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Integrated Use of Vermicompost and Biofertilizers to Enhance Growth, Yield and Nutrient Content of Tomato Grown Under Organic Conditions

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THE use of chemical fertilization leads to high crop yields, but it adversely influences the chemical, physical, and biological characteristics of the soil. Therefore, organic farming is important in several countries worldwide, including developing countries. The present work aimed to study the effect of the integration of two organic sources, namely vermicompost and biofertilizers, as a substitution for chemical fertilizer, on the growth, yield, and quality of tomato (cv. Ellisa $F_{1)}$, grown in an organic farm. The present work was conducted at a private organic farm, Sharqia Governorate, in the summer seasons of 2019 and 2020. This experiment included nine treatments, namely, 1. Chemical Fertilizer (Chem Fert) at 150: 60: 72 kg/feddan, 2. Vermicompost (Vermi) at 4 ton/feddan, 3. Vermicompost + Phosphate dissolving bacteria (Vermi + PSB), 4. Vermicompost + Vesicular-arbuscular mycorrhizal (Vermi + VAM), 5. Vermicompost + Azotobacter + Azospirillum (Vermi + Azoto), 6. Vermi + Azoto + Azos + PSB, 7. Vermi + Azoto + Azos +VAM., 8. Vermi + PSB + VAM and Vermi + Azoto+ Azos + PSB + VAM. The treatments of Vermi + PSB + VAM and Vermi + Azoto+ Azos +PSB + VAM significantly increased plant height, number of branches, leaf area, and leaf contents of chlorophyll, N, P, K, Mg, Fe, Zn, B, and Mn. They resulted in remarkable increase in yield traits (number of fruits/plant, fruit yield/plant, fruit yield/feddan), and improved all fruit chemical traits (total sugar, TSS, vitamin C and lycopene), except ß-carotene, as compared to the chemical fertilization.

Keywords: Vermicompost, Phosphate dissolving bacteria, Mycorrhizal, Azotobacter, Azospirillum, Tomato, Growth, Yield, Quality.

Introduction

Tomato (*Solanum lycopersicum* L.) is an important crop grown year-round in different regions of Egypt. The total cultivated area of tomato is 380.011 thousand feddan, which produced about 6493724 tons according to 2019/2020 statistics, with an average yield of 17.08 tons fed^{-1} (FAOSTAT, 2020). Chemical fertilizers are the main source of tomato nutrition in the most cultivated areas. There is no doubt that the utilization of chemical fertilizers leads to the achievement of abundant crop yields. However, excessive chemical fertilization adversely influences the chemical, physical, and biological characteristics of the soil by increasing the accumulation of salts and killing the benefits microorganisms in the soil (Savci, 2012).

Organic agriculture is a holistic production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity(FAO/WHO Codex Alimentarius Commission 1999 in FAO, 2014). In recent years, organic farming has become important in several countries worldwide, including developing countries. The last survey of the International Federation of Organic Agriculture Movements (IFOAM) indicated that organic agricultural land worldwide increased

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from 43.1 million hectares in 2015 to 72.3 million hectares in 2019. There are slightly more than 2 million hectares of certified organic agricultural land in Africa, which constitutes about 2.8% of the world's organic agricultural land. Tunisia had the largest organic area, with 287000 ha in 2018, while Egypt had 116000 ha, representing the fourth largest African country (Willer et al., 2021). Although organic tomato production has advantages regarding the health of consumers and soil, its yield is lower than that produced by using chemical fertilizers. Therefore, efforts should be made to increase the production of organic crops.

Vermicompost is a stable, organic, humus-like product that results from the decomposition of organic waste by different species of earthworms, e.g., *Eisenia fetida, Perionyx excavates*, and *Eudrilus eugeniae*. It has all macro and microelements needed for plant growth in soluble form, in addition to plant hormones, vitamins, and beneficial microorganisms (Olle, 2019). Vermicompost enhances growth and increases the yield of treated plants through achieving the optimum conditions for plant growth *via* improving soil structure, enhancing the activity of soil microorganisms, reducing abiotic and biotic stress, and increasing water holding capacity, soil aeration, and organic matter. The organic matter permits the water and mineral nutrients to be more readily available to the plants. Vermicompost also enhances plant growth *via* its high contents of plant growth promotors like hormones and enzymes (Saha et al., 2022). In addition, soil applications of vermicompost suppressed the severity of plant parasitic nematodes (Xiao et al., 2016), soil borne disease like *Fusarium oxysporum* (Amooaghaie and Golmohammadi, 2017), while foliar application reduced *Alernaria brassica* crops (Amooaghaie and Golmohammadi, 2017), *Phytophthora infestans* and bacterial vascular wilt in tomato (Rabet and Ketabchi, 2021)

Numerous studies were done to study the impact of the application of vermicompost in integration with the chemical fertilizers to complement each other, as it is a soil amendment and a slow-release fertilizer, whereas the chemical ones are as fast-release sources of elements. Theses studied included onion (Asgele et al., 2018), *Phaseolus vulgaris* (Mahmoud and Gad, 2020), pepper (Raghunauth et al., 2023; Zhang et al., 2023) and tomato (Qasim et al., 2023).

