Impact of the Foliar Application of Yeast, Vermicompost Tea, and their Combinations as Biostimulants on Orange Productivity and Fruit Quality

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Increasing the use of chemical fertilizers to keep pace with the continuous increase in population leads to deterioration of soil fertility, air and groundwater pollution, and the disruption of beneficial microbes. Therefore, there is a necessity to use biostimulants. Biostimulants are valuable for sustainable fruit crop production, boosting growth and plant health. Used with fertilizers, they improve nutrient efficiency and resilience, supporting productivity and environmental goals. Biostimulants promote the blooming, development, and yield of fruit plants. The current study was conducted on navel orange trees *cv.* Washington grafted on Volkmeriana rootstock during the 2024 and 2025 seasons to investigate the influence of the spraying of yeast extract (YE) at 0.1, 0.2, and 0.3%, vermicompost tea (VCT) at 2, 4, and 6%, and their combinations: 0.1% YE + 2% VCT; 0.2% YE + 4% VCT; 0.3% YE + 6% VCT, compared to trees that were not sprayed. The trees were sprayed three times: before flowering in March, during full bloom, and one month after the second spraying. The results showed that spraying YE, VCT, and their combinations significantly improved vegetative growth parameters, yield, fruit physical and chemical characteristics, and leaf macro- and micronutrient mineral content compared with non-sprayed trees in both seasons.

DOI: 10.15376/biores.21.2.5024-5040

Keywords: Biostimulants; Orange; Productivity; Fruit Quality; Mineral content; Saccharomyces cerevisiae

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INTRODUCTION

Navel orange (*Citrus sinensis* Osbeck) cv. Washington is planted primarily for export as fresh fruit due to its attractive colors, distinctive smell, delicious flavor, high nutritional value, and health benefits (Ma *et al.* 2020; Karn *et al.* 2021). Moreover, orange is a good source of vitamin C and potassium (Juraschek *et al.* 2012). In Egypt, the harvested area of oranges is 164 thousand hectares, producing ≈ 3.700 million tons; globally, there were 3.41 million hectares, producing 69.84 million tons (FAO 2023).

Biostimulants are defined as biologically sourced compounds that, in contrast to fertilizers and soil conditioners, promote plant growth, development, and effectively reduce the negative impacts of both abiotic and biotic stresses on crops when applied at very low concentrations (Kauffman *et al.* 2007). Biostimulants have recently gained significant attention in sustainable agriculture due to their natural capacity to enhance photosynthesis, promote plant growth, and improve nutrient-use efficiency (Patel and Saraf 2013; Almutairi *et al*. 2023). Although biostimulants display hormone-like activity and often contain trace levels of plant hormones or their derivatives, their biological effects cannot be attributed exclusively to these hormonal components; otherwise, they would be subject to classification and registration as plant growth regulators (Bulgari *et al.* 2015). Biostimulants are increasingly recognized as a valuable strategy for improving crop performance in modern agricultural systems. They consist of substances or blends of naturally derived organic compounds that stimulate plant growth and productivity, especially under stressful or adverse environmental conditions (Rouphael and Colla 2020). Besides, the application of biostimulants improves plant nutritional efficiency by promoting nutrient uptake and utilization. They contribute to increased crop productivity, enhanced fruit quality attributes, and greater tolerance to abiotic stress conditions. Additionally, biostimulants act as an important source of macro- and micronutrients as well as plant growth regulators, including auxins, cytokinins, and gibberellins (Al-Saif *et al*. 2023a).

Yeast (*Saccharomyces cerevisiae*) extract (YE) has been demonstrated to effectively mitigate the adverse effects of salinity stress in date palm (Darwesh 2013). The YE functions as a biofertilizer because of its beneficial effects on plant growth and its proven safety for both human health and the environment. It is considered a cost-effective biofertilizer that improves plant nutrition and vigor as well as raising the tolerance to abiotic stress (Lonhienne *et al.* 2014). The presence of these nutrients, which play key roles in plant stress-resistance mechanisms, supports enhanced growth and development under saline conditions (Enebe and Babalola 2018). The observed improvements in plant growth following YE application are attributed to its richness in minerals, amino acids, vitamins, and cytokinins (Dawood *et al.* 2019). The YE plays a positive role during the vegetative growth and productivity phases by promoting flower initiation in certain plant species due to its high auxin and cytokinin levels. Additionally, YE contributes to increased carbohydrate accumulation in plant tissues (Hamed *et al*. 2019). Foliar application of YE has been shown to enhance plant growth while improving yield and quality in fruit trees across various plant species. These effects are primarily attributed to increased nutrient uptake, as biostimulants act both as sources of mineral nutrients and as regulators of their availability and release within the plant (El-Nemr *et al.* 2012). Yeast can produce enzymes that promote plant growth, resulting in the production of indole-3-acetic acid, and phosphate solubilization (Fu *et al*. 2016). Spraying date palm cv. Barhi with YE at 0.2% or 0.4% effectively enhanced productivity and fruit physical and chemical quality characteristics (Mosa *et al*. 2025).

