
	SW	2.83	8.50	3.02	77.350
	LR	2.28	7.67	3.39	69.270
50 cm	Control	1.80	7.47	4.16	67.970
	ML	2.67	9.67	3.67	97.000
	SW	2.50	8.87	3.56	90.170
	LR	2.20	8.17	3.72	80.630
60 cm	Control	1.77	7.40	4.23	88.470
	ML	2.50	9.24	3.71	114.200
	SW	2.20	8.57	3.90	111.100
	LR	1.89	7.50	4.04	96.810
LSD0.05		NS	0.71	NS	2.043
Second season					
30 cm	Control	1.85	6.94	3.09	63.723
	ML	2.94	9.03	3.37	92.793
	SW	2.51	8.73	2.64	75.407
	LR	2.26	6.95	2.40	51.010
40 cm	Control	2.44	7.10	3.03	63.367
	ML	2.54	8.58	2.71	89.320
	SW	2.95	8.12	2.91	76.347
	LR	1.86	7.38	3.18	68.793
50 cm	Control	1.73	6.89	3.85	67.753
	ML	2.42	9.27	3.78	96.090
	SW	2.28	8.70	3.49	90.247
	LR	2.03	7.79	3.99	80.693
60 cm	Control	1.59	7.60	4.05	89.120
	ML	2.37	9.14	3.87	111.387
	SW	2.47	8.53	4.59	110.367
	LR	1.97	7.43	4.80	96.980
LSD0.05		NS	NS	NS	1.659

The highest values of fruit diameter (2.93 cm) were recorded by the plants spaced at 30 cm and sprayed with seaweed extract (30 cm × SW) as well as 40 cm sprayed with moringa leaf extract (40 cm × moringa extract) in the 1st season and the same trend in the 2nd one with no significant differences between them in both seasons. As for fruit length, the longest fruit was exhibited by the plants spaced at 30, 50, and 60 cm sprayed with moringa extract (30, 50, and 60 cm × ML), followed by the same spaces sprayed with seaweed extract (30, 50, and 60 cm × SW) in the 1st and 2nd seasons, with no significant differences between them in both seasons.

Moreover, the plants spaced at 30 or 40 cm and sprayed with seaweed or moringa leaf extract showed desirable low fruit shape index (Consumer point of view) comparing with the 50 or 60 cm plant spacing. Data, also, presented in Table 3 noticed that the average fruit weight ranged from 51.39 and 51.01 g (LR × 30 cm) to 114.2 and 111.387 g (ML × 60 cm) in 1st and 2nd season, respectively. However, the interaction of 60 cm plant spaces with seaweed extracts foliar spraying exhibited the second highest average fruit weight in both seasons. However, due to decreased population density, this might only enhance individual performance and not make up for the low leaf area per unit area of land (Mishriky and Alphonse 1994.

Correlation:

Simple correlation coefficients between different traits resulted from the sixteen interacted treatments are demonstrated in Table 4.

Pearson's correlation coefficients were positive and significant for several traits. Fruit weight was positively correlated with SL (0.845**), FL (0.655**), PDW (0.650**), FSI (0.611*), PFW (0.596*).

Fruit diameter was negatively correlated with FSI (-0.658**) and positively with NL (0.629**), PDW (0.585*), and PFW (0.544*). A strong positive correlation was detected between fruit length and each of the following variables: NL (r = 0.795**), FD (r = 0.648), SL (r = 0.730**), PFW (r = 0.732**), and PDW (r = 0.726**).

No significant correlations between FSI and each of FL, NL, SL, PFW and PDW. These results were agreement with those obtained by Saran et al (2007), Islam et al. (2010).

The remarkably strong correlation between PFW and PDW (r = 0.91**) suggests that they are closely related and may reflect characteristics impacted by the same environmental factors. Additionally, NL and PDW have a substantial correlation (r = 0.82**), indicating that rising NL frequently coincides with rising PDW.

Table 4. Pearson's correlation coefficients between each pair of nine studied traits in average of both seasons in sixteen interacted treatments.

	FD	FL	FSI	FW	NL	SL	PFW	PDW
FD	1							
FL	0.648**	1						
FSI	-0.658**	-0.036^{ns}	1					
FW	0.092^{ns}	0.655**	0.611*	1				
NL	0.629**	0.795**	-0.214^{ns}	0.540*	1			
SL	0.197^{ns}	0.730**	0.484^{ns}	0.845**	0.582*	1		
PFW	0.544*	0.732**	0.012^{ns}	0.596*	0.748**	0.670**	1	
PDW	0.585*	0.726**	0.010^{ns}	0.650**	0.818**	0.637**	0.908**	1

*** and **: significant at 5% and 1% levels of probability, respectively.**
FD: Fruit diameter, FL: Fruit length, FSI: Fruit shape index, FW: Fruit weight, NL: number of leaves, SL: stem length, PFW: plant fresh weight and PDW: plant dry weight

FL may be a major cause of variation because it has a moderate to strong correlation with the majority of traits (range from 0.655 to 0.795 with FW, NL, PFW, and PDW). Different behavior is shown by FSI, which may be measuring an independent characteristic because of its weak correlations with PFW and PDW and negative correlation with FD (-0.66**).

These results are also in accordance with the findings of (Abusaleha and Dutta, 1990; Lawal, 2000; Eifediyi et al., 2005; Hossain et al., 2010).