Biofertilizers encompass natural products comprising one or more species of microorganisms with the capability to fix nitrogen, dissolve certain soil- bound nutrient elements, or enhance plant growth. The biofertilizers included nitrogen-fixing bacteria (free-living, like *Azotobacter*, associative, like *Azosperillum*, and symbiotic, like *Rhizobium*), phosphate-solubilizing bacteria, like *Bacillus circulant*, potassium-solubilizing bacteria, like *Bacillus mucilaginosus*, as well as vesicular arbuscular mycorrhizal (AM) fungi, and plant growth-promoting rhizobacteria (Kumar et al., 2022). In earlier studies, the predominant purpose behind employing biofertilizers was to decrease the dependency on chemical fertilizers. These biofertilizers were harnessed as an economical and environmentally amicable fertilizer option, frequently through their combined application with chemical fertilizers (Kumar et al., 2022). The studies of the combination use of bio and chemical fertilizers included pepper (Raturi et al., 2019; Franczuk et al., 2023), strawberry (Kumar et al., 2019), and tomato (Reddy *et al*., 2018, Singh et al., 2018 and Ahmed et al., 2022).

Limited efforts have been undertaken to examine the consequences of integrating the use of bio- and organic fertilizers on the yield and quality of vegetable crops. In organic agriculture, no chemical fertilizer is allowed to be applied. Therefore, the present work aimed to study the effect of integration of two organic sources, namely vermicompost and biofertilizers, as a substitution for chemical fertilizer, on the growth, yield, and quality of tomato, grown in an organic farm.

Materials and Methods

The present study was conducted at a private organic Farm, Sharqia Governorate, 60 km northeast of Cairo, in the summer seasons of 2019 and 2020.

Experimental set up

Transplants of tomato, namely cultivar Ellisa F_1 (Nunhems company) Netherland, were transplanted on March 15th and 17th , 2019 and 2020, respectively, at 0.6 m between transplants under a drip irrigation system, in both seasons. Climatic data from Sikum Meteorological Station indicates weather experienced during the spring and summer of 2019 – 2020 (Table 1).

The experimental design was a randomized complete blocks design (RCBD) in three replicates. Treatments consisted of nine different fertilization regimes; the recommended chemical fertilizer (Chem Fert) at 150: 60: 72 kg/feddan according to El-Sayed (2009), vermicompost (Vermi) soil application at 4 tons/fed., vermicompost + phosphate dissolving bacteria (Vermi + PSB), vermicompost + vesicular-arbuscular mycorrhizal (Vermi + VAM), vermicompost + *Azotobacter* + *Azospirillum* (Vermi + Azoto +Azos), Vermi + Azoto + Azos + PSB, Vermi + Azoto + Azos +VAM, Vermi + PSB + VAM, Vermi + Azoto+ Azos + PSB + VAM. The length of the plot was 30 m and the width was 1.5 m with an area of 45 m^2. The soil texture of the experimental site was sandy soil (Table 2).

Sources and application methods of fertilizers

Because the farm is an organic one, chemical fertilizers were applied manually to the soil in the form of calcium superphosphate (15.5% P_2O_5) at a rate of 60 kg P_2O_5 during soil preparation, while potassium was used at a rate of 72 kg/fed in the form of potassium sulfate (50% K_2O). Potassium sulfate was divided into three equal doses and added during soil preparation and 30 and 60 days after transplanting.

TABLE 1. Monthly averages of maximum and minimum air temperature, relative humidity (RH), wind speed (WS), wind direction and solar radiation for 2019 and 2020 summer seasons.

	Temperature (°C)			RH	WS (m/s)		Wind direction dig (deg)		Solar radiation Dgt
	Avg	Max	Min	(%)	Avg	Max	Avg	Max	(MJ/m2)
					2019 season				
March	14.79	23.98	9.19	46.86	0.63	1.97	222.70	214	0.79
April	16.05	28.40	12.35	48.39	0.63	2.25	244.56	226.23	0.74
May	19.39	36.70	17.31	38.28	0.59	2.21	225.29	219.03	0.80
June	29.61	38.10	23.89	50.36	0.64	2.09	237.6	228.73	0.82
July	30.33	39.66	24.78	52.78	0.58	2.00	233.90	223.74	0.79
					2020 season				
March	14.98	24.95	9.96	54.87	0.63	1.96	228.87	218.41	0.74
April	21.39	27.85	12.39	54.20	0.81	2.40	249.73	224.36	0.81
May	26.19	33.36	19.35	46.05	0.72	2.22	233.03	219.93	0.89
June	28.43	36.79	21.9	47.40	0.67	2.07	233.96	225.16	0.84
July	29.71	40.04	24.05	58.37	0.61	1.97	226.38	218.25	0.68

TABLE 2. Chemical and physical analysis of the soil at the experimental site in 2019 and 2020 summer seasons.