Vermicompost leachate (VCT) has recently gained attention as a well-studied biostimulant derived from aqueous extracts of earthworm-processed organic matter. This brown liquid, obtained by percolating water through vermicomposting systems, contains amino acids, humic substances, beneficial microorganisms, enzymes, nutrients, and trace levels of plant growth regulators such as auxins and cytokinins. Its bio-stimulatory potential is attributed to the individual and synergistic interactions of these components, which collectively enhance plant growth and development (Aremu *et al.* 2015; Wongkiew *et al.* 2023). The liquid form of vermicompost shows excellent potential for crop production and protection. It is believed that nutrients and microbes transfer from VCT into a liquid solution, typically called vermicompost tea, making it more useful (Pant *et al.*

2009). The VCT also has considerable potential for pest control due to its phenolic compounds, which make plant tissues unappealing to pests (Pathma and Sakthivel 2012). The VCT, recognized as an organic biofertilizer, is rich in beneficial microorganisms, essential nutrients, and plant growth-promoting compounds, and its application enhances both plant growth and yield (Arancon *et al.* 2020). Organic amendments, such as VCT, have become good alternatives to synthetic agrochemicals, providing a sustainable method for enhancing soil fertility and promoting plant growth (Yatoo *et al.* 2021). These inputs are rich in nutrients, contain diverse microbial populations, and are rich in bioactive compounds, significantly improving soil quality and overall plant health (Pilla *et al.* 2023; Rehman *et al.* 2023). Similarly, VCT is known for its capacity to activate plant defense systems, enhance soil health, and increase microbial activity in the rhizosphere (Souffront *et al.* 2022). In contrast to other organic fertilizers that require time to decompose before releasing nutrients, VCT provides immediate nutrient availability to plants, thereby enhancing growth and suppressing phytopathogens (Sivasabari *et al.* 2023; Vambe *et al.* 2023).

This study was conducted to investigate how spraying yeast extract or vermicompost tea, either alone or in combination, affects the growth, yield, and fruit quality of Washington navel orange trees.

EXPERIMENTAL

This study was conducted in the Nubaria Region, Behaira Governorate, Egypt, on 12-year-old “Washington” navel oranges grafted on Volkameriana rootstock during 2024 and 2025.

The Applied Biostimulants

The orange trees were sprayed by yeast (*Saccharomyces cerevisiae*) extract (YE) at 1, 0.2, and 0.3%, vermicompost tea (VCT) at 2, 4, and 6%, and their combinations: 0.1% YE + 2% VCT (combination 1); 0.2% YE + 4% VCT (combination 2); 0.3% YE + 6% VCT (combination 3), as compared to not-sprayed trees (control). The trees were sprayed three times: first before flowering in March, during full bloom, and a month after the second spraying in 2024 and 2025 seasons. The treatments were arranged in a Randomized Complete Block Design (RCBD) in five replicates, with a total of 50 trees. The trees under study received all the applied and horticultural treatments followed in the orchard.

Table 1. Composition of Vermicompost Tea

pH (1:5)	EC (1:5) dsm^{-1}	Macronutrients (%)					Micronutrients (ppm)			
		N	P	K	Ca	Mg	Fe	Zn	Mn	Cu
6.93	3.12	357	68	288	217	64	9.7	1.4	1.2	0.9

The above-mentioned treatments were tested by studying their influences on the following parameters:

Vegetative Growth Parameters

At the end of the vegetative period, the shoot length and diameter in centimeters were measured using a vernier caliper. Total chlorophyll content (SPAD) was determined in fresh leaves by taking 10 readings from the mature leaves of each replicate.

