Environment, Biodiversity & Soil Security
http://jenvbs.journals.ekb.eg/

Optimizing *Helianthus tuberosus* Productivity through Microbial Community of Vermicompost and Its Tea Formulations under Soil Affected by Salinity

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THROUGH its life cycle, plants face a number of abiotic and biotic stresses such as salinity stress, it is one of the most environmental factors restraining crops production. *Helianthus tuberosus* is a valuable vegetable crop with rich nutritional and medicinal properties. Therefore, there is an urgent need to search for environmentally safe and sustainable approaches to mitigate the harmful effects of salinity on *H. tuberosus* and improve its production. In this study, we used vermicompost and vermicompost tea to ameliorate salt-induced stress by regulating the soil bacterial community. The current study aims to investigate the effects of vermicompost, different dilutions of vermicompost tea treatments with or without molasses or whey on soil bacteriomes, and *H. tuberosus* (Fuseau genotype) growth, physio-biochemical changes under soil affected by salinity in two-season experiments. The results support our hypothesis that vermicompost tea with different additives leads to an increase in soil bacterial community, significantly enhancing *H. tuberosus* growth and yield components in a concentration-dependent manner. The combination of 20% vermicompost tea with molasses showed the maximum positive effects, followed by the 20% whey vermicompost tea combination on the growth, productivity, and yield quality of *H. tuberosus* compared to the other treatments. Positive correlations were observed between tuber fresh weight and most of the studied traits. The findings of this study can offer valuable insights that vermicompost tea could be utilized for optimizing *H. tuberosus* cultivation under salinity stress, aiding in the development of effective strategies to enhance crop productivity and mitigate the negative impacts of salinity on agricultural systems.

Keywords: sustainable agriculture; Total count; molasses; whey; soil bacterial.

1. Introduction

Helianthus tuberosus L. is a perennial plant native to North America that is also known as Jerusalem artichoke, sunroot, topinambour, sunchoke, or earth apple. It belongs to the Asteraceae family. It is a vegetable with medicinal properties, bioactive chemicals may as use a potential novel treatment for Alzheimer's disease (Zhu et al., 2023). Its tubers were consumed fresh, stewed or they were added as flour in food products to enhance their functional properties (Yan *et al*., 2022; Petkova *et al*., 2014). It has a tall stem, large foliage, and bright yellow bloom; it looks similar to a sunflower (above ground) and a potato (underground). *H. tuberosus* produces a lot of fleshy tubers a ginger-like semblance (Yuan *et al*., 2012; Nair *et al*., 2010). It has lately received a lot of attention due to its favorable properties, such as high productivity and elevated growth rate with minimal fertilizer requirements (Kotsanopoulos *et al*., 2019). Also, it is may make a large contribution in meeting the growing future challenges for bioenergy production (Kotsanopoulos *et al*., 2019; Paixão *et al*., 2018; Long *et al*., 2016).

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Received: 25/12/2023; Accepted: 29/12/2023
DOI: 10.21608/JENVBS.2023.258248.1236

Despite *H. tuberosus* is not identified as a commercial plant species that is widely farmed, it is emerging as a product that is gaining popularity in recent years due to its great adaptability, relatively easy culturing, and high inulin level. It has a number of advantageous characteristics over traditional agricultural crops, including high growth rate, good tolerance to frost, drought, salinity and it can grow well in barren, poor-quality land (Li *et al*., 2013; Gao *et al*., 2011). *H. tuberosus* is a promising vegetable crop, which is recently introduced to Egypt. The plant can grow in almost all type of soil and therefore suitable for cultivation in the new lands in Egypt for local marketing or export (Fatih *et al*., 2020; Moustafa *et al*., 2018).

Salinity is the main stress that affect plants' life throughout the world (Nazari *et al.*, 2019)., salinity will affect approximately 50% of arable lands globally by 2050. Currently, traditional approaches are not well suited to research trial to control salinity problems (Omer, 2021). Traditional management techniques of agroecosystems are mainly based on the addition of nutrients and water to compensate for nutritional deficiencies, and not on the removal of accumulated salts. This exacerbates soil problems caused by salinization associated with fertilization (Santoni *et al.*, 2022). Therefore, modern salinity management techniques such as vermicomposting not only have minimal environmental impact but also foster robust plant growth. Consequently, these strategies show great promise in terms of concurrently mitigating salinity and augmenting plant productivity.

Vermicomposting represents a novel eco-friendly approach to mitigating both biotic and abiotic stresses on plants (Omer, 2021). The utilization of specific earthworms (such as *Eisenia foetida sp*.) in the conversion of solid waste into nutrient-rich organic compost holds the potential to effectively boost both plant health and fertility (Yuvaraj, 2021). A study conducted by Aboelsoud and Ahmed (2020) demonstrated that vermicomposting exhibited superior efficacy compared to biochar and polymer in alleviating the adverse effects of drought stress on maize and wheat plants. Furthermore, Rashed and Hammad (2023) concluded that the negative attributes of soil affected by salinity can be remedied through the simultaneous implementation of compost tea as a foliar application. Application of compost and foliar sprays (compost tea) had positive effect on plant growth (Omara and Farraga 2022). El-banna *et al* (2021) have documented that vermiwash contains beneficial microorganisms and hormones that promote plant growth, such as indole acetic acid, gibberellic acid, and humic acid. These substances contribute to the advancement of plant development and prevention infections. Beneficial microorganism-s, such as nitrogen-fixing bacteria, possess the capability to mitigate the detrimental impact of salt stress on wheat plants and augment productivity, as noted by El-Akhdar *et al* (2019).

However, the effectiveness of microorganisms and their activity and survival after application to the rhizosphere cannot usually be guaranteed. This is because the effective functioning of microorganisms depends on many environmental factors such as soil type, aeration, pH, water availability, temperature, and cultivated species. It depends on Pesticide application, the interaction of bacterial communities, and plant growth stages (Tabassum *et al*., 2017). When introduced into the soil as "biofertilizers", microbial densities often decrease rapidly because these bacteria are not adapted to soil conditions and cannot compete with other rhizosphere microorganisms for organic carbon energy sources (Ali *et al*., 2019). The development of organic nutrient solutions that use organic materials in combination with microorganisms that can mineralize nutrient ions before contacting the rhizosphere will ensure both plant nutrient availability and phytonutrient availability.

Nowadays gradual deficiencies in soil organic matter, reduced yield of crop, and quality are alarming problems in Egypt. So, in this study, we conducted a field experiment to evaluate the impact of vermicompost and vermicompost tea application on *H. tuberosus* crop performance and bacterial community structure.

2. Materials and Methods

2.1. Experiment site and study design

Experiments were conducted at Sakha Horticulture Research Station, Kafr El-Shaikh Governorate, North Delta, Egypt during the two summer seasons of 2020 and 2021. The location altitude is about 6 meters above the sea level, 31.094059◦ N, 30.933899◦ E. The soil physicochemical and biological properties were measured in soil analysis laboratory and the results are presented in Table 1, while the chemical specification of the vermicompost treatments are reported in Table 2. The experiments were set up in randomize complete block design (RCBD) with three replications.

Table 1. Average values of some physicochemical and biological properties of the experimental site during the two cropping seasons.

Soil depth (cm)	Soil physical properties							
	Soil moisture characteristics				Particle size distribution (g kg^{-1})			
	F.C (%)	W.P. (%)	A.W (%)	B.D. (kg m^{-3})	Sand	Salt	Clay	Soil texture
0-20	44.11	22.01	22.10	1.29	173.1	255.1	571.8	Clayey
20-40	40.52	20.28	20.24	1.31	188.5	247.6	563.9	Clayey
	Soil chemical properties							
Soil depth (cm)	pH	EC (dS m^{-1})	ESP (%)	CEC (cmolc kg^{-1})	OM (g kg^{-1})	$CaCO_3$ (g kg^{-1})		
0-20	8.17	6.70	14.75	37.15	17.8	27.8		
20-40	8.20	7.61	16.90	36.10	16.4	26.9		
	Soil biological properties (cfu g^{-1} dray weight soil)							
Soil depth (cm)	TCB		TCF		TCA			
0-20	123×10^6		71×10^4		67×10^5			

F.C.: Field Capacity**; W.P.:** Wilting Point; **A.W.**: Available Water; **B.D.**: Bulk Density; **pH**: was determined in soil water suspension (1:2.5); **EC**: was determined in saturated soil paste extract; **ESP:** Exchangeable Sodium Percent; **CEC:** Cation Exchange Capacity; **OM**: Organic Matter; **TCB**: Total count of bacteria; **TCF**: Total count of fungi; **TCA**: Total count of actinomycetes.

Table 2. The physical and chemical characteristics of the vermicompost (VC) and the vermicompost tea (VCT).