Years	Chemical analysis								
	Anions mg/l			Cations mg/l				Available nutrients mg/kg soil	
	HCO_3^-	Cl^-	SO_4^{2-}	Mg	Na	Ca	K	N	P	K
2019	719.8	248.5	362.40	75.1	158.7	217.8	89.7	15	4.5	35
2020	615.6	302.6	296.32	75.3	160.8	213.3	93.2	14	5.5	40

	Mechanical analysis					Chemical analysis	
	Coarse sand	Fine sand	Silt	Clay	Texture	OM %	pH	EC (dS/m)
2019	18.2%	36.2%	27.3%	18.3%	Sandy	1.6	7.83	1.49
2020	18.3%	36.3%	27.5%	17.9%	Sandy	1.5	7.75	2.00

Nitrogen was applied at 150 kg/feddan in three equal doses in the form of ammonium sulfate (20.5% N) added during soil preparation and ammonium nitrate 30 and 60 days after transplanting. Vermicompost was obtained from the Central Laboratory for Agriculture Climate (CLAC), Agriculture Research Center, Ministry of Agriculture, Egypt. Vermicompost application was done right before transplanting (25 kg of vermicompost were applied to each plot). Therafter, labourbs incorportated the vermicompost with the soil. Azotobactereen was used as a source of *Azotobacter* and *Azospirillum*, while Phosphoreen was used as a source of *Bacillus megaterium*, i.e., PSB. These two biofertilizers were obtained from the Ministry of Agriculture in Egypt. Both biofertilizers have a number of 106–108 cells liter^{-1}. The recommended rate was 5 L feddan^{-1} for each biofertilizer applied. On the other hand, VAM was obtained from the Biological Unit, Faculty of Agriculture, Ain Sham University. VAM was used at a rate of 10 liters feddan^{-1}. The three different biofertilizers were added twice; the first time by dipping the seedling tray in the solutions of biofertilizers before transplanting, and the second one as a soil dressing using a backpack sprayer two weeks after transplanting.

Usual practices

BioHealth (*Bacillus subtilis* and *Trichoderma harzanum*), a bio fungicide (Humintech Co., Germany), was used twice after transplanting at the rate of 1 litre feddan^{-1} added through the irrigation system to avoid infection with soil-borne diseases. Micronized sulfur (KZ Co., China) was used at a rate of 1.5 kg feddan^{-1} alternately every week with Biofly (*Beauveria bassiana*) (from Biotech Co.), used at a rate of 1,5 liters feddan^{-1} for plant protection against fungal diseases (early blight, late blight, powdery mildew) and pest infestation (white fly and *Tuta absoluta*), respectively. Starting from flowering, foliar application of calcium was applied to avoid appearing of calcium deficiency symptoms on tomato plants. Beta (12% CaO) from El Hanaa Co., Egypt, was used three times with the recommended rate of 5 liters feddan^{-1}. The experiment was irrigated with drip irrigation.

Data Recorded

Two months after transplanting, five plants from each plot were randomly chosen for growth characteristic measurements. Plant height, number of branches, and number of leaves per plant were determined. Leaf area using the portable laser leaf area meter model CI-202, CID Bio-Science, USA, and relative chlorophyll content (SPAD reading using chlorophyll meter SPAD-5O_2, Konica Minolta Sensing, Inc., Japan were determined.

Samples of 100 grams were taken from leaves two months after transplanting, and they were dried in an oven at 70 °C for three days until a constant weight to determine the concentrations of macro (N, P, K, Ca, and Mg), and microelements (Fe, B, Mg and Zn) concentrations in dried oven leaves as described by Kalra (1998).

Days to 50% flowering was determined. Fruits were harvested for five weeks, starting three months after transplanting. At every harvest time, each plot was weighed separately to determine the plot yield. At the end of harvest, the total yield of fruits was estimated, then the data were transformed into yield/feddan. Four plants in each plot were separately harvested to calculate the number and yield of fruits/plant. Thereafter, the average fruit weight was calculated by dividing the total yield on total number of harvested fruits.

Samples of 10 uniform, fully red-ripe fruits were harvested at the peak harvest (3rd picking) from each plot to estimate fruit quality traits (polar and equatorial diameters, firmness, juice pH, TSS, contents of pigments, total sugar, and vitamin C) as described below. Fruits were washed with distilled water for analysis of fruit quality traits. Fruit's polar and equatorial diameters were first measured using Vanier calipers. Then fruit firmness was measured using HOJILA fruit firmness penetrometer gauge GY- 2, Hojila Co., USA.

Fruit extract was obtained by blending and filtering the flesh. Total soluble solids (TSS) were measured by using a hand refractometer (Atago Digital, Japan) according to the method in A.O.A.C. (2012). The pH value was estimated by immersing the glass electrode of a pH meter into the fruit extract as indicated in A.O.A.C. (2012). Total acidity was measured as mentioned in A.O.A.C. (2012). Vitamin C (ascorbic acid) was determined as described in A.O.A.C. (2012). Total sugar was determined as indicated in A.O.A.C. (2012). Fruit pigments, i.e., lycopene and ß-carotene, were determined according to the method of Nagata and Yamashita (1992).

Statistical analysis

TABLE 3. Physical and chemical properties of vermicompost used in the summer seasons of 2019 and 2020.

Analysis	UNITS	Vermicompost	
		2019 season	2020 season
Weight of 1 m3	Kg/m^3	755	780
O. M	%	31.22	33.2
C/N ratio		12.27	12.5
pH		7.2	7.5
EC	dS/m	5.6	5.2
N	%	1.75	1.8
P	%	0.9	1.02
K	%	1.13	1.3
Ca	%	0.7	0.9
Mg	%	0.67	0.65
Fe	ppm	802	667
Mn	ppm	190	213
Zn	ppm	110	130
Cu	ppm	34.0	53
Pb	ppm	9.0	10.03

Data were statistically analyzed using MSTAT-C v. 2.1 (Michigan State University, Michigan, USA). Means of treatments were compared based on the least significant differences (LSD ≤ 0.05) test according to the procedures mentioned by Snedcor and Cochran (1980).