Fruit set %, fruit drop %, and fruit number

The total number of flowers at full bloom in May and then the number of set fruits were reordered for both years of study, and then the fruit set percentages were calculated using Eq. 1:

$$\text{Fruit set \%} = \frac{No.\ of\ set\ fruits}{No.\ of\ flowers} \times 100 \tag{1}$$

The fruit drop percentage was calculated using Eq. 2:

$$\text{Fruit drop (\%)} = \frac{No.\ of\ fruitlets\ at\ initial\ set - No.\ of\ harvested\ fruits}{No.\ of\ fruitlets\ at\ initial\ set} \times 100 \tag{2}$$

Fruit yield

Fruit yield (ton/ha) was assessed by multiplying the weight of fruits/tree × number of trees/ha.

Fruit Quality

Fruit physical quality

The fruit length and diameter were measured with a digital vernier caliper. Fruit weight was averaged from 10 samples. Fruit volume (cm^3) was calculated from water displaced in a 1000-mL graduated cylinder. Fruit firmness was measured in kg/cm^2 using a Magness-Taylor pressure tester.

Fruit chemical quality

The total soluble solids (TSS %) in fruit juice were measured with a hand refractometer (ATAGO, Tokyo, Japan). Total acidity (%) was calculated as citric acid per 100 mL of fruit juice (AOAC 2005). The phenol–sulfuric acid method was used to estimate total sugars by treating 1.0 mL of the sample with 1.0 mL of 5% phenol and 5.0 mL of concentrated H_2SO_4, then measuring the absorbance at 485 nm. Reduced sugars were estimated using the 3,5-dinitrosalicylic acid (DNS) method, with 2.0 mL of the sample and 1.5 mL of DNS at 80 °C for 10 min and measured at 510 nm (Lam *et al.* 2021). The content of ascorbic acid was determined by titration using 2,6-dichloro phenol indophenol (Nielsen 2017). Fruit carotene content was calculated using the method of Aquino *et al.* (2018) at a wavelength of 440 nm.

Nutritional Status

After harvesting the fruits in the 2024 and 2025 seasons, 40 leaves from the middle part of each shoot were collected from each tree (Arrobas *et al*. 2018). The leaves were thoroughly washed with tap water, followed by a rinse with distilled water. They were then dried at 70 °C until reaching a constant weight, ground, and digested with H_2SO_4 and H_2O_2 until the solution clarified. The nitrogen content was analyzed using the micro Kjeldahl method (Wang *et al*. 2016). Phosphorus levels were determined through the Vanadomolybdo method (Wieczorek *et al*. 2022), while potassium content was measured with a flame photometer (Asch *et al*. 2022). The micronutrients Fe, Mn, Zn, and B were quantified using atomic absorption spectro-photometry.

Statistical Analysis

The data obtained were subjected to one-way analysis of variance (Ott and Longnecker 2015). A least significant difference at 0.05% was used to compare treatment means, and the measurements were performed using CoHort Software (Pacific Grove, CA, USA) (Snedecor and Cochran 2021).

RESULTS

Spraying of VCT and YE positively improved the vegetative growth parameters in terms of shoot length, diameter, and leaf total chlorophyll compared to untreated trees (Table 2). The results showed that spraying combination 3 yielded the best performance, improving shoot length, diameter, and leaf chlorophyll content more than the other sprayed trees, followed by spraying combination 2 in both experimental seasons.

Table 2. Effect of Spraying YE, VCT, and Their Combinations on Shoot Length, Diameter, and Leaf Chlorophyll of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Shoot Length (cm)		Shoot Diameter (cm)		Total Chlorophyll (SPAD)	
	2024	2025	2024	2025	2024	2025
Control	9.24f	10.00f	0.11e	0.13e	68.48g	70.89g
0.1%YE	9.60ef	10.18f	0.12de	0.13e	71.96f	72.72fg
0.2%YE	10.24de	10.58ef	0.13cd	0.15cd	75.46de	75.99de
0.3%YE	10.80bcd	12.80c	0.14bc	0.17b	78.90bc	78.43bcd
2%VCT	9.60ef	10.40ef	0.12de	0.14de	73.70ef	73.94ef
4%VCT	10.38cd	10.88de	0.13cd	0.15cd	77.11cd	76.48cd
6%VCT	11.10bc	13.30c	0.15b	0.17b	79.42b	78.41bcd
0.1% YE + 2%VCT	10.66bcd	11.42d	0.13bcd	0.16bc	77.66bc	78.85bc
0.2% YE + 4%VCT	11.36b	14.58b	0.16a	0.19a	79.78b	80.03b
0.3% YE + 6%VCT	12.72a	15.46a	0.17a	0.19a	82.30a	83.30a
$LSD_{0.05}$	0.67	0.64	0.01	0.01	2.08	2.38

Treatments with the same letter in a column are not significantly different.