Parameters	*VC*	*VCT*	*VCT + molasses*	*VCT + whey*
pH	7.5	9.06	8.5	6.2
EC (ds m-1)	10.6	9.95	9.18	8.93
Organic matter (%)	39.84	12.3	8.5	12.54
Organic carbon (%)	11.51	4.23	1.25	3.65
Total nitrogen (%	1.8	1.6	1.9	1.3
Total phosphorus (%)	1.2	1.00	1.3	1.1
Total potassium (%	1.4	0.77	0.81	0.79
Sodium %	0.9	0.8	0.7	0.5
Calcium%	1.8	2.3	4.0	3.4
Magnesium %	0.6	0.8	1.0	0.5

2.2. Preparation of vermicompost tea formulations.

Vermicompost (obtained from Central Laboratory for Agricultural Climate, Agriculture Research Center, Giza, Egypt) was used for the production of vermicompost tea. Vermicompost was mixed with chlorine-free water in a ratio of 1:10 (w/v) in polyethylene non-degradable 10 L containers at room temperature (25 ºC). Molasses and whey were added as nutritious (carbon sources) for beneficial microorganisms. A small air pump was employed to inject air into the water, promoting aerobic conditions. The system was operated for 30 hours until the solution color turned into dark brown. Various concentrations of vermicompost teas at 10% and 20% were utilized with distilled water serving as the control treatment.

2.3. Experimental procedures

H. Tuberoses of "Fuseau" cultivar were obtained from the Vegetative Propagated Vegetables Department, Agricultural Research Center, Giza, Egypt. Tubers were planted in April^{1st} in both seasons.

The impact of employing two different concentratio-ns (10% and 20%) of vermicompost tea as a soil drench at various growth stages (15, 30, and 45 days) with a rate of 100L/feddan was examined. All treatments were divided into plots each plot (3x3.5 m) consisted of rows (70 cm apart) were planted in the middle of each row (40 cm apart). Normal agricultural practices were adopted as recommended. The harvest process started after the appearance of maturity signs (November 15th). In addition to control, seven treatments were made as follows: T1 Control (water only), T2 (Vermicompost at 1.5 ton/fed), T3 (20% Vermicompost tea), T4 (20% Vermicompost tea + molasses), T5 (20% Vermicompost tea + whey), T6 (10% Vermicompost tea), T7 (10% Vermicompost tea + molasses) and T8 (10% Vermicompost tea + whey).

2.4. Data enrollment

2.4.1. Vegetative growth and yield components

Plant height (cm), No. of main stem plan^{-1}, leaf area (cm^2) and leaf dray matter (%) were recorded before blooming and when plants were fully vegetative grown. At harvesting time, five plants were chosen randomly and pulled out from each plot and divided into shoots and tubers. Tubers were washed in tap water to remove soil particles to record following traits: Tubers number plant^{-1}, average tuber weight (g), total yield plant (kg), tuber dray matter (%) and weight loss (%) calculated as follow:

Weight loss % = (Initial weight - Final weight/ Initial weight) x100

2.4.2. Physiological and biochemical determinations

Total chlorophyll content (mg g^{-1} FW) was determined according to Moran (1982). Total nitrogen in tuber was determined according the methods described by Chapman and Pratt (1962). Total phosphorus and potassium in tubers were determined according to Jackson (1973**)**. Total protein was determined using the calculation of total nitrogen by multiplying 5.7 (A. O. A. C., 2005). Total carbohydrate was determined according the methods described by Dubois et al., (1956). Inulin content was determined in tubers according to the method of Winton and Winton (1958).

2.4.3. **Collection and analysis of soil sample**

Rhizosphere soils were sampled at three periodic growth stages at vegetative, flowering and harvesting. The samples were collected by taking the soil attached with roots of *H. tuberosus* plants by uprooting the plants carefully. The root samples along with adhering soil were stored at 4°C and used for further studies. These samples were used for analysis of total bacteria (TB), nitrogen fixing bacteria (N FB), phosphate solubilizing bacteria (PSB) and Potassium solubilizing bacteria (KSB) population. TB, NFB, PSB and KSB population were determined by serial dilution plate count technique (Thompson, 1989; Diaz-Ravina *et al*, 1993). The numbers of TB were determined by nutrient agar medium. The phosphates solubilizing bacteria grown on Pikovskaya medium plates (Gaur, 1981). Azospirillum grown on Okon medium plates (Okon, 1977) and Ash manitol agar plates, for Azotobacter (Rao, 1994). The number of bacteria colonies was estimated after 1 week of incubation at 28° C. KSB are enumerated by serial dilution plate method using modified Aleksandrov medium (Meena *et al*., 2015).

2.5. Statistical analyses

The significantly differed means were compared using Duncan's Multiple Range Test (1955) at a 5% probability level (P < 0.05) using COSTAT software. The final results are shown as mean values with standard deviations (±SD) from at least three biological replicates in each season. Charts were created in Microsoft Excel 2016. The Pearson correlation coefficients were calculated for the two seasons to investigate the relationship between the studied traits that was visualized by SPSS software (IBM SPSS).

3. Results

3.1. Vegetative growth characteristics

The data pertaining to the effect of vermicompost (VC), vermicompost tea (VCT) and combination of vermicompost tea plus molasses or whey application on the vegetative growth traits of *H. tuberosus* plants are given in Table 3 and Fig.1.

Table 3. Mean performances of the vegetative traits of *H. tuberosus* plants during 2020 and 2021 seasons.

Growth season	Treatments	Plant height (cm)	No. of main stem $plan^{-1}$	leaf area (cm2)
1st season	T1	131.00±1.73 g	2.67±0.58 c	426.66±7.59 d
	T2	162.67±2.52 f	3.33±0.58 bc	526.86±13.59 c
	T3	176.67±2.89 d	4.67±1.53 abc	545.91±10.59 c
	T4	215.67±1.15 **a**	6.00±0.00 a	777.32±35.93 a
	T5	212.33±2.52 a	5.67±0.58 a	742.61±9.49 a
	T6	170.00±3.00 e	4.00±2.00 abc	541.48±36.59 c
	T7	196.67±2.89 b	5.33±1.53 ab	652.50±42.59 b
	T8	190.00±5.00 c	5.00±1.00 ab	649.31±82.42 b
2nd season	T1	133.33±1.15 g	3.17±0.14 e	477.83±8.47 d
	T2	165.17±1.26 f	3.90±0.61 de	589.94±15.28 c
	T3	179.33±3.22 d	4.92±0.84 bcd	611.08±12.03 c
	T4	218.67±0.58 a	6.85±0.00 a	870.45±40.03 a
	T5	214.83±2.84 a	6.45±0.69 ab	831.45±10.30 a
	T6	173.00±3.00 e	4.75±0.28 cde	606.25±41.09 c
	T7	199.00±1.00 b	6.05±1.83 abc	730.95±47.51 b
	T8	193.67±4.04 c	5.65±1.20 abc	727.25±92.49 b

Means within a column followed by the same letter do not differ significantly (P < 0.05) according to Duncan's Multiple Range Test. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC), vermicompost tea (VCT).

Obtained results exhibit clearly that all the studied growth parameters expressed as plant height (cm), number of main stems $plan^{-1}$ and leaf area (cm^2) in Table 3 as well as leaf dray matter percentage in Fig.1 were significantly affected by all treatments consistently in two seasons. Date confirmed that all of the studied growth parameters of *H. tuberosus* plants were significantly increased of all treatments when compared with the control during both seasons of our studies.

It is clear that treatments with combination of 20% VCT plus molasses or whey increased significantly plant height, number of main stem per plant, leaf area and leaf dray matter percentage followed by combination of 10% VCT plus molasses or whey compared to the other treatments during both seasons (Table 3 and Fig.1).