Results

Vegetative growth parameters

Results shown in Table 4 clearly indicate that vegetative growth parameters (plant height, number of branches, leaf area and number of leaves per plant) and chlorophyll readings were significantly affected by application the mixtures of bio and organic fertilizers. The treatments of Vermi + PSB + VAM and Vermi + Azoto + Azos + PSB + VAM significantly increased plant height, number of branches, number of leaves per plant, and chlorophyll reading in the two seasons, in addition to leaf area in the second season as compared to the chemical fertilization(control). Moreover, the treatment of Vermi + Azoto + Azos + PSB + VAM recorded the highest significant mean values. Likewise, the treatments of Vermi + Azoto + Azos + PSB and Vermi + Azoto + Azos +VAM also significantly enhanced the values of leaf area, number of branches per plant and chlorophyll content, while Vermi + PSB showed the highest mean value of chlorophyll content in both seasons. On the contrary, using Vermi alone significantly exhibited lower mean values of plant height, number of branches and number of leaves per plant as compared to chemical fertilization. Also, a similar reduction effect was noticed due to Vermi + PSB on plant height and number of leaves and Vermi + Azoto + Azos on plant height in the first season.

Leaf's chemical contents

Results listed in Tables 5 and 6 show the effect of organic and bioorganic fertilization on macro- and microelements contents in tomato leaves. All treatments significantly increased leaf contents of N, K, Fe, Zn and Mn in both seasons as compared with chemical fertilization (control). Leaf's Ca content was significantly increased in all treatments except for Vermi treatment in the second season as compared with chemical treatment, while leaf's Mg content was significantly increased as a result of Vermi + VAM, Vermi + Azoto + Azos + VAM, Vermi +PSB + VAM and Vermi + Azoto + Azos + PSB +VAM in the second season. Resulted, also, revealed that the treatments of Vermi + VAM, Vermi + Azoto + Azos + VAM, Vermi +PSB + VAM and Vermi + Azoto + Azos + PSB +VAM recorded the highest contents of Zn and Mn. Mixtures of Vermi + VAM and Vermi + Azoto + Azos + VAM recorded the highest leaf contents of Fe. Furthermore, all other mixture treatments exceptthe Vermi treatment increased B in the first season.

Tomato flowering, yield and its components

Results in Table 7 indicate that using the mixtures Vermi + PSB + VAM and Vermi + Azoto + Azos + PSB + VAM delayed flowering in the second season. In contrast, the application of mixtures of Vermi + Azoto + Azos + PSB, Vermi + Azoto + Azos +VAM, Vermi + PSB + VAM, Vermi + Azoto + Azos + PSB + VAM were superior and resulted in remarkable increase

TABLE 4. Effect of bio- and organic fertilization treatments on vegetative growth characters and chlorophyll readings of tomato plants 60 days after transplanting in the summer seasons of 2019 and 2020.

Treatments	Plant height (cm)	Number of branches	Leaf area (cm^2)	Number of leaves	SPAD readings
			2019 season		
Chem Fert	62.68 b	5.79 b	79.21d	60.88 abc	47.73 c
Vermi	50.85 de	4.53 c	78.68 d	50.95 e	37.80 d
Vermi + PSB	48.68 e	5.79 b	81.71 cd	53.35 de	55.45 ab
Vermi + VAM	57.08 c	6.37 b	81.80 cd	56.10 cde	54.72 ab
Vermi + Azoto + Azos	51.66 d	6.09 b	86.84 ab	56.42cd	52.19 bc
Vermi + Azoto + Azos + PSB	56.17 c	8.32 a	85.49 abc	57.42 bcd	56.13 ab
Vermi + Azoto + Azos +VAM	61.84 b	7.70 a	87.56 ab	59.95 abc	57.87 a
Vermi + PSB + VAM	67.50 a	7.84 a	83.16 bcd	62.32 ab	56.11 ab
Vermi + Azoto+ + Azos + PSB + VAM	68.71 a	8.13 a	87.87 a	63.31 a	58.88 a
			2020 season		
Chem Fert	62.19 bc	6.98 cd	81.21 c	59.59 bc	49.94 c
Vermi	52.92 de	4.84 e	80.34 c	51.24 e	41.12 d
Vermi + PSB	51.38 e	6.13 d	82.13 bc	52.71 de	57.41 ab
Vermi + VAM	55.05 cde	7.08 bc	82.34 bc	60.34 bc	55.34 bc
Vermi + Azoto+ Azos	58.17bcde	6.81 cd	87.00 a	56.76 cd	54.74 bc
Vermi + Azoto + Azos + PSB	60.76 bcd	8.59 a	86.12 ab	61.54 bc	58.25 ab
Vermi + Azoto + Azos +VAM	64.40 b	7.96 ab	88.30 a	62.37 b	58.99 ab
Vermi + PSB + VAM	74.27 a	8.01 a	88.19 a	64.42 ab	56.89 ab
Vermi + Azoto + Azos + PSB + VAM	75.07 a	8.77 a	90.06 a	68.00 a	61.70 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

TABLE 5. Effect of bio- and organic fertilization treatments on leaf's macro elements content of tomato plants 60 days after transplanting in the summer seasons of 2019 and 2020.