Fruit-set percentages were markedly increased by the spraying of YE and VCT compared to the sprayed trees during the experimental seasons (Table 3). The highest fruit-set percentages were markedly increased by spraying combination 3, followed by combination 2 and 6% VCT, compared with not-sprayed trees. Moreover, spraying 0.3% YE and combination 1 both positively improved fruit set percentages in the two seasons. On the opposite side, these sprayed treatments significantly minimized the fruit drop percentages compared to untreated trees.

Table 3. Effect of Spraying of YE, VCT, and Their Combinations on the Fruit Set and Fruit Drop Percentages of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Fruit Set %		Fruit Drop %	
	2024	2025	2024	2025
Control	3.82c	3.97e	83.92a	82.38a
0.1%YE	4.13bc	4.24d	81.10b	79.74b
0.2%YE	4.31b	4.69c	78.24c	75.83cd
0.3%YE	4.60b	5.02b	74.80de	73.58de
2%VCT	4.18bc	4.30d	79.80bc	77.31bc
4%VCT	4.41b	4.82bc	77.20cd	75.90cd
6%VCT	5.11a	5.34a	75.20de	73.25de
0.1% YE + 2%VCT	4.41b	4.94b	75.60de	73.73de
0.2% YE + 4%VCT	5.11a	5.35a	73.04ef	72.79e
0.3% YE + 6%VCT	5.31a	5.44a	71.00f	72.26e
$LSD_{0.05}$	0.42	0.21	2.51	2.45

The fruit yield was greatly improved by spraying orange trees with YE or VCT, individually or in combination, compared with untreated trees (Table 4). Additionally, the greatest significant increases in fruit yield were observed with the spraying of combination 3, followed by combination 2, compared with the other applied treatments in the two seasons. Additionally, spraying 6% VCT or 0.3% YE markedly improved fruit yield in the two seasons, more than the application of the lowest concentrations from either.

Table 4. Effect of Spraying YE, VCT, and Their Combinations on the Fruit Yield of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Fruit Yield (kg/Tree)		Fruit Yield (Ton/Hectare)	
	2024	2025	2024	2025
Control	66.40f	64.00g	31.87f	30.72g
0.1%YE	67.40f	67.20fg	32.35f	32.26fg
0.2%YE	72.80e	72.20e	34.94e	34.66e
0.3%YE	76.00cd	76.60cd	36.48cd	36.77cd
2%VCT	68.60f	68.60f	32.93f	32.93f
4%VCT	73.30de	73.00de	35.18de	35.04de
6%VCT	77.00c	78.12c	36.96c	37.50c
0.1%YE + 2%VCT	73.00de	75.80cde	35.04de	36.38cde
0.2% YE+ 4%VCT	80.40b	82.40b	38.59b	39.55b
0.3%YE + 6%VCT	84.30a	86.20a	40.46a	41.38a
$LSD_{0.05}$	2.88	3.53	1.38	1.70

Spraying orange trees with YE or VCT, either alone and together, increased fruit weight, length, diameter, and firmness across both seasons compared to untreated trees (Table 5).

Table 5. Effect of Spraying YE, VCT, and Their Combinations on the Fruit Weight, Length, Diameter, and Firmness of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Fruit Weight (g)		Fruit Length (cm)		Fruit Diameter (cm)		Fruit Firmness (lb/in^2)	
	2024	2025	2024	2025	2024	2025	2024	2025
Control	266.40f	284.00f	8.32e	8.30d	7.73d	8.02d	14.38e	14.42f
0.1%YE	272.20ef	284.60f	8.44de	9.23c	8.10c	8.22c	14.50de	14.66ef
0.2%YE	286.60cd	295.20e	8.52cd	9.71b	8.17bc	8.26bc	14.82de	15.48cd
0.3%YE	301.20b	305.80cd	8.63c	9.84b	8.24bc	8.42b	15.46c	16.00bc
2%VCT	278.40de	291.80ef	8.48cd	9.64b	8.11c	8.21c	14.60de	15.20de
4%VCT	288.40c	297.40de	8.55cd	9.71b	8.19bc	8.34bc	14.88de	15.54cd
6%VCT	304.00b	313.20bc	8.81b	10.14a	8.32b	8.35bc	16.00b	16.00bc
0.1%YE + 2% VCT	291.80c	299.60de	8.62c	9.79b	8.24bc	8.36bc	15.00cd	15.88c
0.2%YE + 4%VCT	314.60a	319.80b	8.92b	10.22a	8.52a	8.63a	16.10b	16.58b
0.3% Ye + 6%VCT	323.20a	331.60a	9.10a	10.23a	8.54a	8.73a	16.86a	17.20a
$LSD_{0.05}$	8.68	8.46	0.14	0.19	0.14	0.15	0.53	0.56