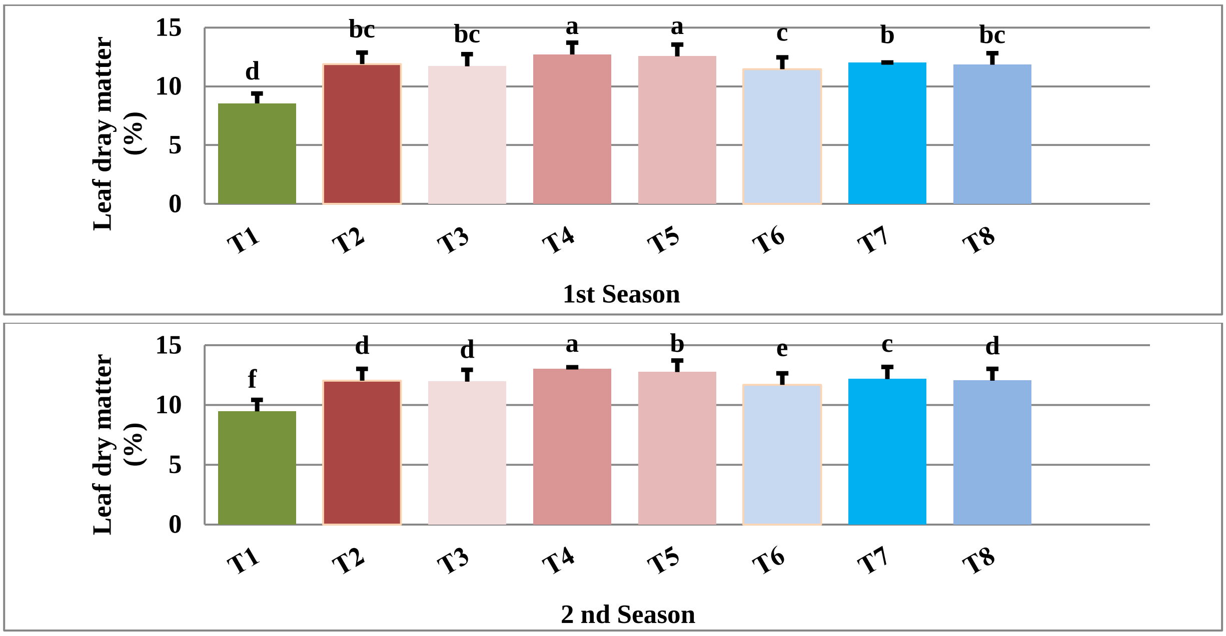


Fig. 1. Mean performances of the leaf dray matter % of *H. tuberosus* plants during 2020 and 2021 seasons.

T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC), vermicompost tea (VCT)

Treatments with VC only, 20% & 10% VCT also produced significantly increased all the studied traits compared to control. No significant difference was found between combination of 20% VCT with molasses or whey for all vegetative growth parameters (Table 3) except leaf dray matter percentage during season two (Fig. 1).

3.2. Yield and tuber characteristics

The results related to the effect of vermicompost (VC), vermicompost tea (VCT) and VCT plus molasses or whey application on the yield and tuber characteristics of *H. tuberosus* plants are given in Table 4 and Fig. 2.

Table 4. Mean performances of the yield and tuber characteristics of *H. tuberosus* plants during 2020 and 2021 seasons.

Growth season	Treatments	No. of tubers plant^{-1}	Total yield plant^{1} (kg)	Average Tuber weight (g)
1st season	T1	50.00±5.00 g	1.07±0.03 f	21.44±1.71 d
	T2	55.67±2.08 f	1.73±0.15 e	31.20±3.46 bc
	T3	66.00±10.00 d	2.20±0.05 de	33.35±1.26 bc
	T4	81.00±10.00 a	4.22±0.08 a	52.71±0.96 a
	T5	79.00±2.65 ab	3.65±0.10 b	46.24±2.19 a
	T6	61.33±1.16 e	1.72±0.21 e	27.97±3.04 cd
	T7	75.33±1.53 b	2.85±0.05 c	37.84±0.61 b
	T8	70.33±0.58 c	2.30±0.83 d	32.69±11.79 bc
2nd season	T1	52.5±5.25 g	1.11±0.09 f	21.39±3.67 d
	T2	58.45±2.19 f	1.88±0.12 e	32.15±2.71 c
	T3	69.30±1.05 d	2.24±0.52 de	32.26±7.42 c
	T4	84.00±1.05 a	4.67±0.06 a	55.56±1.08 a
	T5	82.95±2.78 ab	4.08±0.15 b	49.28±2.90 a
	T6	64.40±1.21 e	1.92±0.21 e	29.74±2.86 c
	T7	79.10±1.60 b	3.21±0.07 c	40.54±0.16 b
	T8	73.85±0.62 c	2.41±0.05 d	32.59±0.95 c

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

Obtained data demonstrated that all the studied yield and tuber characteristics parameters expressed as the number of tubers per plant, total yield per plant, average tuber weight in Table 4 and tuber dray matter percentage and weight loss percentage in Fig. 2 were significantly affected by all treatments during both seasons.

Significant differences were found between the VCT at different dilution rates plus molasses or whey, the diluted VCT only, VC only and control treatments. The results in Table 4 indicate that all treatments improved all yield and tuber characteristics, with different degrees, compared to the control which sprayed with tap water only.

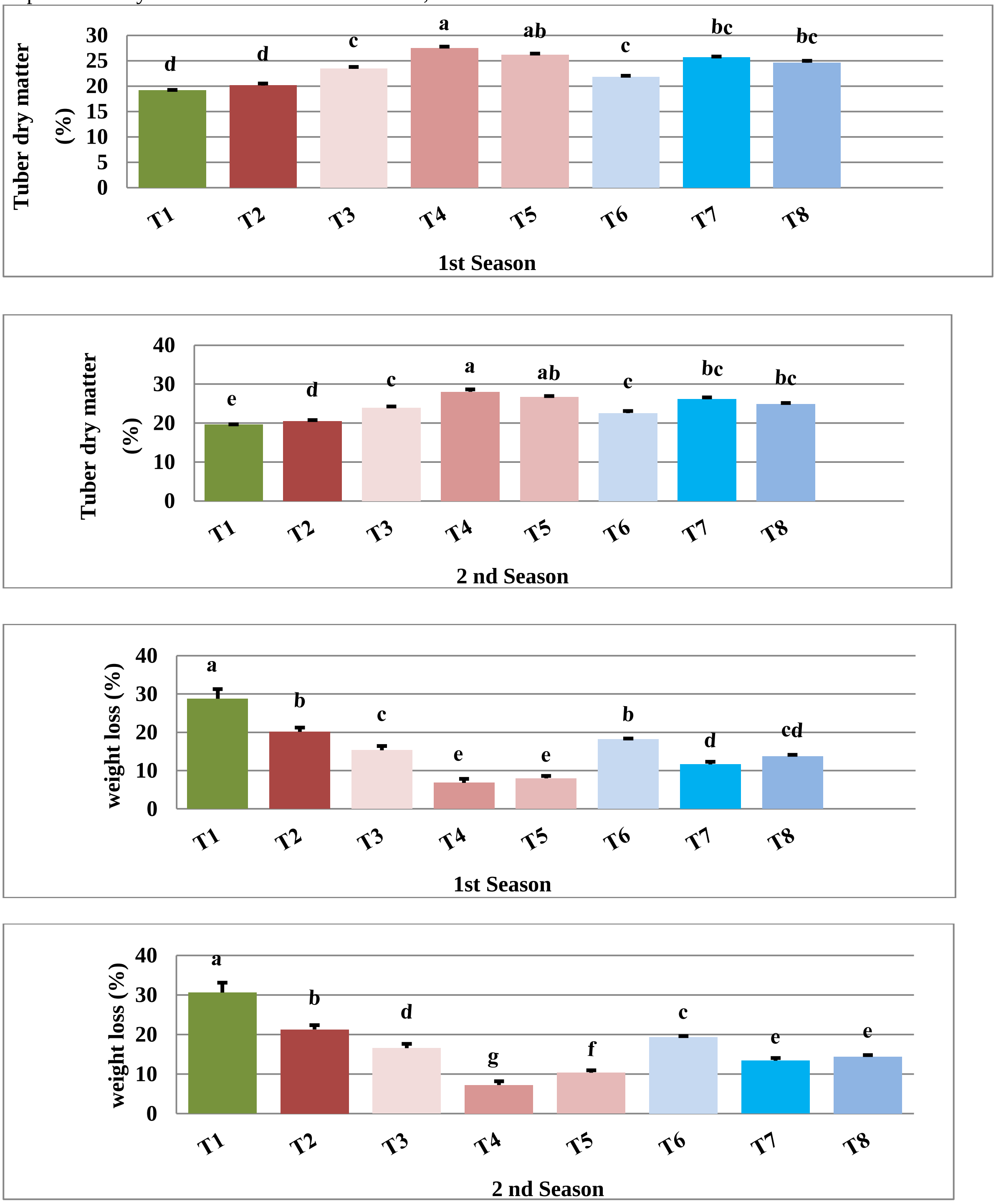


Fig. 2. Mean performances of the tuber dray matter% and weight loss % of *H. tuberosus* during 2020 and 2021 seasons. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

The data outlined in Table 4 point to plants treated with combination of 20% VCT plus molasses or whey gave the highest value of the tubers number per plant, total yield per plant, average tuber weight (Table 4) compared to other treatments during both seasons. Incorporation of VCT with molasses or whey had significant positive effects on traits compared to the control, VC and VCT at different dilution treatments.