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
			2019 season		
Chem Fert	1.14 c	0.31 c	1.64 e	0.21 a	0.38 b
Vermi	1.37 b	0.35 bc	1.98 bc	0.21 a	0.41 ab
Vermi + PSB	1.5 ab	0.40 ab	2.02 bc	0.24 a	0.42 ab
Vermi + VAM	1.36 b	0.39 ab	1.88 cd	0.21 a	0.43 ab
Vermi + Azoto + Azos	1.63 a	0.4 a	1.74 de	0.23 a	0.42 ab
Vermi + Azoto + Azos + PSB	1.41b	0.41 a	2.02 bc	0.22 a	0.40 ab
Vermi + Azoto + Azos +VAM	1.52 ab	0.41 a	2.11 ab	0.22 a	0.43 ab
Vermi + PSB + VAM	1.48 ab	0.43 a	2.2 a	0.23 a	0.43 ab
Vermi + Azoto+ + Azos + PSB + VAM	1.54 ab	0.44 a	2.13 ab	0.23 a	0.44 a
			2020 season		
Chem Fert	1.06 e	0.3 c	1.53 f	0.19 b	0.37 b
Vermi	1.22 d	0.33 c	1.8 de	0.22 ab	0.41 ab
Vermi + PSB	1.43 bc	0.43 ab	2.08 bc	0.25 a	0.41 ab
Vermi + VAM	1.41 c	0.40 b	1.95 cd	0.23 a	0.43 a
Vermi + Azoto+ Azos	1.67 a	0.4 b	1.68 ef	0.23 a	0.41 ab
Vermi + Azoto + Azos + PSB	1.44bc	0.40 b	1.98 bcd	0.23 a	0.41 ab
Vermi + Azoto + Azos +VAM	1.54 b	0.43 ab	2.08 bc	0.23 a	0.43 a
Vermi + PSB + VAM	1.51 bc	0.44 ab	2.31 a	0.24 a	0.44 a
Vermi + Azoto + Azos + PSB + VAM	1.55 ab	0.46 a	2.18 ab	0.24 a	0.44 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

TABLE 6. Effect of bio- and organic fertilization treatments on leaf's micro elements content of tomato plants 60 days after transplanting in the summer seasons of 2019 and 2020.

Treatments	Fe (ppm)	Zn (ppm)	B (ppm)	Mn (ppm)
		2019 season		
Chem Fert	116.64 f	65.01 c	19.94 b	211.28 c
Vermi	125.69 e	81.81 b	22.85 ab	265.88 b
Vermi + PSB	133.42 d	82.14 b	24.48 a	266.95 b
Vermi + VAM	153.27 ab	94.68 a	23.70 a	307.71 a
Vermi + Azoto + Azos	145.60 bc	82.95 b	23.85 a	269.58 b
Vermi + Azoto + Azos + PSB	140.29 cd	85.59 b	23.40 a	278.16 b
Vermi + Azoto + Azos +VAM	156.41 a	94.17 a	24.74 a	306.05 a
Vermi + PSB + VAM	140.61 cd	97.5 a	25.37 a	316.87 a
Vermi + Azoto+ + Azos + PSB + VAM	143.24 c	95.34 a	24.76 a	309.85 a
		2020 season		
Chem Fert	112.85 f	62.19 d	18.81 b	215.79 d
Vermi	124.45 e	82.95 c	22.51 a	287.83 c
Vermi + PSB	139.71 d	86.25 c	24.89 a	299.28 bc
Vermi + VAM	157.65 ab	98.64 a	24.33 a	342.28 a
Vermi + Azoto+ Azos	152.02 bc	82.47 c	23.93 a	286.17 c
Vermi + Azoto + Azos + PSB	144.68 cd	89.46 bc	23.91 a	310.42 b
Vermi + Azoto + Azos +VAM	166.43 a	97.77 a	24.79 a	339.26 a
Vermi + PSB + VAM	149.14 bcd	95.16 ab	24.61 a	330.20 a
Vermi + Azoto + Azos + PSB + VAM	152.81 bc	97.71 a	25.13a	339.05 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

TABLE 7. Effect of bio and organic fertilization treatments on flowering, yield and its components of tomato plants in the summer seasons of 2019 and 2020.

Treatments	Days to 50% flowering	Number of fruits/plant	Fruit yield/ plant (kg)	Fruit yield/ feddan (ton)
		2019 season		
Chem Fert	38.05 abc	75.12 e	8.02 c	36.99 de
Vermi	37.71 bc	72.82 e	6.61 d	30.71 f
Vermi + PSB	37.42 bc	81.02 d	7.65 c	35.89 e
Vermi + VAM	38.71 ab	87.98 c	8.09 c	38.91 cd
Vermi + Azoto + Azos	36.49 c	73.76 e	7.37 cd	35.49 e
Vermi + Azoto + Azos + PSB	36.43 c	91.56 bc	9.74 ab	39.75 bcd
Vermi + Azoto + Azos +VAM	37.85 bc	91.68 bc	9.30 b	40.36 bc
Vermi + PSB + VAM	39.77 a	95.22 b	9.67 ab	41.98 b
Vermi + Azoto+ + Azos + PSB + VAM	38.75 ab	99.94 a	10.47 a	45.35 a
		2020 season		
Chem Fert	39.19 bcd	77.14 d	7.72 bcd	37.81 cd
Vermi	38.89 cd	72.08 d	6.76 d	30.28 e
Vermi + PSB	39.37 abcd	85.22 c	8.23 bc	41.21 bc
Vermi + VAM	41.48 abc	93.54 b	8.91 b	45.21 ab
Vermi + Azoto+ Azos	40.62 abc	76.5 d	7.16 cd	36.48 d
Vermi + Azoto + Azos + PSB	35.55 d	96.8 ab	11.15 a	45.96 a
Vermi + Azoto + Azos +VAM	43.38 ab	98.06 ab	10.26 a	46.93 a
Vermi + PSB + VAM	43.67 a	101.36 a	10.48a	47.33 a
Vermi + Azoto + Azos + PSB + VAM	43.62 a	102.56 a	11.07 a	48.03 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

TABLE 8. Effect of bio- and organic fertilization treatments on physical characters of tomato fruits in the summer seasons of 2019 and 2020.