Additionally, spraying combination 3 followed by combination 2 yielded the largest increases in these parameters across the two seasons. Additionally, the highest concentrations from 0.3% YE or 6% VCT were more effective in improving these parameters than the lowest ones in the two seasons. The results showed no remarkable differences in these parameters between spraying with 6% VCT and 0.3% YE.

Table 6 shows that fruit size, pulp weight, and peel weight increased with foliar spraying using YE, VCT, or their combinations, compared to untreated trees across both seasons. Spraying combination 3 on the orange trees significantly improved these physical fruit characteristics compared with the other sprayed treatments. Additionally, the foliar spraying of combination 2 also improved these parameters compared with using YE or VCT individually in both seasons.

Table 6. Effect of Spraying YE, VCT, and Their Combinations on the Fruit Weight, Length, Diameter, and Firmness of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Fruit Size (cm^3)		Fruit Pulp Weight (g)		Peel Weight (g)	
	2024	2025	2024	2025	2024	2025
Control	282.40f	299.40f	231.80f	247.60e	34.60f	36.40d
0.1% YE	287.60ef	301.00f	236.40ef	248.00e	35.80f	36.60d
0.2% YE	303.60d	310.80e	246.60cd	257.60d	40.00de	37.60d
0.3% YE	315.60c	321.60cd	258.00b	264.20cd	43.20cd	41.60c
2% VCT	293.60e	308.20ef	241.00de	255.80de	37.40ef	37.20d
4% VCT	303.80d	313.80de	246.80cd	258.00d	41.60cd	39.40cd

6%VCT	318.40c	328.80bc	259.20b	267.40bc	44.80bc	45.80b
0.1% + 2%	306.40d	314.60de	250.00c	260.40cd	41.80cd	39.20cd
0.2% + 4%	329.20b	335.40b	266.60a	272.80b	48.00ab	47.00b
0.3% + 6%	338.60a	347.60a	271.80a	281.60a	51.40a	50.00a
$LSD_{0.05}$	8.18	9.11	7.34	8.17	3.56	2.83

The fruit chemical characteristics, in terms of TSS, vitamin C, and carotene, were significantly improved by spraying YE or VCT, and by their combinations, compared to non-sprayed trees in both experimental seasons (Table 7). The results showed that the greatest increases in TSS and VC were observed with combination 3, rather than with the other treatments applied. The results also showed no significant differences between the two seasons in the effects of combinations 2 or 1, VCT at 6 or 4%, and 0.2 or 0.3% YE. In contrast, these treatments reduced fruit content, as measured by acidity percentage.

The data in Table 8 indicated that spraying with YE, VCT, or their combinations improved fruit content in total, reduced, and non-reduced sugars compared with untreated trees in both seasons. Moreover, the highest percentages of total and reduced sugars were obtained with the spraying of combination 3, rather than with the other applied treatments, except for combination 2, where the differences between combination 3 and 2 were insignificant. There were no significant differences between spraying 0.2 or 0.3 YE and 4 or 6%, and between combination 1. Additionally, significant differences were detected between the sprayed treatments in fruit content, with reduced sugar percentages.