Data presented in Figure 2 illustrate the tuber dray matter percent and weight loss percent of *H. tuberosus* tubers as affected by VC and VCT at different dilution with or without molasses or whey treatments. Tuber dray matter percent was significantly increased by the VC and VCT treatments application. All treatments produced significantly increased of tuber dray matter percentage compared to the control. The use of the 20% VCT enriched with molasses followed by 20% VCT enriched with whey significantly increased tuber dray matter percent compared to other treatments and control during two seasons. Concerning to weight loss percentage decreased significantly by the VC and VCT treatments application compared with control. Treatments with 20% VCT plus molasses followed by 20% VCT plus whey produced significantly lowest value compared to the other treatments during the two seasons (Figure 2). Meanwhile treatment with tap water as a control gave the highest value in the two seasons (Fig. 2).

3.3. Physiological and biochemical characteristics

The results in Fig.3 showed the effect of VC, VCT and VCT plus molasses or whey of the total chlorophyll of *H. tuberosus* plants during two growing seasons. Among all the treatments, combination of 20% VCT plus molasses, 20% VCT plus whey and 10% VCT plus molasses showed maximum increase in total chlorophyll. The control treatment showed the minimum value of total chlorophyll consistently in two seasons. No significant difference was found between 10 &20 % VCT plus molasses and 20%VCT plus whey. Also, no significant difference was found the other VC and VCT treatments.

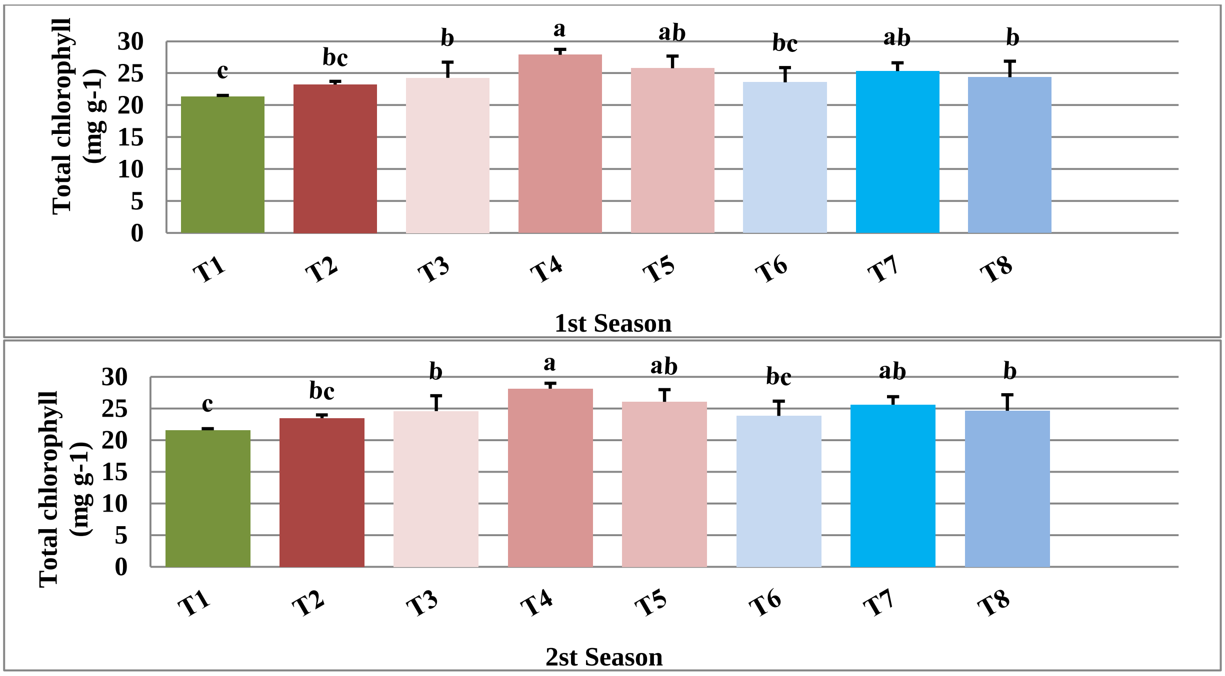
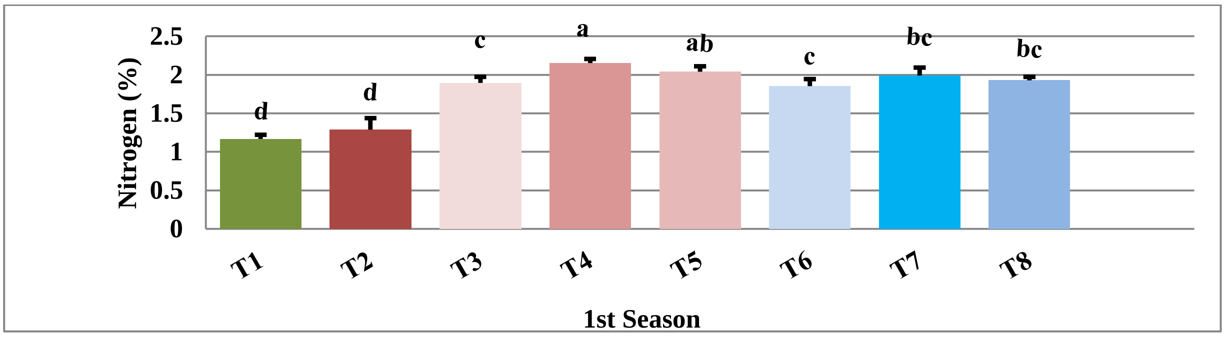


Fig. 3. Mean performances of the total chlorophyll of *H. tuberosus* plants during 2020 and 2021 seasons. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

As regard to the influence of the VC, VCT and VCT with molasses or whey on nitrogen (N %), phosphorus (P %), potassium (K%) and protein contents in *H. tuberosus* tuber, there were significantly affected by all treatment in both seasons (Figure 4). The results of Figure 4 divulged that the use of the VCT at different dilution rates plus molasses or whey and the diluted VCT only or VC only significantly increased the N, P, K and protein content of *H. tuberosus* tubers compared to control during the both seasons. Treatments with combination of 20% VCT plus molasses or whey produced significantly higher values compared to the other treatments during the two seasons.


Nitrogen (%)
2.5
2
1.5
1
0.5
0
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ab
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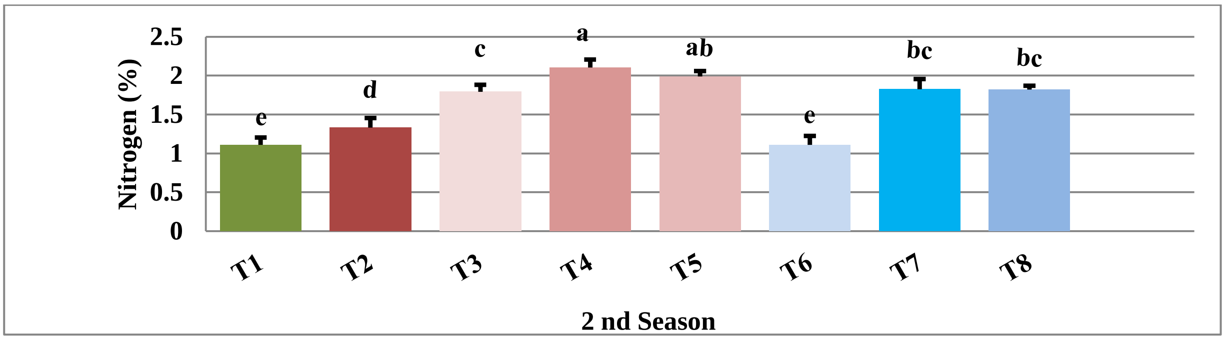
bc
T1
T2
T3
T4
T5
T6
T7
T8
1st Season


Nitrogen (%)
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T5
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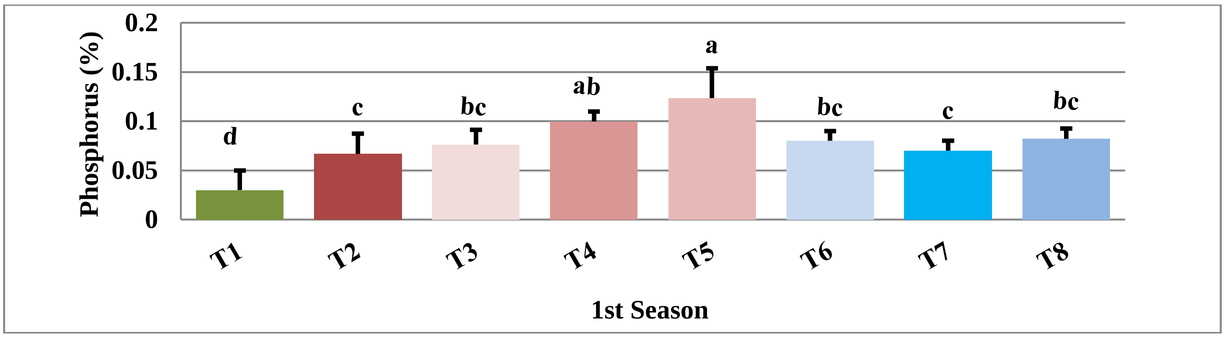
T8
2 nd Season