Analysis of the Heatmap's Findings:

A heatmap depicts a two-dimensional visual representation of data using colour changes from hues to a darker intensity, where the colors all represent different values. In the present study, a clustered heatmap was constructed to know the overall performance of the nine observable traits among the 16 interacted treatments (Figure 2). The variation across the nine assessed traits (T1–T9) for the 16 treatment observations is visually summarized in the heatmap. Trends and extremes can be quickly identified because to the color gradient that goes from blue (low values) to red (high values).

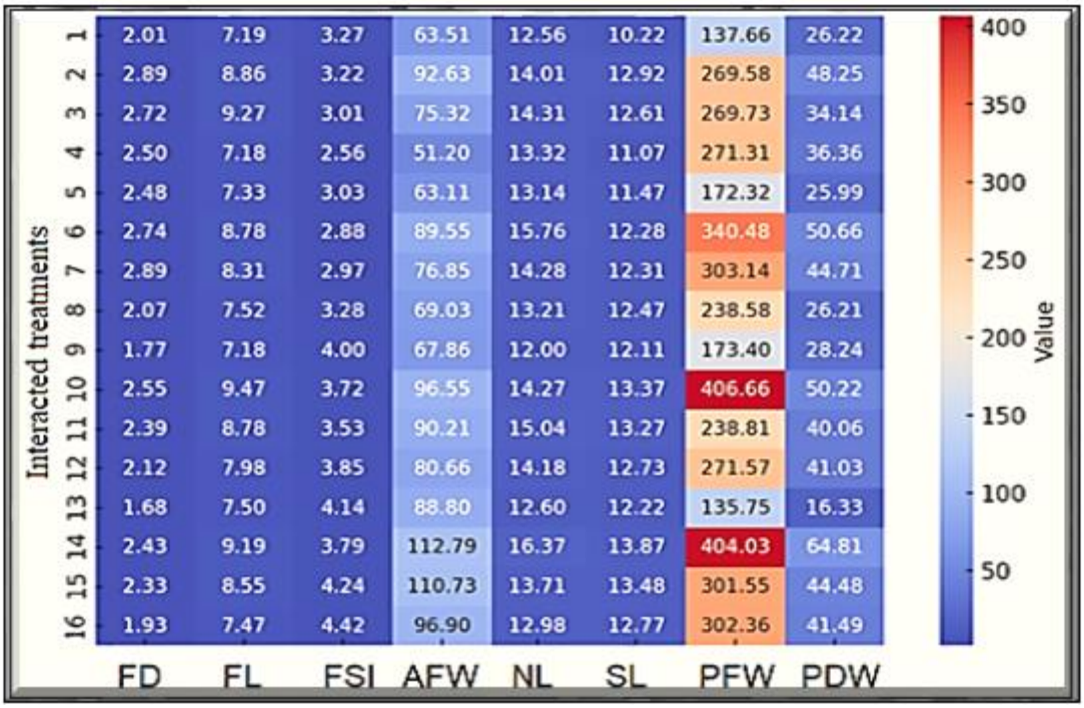

Fig. 2. Heatmap for the eight traits, with values annotated and color-coded to highlight low (blue) and high (red) values

FD: Fruit diameter, FL: Fruit length, FSI: Fruit shape index, FW: Fruit weight, NL: number of leaves, SL: stem length, PFW: plant fresh weight and PDW: plant dry weight

CONCLUSION

It was possible to draw the conclusion that the applied treatments—particularly the licorice root (LR), seaweed (SW) and Moringa leaf (ML) extracts—significantly improved the vegetative development of squash plants in the presence of high temperatures and saline soil, as well as high photosynthesis and mineral uptake efficiency. This could be reflected upon the further growth stages and lead to achieve more fruits yield with good quality. Therefore, the present study strongly admits the use of natural moringa, seaweed and licorice extract as foliar spray treatments to improve growth and productivity of squash plants during summer months under open field conditions.

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دور مسافات الزراعة والرش الورقي المحفز في تحسين نمو وجودة ثمار الكوسة الصيفى

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الملخص

أُجريت تجربتان حقليتان في مزرعة جامعة جنوب الوادي بمحافظة قنا، مصر، خلال صيفَي ٢٠٢٢ و٢٠٢٣ على الكوسة الصيفي في الحقل المفتوح لدراسة تأثير الرش الورقي بمعاملات مختلفة، بما في ذلك مستخلصات أوراق المورينجا (ML)، والأعشاب البحرية (SW)، وجذر عرق السوس (LR)، على تحمل الكوسة الصيفي (Cucurbita pepo L. cv. Eskandarani) للإجهاد البيئي الشديد. بشكل عام، أدى تفاعل الرش الورقي بالمورينجا ٥٪ (ثلاث مرات أثناء التجربة، بعد ٢٠ و٣٠ و٤٠ يومًا من الزراعة)، مع مسافة زراعة ٦٠ سم إلى انتاج نبات قوي كما تم التعبير عنه من خلال معايير النمو الخضري، أي ارتفاع النبات، وعدد الأوراق لكل نبات، والوزن الطازج للنبات، والوزن الجاف للنبات مقارنة بالمعاملات الورقية الأخرى. علاوة على ذلك، تم تسجيل أعلى قيم لمكونات محصول الثمار وجودتها، أي طول الثمار وقطر الثمار ومتوسط وزن الثمار والمحصول ويمكن اعتبارها معاملة مثالية لإنتاج نمو خضري مرتفع، ومحصول، وجودة ثمار عالية في ظل الظروف البيئية لمحافظة قنا والمناطق المماثلة الأخرى.