Table 7. Effect of Spraying YE, VCT, and Their Combinations on Total Soluble Solids, Acidity, Vitamin C, and Carotene of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	TSS %		Acidity %		VC (mg/100 mL)		Carotin (mg/100 g)	
	2024	2025	2024	2025	2024	2025	2024	2025
Control	11.60d	11.66d	1.95a	1.96a	43.60e	43.60e	3.24c	3.47d
0.1% YE	11.76cd	12.00cd	1.93a	1.92b	44.60de	43.60e	3.38bc	3.72cd
0.2% YE	12.42b	12.40bc	1.85b	1.84c	45.40cd	45.00cde	3.66ab	3.84bc
0.3% YE	12.60b	12.62b	1.69d	1.68e	46.40bcd	46.80bc	3.80a	4.09ab
2% VCT	12.28bc	11.94cd	1.90ab	1.87b	45.80cd	44.00de	3.59abc	3.84bc
4% VCT	12.46b	12.48bc	1.78c	1.78d	45.60cd	45.60bcd	3.76a	4.01abc
6%VCT	12.80b	12.64b	1.66de	1.66ef	46.80abc	47.20b	3.82a	4.10ab
0.1% YE + 2% VCT	12.48b	12.62b	1.78c	1.76d	45.60cd	46.00bc	3.80a	3.96abc
0.2% YE+ 4% VCT	12.74b	13.36a	1.63e	1.63f	47.80ab	47.16b	3.78a	4.20a
0.3%YE + 6%VCT	13.50a	13.60a	1.57f	1.58g	48.20a	49.00a	3.90a	4.31a
$LSD_{0.05}$	0.56	0.54	0.05	0.04	1.61	1.68	0.34	0.31

Table 8. Effect of Spraying YE, VCT, and Their Combinations on Total, Reduced, and Non-reduced Sugars of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Total Sugars %		Reduced Sugars %		Non-reduced Sugars %	
	2024	2025	2024	2025	2024	2025
Control	9.22e	9.42d	5.21e	5.31e	4.01b	4.11c
0.1% YE	9.76d	9.62c	5.43de	5.38de	4.33ab	4.24bc
0.2% YE	10.03c	10.14b	5.54d	5.54cde	4.49a	4.60a
0.3% YE	10.21abc	10.21ab	5.71bcd	5.68bc	4.50a	4.62a
2% VCT	10.02c	9.80c	5.54d	5.44de	4.48a	4.36abc
4% VCT	10.05c	10.20ab	5.62cd	5.55cde	4.42a	4.65a
6%VCT	10.27ab	10.32ab	5.86abc	5.72bc	4.41a	4.49ab
0.1%YE + 2%VCT	10.18bc	10.22ab	5.67bcd	5.56cd	4.51a	4.66a
0.2% YE + 4%VCT	10.34ab	10.30ab	5.94ab	5.85ab	4.40a	4.47ab
0.3%YE + 6%VCT	10.42a	10.38a	6.09a	5.96a	4.33ab	4.42ab
$LSD_{0.05}$	0.20	0.20	0.26	0.22	0.33	0.28

The data in Tables 9 and 10 showed that the application of YE or VCT noticeably improved leaf mineral content for macro- and micronutrients compared to untreated trees. Additionally, the highest significant concentrations of N, P, K, Fe, Zn, and Mn were markedly improved by the spraying combination 3, followed by combination 2, compared with the other sprayed treatments. Moreover, spraying orange trees with 6% VCT, and 0.3% YE, positively improved the leaf nutritional content of NPK rather than the lowest concentrations from each of them. There are no significant differences detected between the effects of spraying 0.3% YE and 6% VCT on the leaf mineral content of NPK.

Table 9. Effect of Spraying of YE, VCT, and Their Combinations on Leaf Content (Nitrogen, Phosphorus, and Potassium) of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	N%		P%		K%	
	2024	2025	2024	2025	2024	2025
Control	1.49e	1.55e	0.34d	0.37d	1.28f	1.31f
0.1% YE	1.52e	1.58e	0.37d	0.39d	1.34ef	1.34f
0.2% YE	1.53e	1.66d	0.45c	0.48c	1.41de	1.47e
0.3% YE	1.68c	1.81c	0.52b	0.54b	1.54c	1.58c
2% VCT	1.52e	1.62de	0.36d	0.39d	1.37e	1.34f
4% VCT	1.55de	1.68d	0.47c	0.50c	1.45d	1.44e
6%VCT	1.73c	1.85c	0.56b	0.55 b	1.57c	1.59c
0.1%YE + 2%VCT	1.59d	1.80c	0.51b	0.55b	1.54c	1.53d
0.2% YE + 4%VCT	1.89b	1.95b	0.56b	0.57b	1.69b	1.80b
0.3%YE + 6%VCT	1.96a	2.02a	0.61a	0.62a	1.77a	1.87a
$LSD_{0.05}$	0.05	0.07	0.04	0.04	0.07	0.05