Treatments	Average fruit weight (g)	Polar diameter (mm)	Equatorial diameter (mm)	Firmness (lb/in^2)
		2019 season		
Chem Fert	106.73 a	6.64 a	5.11 cde	2.17 b
Vermi	90.74 b	4.96 c	4.76 de	2.20 ab
Vermi + PSB	94.38 b	5.65 b	5.31 bc	2.19 ab
Vermi + VAM	91.91 b	5.04 c	4.6 e	2.18 ab
Vermi + Azoto + Azos	91.26 b	4.99 c	4.91 cde	2.27 ab
Vermi + Azoto + Azos + PSB	106.34 a	6.96 a	6.14 a	2.20 ab
Vermi + Azoto + Azos +VAM	106.4 a	5.78 b	5.70 ab	2.17 b
Vermi + PSB + VAM	105.53 a	5.32 bc	5.16 cd	2.31 a
Vermi + Azoto+ + Azos + PSB + VAM	106.78 a	6.69 a	5.82 ab	2.20 ab
		2020 season		
Chem Fert	106.99 ab	6.68 ab	5.88 c	2.45 a
Vermi	91.26 e	5.55 c	4.73d	2.40 a
Vermi + PSB	96.59 de	6.04 bc	6.28 bc	2.31 a
Vermi + VAM	97.93 cde	5.92 bc	6.34 bc	2.32 a
Vermi + Azoto+ Azos	94.25 e	5.73 c	5.83 c	2.37 a
Vermi + Azoto + Azos + PSB	113.18 a	6.59 ab	7.05 a	2.40 a
Vermi + Azoto + Azos +VAM	104.65 bc	6.89 a	6.56 ab	2.45 a
Vermi + PSB + VAM	103.35 bcd	6.67 ab	6.50 ab	2.33 a
Vermi + Azoto + Azos + PSB + VAM	107.9 ab	7.33 a	6.87 ab	2.32 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

in yield traits, i.e., number of fruits/plant, fruit yield/plant and fruit yield/feddan as compared to chemical fertilization. Also, using Vermi + PSB and Vermi + VAM led to a significant increase in number of fruits/plant. On the other hand, applying Vermi alone revealed significantly lower values of fruit yield/plant in the first season and fruit yield/feddan in both seasons as compared to chemical fertilization.

Physical and chemical measurements of tomato fruits.

As shown in Table 8, Vermi and Vermi + Azoto + Azos treatments in both seasons and Vermi + PSB and Vermi + VAM in the first season markedly reduced both of average fruit weight and polar diameter, as well as Vermi + PSB and Vermi + VAM mixture in the second season significantly reduced average fruit weight. Reversely, Vermi + Azoto + Azos + PSB, Vermi + Azoto + Azos + VAM and Vermi + Azoto+ + Azos + PSB + VAM in both seasons, and Vermi + PSB + VAM in the second season increased fruit equatorial diameter comparing with chemical fertilization. Vermi + PSB + VAM caused a significant increase in fruit firmness in the first season , while in the second season, all treatments had no significant impact on fruit firmness.

Note: Means with the same letters are not

TABLE 9. Effect of bio and organic fertilization treatments on chemical characters of tomato fruits in the summer seasons of 2019 and 2020.

Treatments	Total sugar (%)	TSS (^{0}Brix)	Titratable acidity (%)	pH	Ascorbic acid (mg /100 g pulp)	ß-carotene (ug\100g F.W)	Lycopene (mg/100 g)
2019 season							
Chem Fert	5.68 d	4.21 f	0.90 a	4.25 a	13.97 f	443.87 a	80.21 f
Vermi	5.44 d	4.67 e	0.88 a	4.26 a	15.26 e	416.75 b	82.48 ef
Vermi + PSB	6.83 c	5.38 cd	0.84 a	4.26 a	15.98 cde	385.68 cd	88.19 de
Vermi + VAM	7.02 bc	5.5 bc	0.81 a	4.26 a	17.28 ab	381.56 cd	87.36 de
Vermi + Azoto + Azos	6.89 c	5.24 d	0.86 a	4.27 a	15.42 de	399.56 bc	97.28 bc
Vermi + Azoto + Azos + PSB	7.44 a	5.80 a	0.81 a	4.27 a	16.35 c	369.93 de	101.73 ab
Vermi + Azoto + Azos +VAM	7.22 ab	5.55 b	0.84 a	4.27 a	16.3 cd	340.68 f	102.73 ab
Vermi + PSB + VAM	7.35 a	5.6 b	0.84 a	4.27 a	16.67 bc	343.31 f	91.86 cd
Vermi + Azoto+ + Azos + PSB + VAM	7.52 a	5.89 a	0.85 a	4.28 a	17.75 a	349.37 ef	105.52 a
2020 season							
Chem Fert	6.62 d	4.36 d	0.91a	4.26 a	13.45 f	456.06 a	81.71 e
Vermi	6.56 d	4.66 d	0.87 a	4.26 a	15.07 e	418.43 b	81.08 e
Vermi + PSB	7.44 b	5.7 bc	0.82 a	4.26 a	15.58 de	393.68 c	86.99 de
Vermi + VAM	7.06 c	5.93 abc	0.84 a	4.26 a	16.99 bc	376.93 c	86.17 de
Vermi + Azoto + Azos	7.19 c	5.45 c	0.85 a	4.28 a	15.74 de	389.56 c	96.07 bc
Vermi + Azoto + Azos + PSB	7.51 ab	6.18 ab	0.81 a	4.28 a	17.13 b	358.06 d	100.48 ab
Vermi + Azoto + Azos +VAM	7.41 b	6.15 ab	0.82 a	4.28 a	15.90 cde	333.18 e	101.11ab
Vermi + PSB + VAM	7.44 b	6.10 abc	0.80 a	4.28 a	16.33 bcd	348.75 de	90.55 cd
Vermi + Azoto + Azos + Azos + PSB + VAM	7.64 a	6.48 a	0.87	4.29 a	18.24 a	336.37 e	104.23 a