Phosphorus (%)
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0.15
0.1
0.05
0
d
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T1
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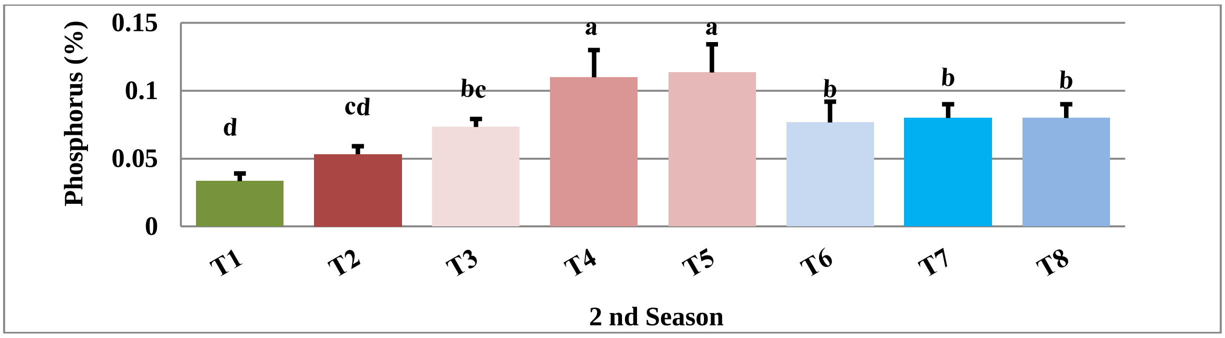
T3
T4
T5
T6
T7
T8
1st Season


Phosphorus (%)
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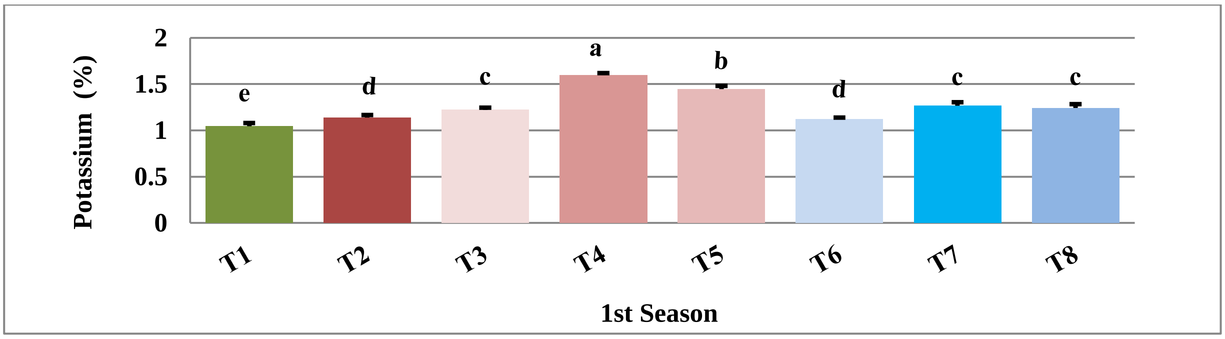
2 nd Season


Potassium (%)
2
1.5
1
0.5
0
e
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c
T1
T2
T3
T4
T5
T6
T7
T8
1st Season

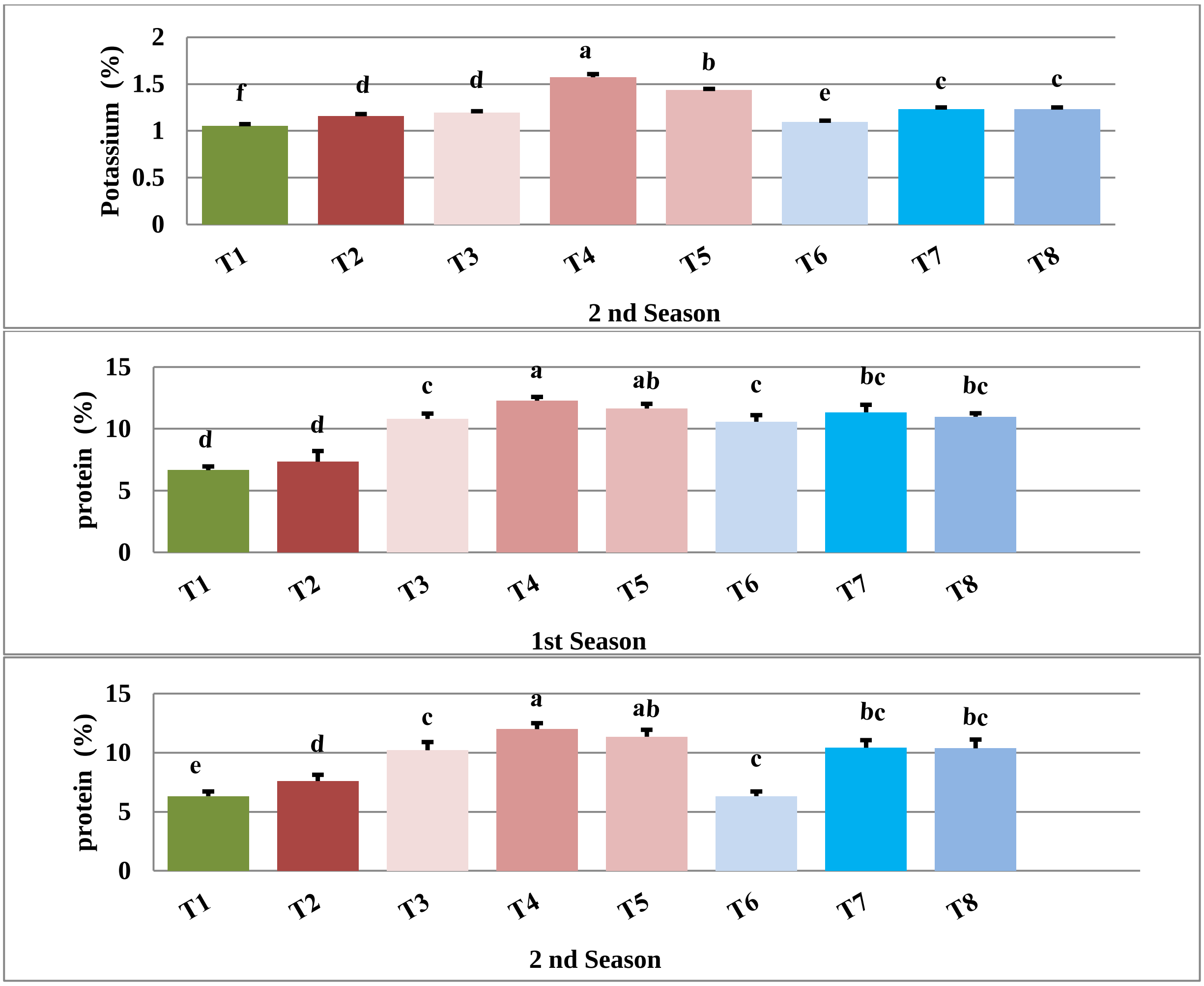
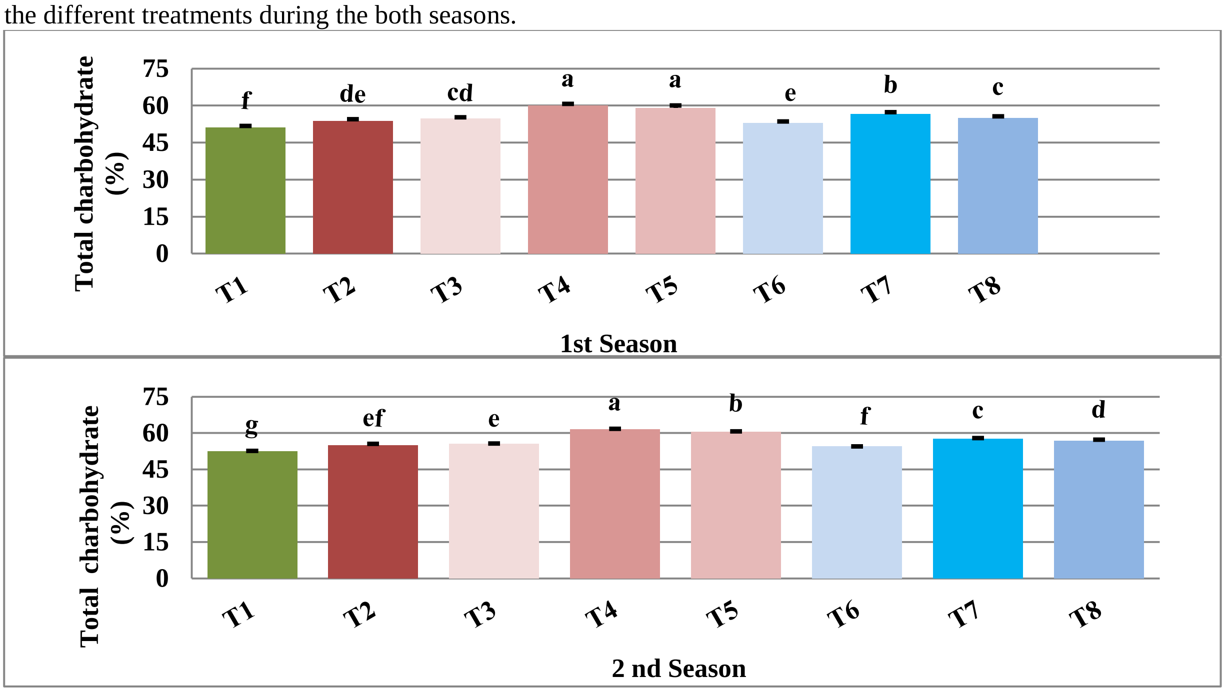