Table 10. Effect of Spraying of YE, VCT, and Their Combinations on the Leaf Content (Iron, Zinc, and Manganese) of 'Washington' Orange in 2024 and 2025 Seasons

Treatments	Fe (ppm)		Zn (ppm)		Mn (ppm)	
	2024	2025	2024	2025	2024	2025
Control	0.40f	0.41f	0.39e	0.41e	0.32g	0.35f
0.1% YE	0.42ef	0.45ef	0.40de	0.42de	0.36f	0.38ef
0.2% YE	0.46e	0.47e	0.42de	0.42de	0.42d	0.44d
0.3% YE	0.63bc	0.63c	0.52c	0.45d	0.44cd	0.49c
2% VCT	0.43ef	0.45ef	0.41de	0.41e	0.38ef	0.39e
4% VCT	0.56d	0.58d	0.45d	0.43de	0.42d	0.43d
6%VCT	0.66b	0.64c	0.52c	0.50 c	0.47bc	0.53b
0.1%YE + 2%VCT	0.58cd	0.59d	0.50c	0.45d	0.42de	0.48c
0.2% YE + 4%VCT	0.72a	0.74b	0.57b	0.61b	0.50b	0.56b
0.3%YE + 6%VCT	0.76a	0.79a	0.63a	0.66a	0.55a	0.61a
$LSD_{0.05}$	0.05	0.04	0.05	0.03	0.04	0.04

DISCUSSION

In the present study, the application of YE as a biofertilizer was found to enhance vegetative growth and productivity in fruit plants. This effect is attributed to its breakdown into amino acids and vitamins, as well as its role as a plant growth regulator. The YE promotes cell division and significantly contributes to the accumulation of dry matter in plant organs by enhancing photosynthesis and respiration processes. Its high tryptophan content supports the biosynthesis of the auxin IAA, which directly regulates cell division, cell wall flexibility, and cell enlargement. Consequently, YE treatment effectively improves fruit tree performance (El-Tohamy *et al.* 2008). Al-Dulaimi and Jumaa (2012) reported that spraying of YE at 10 g L^{-1} on "Black Hamburg" grapevine variety markedly enhanced leaf area, chlorophyll content, and the number of clusters per vine. The YE is abundant in minerals, proteins, carbohydrates, and vitamins, which stimulate the plant's physiological activities, resulting in increased vegetative growth, expanded leaf area, and higher chlorophyll content. Consequently, photosynthetic activity is elevated, producing larger amounts of carbohydrates that are subsequently distributed to various plant organs, including stems, branches, and fruits (Al-Dulaimy and Alrawi 2015). The use of YE has been reported to markedly improve the growth characteristics of date palm (*Phoenix dactylifera* L.) within only a few months after the acclimatization stage (Darwesh 2016; Al-Saif *et al*. 2023b). Al-Karawi *et al*. (2018) reported that foliar spraying of strawberry plants with dry yeast extract (DYE) at 1 and 2 g L^{-1} enhanced their annual vegetative growth, with the 2 g L^{-1} concentration showing the most significant improvement. The DYE is a nutrient source for plants because it contains amino acids, plant hormones, sugars, C, N, P, K, Ca, Mg, and other micronutrients (Manea *et al.* 2019). The YE is composed of a variety of bioactive constituents that promote growth (Abdelaal *et al.* 2021), including essential nutrients (Abdelaal *et al.* 2019), amino acids, vitamins, and enzymes (Taha *et al.* 2020). These components can boost nutrient absorption (Rangel-Montoya *et al.* 2022), activate metabolic processes, and facilitate overall plant development (Ebaid *et al.* 2022). The YE is a natural cytokinin source that promotes cell division and stimulates protein and chlorophyll synthesis. Its richness in macro- and micronutrients, growth regulators, amino acids, and vitamins enhances carbohydrate metabolism, photosynthetic pigments, and enzyme activity, leading to improved plant growth (Mukherjee *et al*. 2020). The YE is a complex composition containing proteins, peptides, nucleic acids, carbohydrates, B vitamins, essential minerals, such as Fe, P, Mg, and Zn, as well as free amino acids like glutamic acid, glycine, alanine, and valine (Tomé 2021). The YEs have been employed to enhance root development and improve plant tolerance to stress (Babaousmail *et al.* 2022). Additionally, YEs can stimulate soil microbial activity and facilitate nutrient cycling (Ebaid *et al.* 2022). Applying YE at 150 mL L^{-1} improved plant height, fresh leaf weight, number of secondary crowns per plant, as well as count, area, and dry matter of leaves, leaf chlorophyll content in strawberry (EL-Metwally *et al.* 2023).