Chemical Fertilizer: Chem Fert., Vermi: Vermicompost, PSB: Phosphate dissolving Bacteria, and VAM: Vesicular-arbuscular mycorrhizal, Azoto: Azotobacter, Azos: Azospirillum

significantly different from one another ($p > 0.05$)

Data presented in Table 9 reveal that although the bio-organic fertilizers exhibited lower ß-carotene which was significant in the most cases, but they significantly improved all other fruit chemical traits, namely, Total sugar, TSS, ascorbic acid (vitamin C) and lycopene in both seasons as compared to chemical fertilization. Both pH and titratable acidity were not affected by all bio- and chemical fertilizers in both seasons.

Discussion

Results shown in previous Tables proved that the application of different mixtures of bio-organic fertilizers had a significant effect on plant growth, and fruit yield and quality of tomato. In this respect, comparing to chemical fertilization, the mixture of Vermi + Azoto + Azos + PSB + VAM followed by Vermi + PSB + VAM showed the highest mean values of vegetative growth traits (plant height, number of branches, number of leaves, and leaf area), chlorophyll reading, leaf's macro elements (N, P, K, Mg, and Ca) and all microelement content (Zn, B, and Mn), yield traits, i.e., number of fruits/plants, fruit yield/plant and fruit yield/feddan as well as improved fruit quality, i.e, total sugar, TSS, ascorbic acid (vitamin C) and lycopene. These results may be attributed to the synergic effect of using vermicompost with the biofertilizers. Vermicompost has all macro and microelements needed for plant growth in soluble form, in addition to plant hormones, vitamins and beneficial micro-organisms (Olle, 2019). The presence of macro and microelements in soluble form (Table 3) pushes the growth of the plants. These results were clear in Tables 4 and 5, where using vermicompost alone caused a significant increase in the leaf contents of N, K, Fe, Zn, B, and Mn. The increase in leaf area led to an increase in the contents of chlorophyll in leaves (Table 4). Such increase in chlorophyll contents increases the physiological activity in plant, which leads to a higher number of fruits per plant and consequently a greater fruit yield. In addition, the presence of plant hormones in vermicompost may also participate in stimulating vegetative growth (Bhattacharya and Chattopadhyay, 2002) and increasing fruit setting and consequently the number of fruits per plant.

As shown in the present results, the mixtures of Vermi + Azoto + Azos + PSB + VAM and Vermi + PSB + VAM showed the highest values of all vegetative growth, chlorophyll and mineral contents of leaf, and yield. The role of biofertilizers alone in increasing these treatments is well known (Kumar et al., 2022) *Azotobacter* (Azoto) and *Azospirillium* (Azos) are free-living nitrogen-fixing bacteria that have a marvelous role in stimulating plant growth, not only through the fixing of atmospheric N2, but also through producing stimulating substances such as auxins, cytokinins, gibberellins, amino acids, and vitamins (Nongthombam et al., 2021). Phosphate-solubilizing bacteria (PSB) change soil-insoluble mineral phosphate and organic phosphate-containing compounds to soluble bioavailable form for plants through the secretion of organic acids and hydrolyzing enzymes that mineralize the insoluble mineral phosphates and the phosphorus-containing organic compounds, respectively (Timofeeva et al., 2022). Vascular arbuscular mycorrhizal (VAM) is a root symbiont fungus that provides the host plants with the essential nutrients, for example, N, P, K, Ca, Zn, and S, and consequently improves growth and increases yield under unstressed and stressed conditions (Begum et al., 2019). So, the synergic effect of using vermicompost with the biofertilizers may result from providing the tomato plants, particularly those grown in sandy soil (Table 2) with the essential soluble nutrients from vermicompost, Phosphate-solubilizing bacteria, Vascular arbuscular mycorrhizal, and secreting stimulating substances such as auxins, cytokinins, gibberellins, amino acids and vitamins from vermicompost and *Azotobacter*, beside increasing the performance of the plant under biotic and abiotic stresses. The stimulative effect on yield, mineral content, chlorophyll contents, and yield were previously reported by Nanjundappa et al. (2019), Ziane, et al. (2021), Franczuk et al. (2023) using AVM, Shafi et al. (2019) using *Azotobacter* and *Azospirillum*, Qasim et al. (2023) using Vermi, Mejía-Bautista et al. (2022) using PSB, Lara-Capistrán, et al. (2020), Ahmed et al. (2022) using PSB and Vermi and Reddy et al. (2023) using Azo + Vermi