Fig. 4. Mean performances of the N%, P%, K% and protein % of *H. tuberosus* plants during 2020 and 2021 seasons. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

The data of Figure 5 showed that the Total carbohydrate (%) and the Inulin (%) were significantly affected with the different treatments during the both seasons.



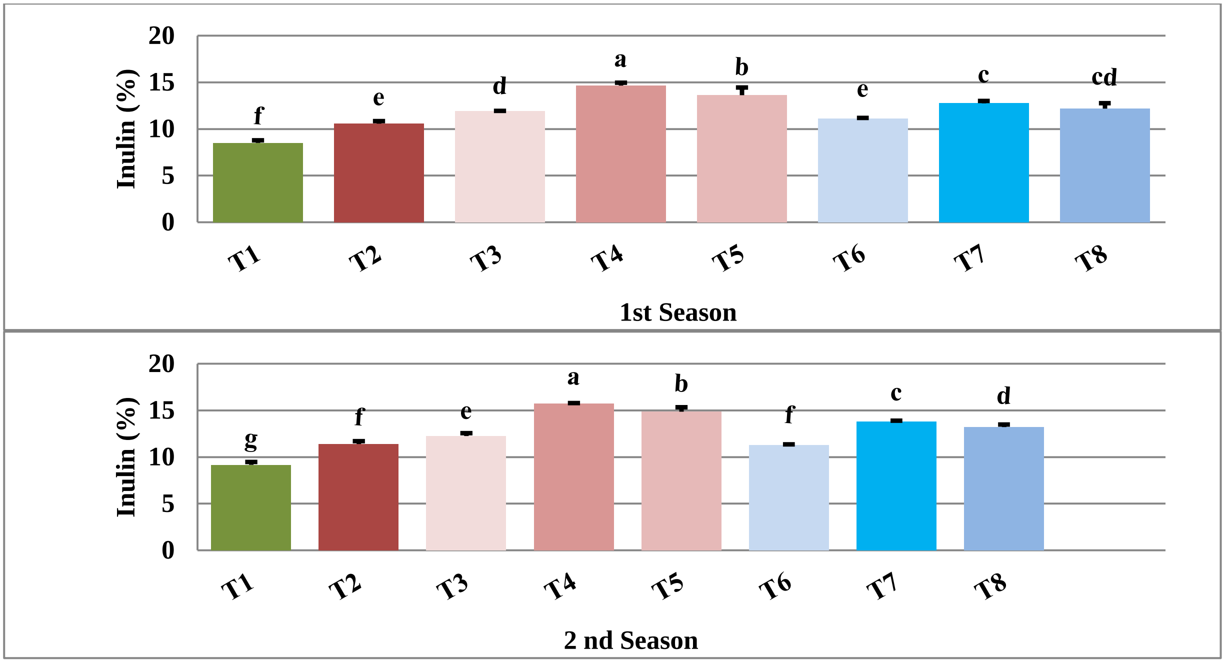


Fig. 5. Mean performances of the Total carbohydrate (%) and the Inulin (%) of *H. tuberosus* tuber during 2020 and 2021 seasons. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

The results revealed that the Total carbohydrate (%) and the Inulin (%) were significantly affected with the different treatments during the both seasons. All Treatments produced significantly increased of the Total carbohydrate and the Inulin content compared to the control. Such results in Figure 5 showed that the Total carbohydrate and the Inulin content of *H. tuberosus* treated with combination of 20% VCT plus molasses increased significantly compared to the all treatments during two growing seasons.

3.4. Microbiological analysis of vermicompost and vermicompost tea

Microbial enumeration unveiled the consequences of additives on altering the quantities of the cultivable communities, as indicated in the Table5 The colony-forming units (CFUs) of bacterial groups in vermicompost tea amended with additives were found to be significantly greater than those observed in the VCT without additive and VC treatment. The number of CFUs of bacteria group in vermicompost tea amended with molasses were significantly higher than that in whey treatment. On the other hand, the population of nitrogen-fixing bacteria was found to be higher than the population of phosphate solubilizing bacteria. The logarithm of total bacterial count ranged between 7.04 to 8.74 inVC M and VCT +molasses, respectively. These effects reflect the importance of adding a carbon source to the VCT to increase the bacterial population.

Table 5. Microbiological analysis of vermicompost and vermicompost tea.

Treatments	TBCs (log CFU g^{-1} dray soil)	Azotobacter (log CFU g^{-1} dray soil)	Azospirillum (log CFU g^{-1} dray soil)	P-solubilizing bacteria (log CFU g^{-1} dray soil)	K- solubilizing bacteria ((log CFU g^{-1} dray soil))
VC	7.05 ^{d}	6.64 ^{d}	6.63 ^{d}	5.07 ^{d}	5.56 ^{c}
VCT	7.66 ^{c}	6.91 ^{c}	6.90 ^{c}	5.57 ^{c}	6.69 ^{b}
VCT+ molasses	8.74 ^{a}	8.13 ^{a}	7.56 ^{a}	5.91 ^{a}	6.89 ^{a}
VCT+ whey	8.05 ^{b}	7.02 ^{b}	7.03 ^{b}	5.72 ^{b}	6.80 ^{a}

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test. vermicompost (VC) , vermicompost tea (VCT)