Vermicompost Tea (VCT) induced the efficacy of inorganic fertilizers, which was likely because the rapid decomposition of organic substances increased the supply of N, P, K, and micronutrients to the crop. This nutrient boost enhanced plant growth, leading to increased metabolic activity and higher carbohydrate synthesis, ultimately resulting in greater productivity (Barani and Anburani 2004). The VCT has been shown to support the growth and development of crops such as strawberries (Singh *et al.* 2010). The VCT is enriched with water-soluble bioactive compounds, including phytohormones such as indole-3-acetic acid and gibberellic acid, fulvic and humic acids, minerals, amino acids, antioxidants, vitamins, and microbial-derived stimulants, which collectively contribute to plant development. These natural compounds play key roles in promoting vegetative growth and can enhance enzyme activity, thereby improving nutrient uptake and photosynthetic efficiency (Singh 2014). In addition to providing essential nutrients, VCT contains growth-regulating substances, including humic acids, auxins, gibberellins, and cytokinins, which influence numerous plant processes related to growth and yield, such as the absorption of macro- and micronutrients (Aremu *et al.* 2015). Because of high content of VCT in vitamins, auxins, gibberellins, and cytokinins, it can induce plant growth and biomass accumulation (Cai *et al.* 2018). The beneficial effects of VCT on crop development are largely due to its ability to retain organic matter and mineral elements, as well as its richness in amino acids, indoleacetic acid, diverse microbial populations, and other biologically active compounds (Wang *et al.* 2018). Moreover, VCT positively influences the concentrations of nitrogen and phosphorus in plants (Pourranjbari Saghaiesh *et al.* 2019). Application of VCT can improve crop productivity, enhance chlorophyll content, by boosting nutrient uptake (Yatoo *et al.* 2021; Souffront *et al.* 2022). Applying VCT at 5% as a foliar spray on pomegranate *cv.* Manfalouty significantly enhanced leaf total chlorophyll and mineral content in N, P, and K. Furthermore, it also improved various fruit physical traits, including fruit weight, peel weight, juice volume, and fruit cracking percentage. Additionally, it reduced the percentage of fruit sunburn and increased the rate of marketable fruit and overall yield. Chemical properties, such as TSS%, acidity%, TSS/acidity ratio, and total anthocyanin content, were also positively affected compared to untreated trees (Abdel Salam and Roshdy 2022). The bioactive constituents of VCT, such as cytokinins, auxins, humic substances, and microbial metabolites, can enhance systemic resistance (Oyege and Balaji Bhaskar 2023; Rehman *et al.* 2023). The VCT is rich in essential nutrients, such as Mg and Fe, which are vital for healthy chlorophyll production. It also contains auxins, gibberellins, cytokinins, and humic acids that can support plant growth and vitality (Mohite *et al.* 2024). Foliar application of VT at concentrations of 0, 2, 4, 6, and 8% exhibited a quadratic effect on both the growth and fruit yield of strawberry plants, without altering the fruit's nutritional composition. Notably, the 4% concentration led to a 50% increase in both the fruit mass and number (de Mendonça *et al.* 2025).

CONCLUSIONS

1. The obtained results indicate that foliar spraying of yeast extract (YE) or vermicompost tea (VCT), individually or in combination, markedly improved vegetative growth attributes, productivity, nutritional status, and fruit physical and chemical characteristics.
2. The best treatment was 0.3 YE + 8% VCT, followed by 0.2 YE + 6% VCT, compared with the non-sprayed treatments.
3. Spraying higher concentrations of YE or VCT was more effective in improving these parameters than the lowest concentration in both seasons.
4. Both YE and VCT have emerged as promising sustainable biostimulators to promote plant growth.

FUNDING

This research was funded by Ongoing Research Funding program, (ORF-2026-561), King Saud University, Riyadh, Saudi Arabia.

ACKNOWLEDGMENTS

The authors extend their appreciation to Ongoing Research Funding program, (ORF-2026-561), King Saud University, Riyadh, Saudi Arabia.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All the required data are included in the manuscript.

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Article submitted: January 20, 2026; Peer review completed: February 28, 2026; Revised version received and accepted: March 8, 2026; Published: April 21, 2026.
DOI: 10.15376/biores.21.2.5024-5040