The treatments of Vermi + Azoto + Azos + PSB, Vermi + Azoto + Azos +VAM, and Vermi + Azoto + Azos + PSB + VAM significantly increased equatorial diameter and significantly improved fruit quality, showing the highest values of total sugar, TSS, ascorbic acid, and lycopene, but they reduced ß-carotene. The present results are in agreement with the previous findings which showed that strawberry plants fertilized with *Azotobacter* at 7 kg/ha produced berries with maximum width, TSS total sugars, and ascorbic acid with minimum titratable acidity in comparison to other treatments (Anurag and Tripathi, 2020). Inoculations with P-solubilizing bacteria and mycorrhizal fungi significantly increased vitamin C in tomato fruits (Chouyia et al., 2022). Mycorrhiza application resulted in significant changes in the total sugar content of pepper fruits (Franczuk et al., 2023). Similarly, using sand: vermicompost (2:1) + *Azotobactor* increased TSS and ascorbic acid in strawberry fruits as compared with sand alone (Reddy et al., 2023). The application of cow vermicompost (Aminifard, 2022) and vermicompost leachate (Cabilovski et al., 2023) led to a significant higher increase in total soluble solids, vitamin C and antioxidant activity, but a lower concentration of total acid of hot pepper and strawberry fruit, respectively. On the other hand, Vermi had no effect on total soluble solids and vitamin C but increased reducing sugar in tomato fruit (Mukta et al., 2015).

Conclusion

Using a mixture consisting of vermicompost at 4 tons/feddan and *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria and arbuscular mycorrhiza for organic tomato production surpassed the manual application of chemical fertilizers at a rate of 165: 60: 75 kg NPK/feddan in total yield by 18.4 and 21.3% in the first and second seasons, respectively. Moreover, this treatment achieved the best fruit quality.

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The author declares no conflict of interest in the publication of this work.

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الاستخدام المتكامل للفيركمبوست والأسمدة الحيوية لتحسين النمو والإنتاجية والمحتوى الغذائي للطماطم المزروعة في ظروف عضوية

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يؤدي استخدام التسميد الكيميائي إلى الحصول على محصول أعلى ، ولكنه يؤثر سلبًا على الخصائص الكيميائية والفيزيائية والبيولوجية للتربة. لذلك ، تعتبر الزراعة العضوية مهمة في العديد من البلدان في جميع أنحاء العالم بما في ذلك البلدان النامية. يهدف العمل الحالي إلى دراسة تأثير التكامل بين استخدام مصدرين عضويين ، وهما السماد الدودي والأسمدة الحيوية ، كبديل للأسمدة الكيماوية ، على نمو وإنتاجية وجودة الطماطم (صنف إليسا F1) المزروعة في مزرعة عضوية. تم تنفيذ العمل الحالي بمحافظة الشرقية في موسمي صيف 2019 و 2020. اشتملت هذه التجربة على تسعة معاملات وهي: 1. سماد كيماوي (Chem Fert) بمعدل 150: 60: 72 كجم NPK / فدان ، 2. الفيركمبوست (Vermi)) بمعدل 4 طن / فدان ، -3الفيركمبوست + البكتريا المذيبة للفوسفات ، -4الفيركمبوست + الميكوريزا، -5الفيركمبوست + الأزوتوباكتر + الأوزسبيرلم ،-6 الفيركمبوست + الأزوتوباكتر + الأوزسبيرلم+ البكتريا المذيبة للفوسفات ، -7الفيركمبوست + الأزوتوباكتر + الأوزسبيرلم+ الميكوريزا،-8 الفيركمبوست + البكتريا المذيبة للفوسفات + الميكوريزا،-9 الفيركمبوست + الأزوتوباكتر + الأوزسبيرلم+ البكتريا المذيبة للفوسفات + الميكوريزا ، أدت معاملات الفيركمبوست + البكتريا المذيبة للفوسفات + الميكوريزا ، الفيركمبوست + الأزوتوباكتر + الأوزسبيرلم+ البكتريا المذيبة للفوسفات + الميكوريزا إلى زيادة كبيرة في ارتفاع النبات وعدد الأفرع ومساحة الأوراق ومحتويات الأوراق من الكلوروفيل و النيتروجين ، الفوسفور و البوتاسيوم و الماغنسيوم ، الحديد و الزنك و البورون و المنجنيز ، و أدت إلى زيادة ملحوظة في صفات المحصول (عدد الثمار / نبات ، محصول الثمار كجم / نبات ، محصول الثمار طن / فدان) ، وتحسين جميع الصفات الكيميائية للثمار (السكريات الكلية ، TSS ، فيتامين C والليكوبين) ، باستثناء البيتا كاروتين ، مقارنة بالسماد الكيميائي

الكلمات المفتاحية: البكتيريا المذيبة للفوسفات ، الفيركمبوست ، + الميكوريزا ، الآزوتوباكتر ، الأوزسبيرلم ، الطماطم ، النمو ، المحصول ، الجودة.