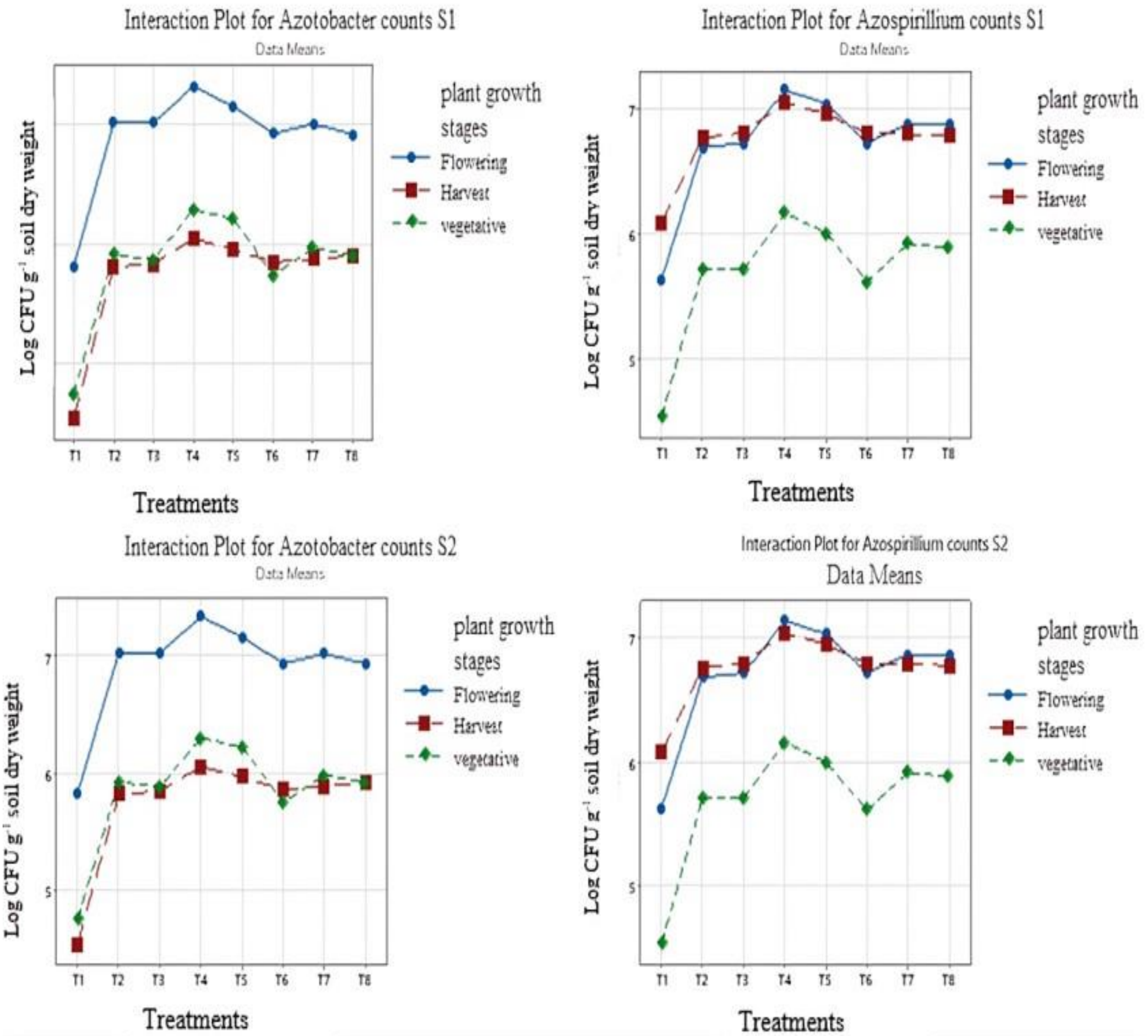
3.5. Soil bacterial communities

To investigate the impact of vermicompost and vermicompost tea on bacterial density, the colony forming unit (CFU) technique was used. The population of the bacterial group in the rhizosphere showed dynamic changes across the different plant growth stages. The analysis presented is exploratory and intended to highlight interactions of potential merit for future investigations. Treatment with VCTs produced significant shifts in the rhizosphere microbial community abundance that contrasted with additives of VCTs. It is reasonable to observe that the total bacterial count demonstrated the highest numerical value among the various groups, while total solubilizing bacteria exhibited the lowest count.

Results detected that total bacterial count, N-fixing, P and K solubilizing bacteria of rhizosphere soil were higher in T5. Comparison of different growth stages of plant indicated that the maximum bacterial community were at the flowering stage followed by vegetative and then harvest stage in all treatments, but Azospirillum has higher counts in flowering and harvest stages.

3.6. Correlation coefficient analysis of variences among the studied traits

According to the statistical analysis of the data on morphophysiological traits, strong and significant correlation was confirmed on all of the studied parameters a 5% probability level, based on the LSD test conducted on combined data of the two season (Table 6). The interacting effect of VC, VCT and combination of VCT plus molasses or whey were significant for all morphophysiological traits at a 5% probability level. There was significant positive correlation between tuber fresh weight, total yield per plant and all the other traits in this study except the weight loss.



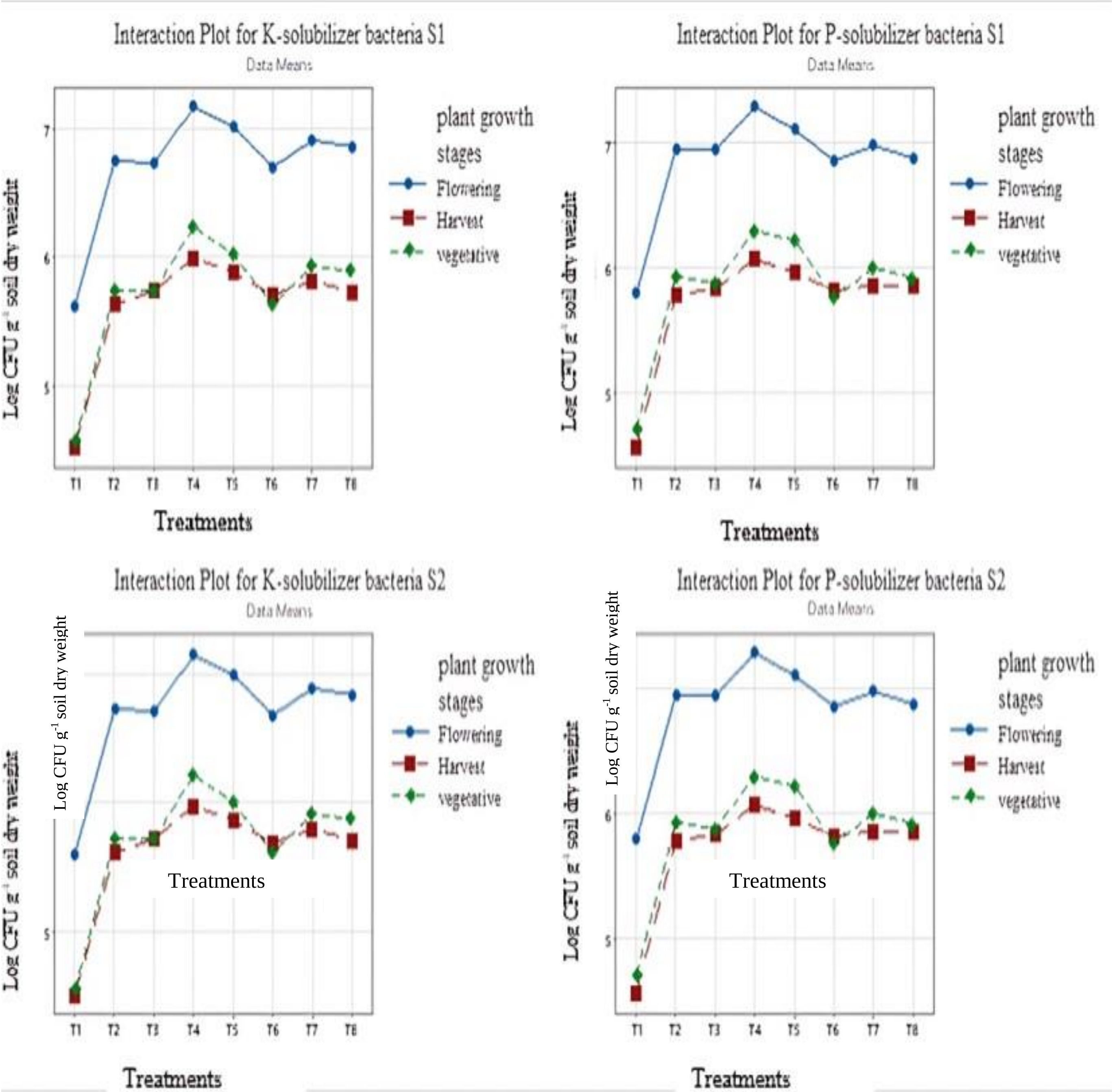


Fig. 6. Effect of different treatments on soil bacterial community at different plant growth stages. T1=Control; T2=VC; T3=20% VCT; T4=20% VCT+ molasses; T5=20%VCT+ whey; T6= 10%VCT; T7= 10% VCT+ molasses; T8=10% VCT+ whey. vermicompost (VC) , vermicompost tea (VCT).

Table 6. Correlation coefficients for parameters measured in of *H. tuberosus* plant cultivation experiment, (combined data of 2020 and 2021).

	Plant height	n. of main stems	leaf area	leaf dray matter	Tubers n. plant-1	Total yield per plant	Tuber fresh weight	Tuber dry matter	N	P	K	Protein	Total carbs	Inulin	Weight loss
Plant height	1														
number of main stems	.83**	1													
leaf area	.95**	.81**	1												
leaf dray matter	.81**	.74**	.74**	1											
Tubers number per plant	.962**	.79**	.91**	.69**	1										
Total yield per plant	.92**	.76**	.91**	.72**	.91**	1									
Tuber fresh weight	.88**	.72**	.86**	.74**	.84**	.98**	1								
Tuber dry matter	.96**	.84**	.92**	.71**	.97**	.92**	.86**	1							
N	.82**	.72**	.73**	.68**	.83**	.76**	.71**	.85**	1						
P	.89**	.71**	.84**	.70**	.80**	.82**	.81**	.81**	.71**	1					
K	.89**	.71**	.90**	.65**	.86**	.96**	.94**	.88**	.69**	.81**	1				
protein	.94**	.83**	.89**	.74**	.94**	.87**	.82**	.97**	.84**	.82**	.84**	1			
Total carbohydrates	.95**	.79**	.94**	.73**	.93**	.97**	.94**	.92**	.75**	.84**	.96**	.88**	1		
Inulin	.99**	.81**	.93**	.78**	.96**	.95**	.92**	.96**	.82**	.86**	.92**	.94**	.961**	1	
Weight loss	-.99**	-.80**	-.92**	-.81**	-.96**	-.91**	-.87**	-.95**	-.84**	-.87**	-.87**	-.94**	-.94**	-.98**	1

4. Discussion

H. tuberosus has gained popularity as a new vegetable appearing in markets over the past few years. This crop is privileged of the carbohydrate inulin rather than starch in its tubers. To improve the quality and storability of *H. tuberosus*. Agricultural soil impacted by salinity is a subject of concern in numerous countries (Otlewska, *et al*., 2020). Among the diverse approaches, vermitechnology facilitated by earthworms remains one of the most effective methods for mitigating the effects of salt stress and augmenting crop yield (Roy and Chowdhury, 2020). The present investigation examined the potential role of vermicompost in alleviating the toxicity of salt by evaluating various parameters associated with alterations in the microbial community, plant growth, yield production, and Physiological parameters.

High-quality commercial vermicompost, appropriate for utilization as an amendment in organic agriculture, was utilized in the production of VCTs infused with whey and molasses. These additives were employed to supply carbon sources, thereby promoting the proliferation of microbial populations in VCTs. The chosen additives displayed unique chemical properties (for example, molasses had a higher pH than whey, which had a higher organic carbon content), which supposedly impacted the quality of the resulting VCTs.

The results indicated that the population of the bacterial group was more prevalent in molasses VCT compared to whey VCT (Table 5), aligning with the findings of Kim *et al*. (2015) who demonstrated a correlation between acidic pH and bacterial population.

By the utilized of organic materials alongside microorganisms that can mineralize nutrient ions before reaching the rhizosphere, both plant nutrient availability and phytonutrient availability can be ensured which is reflected in the increased soil bacterial community after the use of VC and VCTs (Jangra *et al*., 2019). On the other hand, the higher content of nutrients under VC and VCTs application can be related to the stimulation of the activity of beneficial microorganisms, water retention capacity, and gradual release of nutrients during different plant growth stages . The bacterial population differed with the stage of crop growth, higher bacterial population was observed at the flowering stage compared with the other stages (Fig. 6), this could be attributed to a higher degree of plant metabolism activities at the flowering stage, thereby, secreting higher amount of root exudates which act as substrates to microbial population (Mairan and Dhawan, 2016).

Microorganisms are key players in nutrient cycling and acquisition by plants (Bulgarelli *et al*., 2013). These microorganisms can impact their host plants through mechanisms such as nitrogen fixation, production of organic acids, nutrient absorption, and synthesis of vitamins, amino acids, auxins, and gibberellins, all of which promote growth. This was reflected in terms of higher vegetative growth, productivity, tuber quality, and storability of *H. tuberosus* compared to the control as shown in Table 3& 4 and Fig.1 & 2. Total chlorophyll was significantly increased with all VC and VCTs treatments (Fig. 3), which was very obvious due to the higher concentration of K in them. Potassium plays an important role in the biosynthesis of chlorophyll, protein, nucleic acid, and other constituents (Das *et al*., 2018).

VC and VCT treatments increased N, P, K content and carbohydrate percentage (Fig. 4 & 5). These results agree with Basak *et al*., (2013) showed that higher amounts of plant nutrients were continually supplied to *H. tuberosus* through the growing season by the usage of VC and VCT treatments, which facilitated increased N, P, K content and caused better crop nutrition. Furthermore, El-Ghadban *et al*. (2002) noted that organic composts also enhance the carbohydrate percentage and macronutrient content, potentially due to increased root surface area, improved water-use efficiency, and enhanced photosynthetic activity. The addition of vermicom-post and vermiwash increased the growth parameters of potato plants and reduced the impact of salinity stress (Gomez *et al*., 2017). Pant *et al*., (2011) illustrated that the use VC and VCTs improves agricultural output, nutrient quality, and plant health. Amin et al., (2016) showed that the application by VCT with irrigation water can significantly increase onion bulbs yield compared to control.

Our findings demonstrated strong positive correlation between soil bacterial community and vegetative growth, yield, Physiological and biochemical parameters as showed in Fig 7& 8.

The results revealed that the vegetative growth (plant height, number of main stems plan^{-1}, leaf area and leaf dray matter percentage), yield (number of tubers plant^{-1}, total yield plant^{-1}, average tuber weight and tuber dray matter percentage) and N, P, K, protein, total carbohydrate and Inulin contents in *H. tuberosus* tuber increase with increase Soil bacterial communities, in the other hand tuber weight loss decreased.

5. Conclusion

In conclusion, *H. Tuberoses* is a promising and an important crop for the industrial and medicinal sectors. The results of this study indicate that incorporation of vermicompost and vermicompost tea only or combination with molasses or whey enhanced the vegetative growth, yield, physiological and biochemical traits of *H. Tuberoses* plants, also bacterial communities of rhizosphere soil. This study also indicates that vermicompost and vermicompost tea could be utilized effectively for plant production at low input-basis farming. However, further study is essential to identify the plant growth promoting substances in vermicompost and vermicompost tea in order to determine its feasibility in crop production.

Conflicts of interest: There are no conflicts to declare

Acknowledgments: We would like to express our sincere gratitude to our colleagues who played a crucial role in the success of this research. Their invaluable contributions, insights, and collaborative efforts greatly enhanced the quality and depth of our work. We are truly thankful for their support and dedication throughout the research process.

	T.bacterial	Azotobacter	Azospirillum	P-solubilizer	K-solubilizer	Plant height (cm)	n. of main stem plant-1	leaf area (cm2)	total ch.	leaf dry matter %
T.bacterial	1									
Azotobacter	0.8685	1								
Azospirillum	0.8132	0.9903	1							
P-solubilizer	0.8617	0.9995	0.9916	1						
K-solubilizer	0.8255	0.9900	0.9975	0.9908	1					
Plant height (cm)	0.7535	0.9029	0.9110	0.8981	0.9142	1				
n. of main stem pla	0.5545	0.6804	0.7077	0.6834	0.7021	0.8281	1			
leaf area (cm2)	0.7147	0.8105	0.8123	0.8031	0.8191	0.9465	0.8006	1		
total ch.	0.6248	0.6747	0.6838	0.6750	0.6932	0.7420	0.7539	0.7423	1	
leaf dry matter %	0.7769	0.8934	0.8889	0.8942	0.8798	0.8067	0.7380	0.7348	0.7756	1

Fig. 7. Correlation coefficients for soil bacterial communities and vegetative growth parameters measured in of *H. tuberosus* plant cultivation experiment, (combined data of 2020 and 2021).

	T. bacterial	Azotobacter	Azospirillum	P-SB	k- SB	Tubers number p	Total yield	Tuber fresh w.(g)	Tuber D.M. %	N %	P %	K %	protein%	Total charbohydrate %	Inulin %	Wieght loss %
T. bacterial	1															
Azotobacter	0.618	1														
Azospirillum	0.604	0.980	1													
P-solubilizer	0.626	0.998	0.984	1												
k- solubilizer	0.594	0.985	0.997	0.988	1											
Tubers number plant-1	0.647	0.738	0.827	0.760	0.808	1										
Total yield plant-1 (kg)	0.820	0.715	0.776	0.736	0.767	0.912	1									
Tuber fresh W. (g)	0.829	0.730	0.772	0.749	0.769	0.841	0.984	1								
Tuber D.M.%	0.678	0.720	0.810	0.742	0.796	0.973	0.919	0.859	1							
N %	0.710	0.748	0.776	0.759	0.763	0.831	0.762	0.713	0.853	1						
P %	0.722	0.779	0.832	0.784	0.815	0.810	0.822	0.809	0.814	0.712	1					
K %	0.861	0.675	0.724	0.694	0.718	0.857	0.961	0.943	0.876	0.693	0.810	1				
protein%	0.645	0.744	0.821	0.763	0.808	0.939	0.873	0.822	0.970	0.836	0.816	0.839	1			
Total charbohydrate %	0.790	0.744	0.804	0.765	0.798	0.930	0.973	0.940	0.924	0.745	0.843	0.961	0.883	1		
Inulin %	0.743	0.834	0.893	0.849	0.885	0.959	0.952	0.919	0.964	0.823	0.855	0.924	0.937	0.961	1	
Wieght loss %	-0.70	-0.87	-0.93	-0.89	-0.92	-0.96	-0.91	-0.87	-0.95	-0.84	-0.87	-0.87	-0.94	-0.94	-0.98	1

Fig. 8. Correlation coefficients for soil bacterial communities, yield and physiological and biochemical parameters measured in of *H. tuberosus* plant cultivation experiment, (combined data of 2020 and 2021).

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